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MODERN GASWORKS PRACTICE

MODERN GASWORKS PRACTICE

SECOND EDITION, ENTIRELY REWRITTEN AND GREATLY ENLARGED

BY

ALWYNE MEADE, ASSOC.M.INST.C.E.

Engineer of the Wapping Works of the Commercial Gas Company; Formerly Lecturer in Gas Engineering at the Polytechnic, W., and in Gasworks Practice at Westminster Technical Institute; Miller Prizeman (1910) and Telford Premiumist (1918) of the Institution of Civil Engineers; Contributor of Gasworks Section to Kempe's Engineers Yearbook, and on Water Gas, etc., to Thorpe's Dictionary of Applied Chemistry; Author of "The Retort Setting in Theory and Practice," etc., etc.

LONDON

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1921

PREFACE TO THE SECOND EDITION

At the outset the author would like to put on record his great appreciation of the manner in which the first edition of his book was welcomed by the gas industry as a whole. When he originally embarked on the arduous task of attempting to provide a really comprehensive reference book he little realized the time involved and the close attention to every detail which is demanded in the interests of accuracy.

The preparation of the second edition has, if anything, been more exacting than the compilation of the first; for in the past four years the technique of gasworks methods has undergone nothing less than an upheaval. As a result, the greater part of the material contained in the original edition has had to be rewritten. Moreover, the present volume has undergone an increase in bulk of 50 per cent. as compared with its predecessor; and, as yet, there is no indication as to when finality in this direction may be reached.

Some apology is due for the long time during which the book has been out of print, but my readers will understand that one was compelled to await some semblance of quiescence in gasworks developments before putting into permanent form principles and ideas which might prove of but ephemeral interest. The process of evolution continues apace, but a certain amount of stability is noticeable now that the Gas Regulation Act is no longer a novelty. On the other hand, great changes are still to be expected, for the gas engineer can never be content to call a halt until he has solved the problem of producing and distributing the cheapest form of gaseous heat unit.

Under circumstances of the most anomalous nature the author has endeavoured to keep abreast of the times, and—whatever the general impression of his attempt—he will at least be consoled by the consciousness of an effort to give of his best.

A. M.

London, E.1.
September, 1921.

PREFACE TO THE FIRST EDITION

THE gas industry in this country, in spite of its magnitude, is particularly ill-furnished with anything in the nature of a general work of reference dealing with really modern practice. The deficiency, however, can be readily understood when consideration is given to the immensity of the task with which the intending author is faced, the sacrifice of time involved, and, above all, the difficulty of keeping pace with principles and ideas which are in a perpetual state of development. Such prospects, in fact, may well be calculated to damp the enthusiasm of the most determined aspirant.

The author entered with a light heart upon the task of endeavouring to remedy the deficiency, but after twelve months of continuous work, with no prospect of the end in view, " a change came o'er the spirit of my dream," for the enormity of the subject was such that there seemed little hope of ever winning through. However, a plunge into the struggle for another few months brought matters to a conclusion, and the present volume, whatever its merits or shortcomings, is put forward in the hope that it may prove of some assistance and, perhaps, enjoyment to the highly trained gas engineer of to-day. It must be realized at the outset that so far as the principles and practice of modern gasmaking are concerned no single individual can lay claim to omniscience, and on no account would the author presume to be especially fitted for the task he has undertaken. No pains have, however, been spared to develop the book essentially on the ideas of the practical man, whilst every precaution has been taken to avoid inaccuracies. In the latter connection the author has taken advantage (perhaps, at so busy a time, too much advantage) of the help of his many friends in the industry, with the result that nearly every chapter has been submitted for suggestions to an expert in the particular branch with which it deals. This assistance, involving as it has in many cases some considerable labour, has been most generously given, and acknowledgment to the full is due to the following gentlemen for their services :—

Mr. G. F. Handel Beard, Mr. F. J. Bradfield, Mr. A. F. Browne, Mr. F. J. Bywater, Professor J. W. Cobb, Dr. H. G. Colman, Mr. E. V. Evans, Mr. G. M. Gill, Mr. Thos. Glover, Mr. W. R. Herring, Mr. Charles Hunt, Mr. Frank H. Jones, Dr. R. Lessing, the late Professor Lewes, Mr. R. J. Milbourne, Mr. Jas. Stelfox, Mr. J. W. Scott, Mr. B. B. Waller, Mr. P. E. Williams, and Mr. Henry Woodall.

In addition, my thanks are due to Mr. Geo. Evetts, Assoc.M.Inst.C.E., who has read through a large portion of my manuscript, and from whom I have received many

valuable suggestions. Mr. W. F. Brown voluntarily took upon himself the task of reading through the volume in its entirety, checking all figures, chemical equations, etc., with the utmost diligence and with great help to myself. Needless to say, the author is nothing without his publishers, and it is not possible to speak too generously of the assistance I have received from this direction, or to express my gratitude too fully for the enterprising manner in which my volume has been put together. I am indebted to the editors of the *Gas World*, the *Journal of Gas Lighting*, and other technical papers, for permission to make use of the material contained in various articles I have written for them.

Finally, I have the gratification of being able to preface my book with a forenote written by Mr. Stanley H. Jones, M.Inst.C.E., chief engineer and general manager to the Commercial Gas Company. In acknowledging this support it may not be out of place to record the fact that the whole of my training in the profession was carried out under his supervision. Consequently, the principles instilled into my mind are largely those of the Commercial Gas Company, principles which, judging from results the world over, are not to be despised.

A. M.

Wapping Works, London, E.
November, 1916.

INTRODUCTORY NOTE TO THE FIRST EDITION

THE Author has paid me the compliment of asking me to write an introductory note to his book MODERN GASWORKS PRACTICE, and it affords me peculiar pleasure to do so, for I have known him throughout his professional career. He has thrown himself into his subject with characteristic thoroughness, dealing with the works side of gas engineering from alpha to omega, and his treatise will be, I venture to think, a most useful addition to the bookshelves of present-day gas engineers.

The Author's literary work is a fitting sequel to his technical ability and skill as known to and appreciated by one who has had the fullest opportunity of judging—*ἀρχὴ ἄνδρα δείξει.*

STANLEY H. JONES.

COMMERCIAL GASWORKS, STEPNEY, E.
November, 1916.

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MODERN GASWORKS PRACTICE

INTRODUCTION

THE modern gas engineer, beyond realizing that William Murdoch was the first individual to turn coal gas to some practical use, has in many cases a somewhat restricted knowledge of the general historical facts connected with the inception and development of the immense industry to which he belongs. Perhaps, however, this is not surprising when consideration is taken of the multifarious duties and accomplishments now demanded of such toil-worn officials, who, in order to excel, must combine the qualities of engineer, scientist, and administrator, in addition to possessing a specialized knowledge of their primary subject. Under the circumstances it has been thought advisable to trace out briefly the more important links connecting the discovery of destructive distillation with the orderly scientific procedure known to us to-day, in the hope that the reader with a taste for historical incident may find this volume of some small interest and assistance.

The word "Gas" is of somewhat uncertain origin, but in all probability it is derived from the Dutch "geist," meaning "spirit," although some etymologists state good reasons for supposing that the term was initially connected with "chaos." The existence of "fire-damp," which is more or less closely allied to coal gas, appears to have been discovered at a comparatively early date, for Thomas Shirley in 1667 published an extended account of his researches in connection with a burning spring near Wigan. After this there were many similar observations of the production of gas by the decomposition of vegetable matter; but credit for the discovery of destructive distillation most probably lies between the famous Boyle and the Rev. John Clayton, who corresponded in the neighbourhood of the year 1690 on the existence of this phenomenon. It was not, however, until nearly a hundred years after this that serious thought was given to the possibility of utilizing gas as an illuminant. Who was the actual originator of the idea is still a matter for dispute, for several persons seem to have independently conceived the notion at the same time. There was the Belgian, Minckelers; the Frenchman, Phillippe Lebon; and, in this country, Lord Dundonald and Murdoch; but entire credit is usually given to the last-named, who commenced experiments at Redruth, in Cornwall, in 1792. In the same year he distilled a variety of carbonaceous substances, including coal, wood, and peat, and made calculations comparing the cost of light so obtained with that given by the prevailing illuminants at that time, namely

oil and tallow. Five years later he lighted his own premises at Old Cumnock, Ayrshire; whilst in 1802, in celebration of the Peace of Amiens, he arranged for the brilliant illumination of the Soho Works of Boulton & Watt, which firm he had joined.

Attention must now be turned from Murdoch to a man named Winsor, who was attracted by the striking experiments which Lebon was conducting in Paris. Winsor crossed over to France, endeavoured to strike a bargain with Lebon, but failed, and finally returned to England with a full determination to fathom the why and wherefore of the whole business. He studied the subject, mastered it more or less imperfectly, and exploited his invention in Germany. Subsequently he returned to London, and in 1804 gave a series of lectures and exhibitions at the Lyceum Theatre, incidentally raising nearly £50,000 for carrying out his projects. In 1809 he lighted a portion of Pall Mall with gas, this being the first street so dealt with. From then onwards the reputation of the new illuminant was assured, although undertakings existing for its manufacture and distribution had many uphill fights before being established on the road to success. In the same year Murdoch and Winsor came into collision, which resulted in the enterprising plans of the latter being held in abeyance for a time; but 1813 saw the inauguration of the London and Westminster Gas Light and Coke Company, which two years later possessed three manufacturing stations and fifteen miles of street mains. The business of supplying gas progressed with such rapidity that by 1830 more than 200 companies existed throughout the kingdom. Westminster Bridge was first lighted with gas in December 1813, and in the following year the parish of St. Margaret, Westminster. As was only to be expected, the misgivings of the public were at first difficult to quell, whilst profits were non-existent, and the outlook for the future extremely questionable. Soon afterwards the company dispensed with the services of Winsor, who, it is recorded, after his dismissal passed to "the blackness of the tomb in the cemetery of Pére la Chaise, at the age of sixty-seven years."

The history of gas lighting for the next few years is largely the history of this original company, the now famous Gas Light & Coke Company. The pioneer Clegg (who had left the service of the Company on a question of salary) invented the gas-meter in 1815, although it was not turned to any extensive practical use until ten years later. Meanwhile, the influence of competition was beginning to make itself felt, and it would seem that there was some occasion for it when it is remembered that the price of gas at this time was 15*s.* per 1,000 cubic feet. About 1820 the possibilities of oil gas began to be recognized, and a stout and costly resistance was put up by the London companies to a Bill for the promotion of an oil-gas concern. The Bill was ultimately defeated, but in 1823 Bristol was lit by this product under a special Act. In the same year Sir William Congreve (the Home Office inspector of metropolitan gasworks) issued a report showing that the annual production of gas from the three works of the Gas Light & Coke Company was 248 million cubic feet, whilst they possessed 122 miles of street mains. As years went on a bitter rivalry sprang up between the various manufacturing concerns, and serious consideration was given to a scheme for the amalgamation of interests. At first

nothing came of this, but that things were taking a turn for the better is indicated by the fact that in 1855 the premier company was enabled to make a distribution of 6 per cent. At one time there were no fewer than thirteen companies supplying London, but amalgamation proceeded apace, and to-day the enormous requirements of the metropolis are in the hands of merely three companies. The year 1850 witnessed the introduction by Sir William Perkin of the great aniline industry —at one time, unhappily, almost entirely lost to Germany; but partly regained as a result of the exigencies arising from the outbreak of the European War. At the commencement of the war it was at last realized that as a factor in warfare the manufacture of dyes is a " key " industry, and it was, moreover, almost a monopoly of our principal adversary. In fact, both the blue of the Navy and the khaki of the Army were produced with German dyes. By the most praiseworthy efforts of the British chemist and manufacturer the danger of a dye famine was, however, averted, and ultimately the production of khaki and navy-blue dyes outran the production of fabrics. The war, therefore, provided an opportunity for the country to reclaim an industry which was hers by right; and though, as a result of our apathy in the past, the leeway to be made good is extensive, it can at least be said that the German monopoly is not altogether unchallenged.

In 1860 the Metropolis Gas Act came into force, and from then onwards the innumerable concerns which had sprung up in London and the provinces trudged along in a more or less lethargic manner to the accompaniment of increasing profits and abundant dividends. There came, however, a rude awakening in 1883, when the possibilities of electric light were first realized. Shareholders parted with their holdings in apprehension, and the quoted prices of gas stock dropped materially; but far-seeing individuals took the opportunity for increasing their investments, and soon had cause to be gratified at their wisdom. As it happened, the coming of electricity inspired the renascence of the gas industry. Seeing that the uses of gas for lighting were likely to undergo restriction, engineers turned their attention to other means of disposal; and the perfection to which countless appliances have been brought to-day is in no small measure due to the stimulating influence of the rival commodity.

As compared with the practice of the latter half of the nineteenth century, the gas engineering of the present day is chiefly remarkable for the extent to which scientific and economic methods, based on avoidance of waste with maximum efficiency of recovery, have slowly but surely asserted themselves. In the processes involved the chemical specialist has played his rôle, but the ingenious modern plant for carrying out the ideas is due entirely to the engineer; and while the staff-officers of gasworks of any size must primarily possess the general qualifications of the civil engineer, an auxiliary knowledge of chemical science is of the greatest value. There is evidence on every hand that the members of the carbonization industries are learning to recognize more and more that the rule-of-thumb methods of the past century were not worthy of a process which contains such unlimited possibilities, the result being that scientific and practical co-ordination has come to be regarded as the *sine quâ non* in the quest for the ideal.

Some idea of the magnitude of the gas industry in this country may be gathered from the fact that at the present time there exist in the United Kingdom upwards of 1,600 separate concerns promoted for the manufacture and distribution of towns' gas, with a capacity ranging from a quarter of a million to 32,000,000,000 cubic feet per annum. Of these undertakings 831 are operated under statutory powers, 519 being owned by companies and 312 by local authorities. The capital employed by the statutory concerns is approximately £140,000,000. The total annual production of gas in the United Kingdom is 250,000,000,000 cubic feet, which is distributed to some 7,000,000 individual consumers (4¼ million of whom are supplied on the slot-meter system) through 40,000 miles of street mains.

As an essential factor in the prosecution of modern warfare the rôle of the gasworks is already well known, but in honour to an industry which played no mean a part in securing victory in the great European War (1914–1918) some few details of its activities during that distressful period must be put on record. The urgent demand for the principal ingredients employed in the manufacture of modern explosives was met with an immediate response from the gasworks, which—in many cases with nothing more than hastily improvised apparatus—provided the country in the space of two years with thirty million gallons of pure benzene and toluene, or sufficient to make a million and a quarter tons of " Lyddite " and 65,000 tons of T.N.T. In addition, large quantities of special concentrated ammonia, a product practically uncalled for in times of peace, were produced ; while it was to the gas industry that the call went out for sulphuric acid, fuel-oil for the Navy, phenol, and even the charcoal product employed in the manufacture of protective gas-masks. The achievement, in fact, was one worthy of the appreciation of the country as a whole, and should serve as an inspiring record upon which present and future generations of gas engineers may look back with pride.

CHAPTER I

THE PLANNING AND LAYING OUT OF GASWORKS

INTRODUCTORY

The public supply of gas in this country is governed specifically by many local Acts of Parliament, and in general by the Gasworks Clauses Acts (1847 and 1871), the Sale of Gas Act (1859), the Gas and Water Works Facilities Acts (1870 and 1873), and particularly by the Gas Regulation Act of 1920. In addition, London companies are also under the regulations of the Metropolitan Gas Act of 1860. During the period of the European War (1914–1918) several orders of a temporary nature were made under the Defence of the Realm Regulations; while, owing to the exigencies of the war, the Gas (Standard of Calorific Power) Act was introduced in 1916, and the Statutory Gas Undertakings (Temporary Increase of Charges) Bill was passed in 1918. Under the provisions of the 1916 Calorific Power Act the Board of Trade (or the Local Government Board, whichever might be the appropriate department) was empowered to substitute a calorific power standard for an existing candle power standard, on application from the gas undertaking. Public notice was to be given by the undertaking of the calorific standard proposed for adoption, so that any objections raised might be considered by the Department, and an inquiry held, if necessary. The Temporary Increase of Charges Bill of 1918, though it fell miserably short of its objective, was designed to provide relief from sliding-scale and maximum price provisions imposed by former Acts which had proved particularly inequitable under such abnormal conditions as resulted from the war. In effect, it enabled any statutory undertaking adversely affected by circumstances arising out of the war to make application to the Board of Trade for permission to modify its charges to an extent not more than sufficient to enable it to pay a dividend on its Ordinary stock or shares at three-quarters of the standard rate or one-half of the pre-war rate, whichever might be the lower.

The Gas Regulation Act of 1920 may certainly be regarded as epoch-making in the history of gas legislation.

The main provisions of this Act are :—

(*a*) The obligation to charge on the heat unit basis.

(*b*) The adjustment of the Standard or Maximum price (after conversion to the heat unit basis) to meet the additional costs due to after-war conditions.

(*c*) Powers are given to the Board of Trade to limit the percentage of inert constituents if thought fit.

(*d*) The obligation to supply gas at 2 inches water pressure in mains or services of 2-inch diameter and upwards.

(*e*) Powers are given to the Board of Trade to grant such facilities as in the past entailed formal application to Parliament.

As regards (*a*) the gas unit is the " Therm " of 100,000 British Thermal Units and is obtained by multiplying the number of cubic feet as registered by the meter by the " Declared Calorific Value " in B.Th.U.'s per cubic foot, and dividing the result by 100,000. The public is well protected from overcharging in case of the actual quality supplied being lower than that declared. An approved type of recording calorimeter must be used by the gas suppliers.[1] The practical effect of this section of the Act is to give freedom to the gas undertaking to carbonize solid or liquid fuel in the most economic manner possible. Thus, no process is ruled out merely because it produces a low-grade gas. Although no drastic alteration in quality of gas has taken place, yet the Act gives an impetus to any invention or development tending towards the conservation of fuel and the production of cheap heat units. The undertakers must, if necessary, alter the gas-consuming appliances to suit the grade of gas supplied by them.

In connection with (*b*) the Act was passed only just in time to save gas undertakings from financial disaster. The Board of Trade are empowered to add to the existing standard or maximum price (converted to a charge per therm) such reasonable addition as may be required to meet unavoidable increases (in cost of production and supply) which have taken place since June 30, 1914. In debate, and in answer to questions raised in Parliament, it was made clear that the undertakers are to be put in a position to earn pre-war dividends, although a higher rate may in special circumstances be permitted.

Little need be said as regards (*c*) and (*d*). The Board of Trade are given power, if they think desirable, to impose restrictions relating to inerts, limiting the proportion of these to 20 per cent. for a period of two years after the passing of the Act, 18 per cent. for a further period of two years, and 15 per cent. afterwards.

Unless very good evidence can be produced which will prove the harmful effect of inert constituents, it is not anticipated that the powers of the Board of Trade will be exercised in this respect.

With regard to (*e*) the Board of Trade are given very wide powers, both in respect to foregoing matters, and in respect of additional powers.

The necessity for application to Parliament has been considerably reduced, so that the cumbersome and expensive machinery of the Committee Rooms of the two Houses may be avoided, unless powers are sought beyond the scope of the ordinary and special orders which the Board may issue. It is not clear whether power is given to abandon the sliding scale altogether and substitute an irreducible dividend (see later reference to South Metropolitan Gas Act 1920). Neither is it clear whether the Board can substitute a Maximum Price for a Standard or conversely.

[1] It is questionable whether the provision of a recording instrument will be insisted on. In the case of the South Metropolitan Gas Company (the first undertaking to operate on the new basis), the order as to official testing provided for three calorific tests per day at intervals of not less than three hours.

Orders under Section 1 when granted become operative immediately, and refer to mere conversions of methods of charging and adjustment of prices.

Special orders must lie on the table of both Houses for twenty-one days, and do not become law unless no objections are raised. These special order powers are wide, and embrace all the powers permitted under the Gas & Water Works Facilities Act 1870. The Board can also empower purchase in bulk from any source, and enable undertakings to give separate industrial supplies. Further, amalgamations and working arrangements can be effected, and authorization obtained for raising capital or borrowing money.

Lastly, any special Act of an undertaking may be modified by special order under the Gas Regulation Act 1920.

If any Gas Undertaking, two years after the passing of the Act, has not applied for an Order, it is within the power of the Board of Trade to make an Order after giving not less than three months' notice. It is not anticipated that this clause will need to be put into frequent operation, as all statutory undertakings will be anxious to gain relief.

Some non-statutory undertakings may be large enough to merit attention from the Board of Trade in this connection, but it is not expected that the very small non-statutory concern will be troubled.

It is obvious that some undertakings are so small that the purchase of a recording calorimeter, were this insisted on, would appropriate a year's dividend.

Before closing this reference to recent legislation, attention should be drawn to the South Metropolitan Gas Act 1920. This Act was the result of the first attempt to change the method of charging and to work on a post-war basis of selling price. The Act embodied all the proposed legislation of the Gas Regulation Act 1920, and included its provisions in so far as they applied. But a new feature was introduced inasmuch as it parted company with the sliding scale on the old basis, and substituted an irreducible minimum of 5 per cent. dividends for old capital, and 6 per cent. for new money. The Standard or Basic price is 11*d.* per therm, and the above dividends can be paid even if the selling price exceeds the standard. But if the price is reduced, then an arrangement comes into force in which the consumer, shareholder, and employee partake. A sum of money is calculated to represent the difference between the sum actually received and the sum which would have been received had the gas been sold at the basic price. This sum is called the consumers' share and represents three-quarters of the "surplus profit." The remaining one-quarter of the surplus profit, viz., one-third of the consumers' share, is then divided equally between the shareholders and employees.

A further novel point in this Act is a premium to the shareholders and employees should the gas be maintained at a certain standard of purity. If in any year or half-year the carbon bisulphide has been less than one part in forty thousand by volume, then the selling price shall be deemed to be one farthing per therm less in calculating the consumers' share, or one-twelfth of a penny per therm is to be divided between shareholders and workers.

The South Metropolitan Bill in many ways is a model one, and will probably form a basis for many other undertakings in the future.

It does not follow, however, that the division of surplus profits in the same proportion will be the best policy that can be adopted. Each case must be treated on its merits, having regard to previous conditions.

A statutory company has powers and obligations under its own special Act or Provisional Order, as well as being governed by the General Acts, which are incorporated therewith as a whole or in part. A Provisional Order may be granted to a non-statutory company under the Gas and Water Works Facilities Acts authorizing the company to supply gas and conferring the necessary incidental powers. The relation of such a non-statutory company with local authorities and with other statutory companies is similar to that of a statutory company.

Statutory companies and non-statutory companies having powers under Provisional Orders were compelled to supply gas of a prescribed quality within their defined limits of supply, and were usually subject to the infliction of certain penalties if the conditions as to the purity and heating or illuminating power were not complied with. Owing to the extended uses of gas for purposes in which the heating value is of primary importance, Parliament eventually substituted a calorific test for the former universal illuminating test. It is interesting to record that the Gaslight and Coke Company of London had for some time a dual test, but the company was relieved from the older test as a result of application to Parliament during Session 1914.

In many cases, under the original Acts, the price of gas to consumers was graduated on a sliding scale basis, in accordance with which the dividend paid might be increased above a certain standard as the price charged was decreased below an accompanying standard. These two figures were known as the "Standard Price" and "Standard Dividend," and in the case of an increase in price above the standard, the dividend had to decrease.

At the time, Parliament fixed this standard by a consideration of all circumstances tending to affect the price at which the gas could be produced, plus a margin for contingencies. The accompanying dividend was fixed with regard to the history and position of the company, the considerations as to capital, and the position of the money market at the time of the application.

Many older undertakings are governed by a maximum price and a maximum dividend. The former method is more satisfactory to consumers and shareholders alike, and is generally adopted, with minor variations, in all new Acts.

In making application to Parliament or the Board of Trade, there are many Standing Orders and Regulations to be complied with. As, however, a Parliamentary Agent must be employed to pilot the Bill or Order through its various stages, the engineer or manager would be advised of all such requirements coming within his (the agent's) province.

A non-statutory company operates as a result of established practice or under the goodwill of the local authority. In opening roads, they may have to obtain the sanction of more than one local authority, *e.g.* for district and main or county roads.

A non-statutory company sometimes supplies gas within the area of a statutory company without molestation. A non-statutory company may set up works by permission in the existing area of a statutory local authority, or if already in possession when a statutory authority proposed to extend its limits, may continue to operate by agreement. Generally, Parliament will respect the rights of a non-statutory company in such circumstances, and will not grant the statutory company the extension of limits unless some such agreement is effected, or unless the non-statutory undertaking were brought out by agreement or arbitration.

Under the Public Health Act of 1875, a local authority outside the Metropolis may become gas supplier. It may purchase an existing undertaking by agreement, or it may set up its own works to supply the whole or part of its district. The latter proceeding may or may not leave another concern supplying a portion or portions of its district. The local authority, in addition to supplying its own ratepayers, often supplies a much wider district. The price charged in outlying districts will in many cases be greater than that prevailing in the inner district, both in the cases of companies and local authorities.

Purchase may be effected by obtaining a " Purchase Clause " in the Bill when the company is applying to Parliament, or by the promotion of a special Bill, which may or may not embody other powers. Parliament does not recognize it as a universal principle that the undertaking should be transferred, and the local authority must bring proof either that there has been serious mismanagement in the past, or that it is to the interest of the ratepayers and consumers that they should be the gas authority.

The price paid for any such transference may be settled by agreement, failing which a price must be fixed by arbitration.

The local authority has similar powers to a company, but has a greater security when raising its capital, *i.e.* the financial backing of the rates ; but, unless expressly authorized, it cannot supply outside its own area.

A local authority may include the whole of a neighbouring district in its area of supply, or both areas may be supplied by a Joint Board.

In settling the price paid for transference, the following points are considered, amongst others :—

(1) Amount of maintainable profit, as this is usually the basis on which the concern is bought.
(2) Number of years' purchase.
(3) Profit on fittings, usually capitalized by taking three to five years' purchase.
(4) Whether the undertaking is statutory or non-statutory.
(5) Allowance for surplus or deficient works.

There is no definite rule as to the number of years which are averaged when dealing with the maintainable profit, three or five being common figures. In arriving at the maintainable profit the following considerations vary the amount actually shown as the balance of the Revenue Accounts.

(*a*) Insufficient or excessive repairs and renewals.
(*b*) Working results above or below the normal.
(*c*) Abnormal conditions regarding prices of coal or residuals.
(*d*) Contracts entered into, or rights and privileges affected by transference.
(*e*) Recent scale of growth and prospects.
(*f*) Fairness of price charged for gas.

Goodwill as such is not saleable, although item (*e*) covers claims for future increased profits. The term of years' purchase is dependent on the interest which an investor can get with equal security. The period varies considerably, ranging from ten to thirty years. The seller rightly claims to be put in an equally good position after the sale ; in other words, he must earn the same income with the same security.

Anything up to ten per cent. is added for compulsory purchase (where it is compulsory) ; that is, for interruption of tenure, expense and trouble in seeking new investments, etc., but this is usually a mere matter of form. Claims may be made in deductions from the total arrived at for immediate necessary expenditure to maintain the profit, or to keep the undertaking in a good position generally. The structural valuation of the undertaking has little bearing on the price paid, and is estimated in order to indicate the capital assets of the concern.

It should be mentioned that in addition to the General Acts named at the beginning of this chapter, the sale of gas in Scotland is governed by the Gas Acts (1864) and the Burghs Gas Supply Acts (1876 and 1893).

The supply of gas in Scotland is very largely in the hands of the local authorities, and in England the counties of Yorkshire, Lancashire and the North generally are much more marked in this respect than the Home and Southern Counties. Whether in the hands of companies or of municipal authorities, however, the industry as a whole is remarkably well managed, and is on a firmer basis now than ever before in its history. Gas for all purposes has ceased to be a convenience, and has become a necessity.

THE CHOICE OF A SITE

The first preliminary to the erection of a gasworks is the selection of a suitable site. Although this task may appear to be one of extreme simplicity, this is by no means the case, and hasty consideration of the matter may have a lasting influence on the welfare of the undertaking. The more important points to be kept in view may be summarized as follows :—

(*a*) Ready access to sea, river, canal or railway. Cartage to and from the works should, as a general principle, be avoided as far as possible, and works having a combination of water, rail and road facilities enjoy an enviable position. This accessibility has a twofold value, viz. : in getting coal and other materials into the works and in the taking away of residuals. Generally, it may be taken that good sea or river access is preferable to rail, more particularly when the undertaking owns its coal ships.

With reference to the last mentioned, the actual construction of sidings is a financial matter, depending entirely on the money to be saved balanced against

the annual charges for construction, working and incidental costs payable to the railway company.

(*b*) The level of the ground should be low in comparison with the districts to be supplied. It is a " golden rule " of gas engineering never to erect a gasworks on a hill. Owing to its specific gravity (0·42 to 0·52, depending on the proportion of carburetted or blue water gas), gas exerts its pressure upwardly; hence where the works is erected on elevated ground unnecessary pressure has to be sacrificed in driving the gas downwards to consumers. With regard to the so-called loss in pressure, this is usually estimated by an arbitrary rule based on general circumstances and inclusive of friction in the mains. The rule prescribes that the loss due to altitude will amount to approximately one inch of water pressure for every 100 feet rise in elevation. Gas pressures, as usually understood, are, of course, not absolute; that is to say, they do not start from zero, but from atmospheric pressure as measured by the barometer. So that, if A is the atmospheric pressure, and B is the pressure of gas in the main, then A plus B is the absolute pressure.

There are generally, of necessity, many points lower than the gasworks, especially in undulating country, but in general, keep low, having regard to other matters mentioned later with reference to flooding.

(*c*) The character of the surrounding property must be considered. A gasworks is essentially a thing of utility, and can lay little claim to æstheticism; therefore the picturesque portions of the district should be respected. For the same reason, a site should not be chosen in the fashionable quarter of the town, otherwise complaints from well-to-do residents will be a continual source of annoyance.

Here it may be mentioned that when applying for parliamentary sanction to make or purify gas on any land, notices have to be served on all owners, lessees and occupiers of dwelling-houses within 300 yards of any portion of the said land, who may petition the House (before Committee) against the adoption of the site.

(*d*) The ground should be suitable for foundations, both as to cost and stability. Before a definite agreement is concluded, trial borings should be made, and the nature of the subsoil determined. Hard gravel, ballast and chalk are the ideal. Many clays form excellent foundations, whilst " made up " ground (such as disused rubbish heaps, tips, etc.) is probably the most treacherous. Running sand, compressible clays, soft peat and fine alluvial soil may turn out to be very untrustworthy and costly. Rock, of course, makes excellent foundations, but is expensive to work, although it may be used for concrete mixing. Further economy may be effected by obtaining sand or ballast from the ground.

Of extreme importance is the permanent water level, and the possible floods level; both affect the cost of works construction, the former in particular. The latter affects the actual operation of the works, for no gasworks can be called satisfactory if always liable to floods. The loss of tar and liquor from underground wells would be considerable and the damage to buildings and plant would be heavy, but the greatest danger would be that of complete stoppage by the extinguishing of furnaces in the retort house. These points are more fully dealt with in Chapter II (Foundations).

A plentiful supply of water under control is, of course, an economic asset, effecting a considerable annual saving. Many of the larger works obtain a cheap supply of water by sinking an artesian well.

(*e*) The distance of the site from the centre of the area of greatest consumption is a further point. The works need not necessarily be erected within its own limits of supply, although it almost invariably is. Owing to high cost of land near the centre of towns, the gasworks is usually situated on the outskirts, or what were the outskirts when the works was erected. In such cases, of course, the additional length of trunk mains must be balanced against the saving in cost of land, and the sale of residuals and cartage costs must in general be considered. For long distance transmission, modern methods of " boosting " or high pressure distribution may be employed, permitting the use of smaller and therefore cheaper trunk mains. Needless to say, the high pressure must be governed down for ordinary purposes. It often happens (after considerable growth) that storage plant has to be erected further out of the town, so that the central site may be occupied for manufacture and purification. A minor factor requiring consideration is the possible danger of pollution to the water supply by percolation, particularly in chalky districts ; and when such things as gasholder tanks are emptied, care should be taken to see that the water, which frequently contains cyanides, is treated or run away where it can do no harm.

CONSIDERATIONS AFFECTING SIZE OF WORKS

Before much headway can be made with the actual definition of the site boundaries, some idea as to the extent of the ground required must be arrived at, this, of course, being dependent upon the quantity of gas likely to be consumed immediately and during the next fifteen or twenty years. It is as well to be generous in the purchase of land, particularly if it is cheap ; and preference should be given to a site which is capable of extension. A square or rectangular site is the most suitable for laying out buildings and plant.

As regards the quantity of land to be purchased, experience is really the only reliable guide ; so much depends upon the nature of the district to be supplied, whether residential or manufacturing, the class of inhabitant, presence or absence of electrical competition, and the price at which gas is intended to be sold. In this respect sales of gas, unlike water, cannot be satisfactorily calculated by an allowance of so much per head of population ; for, although every individual may be credited with a desire for water, the same cannot always be said of gas. As a matter of fact, in the larger cities the average consumption per head per annum is from 6,000 to 10,000 cubic feet, whilst in the smaller towns it may be from 2,500 to 7,500 cubic feet. Fifteen years ago it was a general rule to base the former at 2,000 cubic feet per head and the latter at 1,600 cubic feet. Taking the country as a whole, the average consumption per consumer (not per head) at the present time works out at almost exactly 30,000 cubic feet per annum.

The following table, which relates to the latest figures available at the time of publication, gives an idea as to how matters stand to-day :—

	Cubic feet per head.	Cubic feet per consumer.	Sale in million cubic feet per annum.	Pre-war Price (1914).	Present-day Price [1] (1920).
				s. d.	*s. d.*
Birmingham	24,300	69,600	12,809	1 11	3 7¼
Manchester	8,500	31,000	6,055	2 2	4*s.* to 4*s.* 3*d.*
Nottingham	9,000	25,300	2,310	2 2	3 10
Leeds	6,100	27,300	3,137	2 2	5 1
York	7,300	27,800	604	2 1	3 1
Brighton	13,900	39,400	1,819	2 10	5 6
Hastings	7,600	37,000	466	2 10½	5 0
Guildford	9,500	33,200	226	2 8	4 2
Watford	10,600	37,900	435	2 8	5 6
Canterbury	7,800	31,800	192	2 8	4 6

It is interesting to note that in spite of the higher cost of gas the consumption per consumer has increased considerably in all cases during the past five years. This is more particularly the case with those towns which are of an industrial and manufacturing nature. In the case of Birmingham, the figures must be considered anomalous to a certain extent, owing to the fact that the total sales of gas given include a period of exceptional war activity, during which period the normal population was considerably augmented. In calculating the consumption per head, however, the population at the last census has necessarily to be taken, thus no allowance has been made for the temporary increase. Again, on the census population, Brighton has more than doubled its consumption per head during the past five years. But when consideration is given to the notorious influx of temporary residents to which this resort has had within the last year or so to reconcile itself, the significance of the figure given will be appreciated.

So far as the smaller towns are concerned, it is instructive to note the conditions, a few examples of which are given below:—

	Cubic feet per head.	Cubic feet per consumer.	Sale in million cubic feet per annum.
Faversham	7,730	26,200	82
Hitchin	6,200	26,200	74
Harpenden	10,200	32,300	63
Louth	5,400	26,400	54
Rickmansworth	4,800	22,400	30
Barmouth	4,700	18,500	10
Arlesey	2,400	11,000	5

With the smaller undertakings the consumption per head varies fairly considerably, depending a great deal on whether the district is partly industrial or purely

[1] It will be appreciated that from 1921 the general basis of charging will be per therm = 100,000 B.Th.U.

residential and agricultural. As a general rule it may be said that the smaller the population the less will be the consumption per consumer, this being partly due to the fact that in such districts gas is mainly employed for lighting, and is not generally used for cooking, etc., owing to its cost necessarily being higher than in the large towns.

From the estimating standpoint, the second column of figures is the most useful, for, taking all considerations into account, the number of consumers and their probable average can be fairly closely approached by one of experience. In the above calculations the gas employed for public lighting has been included in the consumers' quantity.

In a general way, a very good idea of the total probable output can be gleaned from an analysis of the situation on lines such as the following :—

Say the district contains 17,500 to 18,500 houses, of which the mains to be laid would permit of access to 17,000 or so. In the circumstances, 90 per cent. of these may be expected, or 15,500.

Then the estimated amount of gas to be sold per annum would be :—

	Cubic Feet. Millions.
6,500 consumers through ordinary meters at 42,000	273
8,500 „ „ "slot" „ 15,000	127
For industrial purposes extra (say 500 consumers)	60
For public lighting (1,200–1,500 lamps).	20
	480

In addition to this sale, about 6 per cent. must be allowed for gas lost by leakage and gas used on the works. This brings the annual production up to 508 millions, or, in round figures, 500 millions. The sale per head then works out at nearly 5,500 cubic feet, or 30,000 cubic feet per consumer, excluding public lighting; which, on reference to the table, is seen to be normal, and satisfactory for estimating purposes.

AMOUNT OF LAND REQUIRED

In considering ground area required, much depends on the manufacturing system it is proposed to employ, but a good guide is to allow a minimum of $2\frac{1}{2}$, and preferably $3\frac{1}{4}$ acres per million cubic feet per diem. So far as the maximum day's send out is concerned, this is now found to amount to 1/230 to 1/260 of the whole year's consumption. That is in normal cases, apart from health resorts or towns having a double heavy season.

Ten years ago this ratio varied from 1/185 to 1/210 ; so that it is now possible to sell from 10 to 15 per cent. more gas with identical plant, owing to the levelling up of the daily load curve. In the same manner the hourly load curve has also been appreciably straightened out, thus saving many undertakings considerable expense in gasholder construction.

In the example taken we get a maximum day's production of 500/240 millions per day=2·1 millions. So that land and plant must be at least equal to this production.

Land required = 2·1 × 3·25 = 6·82, say 7 acres. This will permit of the works being planned with a view to easy and economical extension, a point of great importance in the works design. Also, more land generally means greater economy in working. In many of the old works which have grown up from a smaller beginning in congested districts the ground area falls very much below that given by the above rule. As an example of this a works hemmed in in the East End of London may be mentioned, where the output per diem is 4 million cubic feet on a ground area of only two acres. Cramped conditions of the kind, however, should be rigorously avoided whenever possible.

It is interesting to note that twenty years ago the late Mr. A. Colson expressed the view that 2½ acres were required per million per day as a minimum. Since then the gas-producing capacity of a given area has considerably increased, although the remainder of the plant (except gasholders) has undergone very little change so far as necessary ground space is concerned, but ample room is the essential condition of efficient working, and it is certainly preferable to work on a basis of 3¼ acres per million cubic feet.

CAPITAL EXPENDITURE

The capital expenditure likely to be entailed in the erection of a gasworks and the equipment of the district is difficult to compute with any degree of accuracy until the site is selected and preliminary survey and estimates have been made. So much depends on the prevailing value of materials of construction, the requirements of labour, the geographical position of the town, facilities for conveying materials to the site, etc., that no hard and fast rule, applicable to all cases, can be given.

In preliminary estimates, for parliamentary and other purposes, it is advisable to allow a fair margin to cover possible increases in cost, as the work may be carried out as long as two years after the preparation of the estimate.

In the analyses published by the *Gas World* it is stated that the average capital employed for fifty-five of the largest undertakings is approximately 12*s.* 1*d.* per 1,000 cubic feet for companies, whereas for the undertakings owned by municipal authorities—which are somewhat more highly capitalized than the privately-owned concerns—it approaches 15*s.*[1] The difference is due to the premiums paid on the transfer of the undertaking to the local authorities.

In general, the concerns which have been promoted in the past for the erection of gasworks and for providing a distributing system have found it possible to complete their scheme for approximately £600 per million cubic feet sold per annum, *i.e.* 12*s.* per thousand cubic feet sold per annum. In the case of the larger works, the figure was often reduced to £550 or less, but for the smaller country works the outlay has been considerably greater, a normal figure being £750 to £1,000 per million cubic feet sold, according to size.

At the present day it is seldom that a large town is required to be fitted out with a complete gasworks and supply system; and, consequently, it is the figures

[1] Original capital employed irrespective of later reductions by loan repayment, etc.

for work which has been carried out in the past which are interesting from a statistical point of view. This point is mentioned owing to the fact that as materials and labour have within the last few years appreciated by some 250 per cent. it would be impossible to erect an entirely new works for an outlay calculated on the figures given above.

Capital expenditure, based on output, should with proper management decrease as years go on, chiefly owing to the taking up of increased business with existing plant, or by only slight additional expense for considerably augmented consumption. Here again, though, it must be remembered that additional capital expenditure will at the present day go only a third as far as it did a few years ago. It must, however, be borne in mind that capital expenditure is usually the very crux of a company's condition, so that additional plant should, whenever possible, be paid for out of revenue. In nine cases out of ten the capital charge to be met was, in the past, the heaviest item (proportionally) in the revenue account; and, although prevailing conditions have somewhat altered this, there is still every need to curtail the capital employed as far as possible.

As an example of this tendency, and the improvement effected by expansion of business, the average capital expenditure (excluding floating capital and nominal additions) of the three metropolitan companies was :—

In 1884	12*s.* 5*d.*	per	1,000	cubic feet sold.
In 1895	11*s.* 2*d.*	,,	,,	,, ,,
In 1900	10*s.* 7*d.*	,,	,,	,, ,,
In 1910	10*s.* 5*d.*	,,	,,	,, ,,
In 1915	10*s.* 0¾*d.*	,,	,,	,, ,,
In 1916	10*s.*	,,	,,	,, ,,
In 1918	10*s.* 9*d.*	,,	,,	,, ,,
In 1919	9*s.* 8*d.*	,,	,,	,, ,,

The following figures give an indication of this item, and its relation to various companies and corporations. The figures are the latest obtainable at the time of publication, and they do not include floating capital and nominal additions.

	Shillings per 1,000 cubic feet sold per annum.
	s. *d.*
Companies :	
Gaslight and Coke	9 11
South Metropolitan	9 7
Brighton	8 9
Derby	7 2
Bath	6 9
Hastings	18 5
Newcastle	13 11
Watford	8 2
Reading	7 7
Corporations :	
Birmingham	5 3
Manchester	11 8
Leeds	15 1
Nottingham	11 8
Leicester	11 7

In recent years the capital expenditure on the district has increased rapidly, owing to the development of the prepayment meter business and the greatly extended use of gas cookers, fires, circulators, etc. The first-named item of expense may now be considered as varying from £13 to £18 per house (including cooker), but excluding service, which is common to all classes of consumer. The consumption for this expense may be from 7,000 to 22,000 cubic feet per annum ; and, averaging these figures, we get an expenditure of £850 per million on the gas sold through this channel. There is, of course, an increased receipt from this source, which may or may not give an adequate return on the capital, after allowing for extra cost of collection, repairs, and maintenance.

The result is that, whereas twenty years ago the works usually cost more than the distributing plant, the reverse is now invariably the case. Keeping in mind, however, the general example we are considering, the cost of mains, meters, stoves, etc., comprising the distributing plant, may absorb 55 per cent. of the total, the works and equipment amounting to 38 per cent., whilst engineers' fees, parliamentary and promotion expenses complete the total. A fact not generally realized with regard to works outlay is that the expense of gasholders in many cases accounts for one-fourth or even one-third of the total, and is the most expensive individual item on the works. The remainder is apportioned somewhat as follows :—

Land	2–4	per cent. of works expenditure.
Carbonizing plant (including buildings)	20–27½	„ „ „ „
Purifying plant	5–8	„ „ „ „
Exhausters, condensers, washers, etc.	3–4	„ „ „ „

GENERAL RULES FOR SIZE AND CAPACITY OF PLANT

Gasworks are never designed by rule-of-thumb methods, and the details connected with their construction are mostly the outcome of extended practical experience. For all that, certain constants for the computation of the capacity of the various pieces of plant have come to be recognized, and are given here with the strict warning that they are merely a guide, exemplifying rules and their application. Varying circumstances alter cases, and in laying out the works all those circumstances should be taken into account which would tend to vary sizes from the normal. Although, in the main, the rules given will be found as occurring in general practice, the author wishes to deter the aspiring designer, with little or no actual experience of gasworks erection, from drawing up specifications on such a basis alone.

Land

Allow at least 2½, and preferably 3¼ acres per million cubic feet per maximum day.

Retort House

Dependent upon the gas-making capacity of each "unit," *i.e.* the number of retorts set in each arch. The following table gives approximate figures for the make of straight coal gas per retort per day of twenty-four hours :—

Stop-ended retorts, 9 feet to 10 feet long × 15 inches round.	3,000–4,000 cubic feet.
„ „ 10 feet long × 16 inches round.	4,000–5,500 „ „
„ „ 10 feet long × 21 inches × 15 inches ⊔ or 10 feet long × 22 inches × 16 inches ⊔	7,000–8,500 „ „
"Through" retorts, 20 feet long × 24 inches × 16 inches ⊔	18,000–20,000 „ „
Vertical retorts, Woodall-Duckham type	up to 80,000 „ „
„ „ Glover-West type	up to 50,000 „ „
„ „ Intermittent type (5 metres long)	16,000 „ „

In the case of vertical retorts in particular the capacity per retort may be considerably augmented by judicious steaming of the charge. The figures given for these systems refer to straight coal gas only.

Instead of speaking of the make per retort per diem, it is usual among gas engineers to work on a basis of "make per mouthpiece" per diem. This is particularly the case with horizontal and inclined retorts; thus the "make per mouthpiece" for a stop-ended retort would be 3,000 to 8,500 cubic feet, the same as the make per retort. For a "through" retort it varies from about 6,500 to 10,000 cubic feet, *i.e.* half the make per retort, this being due to the fact that the retort has two mouthpieces—one at each end.

Coal Storage

It is customary, and it has been found advantageous, to provide for storage under cover sufficient for twenty-one maximum days' production. In recent years, owing to the unsettled condition of the labour market, the larger companies have (war conditions apart) endeavoured to store sufficient supplies for their needs for two or three months; hence recourse has to be had to stacking large heaps out in the open. No undertaking can in normal times afford to risk three weeks' storage, although this is still a common and sufficient allowance for that kept under cover. The calculation of the cubical capacity required for storing a definite quantity of coal may be closely arrived at by assuming that 1 ton of average gas coal occupies 42 to 43 cubic feet of space. One ton of gas coke requires a space of about 85 cubic feet. Coal should not be stacked to a greater depth than 20 feet, owing to the danger of spontaneous combustion. (See page 371.)

Condensers

Owing to the many advantages attendant upon the use of water condensers, they are now frequently employed in preference to the original atmospheric type; the latter, however, are still used in small and medium-sized works, and are not without their good points. It should be remembered that the initial stages of condensation should be effected slowly.

There are several rules for the capacity of air condensers, and the variable nature of the results they give shows that engineers are by no means agreed on the subject. A common and reliable rule is the following:—

Allow 5 square feet of atmospheric condensing surface per 1,000 cubic feet of gas made per day (maximum day's production to be taken). This area includes all pipe from the outlet of the hydraulic main to the outlet of the condenser, and permits

of a small deduction being made if there is a further long distance to the inlet of the exhauster. Various authorities recommend increasing surfaces up to nearly double this amount.

As regards water-cooled condensers, there is considerable variation, according to type, amount and speed of water circulation, etc., but for general purposes about 3 square feet per 1,000 cubic feet per day should be allowed, *i.e.* about one-half of that necessary with the atmospheric type.

Exhausters

Except on very small works, say less than 10 or 12 millions, the exhausting plant is generally laid down in duplicate, to allow of repairs or adjustments to one set. A useful combination for medium-sized works is one set equal to the maximum winter's production and the second equal to that of the summer. It should be remembered that the cost price of exhausting machinery increases at an appreciably slower rate than capacity; hence it is often convenient, and in a growing place absolutely necessary, to lay down exhausters in excess of immediate requirements. Slower running of an undertaxed exhauster will always make for smoother work and longer life.

In a works of 4 to 6 millions per annum the saving to be effected in purchasing an exhauster is problematical, after paying interest on capital and running costs. For works over 6 millions the buyer is on safe ground, and in such works (say less than 15–20 millions) it is usual to drive by gas engine, which provides power for operating tar, liquor and other pumps. If working to exact capacities, it is merely necessary to take a very small margin over the maximum day's production, which is arrived at by dividing the yearly production by 240. The maximum day divided by 20 or 22 will give the maximum hour, which is the usual way of tabulating exhauster capacities. The effective hourly capacity of an exhauster is guaranteed by the makers, and reference to catalogues gives all particulars relating to standard sizes, space occupied, etc.

For the capacity of a four-blade exhauster, the following formula may be taken; it is not, however, recommended when dealing with very large (over 4 feet) or very small exhausters:—

$$Q = 65\ D^2\ L.N.$$

Where Q = cubic feet passed by exhauster per hour.
D = inside diameter of outer drum in feet.
L = length of drum in feet.
N = number of revolutions per minute.

About 20 per cent. of the amount arrived at must then be deducted for "slip."

The power necessary to drive exhausters is dependent on their capacity and the total back pressure to be overcome. (See Chapter XV.) The power required at the engine is slightly more than that necessary at the exhauster shaft, the extra being dependent on the method of driving, whether direct coupled or through shafting.

Generally, however, the maker has a standard engine to a certain sized exhauster,

leaving sufficient margin, and unless stated otherwise by the purchaser, this standard size will be supplied.

Wet Purification Plant

This may include one, two, or three of the following types of plant :—

Tower scrubber.
Livesey type washer.
Mechanical washer.
Washer-scrubber.
Purifying machine.

The last mentioned includes one or two makes of mechanical apparatus which remove both tar and ammonia. The washer-scrubber is mechanical, and the many different patterns conform to one general type. Livesey washers, made by many firms, are not mechanical ; and the first mentioned in the list is usually fed with water or liquor by mechanical means. In many cases two pieces of plant in the above list are associated with a tar extractor of the Pelouze pattern. By far the most common combination is a mechanical washer-scrubber followed by one or more tower scrubbers. If two are adopted, the last is fed with clean water, which should, if desired, remove the whole of the ammonia.

In small works, it is common to have only one or two tower scrubbers, with no mechanical washing apparatus whatever. When associated with a mechanical apparatus, the scrubber allowance should be at least equal to 5 or 6 cubic feet per 1,000 cubic feet of gas per day. Newbigging and Herring recommend 9 cubic feet. In cases where no washer-scrubber is employed, the aggregate capacity of ordinary washers and scrubbers must be increased to 10 cubic feet per 1,000. In very small works where only one tower scrubber is used, this figure might with advantage be increased to 12 cubic feet. The ratio of the height of a scrubber to its diameter varies in normal cases from $2\frac{1}{2}$ to 5.

With regard to the other forms of apparatus mentioned, each manufacturer has his own standard sizes of plates for varying capacities, but as a general guide the following figures will be found useful :—

Livesey washers	$\frac{1}{7}$–$\frac{1}{5}$ cubic feet per 1,000 cubic feet per day.
Washer-scrubbers	$\frac{1}{2}$–$\frac{3}{4}$ „ „ „ „ „ „ „ „

Dry Purification Plant

If it is necessary or desirable to remove sulphur compounds other than sulphuretted hydrogen, the purifier capacity is increased, this frequently calling for the use of lime in addition to oxide of iron (or its equivalent). Under such circumstances it is advisable to increase slightly the size of the vessels, as well as further increasing the capacity by means of catch boxes. It should be remembered that if more area can be given than in the following rules, it is never wasteful, purification charges undergoing reduction, whilst the first cost of the plant increases slowly as compared with the capacity. In other words, the smaller the boxes the more expensive do they become per unit of purifying capacity. For oxide purification

only (for a set of four purifiers) an area of 0·5 square foot per 1,000 cubic feet per day should be provided as a minimum in each box. If lime is used this figure should be increased to 0·6 square foot, or to 0·65–0·7 if no catch boxes are provided. For the total amount of purification space necessary (*i.e.* the combined area of all boxes) the rule given by Hunt is useful. This states that for lime and oxide purification 20 to 30 square feet per ton of coal carbonized per day should be allowed.

A further rule, based on the amount of oxide in the boxes, is that one ton of oxide may be expected to purify about 2 million cubic feet of gas before becoming finally spent.

The maximum figure can only be obtained when air is put into the boxes for revivification. A further rule is that for each 1,000 cubic feet of gas per day allow $1\frac{1}{2}$ to 2 cwts. of oxide in each of four boxes.

In designing plant for a growing works, it is necessary to provide for the more or less immediate future, and it is advisable to erect only three boxes, making provision for the easy addition of the fourth. In this case the boxes in the set of three should be made 50 or 60 per cent. larger than those necessary in a set of four (say 0·8–0·85 square foot per 1,000 cubic feet per day for the area of each box). In the case of a very small works with prospect of growth, two boxes with facilities for extension can be put in with advantage, in which case each box should be made 3–$3\frac{1}{2}$ times as large as if there were four (1·5 to 1·7 square feet per box per 1,000 cubic feet per day). By adopting this plan the first cost is not increased, and money is saved when extensions are carried out.

The size of connections for purifiers may be calculated as follows:—

$$\left.\begin{matrix}\text{Diameter of pipes} \\ \text{in inches}\end{matrix}\right\} = \sqrt{\text{Area of each box in square feet.}}$$

For small purifiers make no deduction from the figure so found, but in large and medium-sized boxes deduct $\frac{1}{6}$ to $\frac{1}{4}$.

Small boxes are from 3 to 4 feet deep, and large ones may run from 6 to 8 feet, 6 feet being most common. The intermediate sizes vary from 4 to 6 feet in depth. Purifiers vary in size from 12 square feet in area up to 40 feet square, the latter size being suitable for a $2\frac{3}{4}$ to 3 million cubic feet a day unit. For constructional reasons, convenience in working, lifting covers, emptying, etc., when the works is larger than this it becomes necessary to divide the gas into streams, each with its own set of boxes. In works making less than $2\frac{3}{4}$ to 3 millions per day this system is also in operation owing to development in the past, and it is very useful where different sized units are in use, the larger set being operated in summer and both sets in winter.

Thus a 3 million a day works would have 35 or 36 feet boxes for its larger unit and 24 feet boxes for the smaller unit. The former unit would probably be sufficient for eight months in the year, and both sets would be in use for the remaining four months. The larger set would then take 27-inch connections and the smaller 18-inch to 20-inch.

For carburetted water-gas purifiers it is advisable to take 0·8 square foot per 1,000 cubic feet per day for each box, again assuming four boxes to the set.

Governors

Dependent entirely on the nature and conditions of the district to be supplied. Absolutely no rules can be given attempting to cover more than the simplest possible case, *i.e.* a level district, with the gas sold in one centre, in which instance the one necessary governor is of the same size as the main outlet pipe from the works.

Storage Capacity

The levelling up of the hourly load curve in recent years has had a marked effect on the amount of storage necessary. In spite of considerable increases in annual sales, none of the three metropolitan companies has built a gasholder for many years, and as the South Metropolitan Company is here included, the question of storage cannot be due entirely to the use of carburetted water gas, although it is naturally influenced by the presence and capacity of the water-gas plant. The other factor affecting the storage required is the nature of the supply, whether chiefly lighting, or power, or cooking; the last two, if in large quantities, causing the peak to be from 11.30 a.m. to 1.30 p.m., or thereabouts, instead of during the evening.

Where the load curve is assisted in this manner and surplus water gas is available, the storage can safely be reduced to 18 hours' maximum make. Otherwise 21–24 hours' should be provided for. It is as well not to rely on the surplus water-gas plant other than as a means for meeting emergencies, such as fogs or breakdown in coal-gas plant. With reference to ground space occupied, it may be mentioned that gasholders require, roughly, 20 per cent. more room than the combined retort houses and coal stores, under normal conditions.

It will be understood that the storage capacity on the daily make basis is very elastic, as the newest holder is almost invariably the largest; consequently before this is put into operation the storage is deficient, whilst immediately afterwards it may be excessive, provision being made for the future.

A common method of providing for future development is to build the tank and one or more lifts with all arrangements for adding a further (outer) lift in the future. Thus the capacity of such a holder may be increased from 50 to 100 per cent. with a comparatively small expenditure. It must be remembered, however, that this method cannot be adopted where one holder is relied upon, or where the other storage is so small that it cannot be reduced even in the slackest season of the year; for the holder must necessarily be out of action for some weeks during the alterations. Albeit, many undertakings have gone through this ordeal on 12 hours' storage, even when based on the minimum day (8–9 hours of maximum day).

The proportions of gasholders are discussed in Chapter XIX, but for single lift holders allow height equal to 0·3 to 0·4 of the diameter, and for multiple lift holders 0·6 to 1·0 of the diameter. This excludes tanks in both cases.

Tar and Liquor Storage

Ample tar storage is advisable, as it assists the manager in times of low prices, in addition to which the demand is a fluctuating one.

If the works manufacture its own sulphate, it is advisable not to store ammoniacal liquor for too long, owing to evaporation and other losses. A general guide is 5 weeks' (maximum) storage for tar and liquor.

Sulphate Plant

Assuming that sulphate is made ten or twelve times a year, the plant should have a capacity of 3–3½ tons of sulphate per 24 hours for every million cubic feet of gas per maximum day. This allows for sulphate making during six days. If it is proposed to make at different periods, or for more or less days, the adjustments can be made accordingly. This, of course, refers to the distinct plant for producing sulphate, but it has to be borne in mind that a few of the smaller works are now employing the semi-direct method of recovery whereby the gas is passed, during the process of manufacture, through an acid bath, and sulphate is recovered continuously. This is a process which, as its original defects are overcome, is likely to be much more generally adopted, although some works which installed the process a few years ago have now abandoned it owing to working difficulties.

Works Mains

It is difficult to give definite rules, but the following will form a rough guide, based on particulars of many works :—

Mains	5	inches	diameter	suitable	for	works	of	3	to	4	million	cubic	feet	per annum.
,,	6	,,	,,	,,	,,	,,		6	,,	10	,,	,,	,,	,,
,,	8	,,	,,	,,	,,	,,		15	,,	25	,,	,,	,,	,,
,,	10	,,	,,	,,	,,	,,		30	,,	45	,,	,,	,,	,,
,,	12	,,	,,	,,	,,	,,		55	,,	90	,,	,,	,,	,,
,,	15	,,	,,	,,	,,	,,		100	,,	150	,,	,,	,,	,,
,,	18	,,	,,	,,	,,	,,		200	,,	300	,,	,,	,,	,,
,,	20–21	,,	,,	,,	,,	,,		350	,,	450	,,	,,	,,	,,
,,	24	,,	,,	,,	,,	,,		500	,,	600	,,	,,	,,	,,
,,	30	,,	,,	,,	,,	,,		600	,,	900	,,	,,	,,	,,

GENERAL NOTES ON THE LAYING OUT OF WORKS

Having decided upon the sizes of buildings and plant, the engineer's next task is that of setting these out on the site at his disposal. Each site will have its own particular conditions, but the following points may be taken as applicable to all circumstances.

The retort house and coal stores should be adjacent to the point of coal intake; and, in laying out, the disposal of coke must also be kept in mind. If possible, arrange for the coal storage which is not under cover to be convenient for the retort house, and allow plenty of room for coke storage, and for pulling up carts, etc. High coke tips should be avoided, as they are expensive and give rise to excessive quantities of breeze. The coal and coke handling should be quite separate (on opposite sides of the building, if possible); and, if the site is not being filled up at once, room should be left for enlarging without undue destruction. Provision should be made for any items of extension which may be contemplated. The site

should be laid out for what it is comfortably capable of, so that each piece of plant may have room for extension up to that limit. Cartage ways and other means of access must, if possible, be left around all buildings.

Boilers should be central for feeding exhausters, mechanical washers, sulphate plant, pumps, etc.; whereas gasholders should be kept on the side towards the populated parts, thus partly shielding the works, with the purifiers and sulphate plant far away from entrance gates and roads. Plenty of room should be left near the purifiers for laying out oxide, a generous portion of this being under cover. A point which is often overlooked is that of keeping the gasholders as far as possible from the causes of corrosion, such as the water-gas plant, chimneys, sulphate plant, etc.; whilst purifiers should be some distance from the boiler houses. The ideal place for scrubbing plant, in fact all plant for the extraction of tar and ammonia, is next to the storage wells—thus avoiding long distances for pumping. It is scarcely necessary to add the warning that all underground tanks should be kept out of the line of heavy traffic.

CAPITAL COSTS OF WORKS

To arrive at a decision with regard to the plant to be laid down entails much more consideration since the introduction of the Gas Regulation Act. This Act gives freedom to an undertaking to declare any calorific value it chooses; the provision of plant, therefore, is dependent upon various considerations, amongst which the following are the more important:—

(*a*) The special demands of the district to be served, whether industrial or domestic. Also any particular demands for special industries.

(*b*) The relative values of coal and by-products.

(*c*) The capital cost for various carbonizing installations, *i.e.* horizontal retorts, vertical retorts (both with and without steaming), water gas (blue or carburetted), complete gasification plant.

(*d*) The size of trunk mains, and the sizes of consumers' services, meters, and heating appliances.

The thermal balance of all methods included under (*c*) must be considered in relation to the cost of coal and residuals, capital expenditure entailed, manufacturing wages, flexibility of control, and other factors.

In the following case a typical instance is considered of an undertaking declaring a calorific value of 475 B.Th.U. per cubic foot, the conditions being complied with as follows:—

3 parts of straight coal gas of 530 B.Th.U. per cubic foot
brought down with
1 part of blue water gas, slightly carburetted water gas, or gas from a complete gasification plant with a calorific power of, say, 340 B.Th.U.

This gives an average mixed gas of about 482 B.Th.U. per cubic foot, *i.e.* a slight margin above the "declared" calorific value.

The above-mentioned proportion of lower grade gas gives a certain amount of flexibility in manufacture, and in this way allowance may be made for bad coals,

breakdown, etc. There is, of course, always a good deal of flexibility with a coal-gas plant. For instance, the coal gas yield could be stretched a further 500 cubic feet per ton of coal, the falling off in quality being made up by a slightly richer gas from the complete gasification plant, or a little more oil in the carburetted water-gas plant. The whole, of course, is essentially a question of relative economy.

ESTIMATED COST FOR A 500-MILLION WORKS

In drawing up specifications for a gasworks of some definite capacity it is invariably the practice to put down apparatus of a sufficient size to take up future requirements.

In the following estimate, however, this has not been done, for it is desired to show the reasonable cost of producing and distributing about 500 million cubic feet per annum—the expenditure on a works having its apparatus designed with a view to dealing with an output of an additional 20–40 per cent. cannot be taken as exemplifying the minimum outlay. For this reason the figures will probably be considered by some as being on the low side.

It is assumed that about 25 per cent. of water gas will be made, on the average. All costs include foundations, and relate to average conditions such as prevail at the present day. It will be appreciated, however, that any endeavour to standardize costs under prevailing conditions is a most unsatisfactory task, and the author includes the following table merely as an illustration and approximate guide as to how the total expenditure is absorbed.

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
Land . .	1½ acres per 100 millions per annum, or 3¼ acres per million per diem.				
	7 acres at £700 . . .	4,900	22·3	39·2	0·58
Horizontal Retort Bench Foundations, Flooring, all Iron-work and Accessories	Settings of "tens" suitable, 20 feet retorts (*i.e.* five tiers of two) as occupying least ground space. Assume "make per mouth-piece" 9,000 cubic feet per diem, machine charging.				
	Carried forward . . . . £	4,900	22·3	39·2	0·58

		£	£ per mouthpiece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . £	4,900	22·3	39·2	0·58
	Required make (maximum per day) $= \frac{\text{annual make}}{240} = 2{\cdot}1$ million cubic feet. Less 25 per cent. for water gas, 1,600,000 cubic feet of coal gas per diem. Make per setting $9{,}000 \times 20 =$ 180,000 cubic feet. No. of settings required $\frac{1{,}600{,}000}{180{,}000}$, say 9. In addition 20 per cent. should be allowed for retorts "scurfing" or otherwise out of action, bringing the total number of beds up to 11. Average cost, including foundations and accessories, chimney, etc., £160 per mouthpiece, *i.e.* 220×160	35,200	160·0	*281·6	4·14
Retort House and Coal Store	Capacity in cubic feet required for 11 settings. *Length.*—Each setting 9 feet 6 inches + 12½ per cent. for passages, outside walls, etc. = 120 feet. *Width.*—Assume projector charging from one side only.				
		ft.			
	Width of bench . . .	20			
	Floor space. Charging side	23			
	,, ,, Discharging side	17			
	Total	60			
	Carried forward . . . . £	40,100	182·3	320·8	4·72

* See note page 28.

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . £	40,100	182·3	320·8	4·72
COAL STORAGE	Three weeks' storage under cover. Max. day's coal consumption $= \frac{1,600,000}{12,800} = 125$ tons. Three weeks' storage $125 \times 21 = 2,625$ tons. Coal will occupy $2,625 \times 42 = 110,200$ cubic feet.				
	Depth must not exceed 20 feet, preferably 16 feet. Length of house is 120 feet. Then required width for coal store (if coal stacked 16 feet deep) to give this capacity = 58 feet, say 60 feet. Total effective width of house				
		ft.			
	$= 60 + 60 =$ . . .	120			
	Add for division walls .	2			
	Total internal width .	122			
	Height.—Dependent upon type of house. Stage house most suitable.				
		ft. in.			
	Height, ground level to working stage . .	9 6			
	Height, working stage to top of settings . .	15 0			
	Height, additional head-room for continuous hoppers, coal conveyors, etc.	16 6			
	Total to eaves . .	41 0			
	Carried forward . . . . £	40,100	182·3	320·8	4·72

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . . £	40,100	182·3	320·8	4·72
	Rise of roof about $\frac{1}{4}$ of span $\frac{60}{4}$ = 15 feet. *Internal Capacity.*—120 feet long × 122 feet wide × 48 feet high (this is mean height of building to half-way up roof) = 700,000 cubic feet. Assume a steel-framed, brick-panelled structure at 6½*d.* per cubic foot (including foundations)	19,000	86·4	*152·0	2·23
Coal Elevators	Breakers, conveyors, breaker pits, overhead hoppers, coke trucks, rails, etc. In this case average cost per mouthpiece for above would be £42. 220 mouthpieces at £42 . . .	9,250	42·0	74·0	1·09
	N.B.—Coke conveyors would be in addition to this, say £11 to £14 per foot, or an additional cost of £2,500 to £3,200, according to length	2,800	12·7	22·4	0·33
	Projector, pusher, trolley wire, cabling and accessories . .	4,800	21·8	38·4	0·56
Power Plant	Gas engines, dynamos switchboard, cabling and all accessories. In this case average cost per mouthpiece £14 to £17.	3,500	15·9	28·0	0·41
Condensers	Max. hourly make = $\frac{\text{daily make}}{22}$				
	Carried forward . . . . £	79,450	361·1	635·6	9·34

* Owing to the excess retort capacity allowed, the figures given (£281·6 and £152) for complete cost of retort house would naturally undergo some reduction if full carbonizing capacity was made use of.

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . £	79,450	361·1	635·6	9·34
	$= \frac{1,600,000}{22} = 75,000$ cubic feet per hour.				
	Two water-tube condensers to take 35,000 to 45,000 cubic feet per hour each, fitted complete. .	2,700	12·3	21·6	0·32
EXHAUSTERS	One at 80,000–90,000 cubic feet per hour.				
	One at 60,000 cubic feet per hour.				
	Engine of about 10 h.p. required for large exhauster, 7½ h.p. for smaller one. (Note that two exhausters are provided, the smaller set to be used for summer output)	2,000	9·1	16·0	0·24
WASHER-SCRUBBER	Say vertical centrifugal type to take 80,000 cubic feet per hour. Complete with engine and bevel gear drive	2,000	9·1	16·0	0·24
TOWER SCRUBBERS	Total capacity on basis of 6 cubic feet per 1,000 cubic feet of gas per diem. 1,600 × 6 × 9,600 cubic feet.				
	Two scrubbers each 35 feet high by 14 feet diameter would be suitable, thus giving 5,400 cubic feet for each vessel; an allowance of 12 per cent. in excess of the maximum	5,600	25·4	44·8	0·66
	One could be cleaned out at a time in the summer.				
DRY PURIFICATION PLANT	Assume that oxide only is to be used. Then a set of four purifiers at the minimum allowance,				
	Carried forward . . . . £	91,750	417·0	734·0	10·80

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . . £	91,750	417·0	734·0	10·80
	worked in rotation, with two small catch boxes would suffice. Area required for each box 0·5 square foot per 1,000 cubic feet per diem. 1,600 × 0·5 = 800 square feet, *i.e.* boxes 28 or 30 feet square by 6 feet deep.				
	Size of connections as per rule on page 600, $\sqrt{800} - \frac{1}{5} = 28$ less $5\frac{1}{2} = 22\frac{1}{2}$, say 21 inches.				
	Total plant—complete with all valves, lifting gear, etc. . .	11,000	50·0	88·0	1·29
STATION METER STORAGE .	To pass 75,000–80,000 cubic feet per hour, 24 inch connections	2,000	9·1	16·0	0·24
	One holder (in addition to water-gas relief holder) is here assumed, although if the works had grown from small beginnings there would be more. As the works has a water-gas plant, 18 hours' storage should be ample.				
	Total make (water gas and coal gas) 2·1 million cubic feet per diem. 18 hours' storage 1·6 million cubic feet.				
	Telescopic gasholder, with guide framing and tank (brick and puddle).				
	A suitable holder for this capacity would have the following dimensions :—				
	Diameter of tank, 160 feet × 30 feet deep.				
	3 lifts with the following diameters :				
	Carried forward . . . . . £	104,750	476·1	838·0	12·33

		£	£ per mouth-piece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . £	104,750	476·1	838·0	12·33
	157 feet 6 inches 155 feet 152 feet 6 inches with an effective depth of about 28 feet 6 inches. Approximate cost £35 per 1,000 cubic feet	56,000	254·6	448·0	6·59
GOVERNORS.	Dependent upon system of distribution employed, but assuming three in operation	1,100	5·0	8·8	0·13
PUMPS . .	Liquor, tar and water. . . .	800	3·6	6·4	0·09
STEAM BOILERS	(Exclusive of water-gas plant), for driving pumps, exhausters, sulphate plant, etc. Two required—one as a stand-by, including seatings	4,000	18·2	32·0	0·47
BUILDINGS .	(Other than retort and water-gas houses.) *Exhauster House.*—(Say) 20,000 cubic feet capacity, at 1*s.* .	1,000	4·5	8·0	0·12
	Meter and Governor House.—Do. .	1,000	4·5	8·0	0·12
	Boiler House.—12,000 cubic feet, at 9*d.*, also chimney . . .	700	3·2	5·6	0·08
	Generating House, Stokers' Lobbies, etc.—25,000 cubic feet, at 1*s.*	1,250	5·8	10·0	0·15
	Steel-framed purifying shed to cover purifiers and preparing floor, 11,500 square feet area, at 3*s.* 9*d.*	2,150	9·8	17·2	0·25
TAR AND LIQUOR STORAGE	One or more wells brick-rendered. Minimum capacity 5 weeks, maximum make of tar and liquor (say) 190,000 gallons, then capacity required 30,000				
	Carried forward . . . . £	172,750	785·3	1,382·0	20·33

		£	£ per mouthpiece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	Brought forward . . . . £	172,750	785·3	1,382·0	20·33
	cubic feet, *i.e.* well 60 feet × 50 feet × 10 feet deep, divided into two or more sections. Average cost per cubic foot = 1*s.* 6*d.*.	2,250	10·2	18·0	0·26
PAVING, DRAINING, FENCING & INCIDENTALS	. . . . .	3,500	15·9	28·0	0·41
SULPHATE PLANT	(Exclusive of steam boilers), with purifiers for waste gases. Approximate make 325 tons per annum, or (say) 5 tons per day working 65 days per year . .	3,000	13·6	24·0	0·35
	Building for above plant. 30,000 cubic feet, at 1*s.* 2*d.* per cubic foot	1,750	8·0	14·0	0·21
VARIOUS .	*i.e.* Tools, carts, weighbridge, and other appurtenances . . .	2,800	12·7	22·4	0·33
	Offices, laboratory, manager's or foreman's house, furniture and equipment. Stores	15,000	68·2	120·0	1·76
MAINS (Steam, water and gas connections)	On works only	9,500	43·2	76·0	1·12
	Total expenditure on works (less water-gas apparatus) . . £	210,550	957·1	1,684·4	24·7
	From the above it is seen that the complete equipment of a works of this size entails an expenditure of over £950 per mouthpiece, and about £1,680 per ton of coal carbonized per maximum day. This, of course, is exclusive of				

		£	£ per mouthpiece.	£ per ton of coal per max. day.	£ per therm produced per max. day.
	expenditure on water-gas plant. The cost per 1,000 cubic feet per maximum diem would be £131. Based on thermal values the cost is £25 per therm produced per maximum day. At 6 per cent. interest, capital charges would amount to 1½*d.* per therm on the annual production. It must be borne in mind, however, that the land, fencing, offices, stores, and accessories are in excess of the coal gas production, and to this extent the capital and interest may be reduced.				£25

CARBURETTED WATER-GAS PLANT

	£	£ per therm produced per max. day.
Make per day 25 per cent. of total make = 500,000 cubic feet.		
Plant in two sections, each 250,000 to 275,000 cubic feet capacity per diem. Complete with generators, carburettors, superheaters, scrubbers, condensers, and operating floor; also blowers and engines for same, tar well, coke lift, pumps, etc. . . .	10,000	5·87
Boilers and seatings for above	3,200	1·89
Exhausters (in duplicate), 25,000 cubic feet per hour, with engines .	1,250	0·74
Purifiers for oxide of iron only, 20 feet × 20 feet × 5 feet deep, complete with connections and lifting gear	5,000	2·94
Building for water-gas apparatus, 65,000 cubic feet, at 1*s.* to 1*s.* 1*d.*	3,500	2·06
Shed for purifiers, with preparing floor to cover 6,000 square feet, at 3*s.* 9*d.*	1,120	0·66
Oil-storage tank. Forty-two days' consumption at 1 gallon per 1,000 cubic feet of gas made, 21,000 gallons, complete with fittings	700	0·41
Carried forward . . . £	24,770	14·57

	£	£ per therm produced per max. day.
Brought forward . . £	24,770	14·57
Meter to pass 25,000 cubic feet per hour	750	0·44
Relief holder, 35,000 cubic feet capacity, at £125 per 1,000 cubic feet	4,400	2·59
Gas, tar, steam and water connections	750	0·44
Total cost of complete water-gas plant, *i.e.* £61 per 1,000 cubic feet per max. diem	£30,670	18·04
(*N.B.*—For a comparatively small outlay, either section could be increased to 300,000–350,000 cubic feet per diem.)		
Cost of coal-gas plant	210,550	24·77
Total cost of works . . . . . £	241,220	23·83

Cost per million cubic feet *made* per annum . . £482
[1] Cost per million cubic feet *sold* per annum . . £502
Cost per 1,000 cubic feet *made* per max. diem.. . £115
Cost per 100,000 B.Th.U.'s *made* per max. diem. . £23 17*s.*

The costs per therm of the water-gas installation are based on the quality of gas taken in this illustration, *i.e.* 340 B.Th.U. per cubic foot. The figures given are not, therefore, a true indication of the capabilities of a water-gas plant in this direction. Thus, if 1 gallon of oil per 1,000 cubic feet was used for carburation, a thermal value of 400 B.Th.U. per cubic foot would be expected, this giving a reduction of about 15 per cent. on the cost per therm produced[2] per maximum day. If $2\frac{1}{3}$ gallons of oil were used a gas approaching 530 B.Th.U. would be produced, this giving a reduction in the cost per therm of about 36 per cent. as compared with the figure given in the tabulated data above. With a blue water-gas plant (utilizing oil or tar spraying to bring up the quality to 340 B.Th.U.) the outlay would be approximately as follows:—

	£
Generator plant (in two sections)	7,500
Boilers and settings	3,200
Exhausters	1,250
Purifiers	4,500
Buildings	3,000
Purifier shed	1,000
Meter	750
Relief holder	4,400
Connections, etc.	700
	£26,300
Cost per therm per maximum day	£15 10*s.*

[1] Estimated at 480 million cubic feet.
[2] N.B.—This is on capital cost of plant, not manufacturing cost of gas.

For a complete gasification plant the outlay would be approximately the same as above. Considerable saving could, of course, be effected by taking the gas direct from the generator of the water-gas plant to the coal-gas mains, the two undergoing purification, etc., together.

DISTRIBUTION

Without knowing the general outlines of the district and the system of distribution to be adopted, whether high-pressure mains will be run in addition to low-pressure, or whether "boosting" will be necessary, it is difficult to give anything more than an approximate figure under this item.

With present high prices a great saving can be effected by adopting high pressures on the trunk mains in combination with reducing governors on the service mains. Thus, if there are 10 miles of district mains—varying from 12 to 24 inches diameter—the cost of installing these would now be about £80,000. On the other hand, gas could be distributed by high-pressure mains of from 6 to 8 inches diameter at a cost of about £35,000.

As regards services, no undertaking can now afford to instal 40-feet services free of charge, and in many instances the builder or consumer pays the whole or a substantial portion of the cost. Free internal carcassing may now be said to be a thing of the past for consumers through ordinary meters, although some portion of the expense may be borne by the gas undertaking in the case of slot consumers.

The following figures may be taken as typical. In their compilation consideration has been given to the above-mentioned factors.

		£
Mains	About 100 miles; these would vary from about 8 inches high-pressure trunk mains to 4 inches for the smaller service mains	200,000
Services	To supply 6,500 "ordinary" and 8,500 "slot" consumers, also for industrial purposes part cost only.	17,000
Meters	"Ordinary," 6,500, including fixing, at £4 10*s.* each	29,250
	Prepayment installations, 8,500 at £12 10*s.* each, inclusive of meter cooker, 3 fittings, part cost of piping, etc.	106,250
Cookers, Fires, etc.	For "ordinary" consumers (including fixing) (say) 6,500	40,000
	Total cost of distribution equipment . . .	£392,500

N.B.—Columns and lamps for public lighting are usually the property of the local authority; but, if rented from the gas company, the cost to the latter would be about £12 10*s.* per lamp complete, including column, lantern, and service. In the

above instance from 1,200 to 1,400 may be required, entailing an additional expenditure of about £16,500.

SUMMARY

	£	Percentages of total outlay.
Total cost of works	241,220	34·9
Total cost of distribution	392,500	56·8
Engineering and contingencies, 7½ per cent. . .	47,530	6·9
Law and Parliamentary charges, 1½ per cent. .	9,500	1·4
	£690,750	100·0

Capital expended per million cubic feet *made* per annum . . £1,381
Capital expended per million cubic feet *sold* ,, . . £1,439
Capital expended per thousand cubic feet *made* per max. day . £329
Capital expenditure per therm *sold* per annum . . . 6*s.* 0½*d.*
Capital expenditure per therm *made* per max. day . . . £69 6*s.*

If, therefore, a new works had to be built and the district provided at current prices the capital charges on a 6 per cent. basis would amount to 20·7*d.* per 1,000 cubic feet sold, or 4·36*d.* per therm sold. Fortunately, a large proportion of the capital employed in the gas industry was expended during a period of low prices, and it is, accordingly, mainly extensions which demand such an excessive outlay.

This is not the case, however, in small townships now being developed, so that the numerous garden villages and similar projects will be faced with an unprecedented expenditure unless they are within touch of an established gas undertaking.

The foregoing estimate has been set out more or less in detail in order to show the methods employed for arriving at the approximate outlay entailed in the erection of a comparatively large works. In order, however, that some guide may be given as to the manner of estimating for small works, it has been thought advisable to include figures which may be taken as typical for, firstly, a 50 million cubic feet per annum works, and, secondly, for a 15 million cubic feet undertaking. The items given are taken from actual figures for works erected shortly before the war, and the costs are tabulated in order that a ready comparison may be made between the actual costs of each item in the two undertakings, as well as between the pre-war and current costs.

The figures given for Works "A" concern an undertaking selling 50 million cubic feet per annum in a semi-country district, with small mining and other industries, and a population of from 14,000 to 15,000.

The sale of gas is made up as follows:—

1,500 prepayment consumers at 12,000 cubic feet	18	mills. per annum.
900 ordinary consumers at 33,000 cubic feet .	30	,, ,,
Public lighting	2	,, ,,
	50	millions.

The figures for Works "B" are for the 15 million undertaking, made up of three small towns in a partly rural and partly residential district. The sales are accounted for as follows:—

500 prepayment consumers at 11,000 cubic feet	5·5	mills. per annum.
300 ordinary consumers at 32,000 cubic feet .	9·6	,, ,,
Public lighting	0·5	,, ,,
	15·6	millions.

In the latter case it will be noted that the length and cost of mains is excessive, owing to the linking-up of townships by a large proportion of unproductive main. All costs include connections and foundations complete.

COSTS OF WORKS AND DISTRIBUTING PLANT

	"A" 50 millions.		"B" 15 millions.	
	Actual Cost.	Present Cost.	Actual Cost.	Present Cost.
	£	£	£	£
Land: "A," ¾ acre; "B," 1 acre. . .	500	600	300	400
Fencing, paving and draining	160	400	100	250
Retort house and coal store	1,700	4,300	720	2,000
Retort settings, floorings, chimney, accessories ("B" has very small margin) . . .	2,550	7,000	780	2,400
Condenser	150	520	60	220
Exhausters ("A" in duplicate), also engines	350	850	120	320
Coal truckway for feeding store	240	650	—	—
Scrubber	355	1,000	150	500
Livesey washer	100	320	—	—
Purifiers and oxide shed and traveller complete ("A" of ample size, "B" slightly deficient)	1,100	3,750	400	1,350
Station meter	380	1,100	100	280
Holder (one in each case)	5,280	16,000	2,060	6,200
Governor (one in each case)	110	320	45	120
Boilers (in duplicate), seating, and chimney	730	2,000	—	—
Tar and liquor storage.	370	1,000	75	200
Buildings, stores, etc.	650	1,550	340	850
Small pumps, tanks, tools, etc.	180	500	100	300

	"A" 50 millions.		"B" 15 millions.	
	Actual Cost.	Present Cost.	Actual Cost.	Present Cost.
	£	£	£	£
Works connections (small for "A," extensive for "B")	220	800	170	650
Weighbridge	65	200	—	—
	15,200	42,860	5,520	16,040
Engineering and contingencies	1,000	2,000	130	300
Total works costs	£16,200	44,860	5,650	16,340
Mains: "A," 18 miles; "B," 10 miles	9,800	39,000	5,200	20,000
Services, ordinary and slot	2,450	3,000	830	1,000*
Meters, ordinary, including fixing	1,750	4,000	610	1,400
Stoves and fires, ordinary consumers (and fixing)	1,450	4,300	400	1,200
Prepayment installations, complete, including 3 points, 3-1t. or 5-1t. meter, and cooker or griller	6,750	18,000	2,380	6,000*
	22,200	68,300	9,420	29,600
Engineering and contingencies	600	1,200	90	250
Total distribution costs	£22,800	69,500	9,510	29,850
Works	16,200	44,860	5,650	16,340
District	22,800	69,500	9,510	29,850
Parliamentary and promotion costs	2,000	4,040	610	1,210
Total capital outlay	£41,000	118,400	15,770	47,400
Capital cost per million *sold*: Works	324	897	360	1,047
District	456	1,390	606	1,914
Parliamentary	40	81	39	78
Total	£820	2,368	1,005	3,039
Capital Charges on 6 per cent. Basis. Pence per 1,000 cubic feet	11·81	34·10	14·47	44·76
Capital Charges on 6 per cent. Basis. Pence per therm (Based on the sale of Gas at 500 B.Th.U.'s.)	2·36	6·82	2·89	8·95

* Part cost of services or "carcassing."

From the above figures it is seen that a 15 million cubic feet per annum works requires nearly 4*s*. per 1,000 cubic feet for its permanent and floating capital costs. A 50 million cubic feet works would require 3*s*. The figures in themselves should be sufficient to impress upon those who are considering sites for new townships the extreme importance of selecting their sites within easy reach of an established gas undertaking.

CHAPTER II

FOUNDATIONS, GASWORKS BUILDINGS, ETC.

EMPHASIS has already been laid upon the advisability of securing a gasworks site which is of low level in comparison with the major portion of the district to be supplied. The works, however, will not necessarily be erected on the lowest-lying portion, as it may give rise to trouble in connection with water or bad foundations. Certainly, money may usually be saved in the first instance ; but unsuitable, spongy subsoils are almost invariably associated with land of this description, and untold damage may afterwards be occasioned by abnormal flooding. Nevertheless, in some cases other attractions may more than balance the prospect of an excessive expenditure on foundations, and gasworks have before now been erected on land reclaimed from the sea. Accordingly, the choice of the site must not be influenced by consideration of the immediate saving, and the various factors require to be carefully balanced before any hasty decision is come to.

Before a site is definitely purchased, trial borings must be sunk, so that a fair indication of the substrata may be obtained. On an extensive site one such boring is by no means sufficient, as comparatively abrupt changes in the character of the strata are frequently found. The more general practice is to sink a circular boring about four feet in diameter, the sides of the excavation being shuttered up by means of a light wooden casing as the digging advances. The casings are usually worked in about 6-feet lengths. A less costly and laborious method consists in driving down a special boring auger, which brings the core to the surface as it proceeds, thus enabling an accurate knowledge of the character of the subsoil to be obtained. An auger, complete with the necessary boring outfit, is shown in Fig. 1. The first step is to sink a shallow pit 3 or 4 feet deep by about 4 feet square, and to shutter this up with timber. The shear-legs are then erected over the centre of the pit, and the boring rope is connected to the end of a special joint rod, to the other end of which the auger itself is attached. The auger is then drilled into the earth by a twisting motion, and periodically withdrawn by means of the windlass for the removal of the strata. The sketch shows a " clay " auger in use. It is found that with normal soils of the clay and soft gravel type a core of strata about 3 feet in length may be brought up at each operation. In the event of the soil proving extremely hard, and of a rocky nature, a special tool of a chisel type is employed, and the strata broken up by a series of blows. Strata drills of this kind may be used for boring shafts of from 4 inches to 2 feet in diameter ; for most purposes

the smaller holes will give ample indication of the nature of the ground. The 4-inch boring is, however, not to be advised; and for the majority of sites the 8-inch drill—as stipulated by the London County Council—is certainly to be recommended. Having once bored the hole, observations of the rise and fall of water must be made. These should extend over some period, and may usually be carried out merely by dipping at fairly frequent intervals, particular attention being given to the effect of heavy rainstorms, or other causes likely to influence the water level. Trial boreholes must on all occasions be taken lower than the probable depth of the foundations, so as to remove all doubt as to the character of the proposed bed; whilst strata of a gravelly nature should be regarded with suspicion, in that they may eventually prove to be interspersed with seams of running sand.

The information obtained from borings about the nature of the ground is not always reliable. Certain classes of boring machinery, particularly in rock, yield cores which give information of great value, but often it is very difficult to form a just estimation of the ground when the material has to be broken up by the drill before it is brought to the surface. All that is obtained is, after all, a rough idea of the nature of the ground at the exact spot where the boring has been made, and often very different information is obtained if the boring is made 50 feet north, south, east, or west. Again, borings give very little information as regards the quantity of water which may be met with, and dealing with which may be a very important item both in cost and in time. It is also very difficult to determine by borings what effect the pressure of the ground may have on the works or what safe

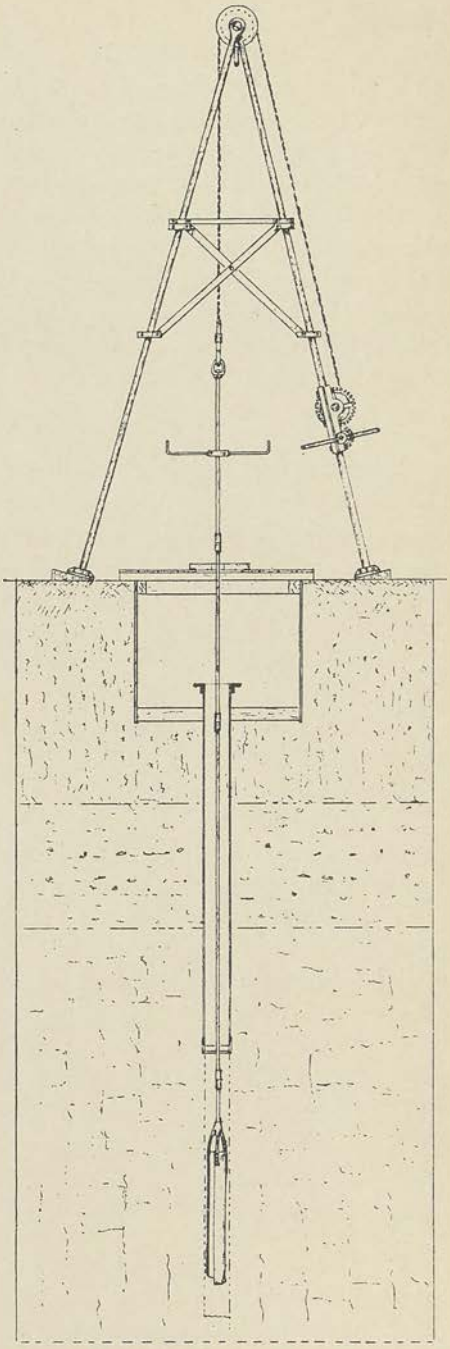


FIG. 1.—STRATA DRILL IN OPERATION, FITTED WITH BORING AUGER TO RECOVER SUBSOIL IN LENGTHS OF 3 FEET 6 INCHES.

foundation pressures can be adopted. In such cases long experience is the principal base to work from, and even then considerable latitude is left to the personal factor and even the imagination of the engineer. There have been cases, though rare, in which the borings have been carelessly and inaccurately made and wrongly described, and sometimes the difficulties of putting down borings are so great that hope of information from that source must be abandoned.

Before the excavation proper for foundations is commenced steps must be taken for the adequate control of all surface and sub-surface water; in fact, it may in abnormal cases be found profitable to lay down a drainage system which is capable of dealing with water to a depth somewhat below that of the proposed excavations. This procedure is, however, decidedly costly, and should only be countenanced in extreme instances.

FOUNDATIONS

When the depth of an excavation exceeds a few feet, some method of timbering must usually be employed, whilst when the depth is greater than 10 feet, considerable precaution is necessary, so much so that the Board of Trade prescribe that in such cases an expert should be called in. The excavation of ground for gasholder tanks calls for particular care and experience. In general, foundations are classed under the two headings of "natural" and "artificial," according as to whether the ground requires special treatment other than shallow excavation. In this country the four most common subsoils to be met with are (*a*) ordinary earthy material, (*b*) hard and soft clay, (*c*) gravel, and (*d*) chalk; and it is the compressible soils of the soft clay and earthy types which demand the greatest amount of attention.

It may be said that as a general rule (particularly where foundations for retort benches are concerned) it will be profitable to put down a solid block of concrete, so long as the total depth does not exceed 5 feet. Beyond this the procedure becomes expensive, and one of the various "artificial" methods should be resorted to. The cost of excavation will, of course, largely depend upon the material which is being taken out; but if a good ganger is in charge, he will often find some means of selling the débris, or of getting it carted away by a local contractor free of charge. When the conditions of the substrata necessitate a comparatively deep foundation, or when the soil is more or less compressible, the following methods may be employed:—

(*a*) Concrete piers.
(*b*) Floating foundation.
(*c*) Piles, either wood, metal, or reinforced concrete.

Particulars of the pier methods are shown in Fig. 2, from which it will be seen that the complete area is first excavated to a depth of a few feet, whilst at intervals shafts are sunk through the soft soil on to the stable ground. The dimensions of these shafts vary with the purpose for which the foundation is required, but they will usually run about 2 feet in width, and extend laterally the entire breadth of

the foundation. For buildings, etc., the piers may be so much as from 20 to 25 feet apart, rough arches being thrown from pier to pier by digging out the ground, so as to form a centering. When dealing with retort bench foundations it is usual to drop down a pier beneath each supporting wall of the main setting-arches ; hence in such cases the piers are pitched at about 8 to 10 feet centres. When the subsoil necessitates sinking to a greater depth than 12 feet, it is advisable to discard the pier method, and to drive down reinforced concrete piles, which may be employed in the form of continuous piers, or spaced at equal distances apart. In the latter case the stability of the upper slab should be ensured by running some type of reinforcement, such as old railway metals, from head to head of the piles, or by introducing one of the many systems of special bars or metal. In fact, any method may be employed which has the effect of forming a continuous slab by binding the heads of the piles together, thus ensuring equal loading.

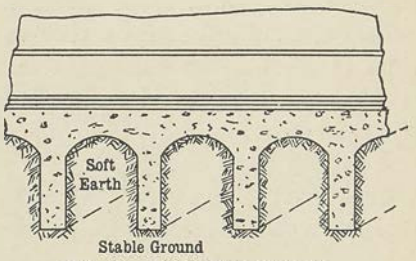


FIG. 2.—PIER FOUNDATION.

As regards the construction and use of piles, it has been shown by experiments carried out by A. S. E. Ackermann that, for equal depths, tapered piles support a greater load per unit volume of the pile than piles having parallel sides. This, in particular, refers to piles driven into clay. The reason is that in the case of tapered piles their surfaces keep in more intimate contact with the clay, with the result that the support due to the friction on their sides is greater than is the case in parallel piles. In order to increase the resistance of piles they should be corrugated as well as tapered. The reasons why parallel piles with blunt ends are not so efficient per unit volume is that the pile in entering the clay rubs the surfaces near the top of the hole so much that the friction (or cohesion) is reduced there, and also because the clay in squeezing laterally from under the end partially loses contact with the sides of the pile, thus also reducing the friction on which the supporting capacity of a pile depends. The mean intensity of friction for the same depth of penetration on the sides of parallel piles is greater in the case of piles of small cross section than in the case of larger ones ; but if the diameter of the pile be reduced beyond a certain amount (the depth of penetration being constant), then the mean intensity of the friction appears to decrease again. Consequently for a given quantity of material of which to make piles a large number of small piles is more efficient than a smaller number of large ones. Pointed piles are more efficient per unit volumes of pile than blunt ones because the points cause a more gradual lateral displacement of the clay, thus leaving it in more intimate contact with the sides of the pile. The action of the point of a pile is to cause the pressure of fluidity to be attained on its surface, whereupon the clay flows out of the way.

The resistance to penetration is considerably greater the lower the temperature of the clay, probably because the pressure of fluidity increases as the temperature decreases. The density of clay decreases as the percentage of water increases.

The work done per unit volume of displacement increases as the angle of taper decreases, but when the taper approaches 0, or is 0, then the work done is less than when the angle of taper is larger. When a disk is forced into clay, the sides of the hole do not crush in (unless a certain critical depth be attained) because the pressure of fluidity of the clay having been attained immediately under the disk, the clay flows laterally; but the moment it has escaped from beneath the disk the pressure is reduced to the statical pressure corresponding to the local head of clay, and when this is less than the pressure of fluidity the clay does not flow into the hole made by the disk. If, however, the penetration of the disk be carried far enough, then ultimately the statical head of clay will be equal to the pressure of fluidity and the sides of the hole near the bottom will crush in.

To-day, the favourite method of dealing with average compressible soil is by means of some type of floating foundation in the form of a raft, often with stiffening ribs as in a large ceiling. That is to say, the weight of the superstructure is distributed over a large area, so that the unit loading on the soil is within the recognized limit. In such cases the distribution of loading must be as equal as possible; otherwise, if sinking occurs, the whole may go slightly out of level. In this respect it must be remembered that it is frequently impossible to avoid a little sinking; but unequal sinking is the great danger. The once familiar type of grillage foundation, embracing an elaborate network of joists bolted together, is now giving way to reinforced concrete work, this having proved to be the most economical form of foundation which can be employed under most circumstances. An alternative but more expensive method is that of employing one of the many forms of metal sheet piling, thus completely enclosing the space to be built over. A very light raft spread over the enclosed area will then suffice. This is certainly an admirable way of dealing with soils of a spongy character. As an illustration of its efficacy, it may be mentioned that in America buildings have been erected on what has practically amounted to a body of water, the latter, being incompressible, affording an ideal support so long as lateral movement is effectively restrained.

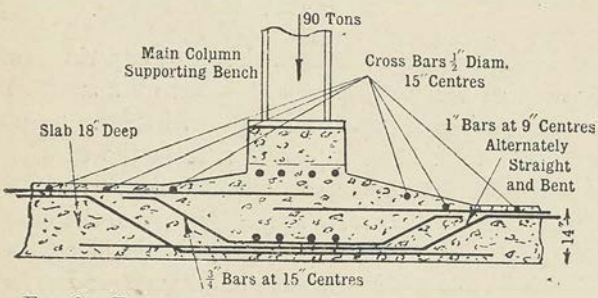


FIG. 3.—TYPICAL REINFORCED RAFT FOUNDATION FOR VERTICAL RETORT BENCH.

Some few years ago it was a common practice to set down raft foundations constructed from timbers tied together, also from fascines; but such methods may now be looked upon as things of the past. As an example of the modern slab foundation, an illustration of a method adopted for the erection of a vertical retort bench and house is shown in Fig. 3. Fig. 4 shows such a foundation with the reinforcement in position before the concrete is inserted. Here the slab is of a more or less shallow nature, but is heavily reinforced by means of indented bars. The

disposition of the bars is such that they are called upon to relieve the concrete of the greater part of the tensional and shear stresses. In the case shown the foundation was required to support several rows of columns, each carrying a load of approximately 90 tons ; accordingly the maximum reinforcement occurred in open squares in alignment with the columns, whilst the remaining portions of the slab were provided with considerably less reinforcement. When foundations of the floating type are employed on the more easily compressible soils, care is necessary to see that no derangement takes place, otherwise adjacent buildings may suffer disturbance. Foundations to-day, however, are not of the massive character employed in the past, owing to the tendency to erect light steel-framed buildings with a comparatively thin filling.

When dealing with reinforced concrete work it is essential that due consideration

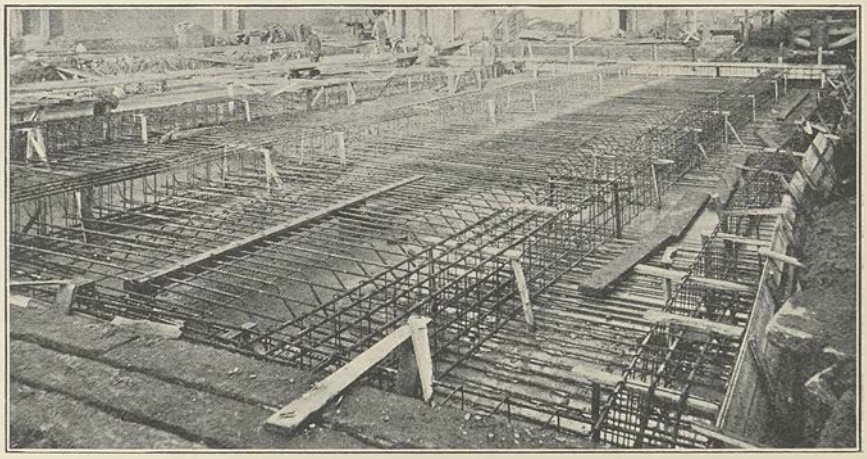


Fig. 4.—Reinforced Raft Foundation for Vertical Retort Bench, showing Indented Bars in position before concreting-up.

should be given to the avoidance of those influences which tend to promote corrosion of the iron and steelwork employed. Dr. Newton Friend has stated that preservation of the metalwork in concrete may be effected in one or more of three ways :— (1) By complete exclusion of air ; (2) by complete exclusion of water, and (3) by rendering the concrete sufficiently alkaline. If the engineer can make his concrete conform perfectly to any one of these conditions he will achieve his purpose, for the reinforcing metal will not rust. Unfortunately in practice materials cannot be relied upon to yield perfect results, but by conforming as nearly as is reasonably possible to all three conditions he may hope so to reduce the tendency to corrosion as to render it negligibly small within finite time.

The following considerations are, therefore, put forward as worthy of careful study :—

1. None of the concrete material should be too coarse, otherwise thorough

mixing and good contact between the different ingredients will not be as perfect as is desirable.

2. It is essential to press or pun the mixture well into position in order to eliminate voids, which tend to increase permeability to water and air and are in consequence highly dangerous.

3. A sufficient thickness of concrete should be applied to the metal. If too thin the concrete may not be sufficiently impervious or may crack mechanically, and thus admit water and air to the metal.

4. Stray electric currents must be avoided. Should the metal become anodic, rusting would take place in consequence of the liberation of oxygen, and this, leading to cracking, would rapidly destroy the cement.

5. Substances likely to contain acids or acid-producing bodies should be avoided. Coke breeze and slags are cases in point, as they frequently contain sulphur compounds.

6. The concrete may advantageously be coated with some waterproofing material to render it still more impervious, provided such proofing is entirely free from acids or acid-producing substances.

The author suggests that in cases where rolled steel joists are buried in concrete, such as in the construction of retort house floors, etc., the steelwork should firstly be painted with a cement wash made into a thin paste from ordinary Portland cement and water, and that the paste should be made thoroughly alkaline by the addition of a small quantity of lime or soda.

The question of the life of concrete is an important one, the main destructive agents being heat, frost, carbon dioxide, and salt water.

Cement or concrete begins to disintegrate under heat when a temperature of about 300° C. is reached, because the combined water is expelled. In reinforced concrete the coefficient of expansion of the concrete is practically the same as that of the steel, and value of reinforced concrete in fire resistance is due largely to this fact. But the heat conductivity of the steel is much greater than that of the concrete. Consequently, if the steel is covered with only a thin layer of concrete at any point, in case of fire, it will become heated more rapidly, expand at a greater rate and so set up internal stresses that may be disastrous.

If freezing occurs during the setting of the cement, the colloidal mass is to some degree prevented from consolidating. During the time prior to the completion of the set, a certain amount of free water exists in the interstices between the hydrating grains of cement. Under normal conditions this water diffuses through the colloidal coating of the grains and is used up by continued hydration. Then as the grains continue swelling they stick together and the mass consolidates. As freezing retards diffusion and hydration, these processes may be delayed to such an extent that the water will evaporate from the mortar and not leave enough for sufficient hydration when the temperature rises. This evaporation of water may occur even though the temperature remains below the freezing point. The effect of this drying is most noticeable on exposed surfaces and is very similar to that produced by using a cement mortar with a dry porous brick.

Further detriment results from the expansion that attends the freezing of the uncombined water. The expansion forces the grains apart, and although the hydration should continue after thawing, the consolidation would be imperfect and the structure lacking in strength. Frost chiefly proves destructive when in the concrete mass there are fissures or hollows. Water collects in such hollows, and the force due to its expansion when frozen is liable to be followed by serious disintegration. Water containing carbon dioxide in solution is undesirable in that the constituents in the cement are liable to be transformed into soluble bicarbonate of calcium. So far as the action of salt or brackish water is concerned, opinions are to an extent contradictory, and when damage occurs it can usually be traced to the effect of alternate exposure to salt water and air. It is said that crystallization of the dissolved salts then occurs in the pores, and that the expansion brought about by this crystallization causes disintegration. The result of several experiments shows, however, that when concrete is carefully made and is constantly immersed in salt water practically no harm results.

Where foundations are above ground level the question of shuttering has to be considered, and it is as well to bear in mind that if the boards are given a good coat of lime-washing before use, they will come away far more easily and leave a clean even surface.

Another consideration is that of retort house subways, elevator pits, etc., which are sunk below the ground level. It is frequently found that water percolates through the concrete forming the walls, and is liable to give trouble. Various methods may be employed to overcome this, one of them being the insertion of a thin layer of pitch about half-way through the wall, and extending from top to bottom. An alternative is to paint the face of the walls with two or three coats of some solution such as " Ironite," the first coat being rubbed well into the pores and allowed to rust before the next coat is applied. This method is, on the whole, preferable to that of rendering the face of the wall with cement.

Allowable Pressures on Various Soils

Gravel (firm) with underlying chalk	6 to 7 tons per square foot
Firm gravel	5 „ 6 „ „ „ „
Firm clay	3 „ 4 „ „ „ „
Gravel (loose) and sand	1½ „ 2½ „ „ „ „
Light earth and sandy loam	¾ „ 1¼ „ „ „ „
Made-up ground (well rammed)	½ „ ¾ „ „ „ „

When slabs of concrete for retort benches are laid down on any type of clay it will be found profitable to drop a layer of fine sand (from 3 inches to 6 inches deep) on to the surface of the clay before filling in with concrete. Concrete, being of a homogeneous nature, readily conducts heat, so that in time the moisture is dried up from the clay, with the result that shrinkage occurs, and the whole may be thrown out of level. The strength of the concrete is a question to which due thought must be given, and this particularly applies to gasworks undertaking extensions, where there is usually a stock of " hard-core " on hand. The gas engineer

is very prone to get rid of his old broken retorts on such occasions, and in many instances there is little reason why these should not be used in moderation. It must be remembered, however, that the modern highly porous retort has a low crushing strength, and in view of this fact it is best excluded from the more important work. Cement concrete is nearly always used nowadays in preference to the lime variety, owing to its greater strength, and should seldom be mixed in higher ratios than 1 to 6, unless the ground is good, in which case a mixture of 1 to 8 or 9 may be safely used. The aggregate is best composed of a fairly coarse ballast, or hard bricks broken to a size not exceeding 2 inches, with an adequate proportion of sand. Care must be taken to see that all mortar adhering to the bricks is removed. Concrete mixers are a present-day fashion, but except for extensive building operations in reinforced work it is questionable whether they effect any marked economy. Many authorities are of the opinion that the hand-mixed material is far superior.

For brickwork purposes cement mortar, though more costly than the lime variety, should be used whenever possible. If lime mortar is to be used, however, a satisfactory mixture will be obtained by the following proportions: 1 of lime to 3 of sand. It has been said that for chimney work lime mortar is more suitable owing to its being more elastic than cement mortar.

It is difficult to lay down any hard and fast rule for the cost of foundations, but in the case of the ordinary rectangular slab an average figure at the present time would be 40*s.* to 50*s.* per cubic yard complete, including excavation to a depth not exceeding 4 feet.

Excavation only varies from 2*s.* 6*d.* to 4*s.* 3*d.* per cubic yard up to a depth of 4 feet; beyond this depth the cost will range between 4*s.* 6*d.* to 7*s.*, which includes light timbering.

MODERN GASWORKS BUILDINGS

Engineers in the past have not neglected to add an artistic touch to the architecture of the gasworks, and evidence of this is seen in the cast-iron embellishments, finials, etc., introduced for the supposed beautification of certain plant and buildings. It would appear, however, that the tendency of the present age is in the direction of utility alone, it being realized that under no circumstances can a gasworks be represented as ornamental; hence simplicity of design has commenced to assert itself at every turn. So far as the general style of buildings is concerned, economy goes hand-in-hand with simplicity of outline; accordingly these two must rank as primary considerations. Other factors bearing on the ultimate decision are:—

(*a*) Wear and tear, the cost of maintenance, re-painting, etc.

(*b*) The choice of materials suited to the purpose for which the building is required, *e.g.* in corrosive atmospheres material such as corrugated iron should be dispensed with.

(*c*) Adaptability for future extensions without the necessity for considerable destruction.

(*d*) Ample provision for the reception and dispatch of materials in connection

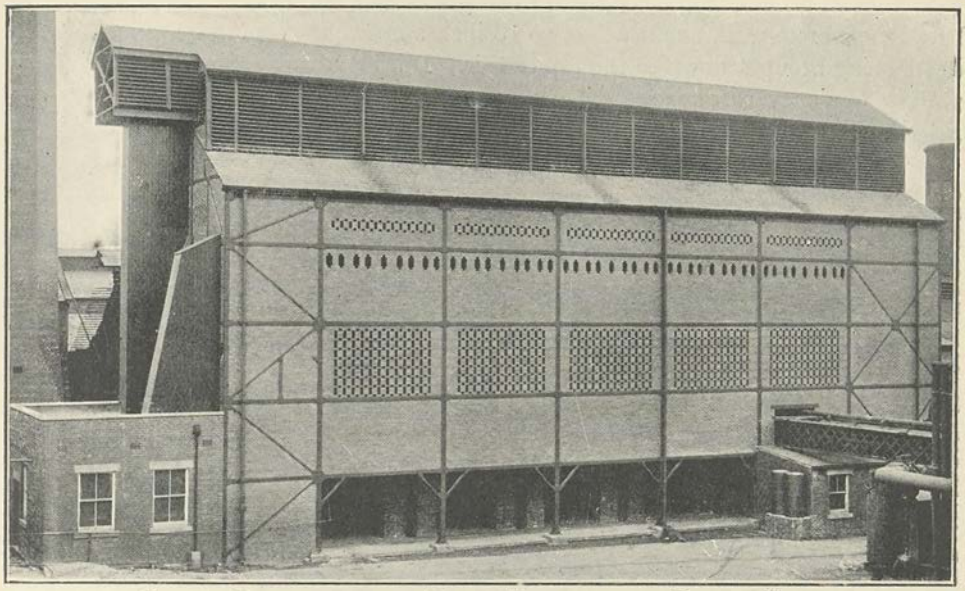


FIG. 5.—STEEL-FRAMED AND 4½-INCH BRICK-PANELLED RETORT HOUSE.

with the operation for which the building is required. In the case of engine houses, large entrance doors should be provided, so that the instalment of larger plant in the future will not necessitate cutting through walls.

(*e*) The buildings should be roomy, and of ample height, with efficient means for ensuring ventilation.

(*f*) There must be an abundance of light.

(*g*) The prevailing conditions should be easy and congenial for the men, facilities being afforded for keeping themselves and their apparatus in a state of cleanliness.

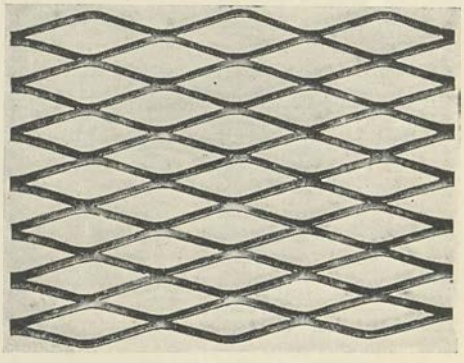


FIG. 6.—EXPANDED METAL.

In the past it was an almost universal custom to erect such buildings as retort houses of substantial dimensions in brickwork, although later the steel-framed structure entirely sheeted with corrugated iron found a certain amount of favour in small works. Both methods, however, have their disadvantages. The first is excellent once it is erected, but the capital expenditure is now excessive, being as much as 11*d*. to 13*d*. per cubic foot, inclusive of roof and foundations. Corrugated ironwork, on the other hand, is economical when considered in the light of first cost, but is a never-ending expense so far as maintenance and painting are concerned. In any case, if a corrugated structure is decided upon, it should be under-

stood that in no circumstances should the sheets be brought down to ground level. A dwarf concrete wall, about a foot to 18 inches in height, should be provided, the sheets being brought down to the top of this. During recent years there has been a growing tendency to dispense with both corrugated iron and massive brickwork, and the light steel-framed house panelled with thin brickwork is making considerable headway in this country. An illustration of this type of building, which can be effectively used for retort house, engine house, and all classes of buildings, is shown in Fig. 5, where the brickwork is $4\frac{1}{2}$ inches thick. The approximate cost, including foundations and roofing, is 5*d.* to 7*d.* per cubic foot of contents.



Fig. 7.—Trussed Concrete House at Poole Gasworks.

Another very cheap method of construction is that which introduces patent metal meshings, such as expanded metal or "Hy-rib." Retort houses and other buildings built up with the aid of such material are primarily provided with a steel frame, as in the case of the brick-panelled house, but the open squares between the main framing are filled in with the metal meshing, and the whole is then given a plaster coating. Examples of expanded metal-work are given in Figs. 6 and 7, whilst the "Hy-rib" is seen in Figs. 8, 9 and 10. The plaster is usually composed of 3 parts of Portland cement to 11 or 12 parts of sand, and the total thickness of the side walls varies from $1\frac{3}{4}$ inches to 3 inches, in accordance with the spacing of the supports. The approximate cost of a building on the "Hy-rib" principle amounts to an average of 5*d.* to $6\frac{1}{2}$*d.* per cubic foot of contents, which includes foundations, sashes, glazing, doors, or roller shutters. For vertical retort houses this type of structure has proved particularly suitable, this being largely due to the fact that the vertical house may be built far more lightly than that for horizontal retorts, owing to there being no heavy floors to support; but it is not to be recommended for buildings having an excessive number of sashes, openings, etc., as the extra cost of providing framing for these is appreciable.

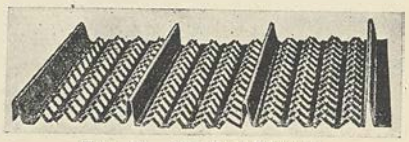


Fig. 8.—Hy-Rib Metal.

COMPARATIVE COSTS OF VARIOUS BUILDINGS

Massive brickwork, old type, slated roof	11*d.* to 13*d.* per cubic foot contents.
Entire brickwork (modern), slated roof	7*d.* „ 10*d.* „ „ „ „
Steel frame, corrugated sheeting throughout	6*d.* „ 7½*d.* „ „ „ „
Steel frame, brick panelling, slated roof	5*d.* „ 7*d.* „ „ „ „
Steel frame, trussed patent metal and plastered, slated roof	5*d.* „ 6½*d.* „ „ „ „

(All complete with foundations.)

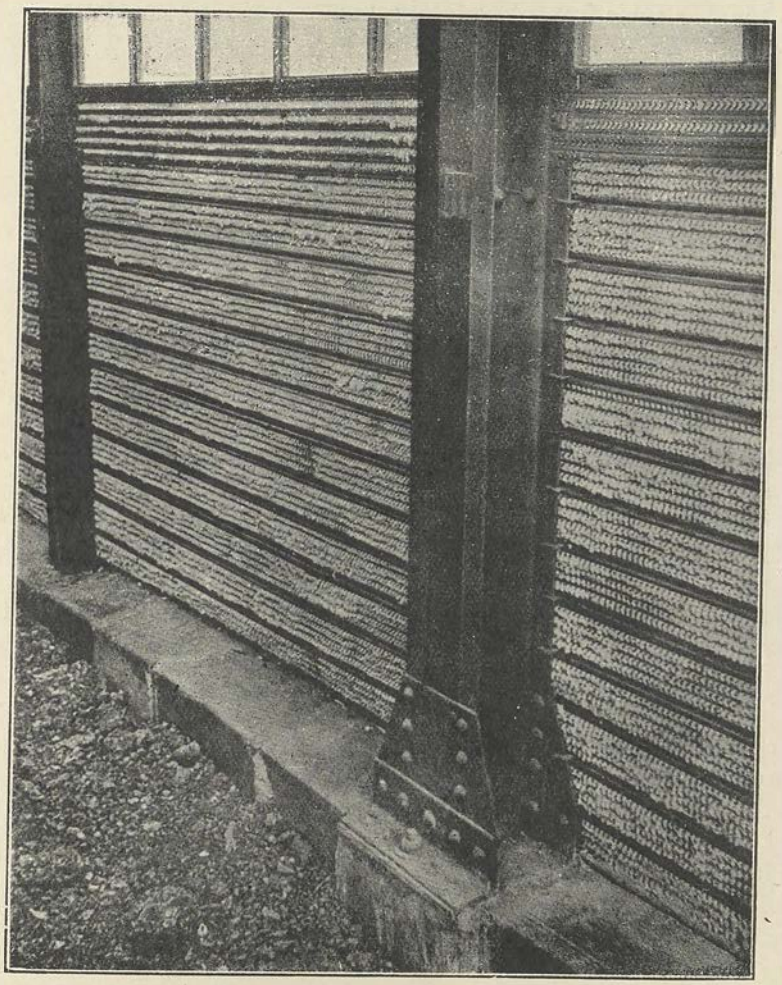


FIG. 9.—INTERIOR VIEW OF HY-RIB WALL AFTER ONE COAT OF PLASTER ON OUTSIDE.

In the case of the last-mentioned item, the expenditure would be made up approximately as follows :—

Foundations	1·5*d.*
Building	3·75*d.*
Roofing	1·25*d.*
	6·50*d.* per cubic foot.

With the concrete structure much depends, of course, on the comparative cost of bricks and ballast on the site. If the latter can be dug from the subsoil the concrete building is inapproachable on grounds of economy. In one instance, prior to the European War, a building of this type was recently erected for rather less than 1¾*d.* per cubic foot. The total capacity amounted to 750,000 cubic feet, the foundations were 6 to 8 feet deep, and the concrete forming the sides was shuttered up to a height of 24 feet, the remaining 10 feet to the eaves being composed of moulded concrete blocks. In this case ballast was obtainable from the site, and the major part of the foundations were composed of 3 parts of coke breeze, 3 parts of clinker, 3 parts of washed ballast, and 1 part of cement. The filling material and concrete blocks were made up of 7 to 8 to 1 concrete, 3 parts of this being ballast. In structures of this type care should be taken to ensure that clinker or breeze in the concrete does not come into actual contact with the steelwork.

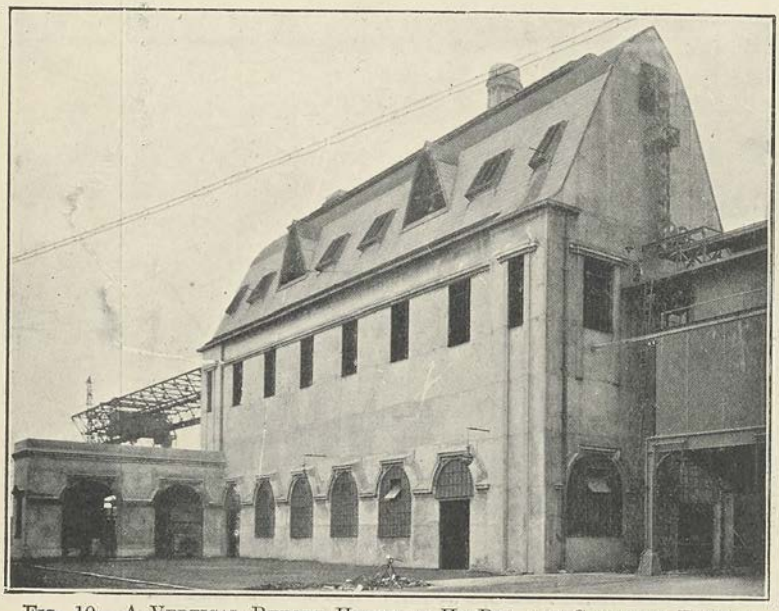


Fig. 10.—A Vertical Retort House in Hy-Rib and Concrete Filling.

So far as retort house construction is concerned at the present time, a usual rough rule for arriving at an approximate cost for a brick-panelled or brick and concrete house per mouthpiece to be installed is the following:—

For stage house	£70 to £125 per mouthpiece.
For subway house	£60 „ £115 „ „

These prices include merely the house and coal store, and no machinery, retort-bench work or flooring. They allow, however, for foundations. The lower margin

given applies to the larger houses of (say) more than 150 mouthpieces. For a medium-sized stage house take £70 to £100 per mouthpiece.

THE DESIGN OF COAL STORES

Although the brick-panelled or plastered-steel structure admirably serves the purpose of affording a covering to the retort bench, the whole question requires somewhat serious consideration when the storage of coal is concerned. Thin plaster, or 4½-inch brickwork walls are in no sense capable of withstanding for long the lateral thrusts of a deep coal heap, and although cases are known where such buildings are being used for the purpose without visible detriment, there is little doubt that the factor of safety is extremely low, and considerable risks must be run. For all this, there is no reason why the light concrete house should not be employed for storage purposes, so long as those portions acting as retaining walls are effectively reinforced on the inner or tension side. A good plan is to employ old railway metals, these being rigidly interlaced with piping or iron rods of about ½-inch to 1-inch diameter. In the light panelled buildings the steel framing must be closer and stronger, whilst a thin wall can be made of many of the patent reinforcements on the market.

If large coal-stocks are to be regularly maintained under cover it cannot be disputed that the entire brick building, panelled and buttressed, provides the best form of shelter. Formerly these structures were erected almost without exception, and the fact that they are still doing duty as both coal stores and houses to-day speaks well for their design and durability; and the same may be said of thick concrete or stone walls. If perfect reliance is to be felt, it is essential that the walls of coal stores should be designed on scientific lines, and the pressures due to the coal carefully computed. For this purpose the well-known Rankine formula for earth pressures may be employed, and the wall will be sufficiently stable if the middle-third condition is neglected, and the resultant pressure cuts the various sections within the width of the base at any one section. In working out the pressure the weight of ordinary bituminous coal may be taken as 54 lb. per cubic foot, and the angle of repose as 45°. Then the formula is:—

$$P = \frac{Wh^2}{2}\left(\frac{1 - \text{Sin } \varphi}{1 + \text{Sin } \varphi}\right)$$

Where P = total pressure per foot run at a depth of h feet.
W = weight of coal per cubic foot = 54 lb.
φ = the angle of repose of coal = 45°.

For instance, suppose it is required to find the thickness of walls necessary for stacking coal to a depth of 15 feet. Then—

$$P = \frac{54 \times 225}{2}\left(\frac{1 - \text{Sin } 45}{1 + \text{Sin } 45}\right). \quad \left(\text{Sin } 45° = \frac{1}{\sqrt{2}}\right)$$

From this, P is found to be 1,042 lb. at a depth of 15 feet, or an average pressure of 69 lb. per square foot. This gives the total horizontal pressure at the bottom

of the wall, and from the triangle of forces the position of the resultant may be found, and, accordingly, the thickness of the wall at the base. If the same treatment is applied to find the pressure at various depths, the allowable decrease in thickness as the wall rises is obtained.

In cases where the wall simply serves as a retaining wall, so that coal can be surcharged above it, the formula must be used in the following somewhat complicated form, viz. :—

$$P = \frac{Wh^2}{2} \cdot \text{Cos } \gamma \left(\frac{\text{Cos } \gamma - \sqrt{\text{Cos}^2 \gamma - \text{Cos}^2 \varphi}}{\text{Cos } \gamma + \sqrt{\text{Cos}^2 \gamma - \text{Cos}^2 \varphi}} \right)$$

where γ is the angle of surcharge.

This, however, reduces itself to a simple and easily workable form when the angle of surcharge is equal to the angle of repose of the coal, as would nearly always be the case. The formula then becomes :—

$$P = \frac{Wh^2}{2} \cdot \text{Cos } \varphi$$

The above treatment, of course, applies to the stacking of broken or small coal. When the coal itself is formed into a wall (as commonly seen in railway yards), a reduced wall-thickness may be taken.

When the erection of coal stores is contemplated, the question of chief importance is as to whether the projected floor-level is of sufficient height to escape ground water after a heavy rainfall, also its relation to the level of the retort-house working stage. The floor should preferably be paved with slabs of stone or concrete, and designed so that moisture can drain away. In this respect the design in Fig. 12 is to be preferred to that shown in Fig. 11. The practice is often followed of dividing

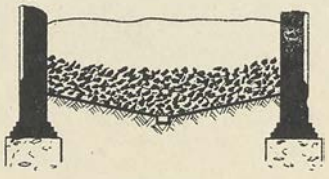


Fig. 11.

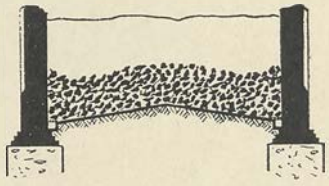


Fig. 12.

the store into separate bins by means of vertical cross-walls, and this is certainly of advantage in preventing a fire from spreading. Moreover, each of these bins can be made of a definite capacity (so many tons per foot of depth), which enables a good idea of the stock to be obtained at a glance. Iron columns and ties passing through bins should be avoided as far as possible, as they are said to favour the spread of fire—in any case, they should be coated with concrete. Plenty of fresh air in the covered store is an important item, for men suffer from the ill-effects of a poorly ventilated building. This is supposed to be due to the vapours of acetaldehyde, which are known to interfere with respiration. Ventilation is best provided for by a continuous louvre running along the roof of the store, or by large openings made above the level at which it is proposed to stack coal.

TYPES OF RETORT HOUSES

There are two standard types of retort houses to be found in use at the present day, whilst a third but less common structure is also met with at some works. These are :—

(*a*) Stage houses.
(*b*) Subway houses.
(*c*) Intermediate type. A combination of (*a*) and (*b*).

Included under (*a*) are all those houses in which the clinkering-floor is on the ground-level, whilst the charging-floor is elevated. The modern vertical retort house, although differing from the horizontal type in many respects, would also come under this heading. The former houses are invariably of greater height than the latter, averaging (for the 25-foot retorts) about 60 feet to the eaves, whilst horizontal houses are seldom more than 40 feet. "Vertical" houses, moreover, can be made of fairly light design, as—unlike the house for "horizontals"—they have only to support themselves, and to withstand the wind pressure to which they may be subjected. In the subway house the charging-floor is on a level with the mean ground-level, the ground being excavated so that producers, slides, etc., are all below. The intermediate type is seldom met with, and includes all those houses which have the charging-floor partly above ground-level and the clinkering-floor below it. The existence of a subway house may in many instances be accounted for by the fact that a works originally started in a more or less small way with direct fired settings —in which case a single floor is sufficient, this being at ground-level. As business increased it may have been decided to adopt some more efficient type of firing, which, owing to the increased room required in order to ensure a deeper fuel bed, means either raising the roof or excavating, the latter course very frequently being preferred. Before making a decision, however, great care is necessary to see that the surface of the proposed foundation will not be below the high-water level. In any case, it is preferable to enclose the whole of the subway with an impervious sheeting. This may be done by lining the sides with concrete, backed with puddle, or with rendered brickwork; but preferably by building twin walls and filling in the intervening space with pitch.

In spite of the increased expenditure entailed with the stage house, it is almost without exception the favourite for modern retort-house work. The conditions under which men are called upon to do their work receive far greater attention than in the past, and it is generally recognized that the intense heat of the majority of subways, with the escaping steam arising from quenched coke or clinker, and the inability to adequately ventilate the subways, is anything but conducive to the honest performance of duty. On the other hand, the stage house can be effectively ventilated, coke quenching is facilitated, and steam can be quickly got rid of. The coke, moreover, can be wheeled out direct into carts, this also applying to ashes and clinker. In the case of the subway house, some means has to be provided for bringing the ashes (and in many cases the whole of the coke) to ground-level.

So far as the intake of coal is concerned, the subway house will in some instances

hold the advantage, in that the coal when deposited in the store is at charging-level. With the medium- and larger-sized houses this cannot, however, be said to be of great importance, owing to the common use of some form of coal-handling plant. With small houses, where hand-charging is in vogue, the point is of some importance.

The distance between the upper and lower floor-levels varies from 5 to 10 feet,

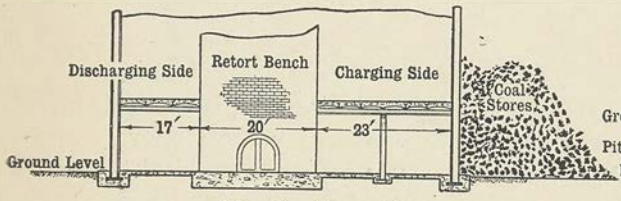


FIG. 13.—STAGE HOUSE.

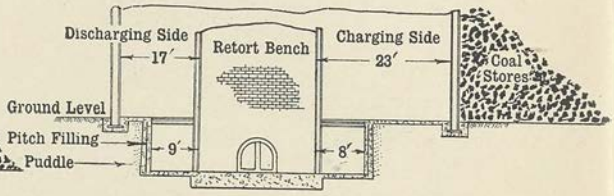


FIG. 14.—SUBWAY HOUSE.

the former being the allowance in very small subway houses; but if adequate depth is to be given to the producer, the height should not be less than 8 feet. As regards this, it will be seen from Fig. 13 that in the stage house the difference between the floor-levels accounts for a certain bulk of coal which has to be brought to the working

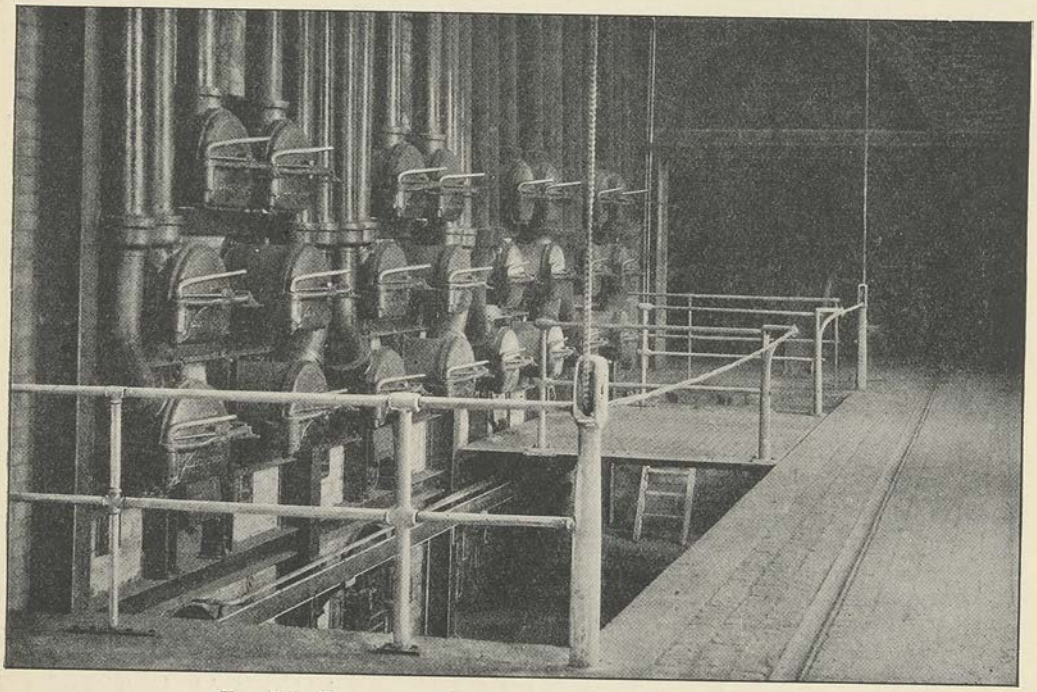


FIG. 15.—TRAVELLING FLOOR FOR SUBWAY RETORT HOUSE.

stage. This increases the cost of handling, unless the store is fitted with elevators for feeding overhead hoppers. This is not the case with the arrangement shown in Fig. 14.

A point which has accounted for a good deal of discussion is the effect of the type of house on the air supply to the producers. Some authorities have objection to the stage type owing to its tendency to set up draughts that may influence the composition of the furnace gases. On the other hand, it is said that a freer air supply is obtained, therefore more regular working of the producers. The author can point to cases where the subway, on the side of the retort bench opposite to that which contains the producers, has been made only some 3 feet in width with no provision whatever for ventilation. An analysis of the air in such a subway shows only some 15 per cent. of oxygen, with the result that it is almost impossible to obtain a sufficiency of secondary air.

As a general rule it will be found that water is the deciding factor, and if this is found near the surface, a stage house should forthwith be decided upon.

Concerning relative costs, it may be taken that the stage house costs anything from £5 to £15 more per mouthpiece than the subway type costs.

In smaller works the subway may be left entirely uncovered, and the retorts operated from a travelling platform running on ball-bearings, and readily operated by hand. In such cases the precaution must be taken of railing off the subway, unless this is provided for by a running cable as shown in Fig. 15.

RETORT-HOUSE ROOFS

The use of timber for the construction of principals must be avoided in retort houses. The building for horizontal benches is usually provided with an all-steel truss ; the well-known " English " or " French " types made up of all-rolled sections are effective and economical. Slates are the most general covering, although many forms of patent compressed asbestos sheets and tiles, costing about 25 per cent. less than slates, have recently been introduced with success. Owing to somewhat heavy deterioration due to corrosion, steel used in retort-house roofs and other work should not be highly stressed, and a factor of safety of 7 on the breaking strength should be allowed for, *i.e.* a stress not exceeding $4\frac{1}{2}$ tons per square inch in tension or compression. All the members of roof trusses should preferably be made from angles or tees instead of flats or rounds, as these sections are better able to withstand the slight compressive stresses which may come on members which are normally in tension as a result of reversal of wind.

RETORT-HOUSE FLOORS

Except in connection with the smaller works the stage house will usually be decided upon, as the many contingent advantages will be found to neutralize the additional first cost entailed. For small works, where stoking apparatus (such as the manual type) is in use, the floor, whether at ground-level or above it, is frequently composed of $\frac{3}{8}$-inch or $\frac{1}{2}$-inch chequer plates, bolted down to cross joists. For the larger works, where heavy machines giving rise to high rolling loads have to be allowed for, additional strength is necessary, and wear and tear on a chequer-plate floor is considerable. Several types of retort-house floors are shown in Fig. 16,

and within recent years a tendency has developed to employ some system of reinforced concrete as shown. A serviceable method of building the concrete arches is that of fixing in sheets of thin metal or corrugated iron, these being left in after the work is finished.

A point requiring attention is that of allowing ample room for expansion of the joists composing the floor; otherwise, when expansion of the bench and joists sets in, serious stressing may result in the ultimate yielding of some portion of the structure. It is certainly preferable to arrange for independent columns some inches from the buck-stays, the main floor girders being carried on these, so that the whole floor is completely independent of the bench.

Owing to the continued quenching of coke, the clinkering of fires, etc., the under portion of the steelwork where exposed is particularly liable to corrosion. An effective method of preventing this is to cover the lower webs of the joists with cement, which may be made to cling permanently by attaching a strip of expanded

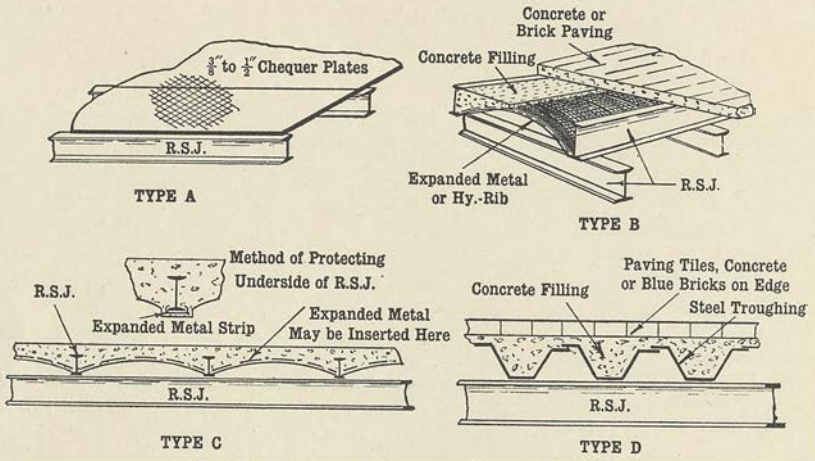


Fig. 16.—Types of Retort-House Floors.

metal as shown in type C, Fig. 16. Another method is that of attaching a ½-inch cast-iron plate to the underside of the bottom flanges of the main joists. The plate should overlap the flange by about an inch on either side, when the joist can be concreted up solid from it.

The variation in size of retort-house floors makes it difficult to lay down more than approximate figures for their cost. In the main, however, the following may now be looked upon as average examples:—

Stage floor.	Chequer plates on single joists . .	6*s.* to 7*s.* 6*d.* per square foot.
,, ,,	Double joists, concrete arches . .	9*s.* ,, 12*s.* ,, ,, ,,
,, ,,	Single joist, trough and concrete .	11*s.* ,, 13*s.* ,, ,, ,,
,, ,,	For charging side, heavy machine .	13*s.* ,, 15*s.* ,, ,, ,,

As the wear upon gasworks floors is somewhat considerable, it is advisable to avoid breeze and clinker in the concrete used for the floors. Where there is

a thickness greater than $3\frac{1}{2}$ inches, the best material will be made from 4 parts of aggregate, 2 parts of sand, and 1 part of Portland cement. If the stresses on the floor are computed, the concrete should be neglected and merely regarded as filling, whilst in the case of large retort-house floors the machine loaded to its maximum should be dealt with as a rolling load. The weight, furthermore, must be assumed to act on three wheels only, this often being the temporary condition of affairs, due to a faulty rail, or to some external influence. The centre columns (*see* Fig. 13) usually associated with these heavy floors must be strong enough to take the rolling load and any eccentricity of loading which may be caused by the above-mentioned factors.

In the erection of ironwork, bolts should only be employed where riveting is impossible or unsuitable ; and, when used, bolts should be burred over after tightening up. The question as to whether holes should be drilled or punched is one of long-standing argument, and it should be remembered that punching, though quicker, gives a tapered hole in addition to setting up crystallization of the metal around the hole, thus causing weakness. Drilled holes are certainly to be preferred, and they should be made $\frac{1}{16}$-inch larger in diameter than the bolt up to $\frac{5}{8}$-inch bolts, and $\frac{1}{8}$-inch larger for bolts above $\frac{5}{8}$-inch.

CHAPTER III

THE HORIZONTAL RETORT BENCH

THE practice of laying retorts horizontally is still the most common in this country. In spite of the perfection to which other types of carbonizing plant has been brought, the older method is as yet able to hold its own, and there is little fear that within the present generation it will be universally supplanted. So far as the smaller works are concerned, the horizontal bench is more convenient, and less costly in the first place; and, up to the present, vertical installations have been chiefly confined to those works where comparatively large quantities of coal can be handled with a considerable saving in working expenses.

There are three types of horizontal settings in common use to-day. These are:

1. Direct-fired settings.
2. Semi-gaseous settings.
3. Gaseous-fired settings.

Types 2 and 3, which are gradually taking the place of the more extravagant direct-fired settings, may again be subdivided as follows:—

(*a*) Generator settings.
(*b*) Regenerator settings.
(*c*) Those heated by means of outside producers of various types.

Although the initial cost of the gaseous-fired setting is greater than that of the direct-fired setting, the additional outlay is soon redeemed by the saving effected in fuel. For this reason even small works are finding it profitable to instal at least the generator principle, and it may be said in general that the direct system should be confined to those works making less than 2 or 3 million cubic feet per annum. In such cases, interest on additional capital and extra labour entailed in supervision make the gaseous system a doubtful advantage. In the "direct" furnace the air passes through the coke in large and often unrestricted quantities, and combines with the carbon to form CO_2 directly. In the gaseous settings the retorts are heated by the exothermic reaction of the combination of CO and oxygen in burning to CO_2. The great drawback of the direct furnace is the difficulty of controlling the air supply, which results in a considerably increased consumption of fuel, together with irregular heating of the setting. In fact, in very small works, where the plant is not making gas throughout the whole twenty-four hours, cases have been known where all the coke has been made use of for heating the retorts, and in isolated

instances an additional quantity of fuel has had to be purchased from outside. About double the quantity of air enters the furnace than is theoretically necessary, which has the effect of retarding combustion and reducing the limit of temperature. This is chiefly due to the large volumes of nitrogen introduced with the air, and the defect has been overcome in some measure by employing the semi-gaseous system.

The quantity of fuel necessary for the carbonization of coal has, by the curtailment of thermal losses in every direction, been reduced to such fine limits that at the present day, under ideal conditions, the coke required is only about 11 per cent. of the original weight of coal. The fuel consumed under the various systems is normally as follows :—

Direct-fired furnace	40 per cent. of coke made used as fuel.
Generator furnace	22 to 26 „ „ „ „
Regenerator furnace	16 „ 20 „ „ „ „
Vertical retorts—	
(*a*) Intermittent type	23 „ „ „ „
(*b*) Continuous type	16½ „ 18½ „ „ „ „
Outside producers	18½ „ 23 „ „ „ „

In giving figures such as the above the basis of coke and breeze made per ton of coal carbonized on which the figures have been calculated must always be stated. In the present instance the yield has been taken as 14 cwts. per ton. It is owing to the widely varying yields of coke from coals that this method of gauging fuel results is somewhat unsatisfactory, and the most reliable basis is that of "lbs. of fuel used per 100 lb. of coal carbonized," such as given in the table below. Chief importance, however, attaches to the coke *actually sold* per ton of coal, and so long as this amounts to more than 10 cwts. the economy of the system of firing is above question.

Direct-fired furnace	28 per cent. of original weight of coal carbonized used as fuel.
Generator furnace	15 to 18 „ „ „ „ „
Regenerator furnace	11 „ 14 „ „ „ „ „
Vertical retorts—	
(*a*) Intermittent type	16 „ „ „ „ „
(*b*) Continuous type	11½ „ „ „ „ „
Outside producers	13 „ 16 „ „ „ „ „

The apparently low fuel figures for the continuous vertical system are chiefly accounted for by the fact that the heat is extracted from the coke before it leaves the retort, and is utilized for heating up either the primary or secondary air before combustion. It must be pointed out, however, that fuel figures for verticals are at present more or less in the nature of experiments, as there has as yet been little opportunity of making comparisons over prolonged periods. The figures given above, in fact, may be looked upon as the most favourable obtained in operating vertical retorts, and for the sake of comparison the following results,[1] obtained

[1] Extracted from figures given by J. West, *Proc. S. Association Gas Engs.*, November, 1917.

from actual tests carried out with continuous verticals subjected to steaming, are appended :—

	Coke sold per ton of coal.	Per cent. used as fuel and in steaming.
(*a*) Beresford Seam Coal	10 cwts.	37·5 per cent. of total coke made.
(*b*) Haigh Moor.	11 „	18·8 „ „ „ „
(*c*) Lanark Washed Nuts	9·25 „	29·6 (approximate).
(*d*) „ „ „	10·12 „	22·0 (approximate).

The above tests would seem to indicate that there is a good deal of divergence in fuel results obtained with verticals. It must be remembered, however, that the figures for coke sold exclude that portion of the coke utilized in making blue water gas *in situ*.

An interesting illustration of the quantity of coke sold per ton of coal carbonized is obtained by a consideration of the average figure of the three metropolitan gas undertakings. These undertakings employ horizontal retorts almost exclusively.

Average Coke Sold per Ton of Coal (Metropolitan Gas Companies).

Year.	Sold.	Per cent. used as fuel.
1895.	9·65 cwts.	22 per cent. of total coke made.
1905.	9·55 „	23 „ „ „ „
1915.	9·71 „	21 „ „ „ „
1916.	9·91 „	20 „ „ „ „
1917.	9·98 „	18 „ „ „ „
1918.	10·05 „	17·5 „ „ „ „

The above figures indicate that the proportion of coke employed for carbonization of the coal shows a gradual tendency to decrease as improved methods of firing are introduced.

THEORY OF COMBUSTION

An elementary scientific fact which must be realized at the outset is that a definite amount of coke, whether burnt at once to CO_2 in the direct fire, or in two stages, as in the gaseous furnace, in each instance yields a similar number of heat units. This may be simply illustrated as follows :—

(1) 1 lb. of carbon burnt direct to CO_2 evolves (approximately) . 14,600 B.Th.U.
(2) 1 lb. of carbon burnt to CO evolves . . . . . 4,400 „
1 lb. of CO burnt to CO_2 evolves . . . . . 4,371 „

1st stage. 1 lb. of carbon—

$$C + \tfrac{1}{2}(O_2) = CO$$

1 lb. C = 2·33$\dot{3}$ lb. CO = 4,400 B.Th.U.

2nd stage . . 2·33$\dot{3}$ lb. CO = 2·33$\dot{3}$ × 4,371 = 10,200 „

Total 14,600 „

From the above it will be seen that the greater efficiency of the gaseous principle is not due to the fact that an increased number of heat units are expelled; the reason is that the heat is obtained in that portion of the setting where it is most useful, and the bulk of gases resulting from total combustion is reduced to the smallest practicable limits. It is not proposed to deal here with the calculation of combustion temperatures, as the procedure is explained in most textbooks on physics, and is of little practical use to the gas engineer.

The ultimate limiting temperature is influenced—

(*a*) By the calorific power of the fuel.

(*b*) By the total weight of the products of combustion and their specific heat.

(*c*) By the temperature of the mixture before combustion.

Of these, the first is under control to only a limited extent, as the fuel used—coke—has to be taken as it comes, the calorific power depending upon the type of coal carbonized at the time. It is largely by working on conditions (*b*) and (*c*) that the increased firing efficiency of the present day has been obtained. With regard to the total weight of the products, it will be seen that the greater the quantity of air admitted to the furnace for the combustion of a definite amount of fuel the greater will be the weight of the waste products over which a fixed number of heat units will be spread. Hence, the ideal condition is that of admitting just sufficient air for combustion, and reducing the weights of the waste products to a minimum—in which case the heat units are concentrated in the smallest possible volume and a maximum temperature is obtained.

It will be as well to explain here the meaning of the term "Calorific Intensity," which must on no account be confused with calorific power, from which it differs. Calorific intensity is measured in degrees Fahrenheit or Centigrade, and is the maximum temperature theoretically attainable under the conditions of combustion prevailing; hence it depends very largely upon the way in which the fuel is employed.

Producer gas resulting from the combustion of coke should theoretically consist of 34·8 per cent. of carbon monoxide and 65·2 per cent. of nitrogen, by volume. In practice, however, ideal conditions are not to be looked for, and the ordinary individual retort-bench producer is considered to be giving satisfactory results when the carbon monoxide content of the gas averages 25 per cent., the carbon dioxide amounting to about 5 per cent., although higher proportions of CO are occasionally found. The modern combustion chamber temperature rarely, if ever, exceeds 1,535° C.(2,800° Fahr.), and under normal working conditions is usually found in the neighbourhood of 1,370° C., with an actual retort temperature of 1,030°–1,100° C. Several causes account for the reduced intensity, among them being the variations in the depth of fuel-bed, the effect of clinker on the velocity of travel of the gases, and the various sources of thermal losses.

The actual temperature of the fire is of some importance; and whilst the recognized gasworks rule is that of keeping the fuel-bed cool, this axiom can be carried too far, for the maximum proportion of carbon monoxide is reached at a fuel-bed temperature of about 750°–800° C. The prevailing temperature is from 950°–1,000° C.

Producer gas from retort furnaces seldom consists of merely CO, CO_2, and nitro-

gen; for, owing to the modern use of a small supply of steam, also to the impossibility of ensuring the entire "burning-off" of all coke charged from the retort into the furnace, a certain quantity of hydrogen and methane is invariably present. The following, in fact, is the average composition under good conditions:—

Carbon monoxide	25	per cent. by volume.
Carbon dioxide	5	„ „
Hydrogen	6	„ „
Methane	1	„ „
Nitrogen	63	„ „

With regard to the regulation of the weight of the combustion products, the gas engineer keeps the weight to a minimum by manipulation of the furnace dampers in conjunction with analyses of the waste gases. In order to allow for variation in the composition of the producer gas no attempt is made to admit the *exact* quantity of air required; but the waste of fuel is curtailed by ensuring a slight excess of air—in other words, by admitting sufficient air until oxygen is present in the waste-flue gases. The absence of oxygen in these gases is a fairly sure indication of the presence of carbon monoxide—the latter being a useful combustible product, and accounting for the blue flame so frequently to be seen emerging from the chimney shafts of improperly worked settings. An analysis of the gas drawn from the waste flues of a retort setting should approximate very closely to—

Carbon dioxide	19·0	per cent.
Oxygen	0·4	„
Nitrogen	80·6	„

If oxygen is absent, then CO will almost surely be present, and the secondary air should be increased until the required conditions are obtained. At the same time, the above percentage of oxygen is quite within the limits of practical adjustment, and any excess should be curtailed by a reduction of the secondary-air supply.

THE EFFECT OF REGENERATION

It has been pointed out that the ultimate combustion temperature is governed in part by the temperature of the mixture before ignition takes place. This being the case, the quantity of heat in the gases before combustion can be added to the heat of combustion; thus the total quantity of heat available for raising the temperature of the waste products is increased in proportion to the intensity of the preliminary heating. Before the introduction of the regenerator, one of the chief causes of loss arose from the escape of the waste products from the retort settings at unnecessarily high temperatures, this occurring in both "direct-fired" and generator settings. In the latter type the secondary air is certainly heated up, but merely at the expense of the producer; and the system owes its greater efficiency mainly to the reduction of losses by radiation, to its flexibility, and to increased facilities for the regulation of the air supply. In such cases the normal temperature at which the gases are allowed to leave the setting is in the neighbourhood of 950° C.; but by the transference of sensible heat from these gases to the inflowing secondary air

the temperature of the gases has, in the modern regenerator, been reduced to 530°–650° C. before their escape is permitted, this accounting for a saving in fuel of from 6 to 11 per cent. compared with the generator setting. In the ordinary way the secondary air approaches a temperature of 950° C. before combustion.

THEORY OF REACTIONS

The exact nature of the reactions occurring in the fuel-bed during the formation of producer gas is still open to doubt. Argument is chiefly waged round the question as to whether the carbonic oxide is formed by direct combination between carbon and oxygen, or whether the greater proportions of it is the outcome of the reduction of carbon dioxide to the monoxide. Some valuable research on the subject has been carried out by Rhead and Wheeler,[1] who found strong evidence of the fact that neither carbon dioxide nor carbon monoxide is formed at the outset, but that both oxides are produced simultaneously as a result of the decomposition of a complex C_xO_y, which they regarded as the primary product of the combination of oxygen and solid carbon. Bone [2] regards this as being the best available hypothesis, and states that the production of the oxides of carbon in such a manner would be accompanied by a rapid attainment and adjustment of a mobile equilibrium in the reversible system—

$$2\ CO \rightleftarrows C + CO_2$$

in consonance with the temperature in each successive layer as the mixture of gases ascends through the fire. The whole theory, however, is complicated by the fact that, during the combustion of solid carbon, the above reversible reaction begins to manifest itself at approximately the same temperature as that at which oxidation begins. Thus, whilst CO_2 may be reduced to CO, the CO may in turn be dissociated into carbon and CO_2, an equilibrium being eventually established. Rhead and Wheeler, however, have recorded that the velocity of the reduction of carbon dioxide to carbon monoxide is invariably very much greater than the velocity at which carbon monoxide is dissociated. Perhaps the whole case cannot be better summed up than by quoting Bone,[3] who says that we are justified in concluding that in the lower layers of the furnace, where the incoming primary air meets the incandescent coke, there probably results very rapidly a mixture of CO and CO_2 in nearly the equilibrium proportions corresponding to the prevailing temperature, and to the partial pressures of these gases, and that at 1,200° C. (2,192° F.) and upwards CO will constitute nearly 99 per cent. of the total oxides of carbon present.

From the practical point of view of the gas engineer, however, it is perhaps as well to regard the finer considerations outlined above as chiefly of academic interest. With the modern appliances at his disposal the gas engineer judges the situation from its practical results, and he knows full well that when the depth of his fuel-bed falls below a minimum of some 4 feet, he obtains a high proportion of carbon dioxide in his producer gas, followed by greater heat in the producer than in the combustion

[1] *Trans. Chem. Soc.*, 1912, 101, 846, also 1913, 103, 461.
[2] *Coal and its Scientific Uses*, p. 171. [3] Loc. cit.

chamber. Hence, one of the golden rules of the retort house is the necessity for maintaining a deep fuel-bed (say, 6 feet) in the producer. Accordingly, in practical circles, it has generally come to be understood that in the ordinary process of the combustion of solid fuel, carbon dioxide is mainly formed under such conditions as prevail in the direct-fired furnace, that is to say, with a shallow layer of coke and an excess of air travelling at a relatively high velocity. The reaction would then merely be—

$$1 \text{ lb. } C + O_2 = CO_2 + 14{,}600 \text{ B.Th.U.}$$

When the fuel-bed is increased in depth, carbon dioxide gives way in great part to carbon monoxide, the general assumption being that the two following reactions occur at the base of the fire :—

(*a*) $C + O_2 = CO_2 + 14{,}600$ B.Th.U. per lb. of C.
(*b*) $2C + O_2 = 2CO + 4{,}400$,, ,,

Accordingly, in the lower layers of fuel there exist simultaneously hot carbon, carbon monoxide, and carbon dioxide, the last named reacting with the upper layers of incandescent carbon according to the well-known endothermic reducing action :—

$$CO_2 + C = 2CO - 5{,}850 \text{ B.Th.U. per lb. of C.}$$

This, of course, is the reversible reaction referred to above, and it must be borne in mind that high temperature favours the formation of carbon monoxide, whereas pressure tends in the reverse direction. As has been pointed out, however, this is a slow reaction, and as, moreover, the CO is being continually withdrawn, the effect of pressure in causing reversal is extremely small. The effect of temperature may be gauged from the results of Rhead and Wheeler, who found that at 850° C. (1,562° F.) the reduction of CO_2 to CO proceeded 166 times more rapidly than the reverse reaction.

The well-known experiments of Karl Wendt have established that, with a 7 feet 6 inches fuel-bed and air blast, equilibrium is attained at a height of from 20 to 30 inches above the plane of entry of the air, and that reversal of the reaction in the zones of lower temperature is shown by a slight increase in the CO_2 content at higher levels of the fuel-bed.

A series of tests carried out by the U.S. Bureau of Mines showed among other things that with a 6-inch bed of anthracite the oxygen is wholly consumed at a distance of from 3 to 4½ inches above the grate. The CO_2 reached a maximum of 15 per cent. at a distance of 2 to 3 inches above the grate, and then began to fall until, at the surface of the fuel-bed, it varied from 7 to 10 per cent. With a 6-inch bed of coke all oxygen disappeared at a height of 4½ inches above the grate.

PRINCIPAL LOSSES OF HEAT

Loss of heat, and, hence, waste of fuel in retort benches results mainly from the following causes :—

(*a*) Imperfect combustion of fuel. This may arise from imperfect regulation

of the air supplies, from bad design of the producers, from neglect to clean the fuel-bed, or from defective chimney draught.

(*b*) The use of a poor quality fuel containing a high proportion of ash.

(*c*) Ill-fitting cleaning doors or producer charging-lids. Also ill-fitting plugs in sight-holes, cleaning boxes, etc.

(*d*) Faulty stoking, resulting in the depth of the fuel falling below the prescribed level. Also neglect to level off the surface of the fuel-bed as far as possible.

(*e*) Poor heat transmission between waste gases and secondary air, resulting in high temperature of main waste-gas flue and chimney. A considerable proportion of the loss under this heading may be recovered by installing a waste-heat boiler system.

(*f*) Abnormal radiation losses, arising from imperfect lagging of all external walls.

(*g*) Extensive variation in the composition of the producer gas. It must be realized that secondary-air adjustment is made to conform with average conditions. Thus the influences which give rise to these conditions should be maintained as consistently as possible. Variation in producer-gas composition may chiefly be traced to fluctuation in the depth of the fuel-bed, probably resulting from too infrequent charging of the producer. The average producer, having a depth of from 6 to 8 feet, should never be permitted to go unreplenished for a period of longer than four hours.

The necessary operation of clinkering has a temporary ill-effect upon the producer gas; for, during the time when this is being carried out, the cleaning doors are open; and, therefore, air is passing through the fuel-bed in unrestricted quantities. The result is that temperatures in the retort setting are temporarily reduced by the excess of air, while the temperature of the fuel-bed is considerably increased owing to the complete combustion which is taking place therein. This means extravagance in the direction of fuel consumption, apart from the dislocation of the normal conditions prevailing with gaseous firing. The effect may be considerably modified by substituting a special type of grate (such as the Grille Grate), and by precluding the formation of clinker. The old-fashioned type of horizontal bar-grate, with its predisposition towards the formation of large masses of clinker, frequently entails a clinkering period of half an hour. With the modern sloping grate, however, removal of the friable ash can usually be effected in less than ten minutes.

In some instances at the present time it is customary to work with the producer cleaning doors removed. Primary-air adjustment is then effected by regulation of the main waste-gas dampers which are closed to about one-fifth of the damper opening employed with the doors in place. The method has its advantages, its chief merit being that the conditions remain practically constant throughout, as there is no increase in the quantity of air passing through the fuel-bed during the process of cleaning the fire. Incidentally, expense is saved as no doors are required. The only defect of such a method of working is that it does not permit of so fine an adjustment of combustion as is given by the employment of primary-air slides. Again,

the conditions are more easily influenced by the effect on chimney draught of changes in the direction and in the velocity of the wind.

(*h*) Insufficiency of producer gas. While, from the standpoint of analysis, regulation of the air supplies may be perfect, indifferent heats are none the less found. This is due to insufficiency of furnace gas. The most ready practical means of ascertaining whether the requisite quantity of gas is passing through the setting is to remove the inspection plug from the combustion chamber and to note, by holding a piece of lighted yarn to the open hole, whether conditions of vacuum or pressure are prevailing in the chamber. If the gas is deficient in quantity a vacuum will be found, and this should be transformed into a slight pressure by increasing the primary air-supply, with, of course, a corresponding increase of secondary air. On the other hand, the vacuum may be caused by excessive pull through the waste-gas dampers. Such conditions, however, are usually accompanied by roaring at the damper, and excessive heat of the base of the flue.

(*i*) Charging with "tacky" coke. A warning is necessary with regard to replenishing producers with badly carbonized or "tacky" coke; and if the charges in the retort are not fully burnt-off, their discharge into the furnaces should be postponed. The effect of sticky coke is to form a distillation zone on the top of the fuel-bed, thus a certain proportion of the heat of the fuel is absorbed in driving off the volatile constituents. Moreover, as the supply of secondary air has not been adjusted to deal with the extra volume of combustibles thus yielded, the result is that complete combustion of the furnace gas is not obtained. The defect shows itself in the form of black smoke issuing from the retort-house chimneys, or by the appearance of a red flame after dark.

(*j*) Short-circuiting. A general loss of efficiency results from short-circuiting, which most usually occurs when furnace linings are badly eroded and require removal. Accordingly, air from the secondary flues is passing into the fuel-bed and is followed by oxidation of the CO to CO_2. If leakage is severe, the only satisfactory manner of putting matters right is to let the bench down and to renew completely the brickwork forming the furnace cheeks. When the old brickwork is removed, the precaution should be taken of stopping up all tile joints in the exposed wall of the regenerator. With a properly constructed regenerator it is very seldom that leakage occurs between the secondary-air and waste-gas ducts. Moreover, as the vacuum in each of these ducts is almost identical, the effect of slight cracks, bad joints, etc., in the parting wall is not particularly serious.

THE EFFECT OF STEAM

Some precaution is necessary in the procedure of steaming the fuel. It is still in some cases the practice to provide water-sealed ash-pans for the producer, so that ashes falling through the firebars are quenched, with the formation of steam. At the same time, a longer life is ensured for the firebars by the provision of a continuous trickle of water—this giving rise to further quantities of steam. The primary duty of the steam is that of keeping the base of the fuel-bed cool in comparison with the remainder, so that excessive fluxing of the ash is prevented, and the formation

of clinker curtailed. In the author's Pressure Grille Grate the primary air is intimately mixed with steam prior to passing into the fuel-bed. Steam in passing up through the fuel is broken up into its elements, the oxygen combining with the carbon in the following manner—

$$C + H_2O = CO + H_2$$

This reaction, being endothermic, deprives the producer of heat; but the heat so lost has been instrumental in generating a further quantity of combustible gases (CO and H_2) which yield up an amount, not far short of the loss, when burnt in the combustion chamber and cooled down in the regenerator. What has in reality happened is that heat has been appropriated from the producer at a point where excessive temperatures are to be avoided and has been transferred, with a certain amount of loss, to the portion of the setting where maximum quantities of heat are desired. In this way steaming has a twofold value.

It will be seen, moreover, that by gasifying a portion of the carbon by means of steam, instead of wholly by air, the resulting gas contains less nitrogen, for that portion gasified by the steam consists of combustible gases alone. When steam is used, therefore, the proportion of combustibles in the producer gas is greater than is the case when air only is employed. Moreover, the rather lower temperature of the producer means a lower temperature of the issuing gas, a fact which in the ordinary type of retort setting is more than balanced by the increased potential heat which the gas carries; but which is of especial importance in those instances where external producers are employed, in which case a certain amount of cooling of the gas takes place before it reaches the combustion chamber. In cases such as the latter, therefore, the greater the exchange from sensible heat into potential heat the higher will the economy of the system be. Primarily, however, steam is employed in gasworks producers as a temperature regulator, the main provision being that of curtailing clinker. The quantity demanded must necessarily depend upon the character of the fuel, the moisture (if any) it contains, and the construction of the grate. The chief consideration is that of preventing fluxing of the ash, and the greater the fusibility of the ash the higher must the steam ratio be. Excessive steam, however, as shown below, leads to impoverishment of the producer gas, and the problem with a bad fuel often resolves itself into whether it is more economical to have an excess of steam and a producer gas of inferior quality, or whether it is preferable to curtail the steam and suffer some inconvenience from clinker troubles.

If the quantity of steam is excessive the fuel-bed will be inordinately cooled, which may result in the oxidation of carbon to CO_2 in the following manner—

$$C + 2H_2O = CO_2 + 2H_2$$

This reaction, being also endothermic, is depriving the producer of heat for the formation of an inert gas, CO_2. Moreover, the presence of excessive quantities of steam is likely to increase the tendency of some of the CO to undergo oxidation—

$$CO + H_2O = CO_2 + H_2$$

In brief, to take an exaggerated analogy, all attempts at working the producer on conditions approaching those of the water-gas generator (necessarily an intermittent operation, owing to the large thermal losses during gas-making) are to be condemned.

A point well worth consideration in connection with the operation of retort producers is the effect of gas composition on efficiency, and the relative values of hydrogen and carbon monoxide as gaseous fuels. For instance, the calorific powers of hydrogen and carbon monoxide are practically identical, hence, at first sight, there seems little need to consider the character of the combustible gases so long as, in total, they conform to the usual figure. Thus we might have two distinct gases with identical proportions of combustibles. In one gas the combustibles might consist wholly of carbon monoxide, and in the second gas there might be nearly equal proportions of carbon monoxide and hydrogen. From the calorific power standpoint there would be nothing to choose between the two ; but, when the question of flame radiation is considered, it must be borne in mind that the radiative power of a CO gas flame is, per unit volume of gas burnt, nearly $2\frac{1}{2}$ times that of a hydrogen flame of the same size. Hence, it has come to be recognized in many of the industries in which producer gas is employed that the best results are dependent upon a high proportion of carbon monoxide and a low percentage of hydrogen.

[The practical working of producers and economy of fuel are further discussed in Chapter IV.]

HORIZONTAL BENCHES : GENERAL CONSIDERATIONS

Direct-fired furnaces, in spite of their inefficiency, are still to be found (particularly as a stand-by) in country works of moderate size. Their chief recommendation lies in the fact that in case of emergency spare units can be put under working conditions in far shorter time than is the case with gaseous settings, thus avoiding the necessity of keeping the latter under slow fires. The original type, however, with air supplies entirely uncontrolled, is now giving way to a more efficient design operated on semi-gaseous lines. This principle is shown in Fig. 17, from which it will be seen that the air entering under the grate is controlled by dampers, so that a portion of the coke is burnt to CO instead of wholly to CO_2. A further supply of air (also under control) is then admitted above the fuel, so that complete combustion takes place. In this way the supply can be regulated within finer limits than is the case when the whole is admitted under the grate, and the excess of air in the flue gases can be reduced by more than one-half.

Works making up to 100 or 120 million cubic feet per annum usually employ the 10-foot stop-ended retort, and where shovel charging is in vogue this system is undoubtedly the most suitable. A later introduction, however, is the 10-foot through bench seen in Fig. 18 ; whilst typical stop-ended settings are shown in Figs. 19 and 20. The single through bench has the advantage that discharging machinery may be used ; and, the back-end of the retort, being close up to the retort-house wall, the coke can be pushed direct into the yard. A modern favourite for

medium-sized works making from 120 to 200 millions per annum is the 14-foot through retort, which may be suitably operated by some of the present-day types of discharging-chargers.

The following average dimensions are given for the various types of benches with their houses :—

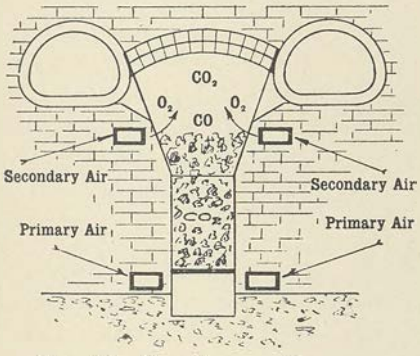


FIG. 17.—SEMI-GASEOUS PRODUCER.

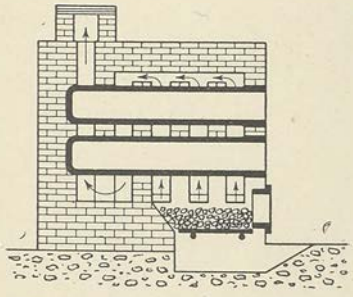


FIG. 19.—TYPICAL DIRECT-FIRED FURNACE.

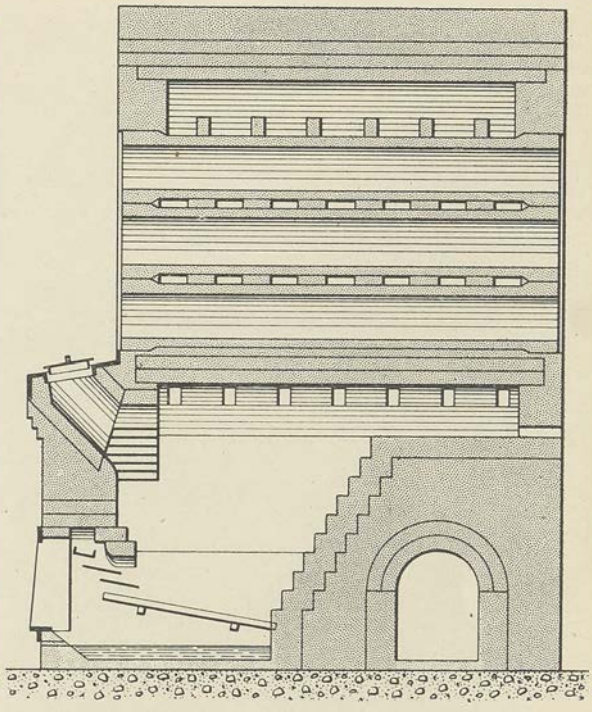


FIG. 18.—TEN-FOOT "THROUGH" RETORT BENCH.

	ft.	in.	
1. Single bench :	1	6	at back of bench.
	12	6	for bench (11 feet 6 inches if retorts are 9 feet long).
	18	0	in front.
	32	0	over-all width inside house.

The height of the bench would be about 11 feet from ground-level, and the height of the house to the eaves 20 to 21 feet.

2. Through bench (scoop charging and no machinery)—
   Bench, 20 feet.
   Each side of bench, 18 feet.
   Total width of house, 56 feet inside.
   Height of bench from top of foundation to top of brickwork, nearly 20 feet for 3 tiers.
   Height of house to eaves (stage type), about 35 feet.

3. Through bench (charging and discharging machinery)—
   Bench, 20 feet.
   Charging side, 23 feet.
   Discharging side, 17 feet.

Total width of house, 60 feet.
Height of bench from top of foundation to top of brickwork, 24 feet 6 inches to 26 feet for 5 tiers.
Height of house to eaves (stage type), 41 feet, with continuous hoppers.
Height of house to eaves (stage type), 36 feet, with hoppers between roof trusses.

The height of the bench naturally depends upon the number of tiers in which the retorts are set, and an approximate rule gives an allowance of 29 inches of height for each tier. This gives the distance from charging floor to the soffit of the main arch.

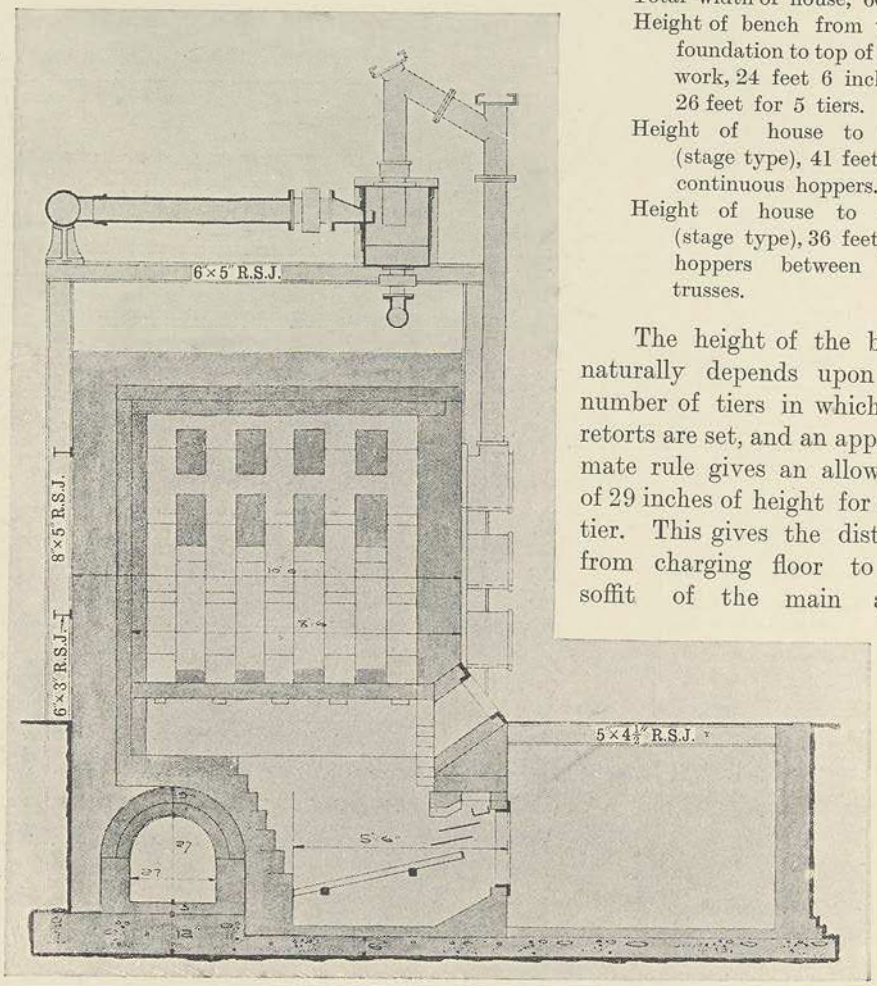


FIG. 20.—REGENERATIVE STOP-END SETTING.

Thus for a setting of 10's in two rows of 5 the height to the underside of the arch would be approximately 12 feet. For a setting of 8's in three rows the height would be 8 feet to 8 feet 9 inches. So far as the width of the main arch is concerned, the dimensions (from inside to inside of pier walls) are as follows :—

For two rows : 7 feet 9 inches to 8 feet 9 inches, depending on the size of retorts employed.
For three rows : 8 feet 6 inches to 9 feet " " " "

Where shovel or scoop charging is employed, it is inadvisable to have more than three superimposed tiers of retorts, otherwise a movable stage has to be used.

CONSIDERATIONS IN DESIGN OF THE SETTING

The question of the capacity of various units has already been discussed in Chapter I (page 18). In the smaller works the unit is of more importance, owing to the necessity of providing for comparatively small fluctuations in output. For this reason it is common to find arches of varying capacity, as is seen in the retort bench shown in Figs. 21 and 22. In the medium and large-sized works the smaller fluctuations can best be coped with by the use of a water-gas plant.

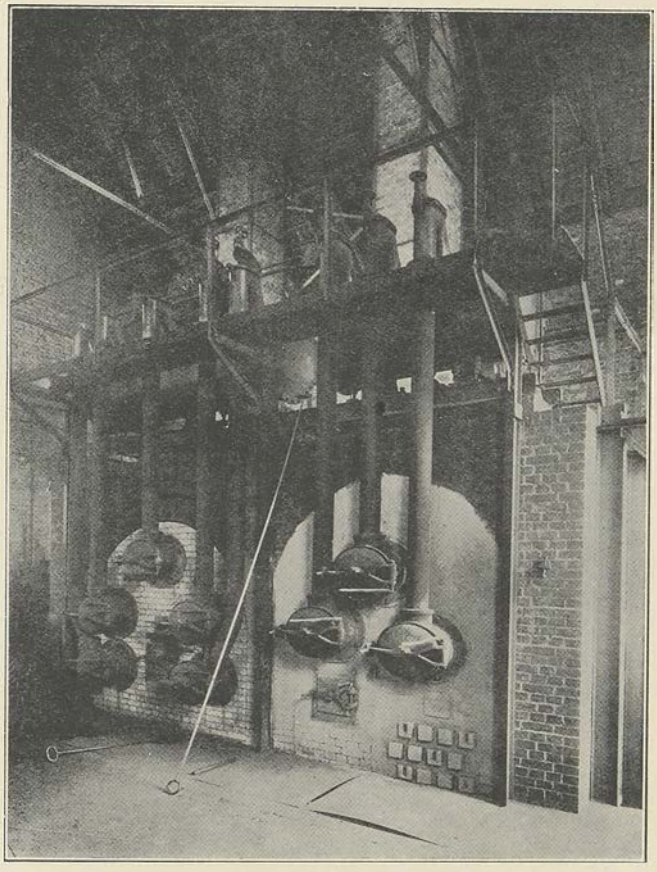


FIG. 21.—RETORT BENCH WITH VARYING UNITS.

While the design of the direct-fired setting is comparatively simple, the various portions of the gaseous setting require particular care and experience if the many demands made upon it are to be satisfactorily met. In connection with the direct setting the following points in construction and working may be given separate notice, although many of those hereafter classified under gaseous settings also apply :—

(*a*) Where the longer retorts (9 feet and 10 feet) are employed, attention must be given to the method of heating the back-ends, otherwise the last foot or so will be dull in comparison with the remainder. This is best coped with by building a special double chamber at the back-end, thus ensuring the thorough circulation of the gases around the retort at this point.

(*b*) The air supply should be regulated, and split up into a primary and secondary supply (semi-gaseous) where possible.

(*c*) Steaming the fuel-bed should be reduced to a minimum. In this type of furnace the waste products escape at high temperatures, and the heat required to raise the steam to the temperature of the setting is appropriated from the heat produced by the combustion of the coke—hence the steam occasions a direct loss. (*See* remarks on the use of steam, page 68.)

Water-cooled firebars should be avoided.

(*d*) All flues must be accessible for cleaning while the setting is at work.

(*e*) The possibility of short-circuiting between the flues—a common fault with these settings—must be provided against.

(*f*) The loss of heat through the walls of the furnace by radiation is proportional to the size of the furnace; thus the furnace having the smallest heat-radiating surface will be the most economical.

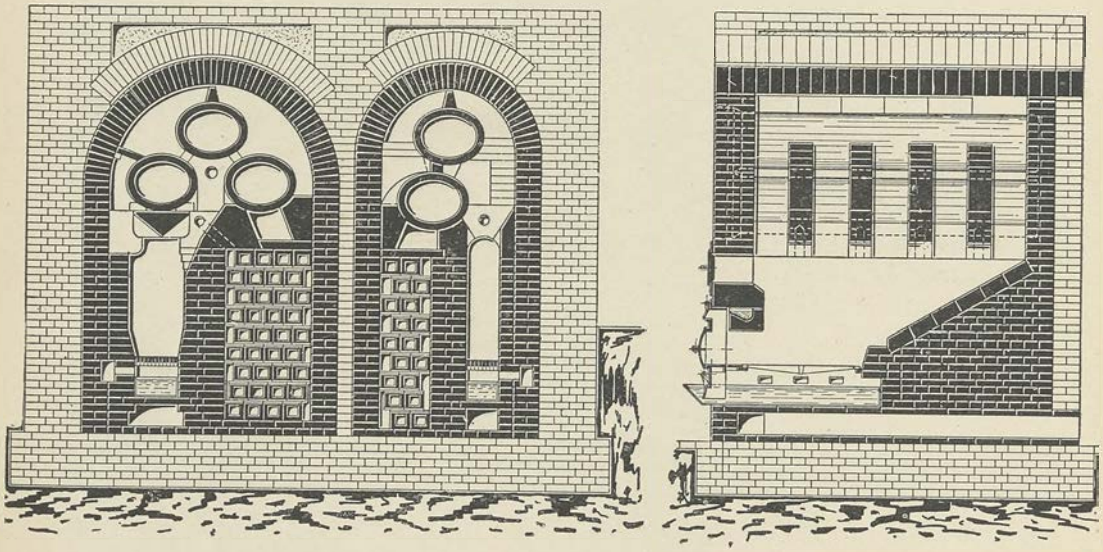


FIG. 22.—REGENERATOR RETORT BENCH WITH VARYING UNITS.

(*g*) The farther back the actual fire stretches, the better will be the heating of the back of the retorts; on the other hand, very long grates are difficult of access for cleaning, etc.

(*h*) If a deep fuel-bed is employed CO will be formed, and this, escaping unburnt, will account for considerable loss. In the smaller grates 12 inches of fuel depth is ample. It should not in any case exceed 18 inches, unless, of course, a supply of secondary air above the fuel is arranged for. This point is often difficult to impress upon the country stoker, as charging the furnace little and often entails considerably more trouble.

(*i*) The front of the fire (above the firebars) must either be sealed with a plate or breezed up so that all air enters beneath the firebars. For direct fires the ordinary horizontal grate is preferable to the modern sloping types.

(*j*) The furnace linings should be isolated from the remainder of the brickwork, and not bonded in in any way. The wear and tear with this type of furnace is extremely heavy, and the furnace requires frequent re-lining.

(*k*) The stop end of the retort frequently breaks away after the bench has been working for some time, and as bricks will then have to be inserted, it is as well to brick up the end (4½ inches) before the retort is put to work in the first place.

(*l*) When starting up settings care must be taken to avoid explosions. The chances of explosions occurring in direct settings are remote, but the experience is by no means unknown. (For further information, *see* page 132 *et seq.*)

GENERATOR AND REGENERATOR SETTINGS

The essential difference between generator and regenerator settings is in the means employed for circulating the waste gases and, in the latter type, for extracting the maximum quantity of sensible heat from them before their escape. In the

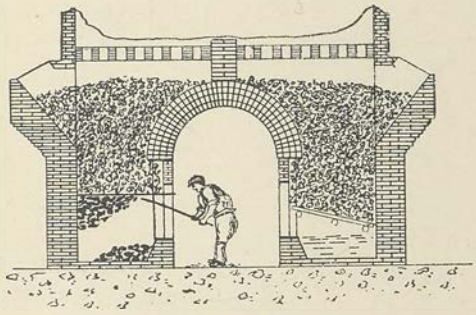


FIG. 23.—DOUBLE FURNACE.

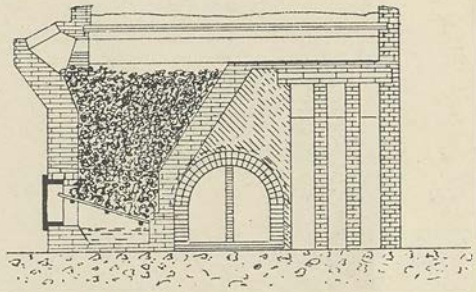


FIG. 24.—SINGLE FURNACE.

generator type the main waste-gas flue travels along the top of the main arches, with the chimneys carried up at intervals, whilst in the regenerator system the waste flue generally runs longitudinally through the entire bench, just above foundation-level. Another important distinction is that with generator settings a double furnace (Fig. 23) is frequently employed, whilst the single furnace (Fig. 24) is now exclusively used with the regenerator bench. The latter embraces the advantages of reduced labour in charging and clinkering, more effectual control of heats, less wear and tear, and considerably improved working conditions for the men. Generator settings are now seldom used in conjunction with " through " retorts. It is interesting to note, however, that the South Metropolitan Gas Company still employs generator settings to a very large extent. In this case a special arrangement of producers is employed, in which each producer supplies gas to one-half of each of three retort settings of the 20-feet " through " type. The result of employing the generator principle in lieu of the regenerator is seen by a comparison of the figures of coke used for fuel by this company with the same figures of the Commercial Gas Company in which regenerators alone are employed :—

Coke used for Fuel.	
South Metropolitan Co.	19 per cent. of total made.
Commercial Gas Co.	13 „ „ „

At the same time it must be borne in mind that the South Metropolitan Company

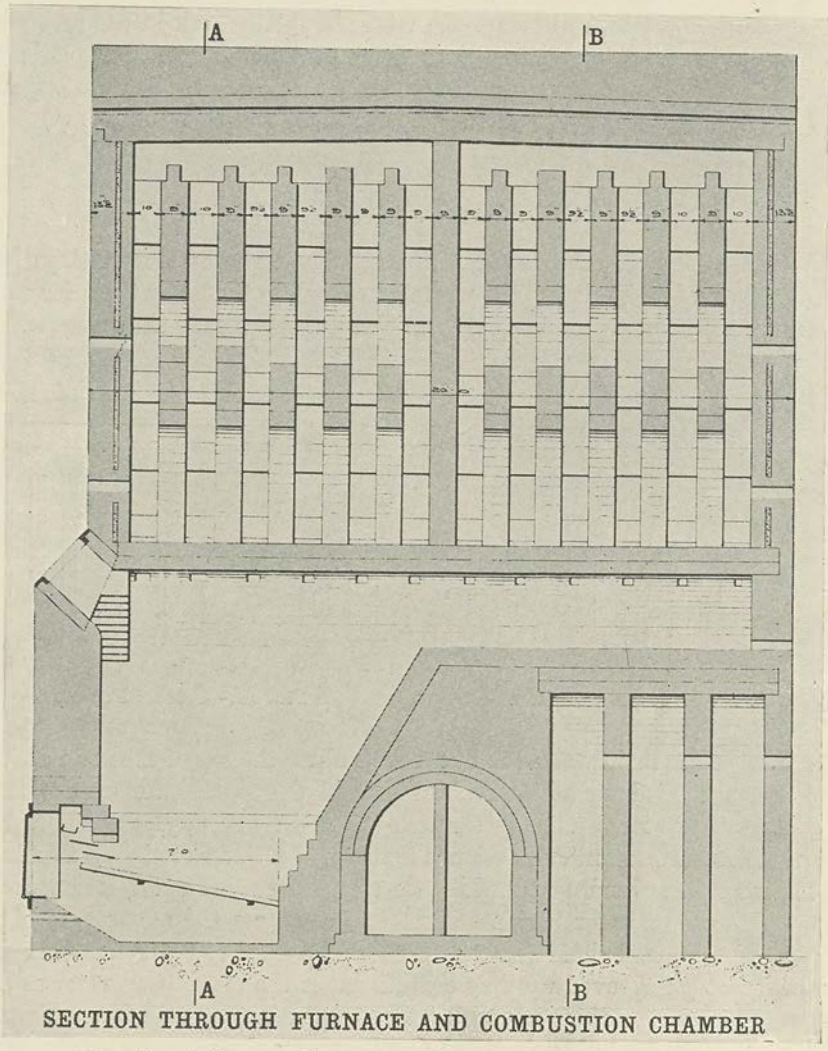


Fig. 25.—A Typical Horizontal Regenerator Retort Bench.

have inevitably to keep settings on slow fires owing to the absence of water gas plant for dealing with sudden demands.

So far as the design of the modern regenerator furnace is concerned, typical working drawings are shown in Figs. 25, 26 and 27, whilst a sectional diagram of the same type of setting is given in Fig. 28. The various portions of the setting

and the considerations to be kept in view in order to ensure long life and effective working are dealt with under their respective headings.

(*a*) Main Arches

The stability of the bench must be ensured, and the tendency of the pier walls

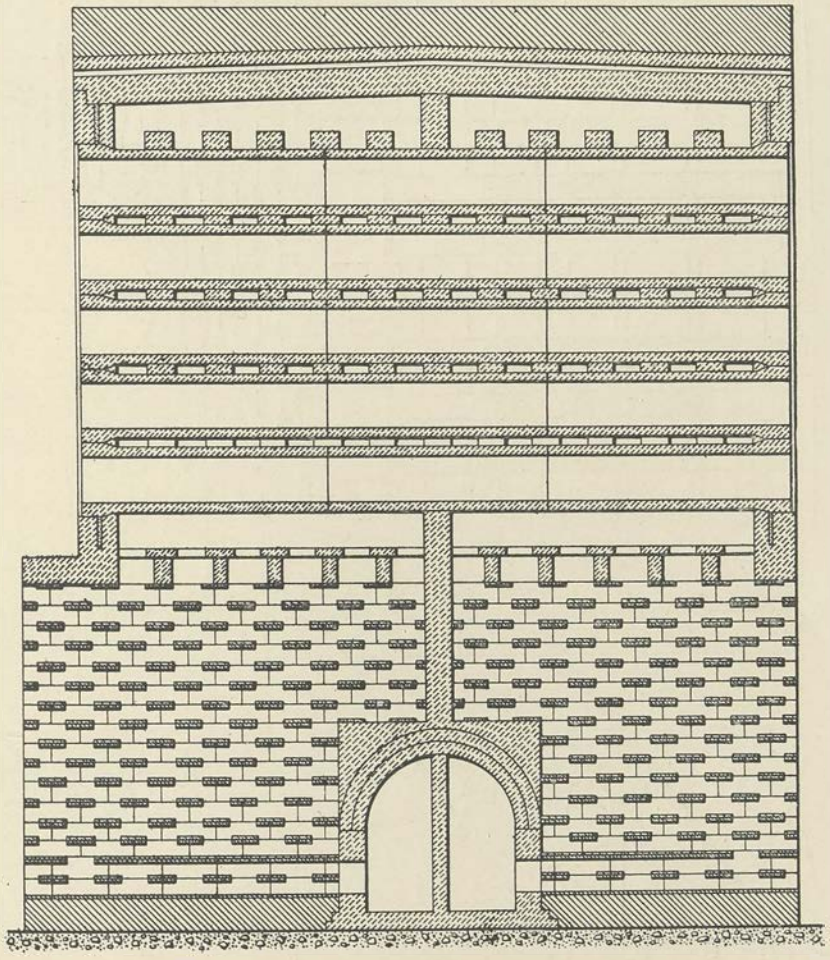


Fig. 26.—Section through Waste-Gas Flues.

to lean slightly from the vertical (due to the thrust of the main arches) must be checked by the erection of substantial end walls and suitable bracing. When the bench contains more than (say) four beds, these buttress walls should never be built less than double the thickness of the ordinary pier walls, whilst it is only necessary to construct the inner 9 inches of firebricks. For reasons mentioned later (*see*

page 227) an ordinary hard stock brick of good quality and shape is perfectly suitable and desirable for the remainder of the work.

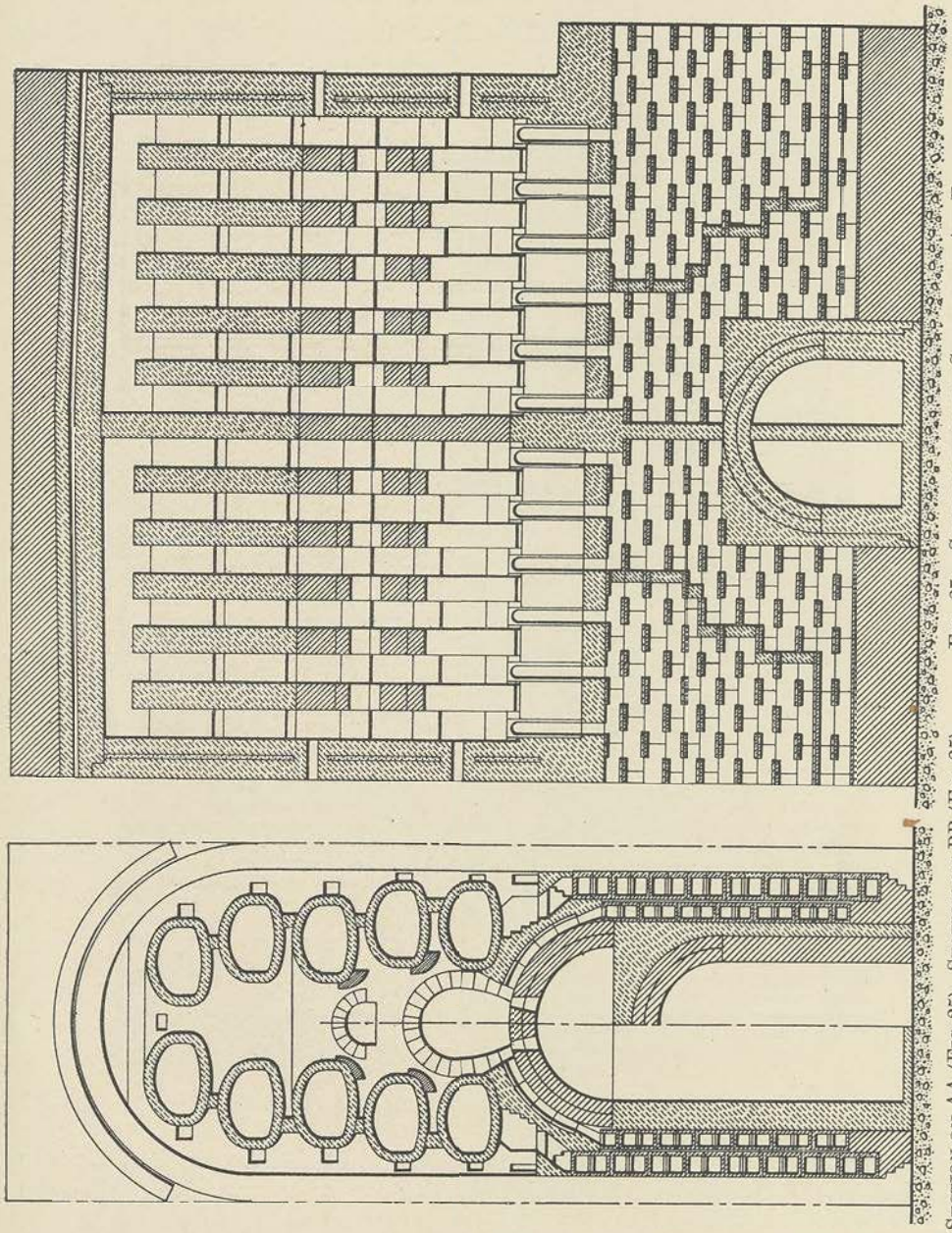


FIG. 27.—SECTION THROUGH SECONDARY AIR FLUES.
SECTION ON AA (FIG. 25). SECTION ON BB (FIG. 25).

As a general rule an 18-inch wall between the arches will suffice for all types of settings, and the two-and-a-half brick wall occasionally seen is wholly unneces-

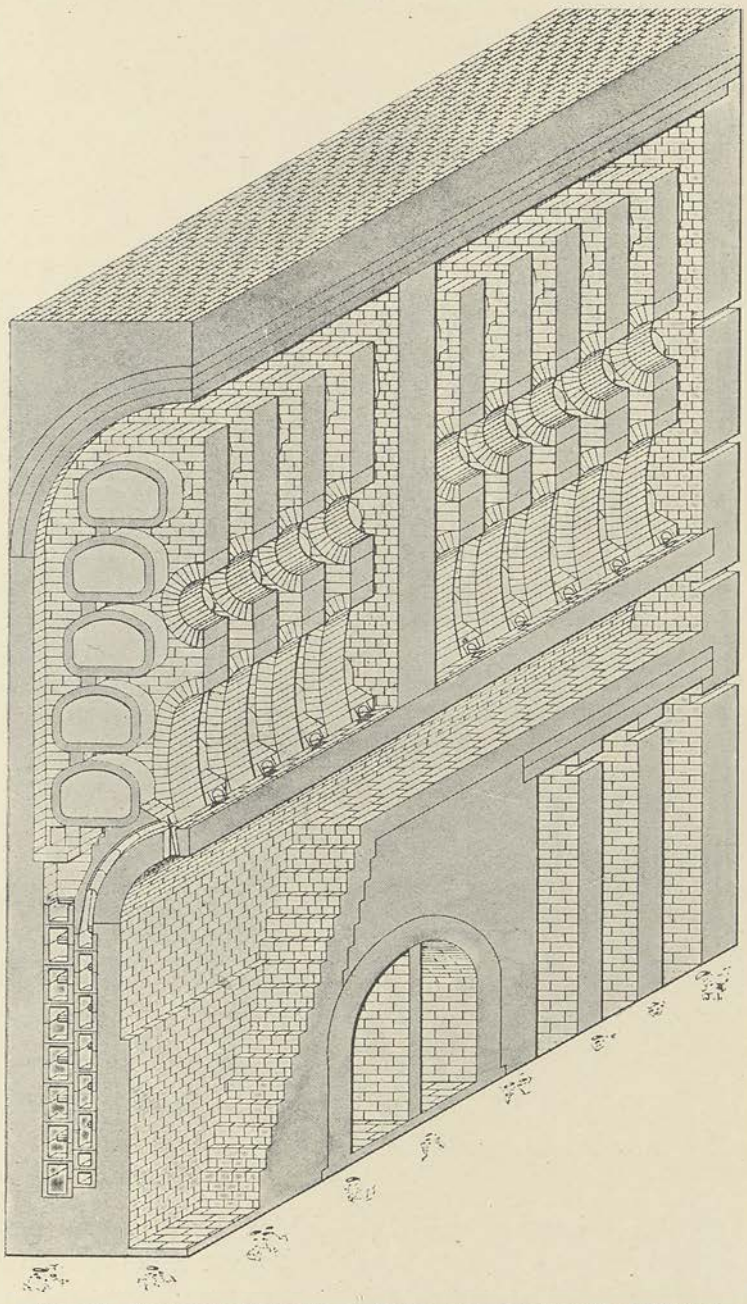


FIG. 28.—SECTIONAL DIAGRAM OF HORIZONTAL REGENERATOR SETTING.

sary. Such walls are, of course, entirely constructed from firebricks, these being carried up round the main arches to a depth of 9 inches. Beyond this, any further

brickwork required for filling up the spandrils, etc., may be of ordinary stock-work or, if preferred, old firebricks well cleaned. A reveal (as shown in Fig. 29) should be left in the pier walls and arches so that a tight joint is obtained when the front wall goes up.

The semicircular main arch is the ideal, as it accounts for practically no horizontal thrust on the side walls. With settings of two vertical rows the semicircle should always be employed; but the greater width necessary with three or four vertical rows makes the use of such an arch somewhat inconvenient. In such cases elliptical or segmental arches are often erected, as in this way excessive headroom above the top tier of retorts is avoided. Care must be taken, however, to see that decidedly flat arches, liable to failure, are abstained from. A generally recognized rule is to the effect that no arch should have a radius of more than 7 feet 6 inches. Many designers will hear of nothing else but a semicircular arch, whatever the type of setting. It is maintained that the excessive headroom does not matter in the least, and, if necessary, can be tiled in and isolated.

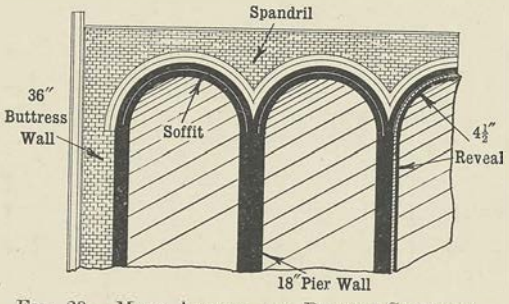


Fig. 29.—Main Arches for Retort Settings. The blacked portion indicates firebrick.

All types of arches are generally built from concentric rings of brickwork,

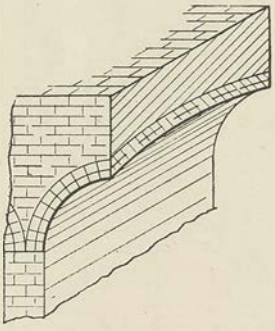


Fig. 30.—Barrel-shaped Setting Arch.

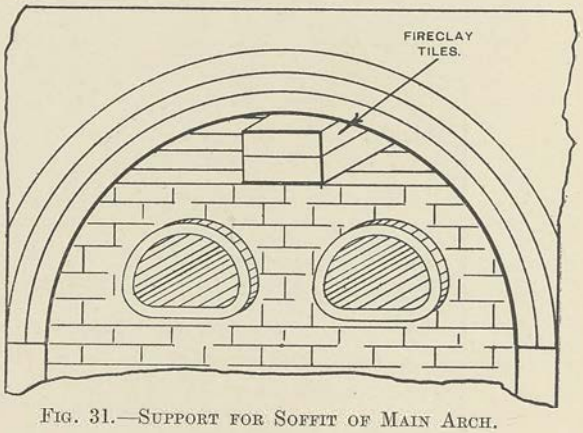


Fig. 31.—Support for Soffit of Main Arch.

although a growing (but more expensive) practice is to employ special radius blocks. When the brick arch is used, however, there should never be less than three rings, as it is almost impossible to prevent some sagging of at least the lowest ring after the arch has been in operation for some time. To overcome this drawback the barrel-arch with a camber in both directions (Fig. 30) has been introduced with marked success, and in times such as the present, when firebricks have reached an abnormal

price, the additional cost of labour involved is trifling in comparison with the gain in other directions. A simple and effective means of preventing the dropping of the inmost ring is to stay up the soffit of the arch by means of tiles supported from the cross-walls of the setting (Fig. 31). It should, however, be seen that expansion of the work below is allowed for, by leaving a space between the top of the tiles and the soffit of the arch. Two inches will usually answer the purpose. The difficulty, however, lies in gauging the amount of expansion, so that when the setting is heated up the soffit just rests on the tiles. Obviously, if there is a space between the two the tiles are useless, whilst if over-expansion takes place they are actually harmful.

In America, some attempt has been made to reduce the losses of heat from radiation by leaving cavities around the main arches, or by employing special channel blocks (Fig. 32). The practice, however, cannot be recommended, as the stability of the work is seriously affected, and radiation losses will not be excessive if the brickwork is carried up at least 18 inches above the top of the arch rings. As a further precaution, the top of the bench is frequently plastered with a thin layer (2 inches) of some non-conducting material. This can be effectively made from waste rope dust and rough asbestos composition composed of ten parts of the former to one part of asbestos. Such work, including the labour, can be carried out for about 7*s.* 6*d.* per square yard.

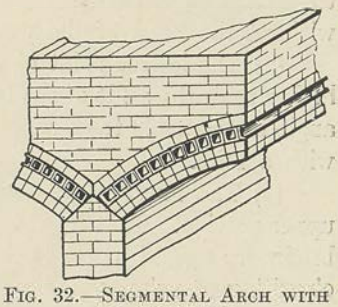


FIG. 32.—SEGMENTAL ARCH WITH AIR CHANNELS.

An objectionable practice, which is happily dying out, is that of filling up the spandrils of the main arches with sand, and putting a paving of bricks on the top of this. Far from preventing radiation, the sand, owing to its close-lying nature, is always accompanied by excessive losses in this respect; and in time, when the work gets old, it is likely to drain through crevices, leaving hollow spaces in the spandrils and giving trouble in the settings owing to its low fusing point.

(*b*) THE PRODUCER

Through retort benches should in all cases be fired with the single rather than the double furnace, as in this way a saving of from 10 to 15 per cent. in fuel consumption can be looked for. The primary consideration is that of ensuring ample depth of fuel-bed, so that the reduction of carbon dioxide to carbon monoxide may effectively take place. In the larger regenerative settings of 8's and 10's it is preferable to allow for not less than 8 feet from the base of the producer to the springing of the producer arch, although in the smaller units this will often be no more than 6 feet. As regards shape, the internal producer is always rectangular. Although on certain scientific grounds it should be square (due to the fact that of rectangular figures the square has the smallest perimeter for a given area, thus exposing the minimum amount of wall surface), it is commonly constructed with the front width about half the distance which it extends backwards at the base. The reason for this is that construction is facilitated, a better distribution of producer gas results,

ample room is left for the regenerator device, and the front wall area is comparatively small. This last is an important point, in that heat radiating through the wall is lost, whereas in the longer side walls it is partly picked up by the inflowing secondary air and recovered. Further considerations which must receive attention are the following :—

(1) The producer lining should be entirely separate from the main body of the brickwork. The wear and tear on this portion of the setting is heavier than that on any other portion, and although a well-built and substantial lining will remain in workable condition for about 600 to 800 days, minor repairs are often necessary every year. Shutting down and restarting, however, is to be avoided as far as possible, owing to the undesirable effect on the working life. The false cheeks to the producer may be built up of a $4\frac{1}{2}$-inch or 9-inch wall. The latter is preferable, and the bricks should be laid all " headers," so that considerable wear can take place without the bond of the work being broken.

(2) The lowest point of the charging door frame of the producer should be no higher than the soffit of the furnace arch, and the frame should be sloped at such an angle as to enable the coke at the back of the furnace to be seen, and to be reached with a rake.

(3) The lower portion of the producer should be slightly narrower than the upper portion. That is, at a point about level with the top of the furnace frame the brickwork should be set back $2\frac{1}{4}$ inches at the sides. This will minimize the short-circuiting of primary air up the sides of the fuel-bed.

(4) The primary air if taken in by vacuum should be admitted through slides in the furnace door, and not by means of channels passing through the brickwork at the side of the furnace. With the ordinary horizontal bar-grate, short-circuiting of the primary air up the front of the fuel-bed may be avoided by " breezing up." A later practice, however, as met with in the " Grille " grate, is that of impelling the primary air in through special cast-iron ducts arranged one on either side of the producer.

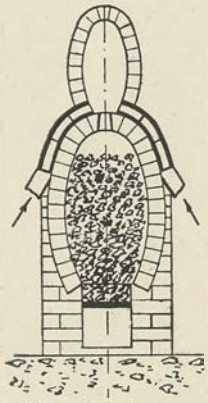


Fig. 33.—Arched Producer.

The general practice is to build up the producer with parallel side walls, a semicircular furnace arch being thrown over these. In some cases additional strength is given to the producer by arching out the side walls as in Fig. 33, but the advantages accruing from this arrangement can scarcely be said to be commensurate with the increased cost. The widening out of the furnace in this way also prevents the short-circuiting of air through the fuel-bed. Whatever the shape of the producer, the front wall should be of 18-inch thickness, and there should not be less than 9 inches solid work between the side walls of the furnace and the regenerator brickwork or tiles.

(*c*) Grate Area

For the common form of horizontal bar-grate the recognized modern rule is

that of allowing $\frac{1}{10}$ square foot of grate area for each lineal foot of retort in the setting, and for effective working this should be looked upon as the irreducible minimum. For a through setting of ten retorts the rule gives a grate area of 20 square feet. There is little doubt that the producer now used in conjunction with the continuous vertical retort owes its economy in part to the increased grate area allotted. In the Woodall-Duckham system this amounts to as much as 28 square feet for each producer, or rather more than $\frac{1}{4}$ square foot per lineal foot of retort in the bench. Mr. Thos. Glover has stated that with certain coals a grate area of $\frac{3}{4}$ square foot per 10 feet 6 inch run of retort is sufficient, but with other coals, containing different proportions of lime and iron in the ash, the clinker is difficult to remove. Another rule is that of allowing 1 square foot of area for each 8 lb. of coke consumed by the furnace per hour. This basis, however, is not altogether satisfactory, as the fuel consumption is arrived at by guesswork, and necessarily varies with the type of coke in use.

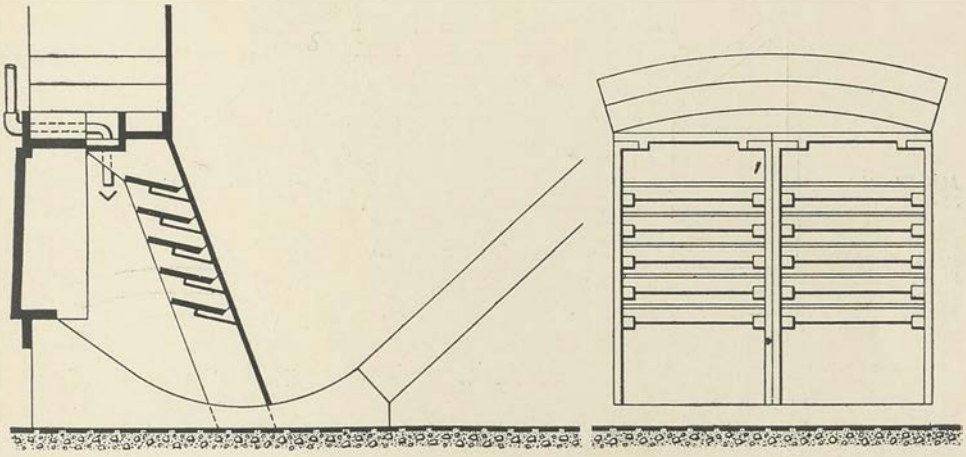


FIG. 34.—TYPICAL STEP-GRATE.

Different rules must be applied when the sloping forms of grates, as described below, are employed.

INCLINED GRATES

Various methods have been introduced to prevent the formation of hard masses of clinker by maintaining conditions that will ensure the inert constituents of the fuel being thrown down as a powdered ash only. With this end partly in view, the "step" grate has been substituted to some extent for the more common firebar method of supporting the fuel-bed. In a typical step-grate (Fig. 34) the fire rests on the base of the furnace, and is supported by a series of water-cooled cast-iron plates arranged in progression. This system is certainly an advance over the more common method; but it has the disadvantage of requiring attention at comparatively frequent intervals. In order to preclude the primary air from cutting in under the soffit of the furnace arch and thus causing local heating of the fuel-bed

(accompanied by clinker formation), also inferior quality of producer gas, it is usually advisable to breeze-up the open space above the top plate. The plates forming the grate may be of cast-iron or steel, but the most satisfactory method is to make them of cast-iron, to the underside of which a couple of thin ($\frac{3}{8}$-inch) strips of mild steel ($1\frac{1}{2}$-inches wide) are riveted across both diagonals.

A development of the inclined grate principle is the author's "Grille" grate, which is operated by taking in the primary air under vacuum through door slides in the ordinary way; or, preferably, by impelling the air through specially con-

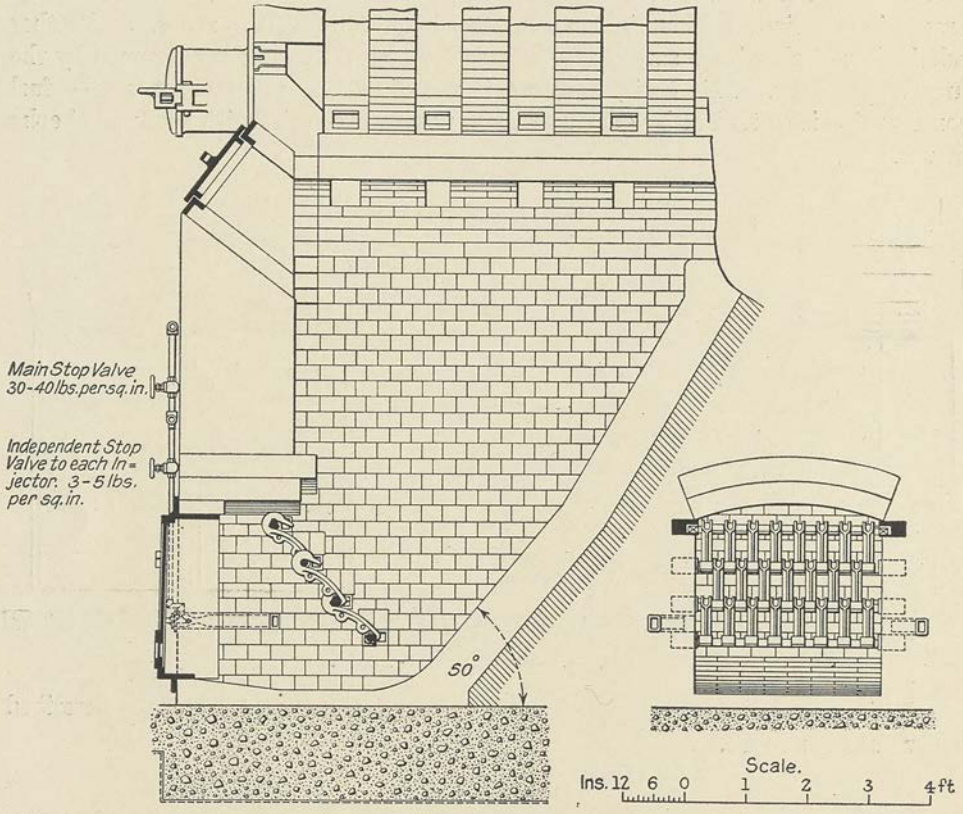


FIG. 35.—THE PRESSURE GRILLE GRATE.

structed cast-iron ducts placed one on either side of the furnace. By means of these ducts, the air (thoroughly admixed with steam) is delivered at a point adjacent to the grate bars. The grate (Fig. 35) consists of specially-designed cross bars and hanger bars, arranged in the form of a grille so as to yield a maximum of grate area. The whole is constructed of special heat-resisting iron, the primary air being injected as explained above. If the air is taken in under vacuum, however, a small supply of steam, issuing from pipes let through the furnace cheeks, is arranged for.

The hanger bars are of S shape, the upper portion of which forms a hook

(strengthened by webs) by means of which the bar is suspended from the supporting or cross bars. The central portion is convex, so that the fuel resting upon the grate is held away from the point of attachment of the hook end. The lower end of the hanger bar is bent round, and (wrapping round the triangular portion of the supporting bars) effects a locking action, which prevents the bars from becoming disengaged during the process of cleaning. To the back of the bars is cast a web, provided with two holes, into which a Y-shaped rod may be inserted when the removal of the bar is necessary. The bars are suspended from supports, which are cast with parts alternately triangular and round in cross section, and provided with square extremities to rest in the supporting boxes.

The bars perform a double function in that (as the triangular portions protrude beyond the circular portions upon which the hanger bars are suspended) each hanger bar is maintained in its right position, while the lower end of the hanger bar engages with the base of the triangular portion of the supporting bar, and effects the locking action referred to. At the same time, while the hanger bars are locked when in their working position, each may at any time be unhooked and removed by disengaging its lower end from the triangular portion of the cross bar by applying to the lower end a slightly forward movement.

The most economical method of working is to arrange for the attendant to gently shake up the fire in between the Grille spaces every eight or twelve hours according to the purity of the coal employed. For this purpose a light pricking bar, made from $\frac{3}{8}$-inch round iron with a 1-inch chisel head is used. At the same time a long-handled shovel should be inserted into the base of the fuel bed beneath the bottom row of hangers, and the dead material should be removed.

The amount of steam required depends entirely upon the quality of the coke employed. In the simple form of grate, where the primary air is taken in under vacuum in the ordinary way and steam is admitted through the cheeks of the producer, a liberal amount of steam should be admitted when first getting to work. This should then be gradually reduced until the amount is just sufficient to ensure that no hard clinker is formed, but that all the inert material is obtained in the form of dust.

When the new pressure system is employed the exact quantity of steam required for the best results must again be found by trial and effect. For instance, when the producer is put on to regular working a liberal amount of steam should again be admitted at first, and the air-regulator should be set so that the requisite quantity of air is impelled. It should be remembered, however, that when the steam is gradually reduced the injector effect is also reduced, thus it is necessary to open the air-regulator slightly in order that sufficient air may be taken in. Experience has shown, however, that once the proper adjustment is obtained it need scarcely ever be interfered with.

With all types of sloping grates, whether they be of the ordinary step pattern or the Grille type, it is *essential* that the fuel in the producer should be kept as deep as possible. Whereas water is employed for cooling the ordinary step grate it should be remembered that it is harmful not only to the working of the Grille grate but also

to the special material from which it is manufactured. It should, therefore, be rigidly avoided.

The grate area required when sloping grates are employed is much less than that demanded by the horizontal bar-grate. For step-grates the minimum area allotted should be 0·8 square foot per ten lineal feet of retort in the setting. With Grille grates the allowance may be reduced to 0·6 square foot per ten lineal feet of retort.

(*d*) Flue and Chimney Area

The retort-house chimney in large houses varies from 50 to 70 feet in height. The chief considerations to be kept in mind are that of taking it well above any adjoining buildings, and that down-draughts and varying winds are avoided. With direct-fired and generator furnaces it is usual to support the chimney from the top of the bench and to run the main waste-gas flue directly into it. With the regenerator setting, however, the chimney is usually sprung from foundation-level, and should preferably be entirely distinct from the bench. So far as its constructional features are concerned, the cross-sectional area is the most important, and must in all cases be adequate. The usual rule, which may be applied with perfect reliance, is to allow 1½ square inches of area per lineal foot of retort in *all settings dependent upon the flue and chimney*. Thus, suppose a bench consisting of eight settings of "tens" is to work on to a common flue and chimney—

The length of retort in each setting is 200 feet.

The length of retort in eight settings is 1,600 feet.

The chimney area required is $1{,}600 \times 1\frac{1}{2}$ square inches, *i.e.* 2,400 square inches, or $16\frac{1}{2}$ square feet.

With large units of through settings 75 per cent. of this is sufficient.

Another rule (due to Herring) is that of allowing 40 square inches per ton of coal carbonized per diem by the whole bench of retorts dependent on the chimney. The following formula (Brooke) is also sometimes used:—

$$A = \frac{5W}{\sqrt{H}}$$

Where A = area of chimney, in square feet.
H = height of chimney, in feet.
W = weight of fuel burnt per minute, in lbs.

In any case, when a shaft is to be erected it should be based upon the first of the rules here given, and the last named may be used as a means of checking. It is inadvisable to connect a chimney to a greater number of beds than ten, as above this (at any rate, for settings of 10's or 12's) its dimensions become somewhat unwieldy. Circular shafts, except for some vertical installations, may now be said to be things of the past, and the rectangular chimney with external batter is most commonly seen. A typical design of this style of shaft is seen in Fig. 36. It will be noticed that a square base 10 feet in height is provided. Some ornamentation (such as oversailing courses, plinths, or panelling in different coloured bricks) is usually added. The batter commences immediately above the square base, and is

usually run in the ratio of 1 to 36 or 1 to 40. A point to remember is that the calculated chimney area refers to the area at the base of the shaft, and the design should be such that, in spite of the reduction of thickness of the brickwork, the cross-sectional area at the summit is the same. In Fig. 36 a batter of 1 in 40 gives an overall reduction in total width of 3 feet, and at both top and bottom the internal dimensions are similar, namely 3 feet 9 inches square.

So far as the thickness of chimney walls is concerned, the following typical instances for various heights are given :—

(*a*) 68 feet high.
Brickwork : 1 foot 10½ inches for 12 feet.
1 foot 6 inches for 16 feet.
1 foot 1½ inches for 20 feet.
9 inches for 20 feet.

(*b*) 65 feet high.
Brickwork : 1 foot 10½ inches for 12 feet, reducing to 9 inches at top. Outside batter 1 in 36.

(*c*) 58 feet high.
Brickwork : 1 foot 10½ inches for 11 feet.
1 foot 6 inches for 14 feet.
1 foot 1½ inches for 16 feet.
9 inches for 17 feet.

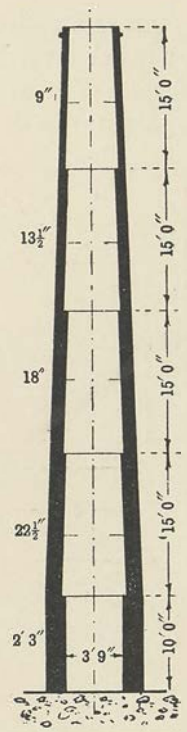


FIG. 36.—CHIMNEY WITH EXTERNAL BATTER.

A small proportion of chimneys is now to be found in which the brickwork is reduced to 4½-inch for some distance in the upper length. It must be strongly emphasized, however, that such design is to be rigidly avoided, the more so in retort-house shafts, where wind and heat have both to be withstood. Chimneys of this description are occasionally to be met with in which no external batter has been provided, the walls running up vertically from base to top. For instance, a group of retort-house shafts is known which are constructed as follows : The shafts are 70 feet in height, the first 30 feet being 13½-inch brickwork, the next 20 feet 9-inch brickwork, and the final 20 feet 4½-inch work. In the 4½-inch portions the corners are constructed of 6-inch work for increased stability. The effect of such design on chimney area is well illustrated by reference to Fig. 37. The effective area at the base is 14 square feet ; whereas at the 9-inch work it has been increased to 27½ square feet, or nearly double.

Retort-house chimneys are usually braced for their entire height, the most general method being to run angle-irons up each corner, the irons being held in position by tie-bars at intervals of about 6 feet. The shaft used in conjunction with regenerator settings should be centrally divided by a 4½-inch wall in the same manner as the main waste-gas flue. It is always advisable to leave inspection doors at the base of the shaft, so that the condition of the waste-gas flue can be readily seen during working, and a vacuum gauge inserted ; whilst provision should be made for a cleaning door, so that dust, etc., may be removed during stoppage. The same

door is also useful for the insertion of a coke bucket when starting up, in order that a natural draught may be stimulated. On the Continent it is occasionally the practice to erect a distinct chimney for each bench of retorts. It is claimed that in this way each furnace may be worked independently, whilst with the common chimney one furnace may influence another. The idea, however, is confined almost wholly to stop-ended retort settings.

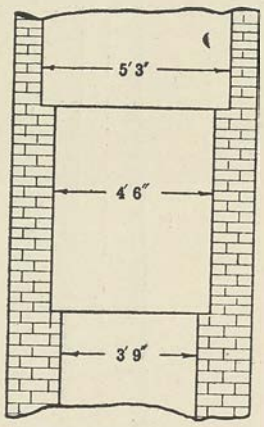


FIG. 37.—SHOWING OBJECTION TO UNTAPERED CHIMNEY.

As regards the bricks for the construction of retort-house chimneys, where stock-work is used a firebrick lining should be provided for the lower half. Nowadays, however, it is far more common for the whole chimney to be built of firebricks, in which case no lining is necessary.

Natural draught depends for its action on the difference of density between the cold air surrounding the shaft and the warm products of combustion. Moreover, the quantity of gas drawn up by a chimney increases in proportion to the square root of the height of the chimney; consequently any increase in height produces only a comparatively small change in the quantity of gases drawn off. As a matter of fact, it is stated that a shaft creates the best draught when the temperature of the issuing gases differs from the atmospheric temperature by 273° C. Accordingly, when the difference between the two temperatures is greater than this, the draught is not so good, and a larger and useless loss of heat takes place. On the other hand, the heat carried off by the escaping gases must not all be considered as loss, for a certain temperature is necessary for the creation of a natural draught.

WASTE HEAT BOILERS

There can be no question that the modern gasworks provides one of the most notable instances of the useless dissipation of waste heat; for, even with the modern producer operated on the regenerative principle, the quantity of heat lost in the chimney gases of a retort setting represents from 18 to 25 per cent. of the total heat supplied. A parallel instance is provided by the coke-oven, with which, although the principle of regeneration is made use of, a loss is shown amounting to 40 per cent. of the calorific value of the fuel employed.

LOSS OF HEAT IN DRAUGHT

It must be recognized that the whole of the heat issuing from a retort-bench chimney cannot be regarded as altogether a direct loss, owing to the fact that a certain amount of energy (in the form of heat) is, in ordinary circumstances, necessary to create a natural draught. If a natural draught is desired, the loss of a portion of the sensible heat in the waste gases is inevitable; but this loss may be reduced to a negligible figure by providing the necessary energy required for the draught by mechanical means.

So far as retort settings are concerned, it will be appreciated that the sensible heat of the waste gases is not the only direction in which thermal loss occurs, for even with the most careful regulation of air dampers it is almost impossible to prevent intermittent appearance of unburnt furnace gases in the waste products, while the proportion of combustibles passing to the chimney is increased by the leakage of coal-gas through defective retorts.

The quantity of waste heat which may be recovered depends not only upon the temperature of the products but upon their average specific heat. Moreover, if cooling below 212° F.[1] can be effected, there will be an additional gain from the latent heat of vaporization of the moisture present. In applying waste-heat recovery in practice the problem offers two alternatives—the recovery of the greater part of the sensible and latent heat by cooling the effluent gases as far as possible, or the reduction of the temperature of the gases to about 400° F., so as to leave a sufficient surplus of energy to provide for a natural draught. In the first instance, it is, of course, necessary to instal apparatus giving an induced draught.

Raising Steam

It is interesting to record that one of the earliest attempts at recovery of waste heat from retort settings consisted of inserting in the base of the waste-gas flues a series of 2-inch or 2½-inch cold drawn steel tubes, served with a water supply from a tank controlled by a ball-cock. A set of the tubes was placed in the waste-gas flues on each side of the producer, and the two sets were then connected across with a rider, from the centre of which an outlet pointed down into the ash-pan.

The approximate quantity of steam which it would be possible to raise from any particular retort bench may be readily computed, once certain factors are known. While many engineers prefer to make their calculations on the basis of volume of the waste products available in unit time (in which case the total volume at normal temperature and pressure, inclusive of steam per lb. of coke, may be taken at 150 cubic feet), the writer is of opinion that, at any rate so far as the preliminary calculations required in connection with gasworks are concerned, it is preferable to work on a basis of weight. When 1 lb. of pure carbon is completely burnt with the exact theoretical quantity of air it gives rise to 12·6 lb. of waste products. In practice the average analysis by volume of dry waste gases obtained from the modern regenerator retort setting is :—Carbon dioxide, 19 per cent. ; carbon monoxide, nil ; oxygen, 0·4 per cent. ; and nitrogen, 80·6 per cent.

From this it may be seen that the gaseous principle employed for heating retorts is capable of comparatively fine adjustment, the excess air being very much smaller in quantity than that found with the ordinary boiler installation. The first step in the calculation is to convert the above volumetric figures into analysis by weight. This is readily done by multiplying each of the volume figures by the corresponding molecular weight, taking the sum of the products so obtained, and then dividing each separate product by the sum of all. In this way it will be found

[1] The Fahrenheit scale has been used here as being more convenient for deducing the formulæ.

that the analysis of the waste products by weight is :—Carbon dioxide, 26·9 per cent. ; oxygen, 0·4 per cent. ; and nitrogen, 72·7 per cent.

The only constituent derived from carbon is the carbon dioxide, and a simple calculation shows that the amount of coke (10 per cent. ash) which yields 100 lb. of waste gases is 8·16 lb. In other words, 1 lb. of coke gives 12·26 lb. of dry gases, a figure which is inclusive of the excess air, but exclusive of steam. It must be borne in mind, however, that to-day it is customary to admit a certain amount of live or exhaust steam to the fuel-bed, and from recent trials the writer finds that in some instances the quantity may amount to nearly 100 lb. per producer per hour. Inclusive of the steam, therefore, the weight of the waste products amounts to 12·76 lb. per lb. of coke consumed. Accordingly, 1 lb. of chimney gases consists of the following :—

Carbon dioxide	0·258 lb.
Oxygen	0·004 lb.
Nitrogen	0·699 lb.
Steam	0·039 lb.
	1·000 lb.

The specific heats, at constant pressure, of the above gases may be taken as :—

Carbon dioxide	0·216
Oxygen	0·218
Nitrogen	0·244
Steam	0·480

Hence, the mean specific heat of the waste gases is :—

Weight of	$CO_2 \times \cdot 216$	= 0·0557
,,	$O_2 \times \cdot 218$	= 0·0009
,,	$N_2 \times \cdot 244$	= 0·1705
,,	Steam $\times \cdot 480$	= 0·0187
Total		= 0·2458 or, say, 0·246 practically.

Retort Bench Possibilities.—If consideration is given to a standard regenerative horizontal retort setting containing ten 20-feet retorts, then the fuel fed into the producer per hour will be in the neighbourhood of 1·6 cwt. This is based on the assumption that 12-hour retort charges of 12 cwt. each are employed, and that carbonization demands 3·3 cwt. of coke per ton of coal. The temperature of the waste gases as they leave the regenerator varies between 1,000° and 1,200° F., more often than not the latter figure prevailing, although theoretically it is higher than is desirable. Accordingly, if the temperature of the available products is taken at 1,200° F., then

$$H = W \times S\ (T - t),$$

where H is the available heat in waste products in B.Th.U., W the total weight of products in lb., S the mean specific heat = 0·246, and T and t are the temperatures F. of the gases before and after passing boiler.

Hence from 1 lb. of coke containing 10 per cent. of ash :—

(*a*) B.Th.U. = 12·76 × 0·246 (1200—60)
= 3580 if gases are cooled down to atmospheric temperature.
(*b*) or B.Th.U. = 12·76 × 0·246 (1200—400)
= 2510 if gases are cooled down to 400 deg.

Thus if the waste heat is to be recovered from a battery of six horizontal retort settings, the approximate quantity of coke burnt in the producers per hour will be (6 × 1·6) = 10 cwt. = 1,120 lb. The heat available, therefore, will be :—

(*a*) Gases cooled to atmospheric temperature, 1120 × 3580 = 4,009,600 B.Th.U. per hour.
(*b*) Gases cooled to 400 deg. F., 1120 × 2510 = 2,811,200 B.Th.U. per hour.

Accordingly, neglecting the dryness fraction, the theoretical quantity of steam at 100 lb. pressure which may be raised from feed water at 60° F. may be obtained direct by dividing the above figures by the total heat required per lb. of saturated steam. To obtain steam at 100 lb. pressure the sensible heat required per lb. of water amounts to 268 B.Th.U., while the latent heat of evaporation is 888 B.Th.U., or a total of 1,156 B.Th.U. Therefore, under condition (*a*) the theoretical quantity of 100 lb. steam obtained per hour would be 3,470 lb. and under (*b*) it would be 2,430 lb. It is questionable, however, whether it is ever possible to obtain more than 65 per cent. efficiency from an installation of the kind ; hence the actual quantity of water evaporated would be in the neighbourhood of 2,250 lb. per hour in the first instance, and 1,580 lb. per hour with partial heat extraction as considered in the second case.

Whole or Partial Extraction ?—When a waste-heat boiler alone is employed it is not possible, nor would it be advisable, to reduce the gases to a temperature approaching that of the atmosphere at the outlet of the boiler. An alternative arrangement is a combination of boiler and feed water heater, the waste products passing first through the boiler and then through the feed heater. In this way, by arranging for a counter-current flow, the gases may be brought down to a temperature little above that of the atmosphere. The problem which arises in connection with feed water heaters, however, is that the surplus heat leaving the boiler is considerably greater in quantity than that which is required to heat up the maximum quantity of water which the boiler can evaporate. Hence, some loss is inevitable, unless a portion of the pre-heated water can be drawn off to give a hot-water supply for some auxiliary purpose.

The question resolves itself into whether (*a*) complete cooling should be effected, in which case natural draught is eliminated, and induced draught by fan has to be employed ; or (*b*) whether it is more economical to reduce the temperature to only such a limit that natural draught will still be preserved. In this connection it should be remembered that in order to retain sufficient natural draught it is not advisable to work with a waste gas temperature of less than 400° F. This method is, perhaps, the better of the two so far as gasworks are concerned, for on such establishments a supply of pre-heated water may nearly always be obtained from the gas condensers or from the cooling tanks of large gas engines. On the author's works one boiler is supplied with water taken from the outlet of water-gas condensers,

the temperature of which is 145° F., while a smaller boiler is provided with water at 90° F., taken from the cooling tanks of a 60 b.h.p. gas engine. Thus, by judicious selection of sources of waste heat, other than that from retorts, it is possible to do a good deal of work which would otherwise be appropriated by complete cooling of the waste gases.

Incidentally it may be noted that the difference in temperature between the steam generated and the exit gases varies normally between 100° and 180° F., according to the type of waste-heat boiler employed. If, of course, complete recovery of sensible heat is desired, then the power required to drive the fan must be set off as a contra-account against the work done by the boiler. The power absorbed by the fan should not, in an example such as has been considered above, be more than 10 or 12 electrical units an hour, the usual drive being by variable-speed direct-current motor. There can be no question, however, that induced draught presents a disadvantage, in that some considerable leakage of cold air through the brickwork of the flues usually occurs when a fan is employed.

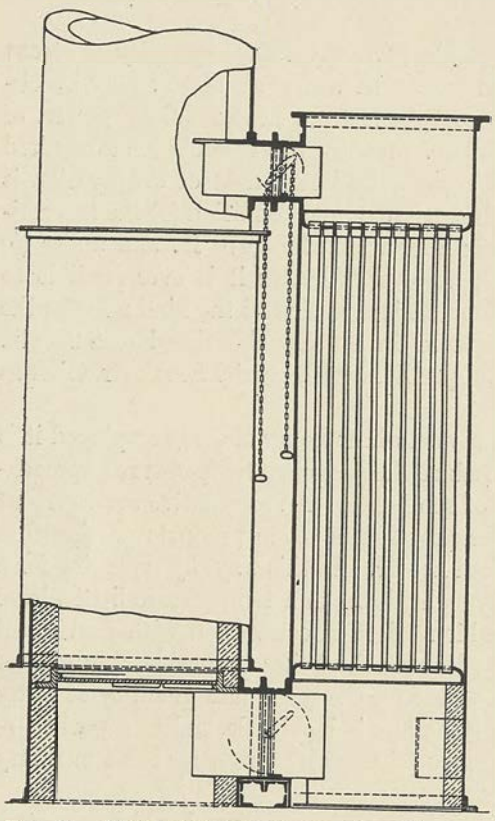


FIG. 38.—THE BONECOURT WASTE HEAT BOILER COUPLED UP TO VERTICAL RETORT-BENCH CHIMNEY.

Losses through Brickwork.—It is in this direction that the Bonecourt method of recovering waste heat differs from the more common system of building a boiler into a brickwork chamber. The Bonecourt waste-heat boiler (Fig. 38) is of the multi-tubular type, the hot gases passing through the tubes, and the water around them. When the ordinary type of multitubular boiler is employed for the purpose, it is usually found that the evaporation obtained per unit of water heating surface is so small that a boiler of unwieldy dimensions has to be installed when large volumes of waste gases are to be dealt with. The Bonecourt boiler, however, is so constructed that evaporation takes place at approximately four times the rate found with the more common forms of multitubular boilers. The increased speed of evaporation entails a moderately high velocity of hot gases over the heating surfaces; consequently the best results are obtained when induced draught by fan is arranged for. It may be noted here that whereas an efficiency of 65 per cent. is comparatively easy to obtain when steam is generated at 100 lb. per square

inch, the average efficiency increases as the steam pressure is reduced, so that with steam at 20 lb. the figure rises to 71 per cent.

Another type of waste-heat boiler is shown in Fig. 39. The latest form of waste-heat boiler (Fig. 40) is that introduced primarily for use with the Glover-West system of vertical retorts. F. W. J. Belton,[1] at Macclesfield Gasworks, has found that by

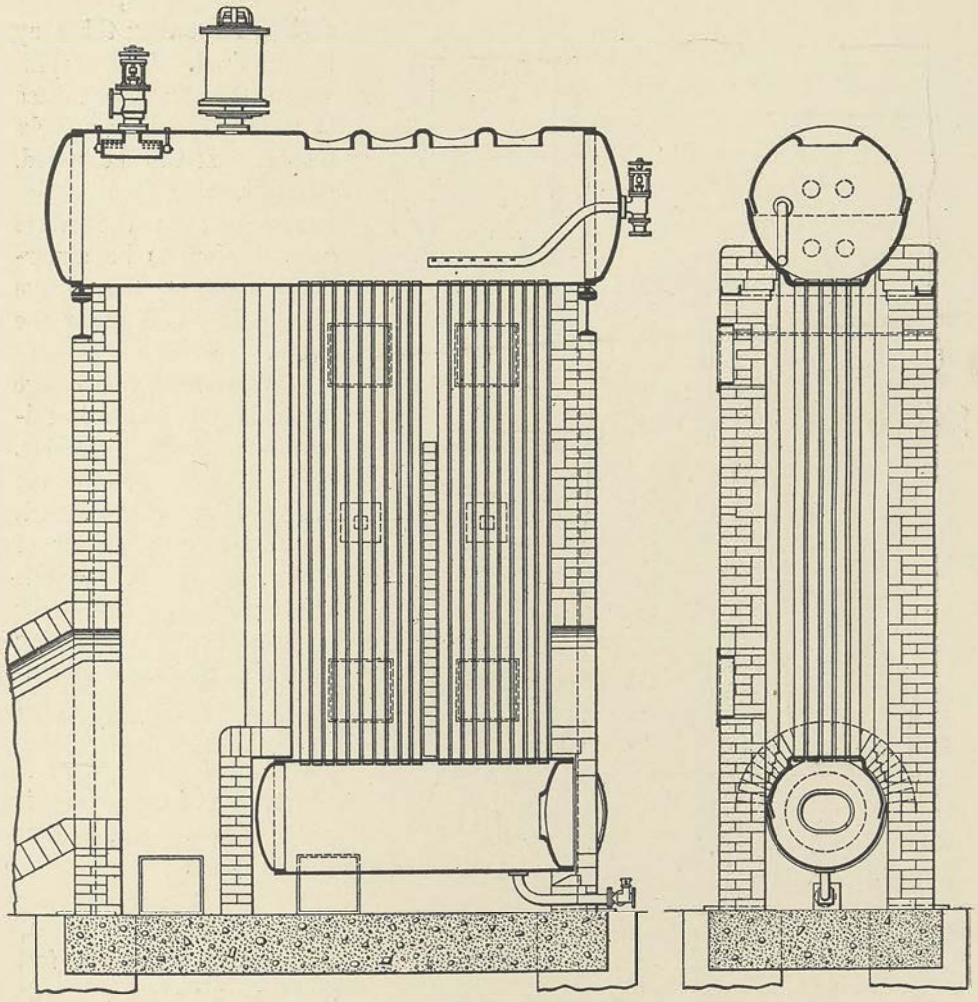


Fig. 39.—Waller's Waste-Heat Boiler.

utilizing the waste heat from vertical retorts he has been able to recover for sale an additional 1·5 cwt. of coke per ton of coal carbonized. A boiler fitted to a retort setting carbonizing 18 tons of coal per day evaporated on an average 450 lb. of water per hour, the pressure of the steam raised being 100 lb. per square inch. The steam is used

[1] In a letter to the author, August, 1920.

for steaming the charge in the retorts, the pressure being reduced to from 25 to 30 lb. The steam then passes through a 1½-inch pipe to superheaters. The temperature of the waste gases at the inlet of the boiler is approximately 850° C. (1,560° F.), and at the outlet 400° C. (752° F.). The water evaporated per ton of coal carbonized is 600 lb. Tests have shown that about 240 lb. of steam per ton of coal was actually used in the retorts, although slightly more than this may be required. The surplus steam, therefore, is turned to assist the ordinary works boilers. It will be noted, however, that the outlet temperature of the waste gases appears to be abnormally high as they leave the setting and enter the boiler.

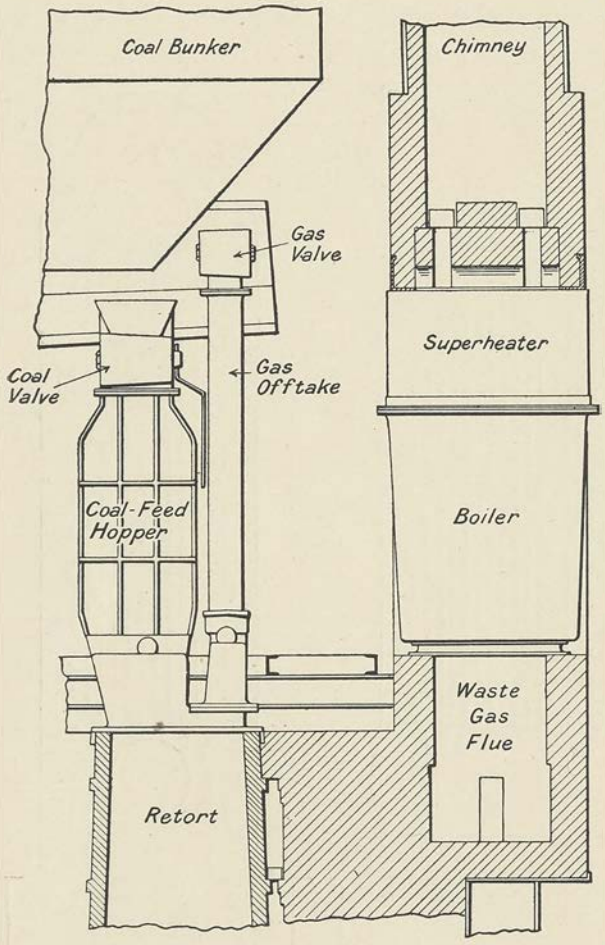


FIG. 40.—GLOVER-WEST WASTE-HEAT BOILER.

Waste-heat boilers are particularly suited to installations of vertical retorts, and as an example of the saving which may be effected, the case may be quoted of a vertical bench of the Woodall-Duckham type now in operation, the chimney gases from which are evaporating approximately 6,000 lb. of water per hour at a pressure of 130 lb. The retort bench in question is carbonizing about 200 tons of coal daily.

Steam raising on gasworks is usually comparatively cheap owing to the fact that on such establishments there is invariably a fair proportion of low-grade fuel available which in some instances would be difficult to dispose of in any other way. The position as regards coke breeze, however, is not what it was a year or so ago, and there would now be little difficulty in finding a reasonable market for it. Incidentally, there is also a demand for tar-breeze briquettes; and, no doubt, a large quantity of the available breeze might be disposed of in this form. If consideration is given

to a normal example where 2,000 lb. of water is evaporated per hour from waste gases, and the highest evaporative value obtained from the rough breeze mixture used on gasworks boilers is assumed to be 7·5 lb. of water per lb. of fuel, then the saving of fuel effected by employing waste heat will amount approximately to 1,000 tons of breeze per annum. With breeze at its present price this does not represent any very appreciable saving in money; but it must be remembered that the retort benches in a comparatively small works would yield 2,000 lb. of steam per hour, so that in the largest works, were all waste heat recovered, the saving would be considerable. Again, there is the question of labour, and in this direction the economy effected is certainly equivalent to the saving in cost of fuel. From figures quoted earlier it will be gathered that by cooling the chimney gases to 400° F. the quantity of steam (at 100 lb. per square inch) which may be generated is equivalent to 40 lb. for every 1,000 cubic feet of gas made. Accordingly, in the case of a comparatively large gasworks producing 1,000 million cubic feet of gas per annum, the steam which would be generated by making use of all waste heat from the retort settings would approximate to 40 million lb. per annum. Stated in terms of fuel, this represents an annual saving of nearly 2,500 tons of breeze.

Effect of Sulphur.—When dealing with waste heat problem it is most important to bear in mind that the coke consumed in producers contains up to 1 per cent. of sulphur. In all cases, therefore, the waste products circulating in the boiler contain a certain proportion of sulphur dioxide. From a series of tests the writer finds that the average content amounts to 38 grains per 100 cubic feet of chimney gas at n.t.p. Corrosion of tubes due to sulphur dioxide need not be feared so long as the gases in contact with the metal are not reduced in temperature below 275° F. If, however, more complete extraction of the sensible heat is aimed at, then particular attention must be given to the tubes forming the feed water heater. These tubes, if of ordinary construction, will probably have only a comparatively short working life, and the expense of cleaning and renewal must be set off against any saving which is shown by the principle of feed water heating. However, tubes may now be obtained which, after treatment by a special process, are more or less proof against the ravages of sulphur compounds; and, providing the initial cost is not excessive, such treatment has probably provided a solution to the trouble. At any rate, the action of sulphur dioxide is a strong point in favour of effecting only partial appropriation of the sensible heat, so that the question of complete extraction is one for the future when further experience has been gathered from prolonged practical acquaintance with modern resistants.

(*e*) Regeneration

Regenerators and generators of various types may be primarily classified as follows:—

Ordinary generators.

(1) Primary and secondary air supply both unheated.

(2) Primary supply unheated. Secondary heated, but at expense of producer.

(3) Primary and secondary supplies both heated at expense of producer.

Regenerators.

(1) Primary air unheated. Secondary air heated by sandwiching between producer and waste gases. This is by far the commonest type.

(2) Primary air unheated. Secondary air heated by sandwiching between two streams of waste gases. In this way the producer is not deprived of heat.

(3) Primary air unheated. Waste gases sandwiched between two streams of secondary air.

(4) Primary and secondary air supplies both heated by waste gases.

(5) Primary or secondary air initially heated by the extraction of sensible heat from the hot coke in the retort. That is to say, in reality the coke leaving the retort is quenched by the ingoing air supply. This arrangement is only practicable with vertical retort systems of the continuous type.

With regard to the merits of the various systems, in the case of the ordinary generator no use is made of the heat in the waste gases, and the secondary or primary air is raised in temperature entirely at the expense of the producer. Compared with no initial heating of the air supply the system does, however, effect some economy in that the air appropriates part of that heat which would otherwise be lost by radiation. It is in connection with this point that so much diversity of opinion exists with regard to regeneration by means of waste gases. Many authorities assert that to admit secondary air through channels adjacent to the producer (Figs. 27 and 49) is uneconomical, and for this reason provision is made for entirely encircling the air with waste gases as in Fig. 48. In support of this theory Brooke gives the following figures :—

	Percentage Efficiency of Regenerator.	Percentage of Total Heat in Secondary Air abstracted from Producer.
Outside producer	100	—
Inside producer. Air flue sandwiched between waste gases	90–95	5–10
Waste-gas flue between air supplies	80–90	10–20
Air flue between side of producer and waste-gas flue	70–80	20–30
Air flue by side of producer	6	94

Too much attention must not, however, be paid to this point ; and it must be remembered that heat will inevitably pass outwards from the hot producer walls and cause loss by radiation. Thus, if the secondary-air flue is adjacent to the producer, it will undoubtedly account for a reduction in the loss from this source. In practical working the distinction between the two types (1 and 2) cannot be said to have a noticeable effect on fuel consumption.

When choice of a regenerator is to be made consideration should, in turn, be given to the following items :—

(1) The surface contact between the regenerator flues and the secondary-air flues must be ample.

(2) Every precaution must be taken to ensure that no short-circuiting takes place. According to the construction of the regenerator this may occur :—

(*a*) Between secondary-air flues and waste-gas flues.

(*b*) Between producer and secondary-air flues.

(*c*) Between producer and waste-gas flues.

(3) There must be ample facilities for the removal of dust, etc., from both waste-gas and secondary-air flues. In some types of regenerator no cleaning is possible until the whole is demolished. In this connection care should be taken to see that the stage floor of the house is not constructed so that it precludes cleaning of the horizontal flues on a level with it.

(4) Means for regulation of the secondary air to distinct parts of the setting should be provided. It is frequently found that the currents of air to the various "nostrils" vary in quantity to a considerable extent. For this reason dual or multiple regulation is arranged for in some types (*see* Figs. 27 and 48).

(5) The baffling arrangement in the secondary-air flues should not be too involved, otherwise an excessive draught will be necessary in order to pull the requisite quantity of air through. High velocity of draught means too rapid travel of the waste gases, which consequently leave the setting before effecting the maximum exchange of heat. It is difficult to give any figure for the thickness of regenerator blocks, and a medium has to be struck so as to afford both good conductivity and stability.

Types of Regenerators

The principle of operation of regenerators is best understood by reference to diagrams, and several illustrations of the most noteworthy types are here reproduced. One of the best-known systems which came into use in the earliest days of regeneration

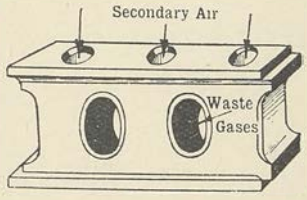


Fig. 41.—Klönne Regenerator Block.

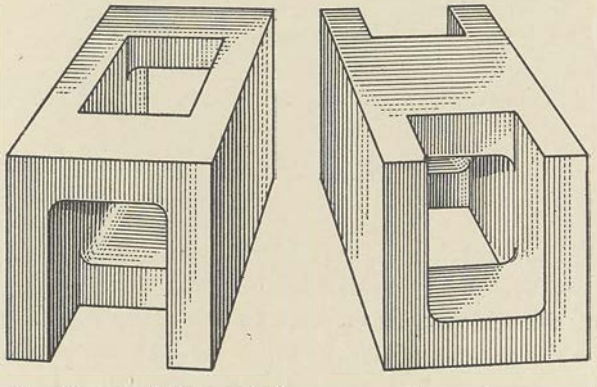


Fig. 42.—Gibbons & Masters' Regenerator Blocks (new type).

was the Klönne. In this system the interchange of heat was brought about by the employment of special blocks as shown in Fig. 41. In the latest Gibbons and Masters' system slotted fireclay boxes, moulded out by machinery, are erected side by side in vertical tiers so that no straight joints occur. This system has the advantage of being particularly simple, only necessitating the use of the two-standard blocks (Figs. 42 and 44), whilst the wall-thickness separating waste gases and secondary air is reduced to 3 inches with complete immunity from short-circuiting.

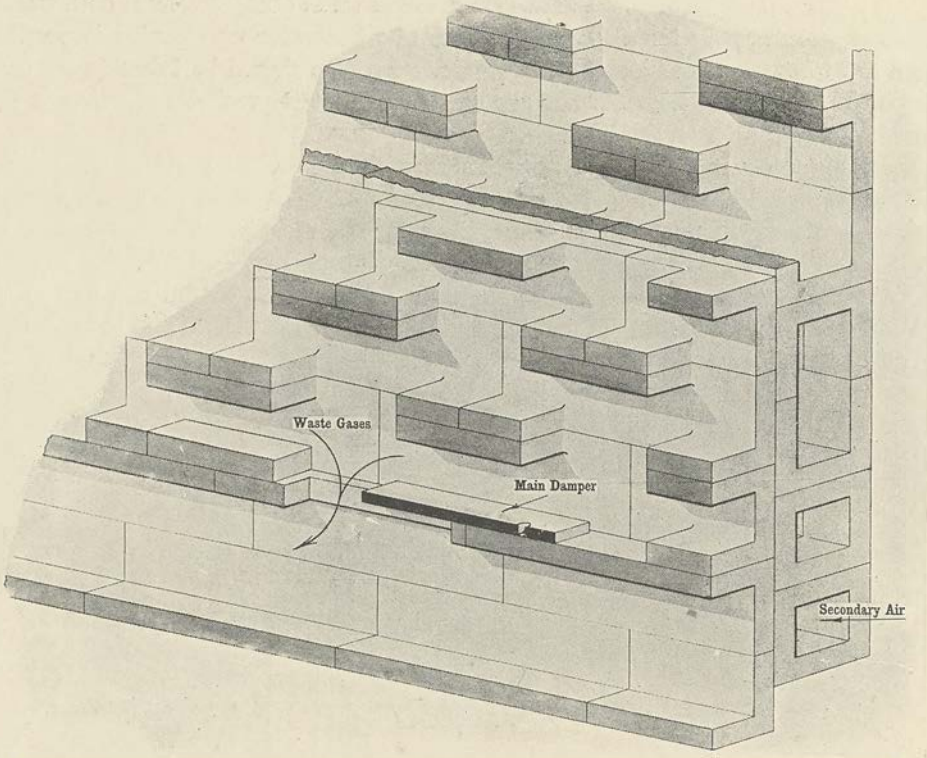


Fig. 43.—Gibbons & Masters' Regenerator System.

In Drake's system rectangular fireclay tubes (Fig. 45) are employed, the waste gases travelling backwards and forwards through these, whilst the secondary air traverses upwards around the outside of the tubes. The tubes are placed end to end, all joints being covered by bricks for the purpose of avoiding by-passing. If through the movement of brickwork by-passing does take place, it can at once be seen and remedied through the front wall of the regenerator. This is done by means of a "paddle" and patching material, in the same way as with a cracked retort. As regards the supply of secondary air, each vertical section is absolutely distinct from

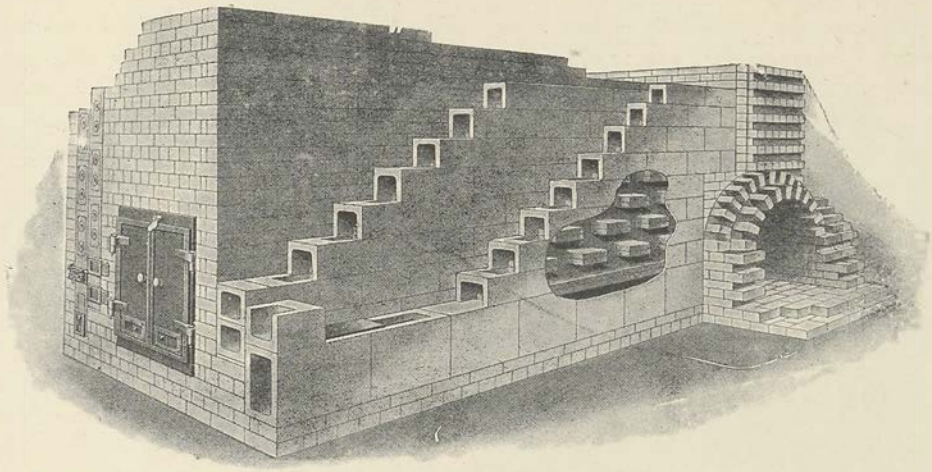


FIG. 44.—GIBBONS & MASTERS' REGENERATOR. NEW TYPE FITTED WITH BLOCKS AS SHOWN IN FIG. 42.

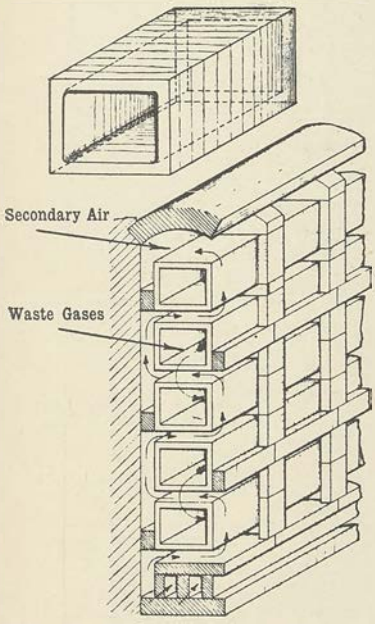


FIG. 45.—ARRANGEMENT OF DRAKE'S PATENT TUBULAR REGENERATOR.

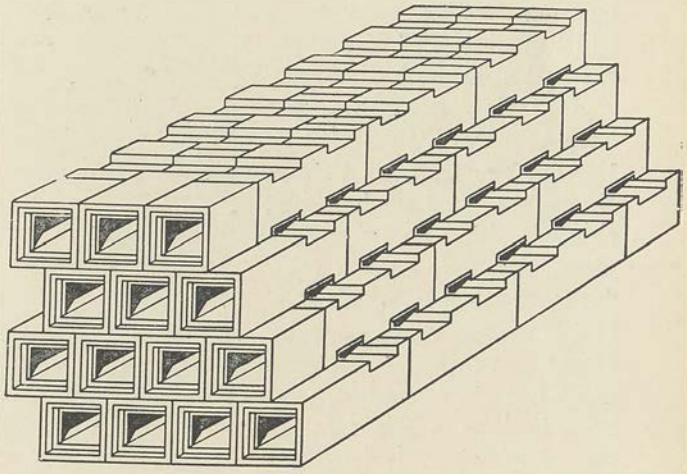


FIG. 46.—THE PINTSCH SYSTEM OF REGENERATION. THE CROSS-FLUES ARE FOR SECONDARY AIR, AND THE LONGITUDINAL FLUES TAKE THE WASTE GASES.

inlet to outlet, therefore under control, and the quantity at any point along the length of the combustion chamber can be regulated at the secondary-air inlet slide.

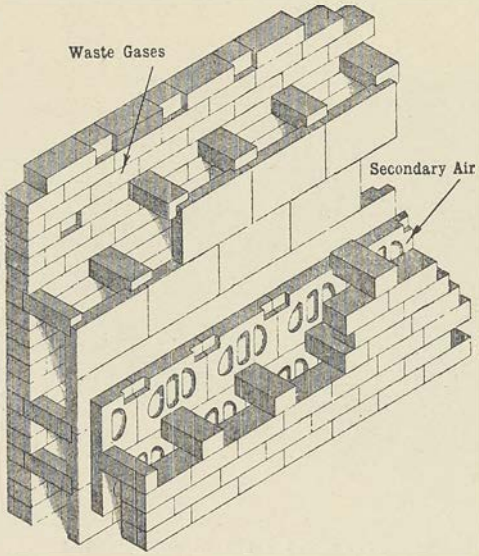


FIG. 47.—BROWN'S REGENERATOR.

A Continental type of regenerator is shown in Fig. 46. In this pattern the walls separating the hot gases and air are reduced to a minimum as regards thickness, and special tubular fireclay bricks are employed. These bricks, placed lengthwise to the furnace, have transverse grooves on the upper and lower outer surfaces and, when put together, form cross-flues between the individual layers. The secondary air, in an ascending stream, passes outside the tubes and through the cross-flues, the waste gases travelling down from the furnace through the tubes. The shaped bricks are rebated at their ends, thus avoiding leakage between the flues.

Brown's patent regenerator is shown in Fig. 47. Ordinary sized firebricks fitting into rebates in the special tiles are used for staying the vertical walls. In building the flues the "bed" and "cross-joints" of the tiles are broken in both directions. The staying bricks do not extend more than half-way through the tiles, so that in the event of one tile breaking, short-circuiting does not take place. Brooke's system (Fig. 48) is another in which contact is arranged for by tubular means. It differs from types given in Figs. 45 and 46, however, in that in this case the secondary air travels inside the tubes, the waste gases circulating around the outside. The ingoing air travels backwards and forwards in a zig-zag direction, and is admitted at two places on each side of

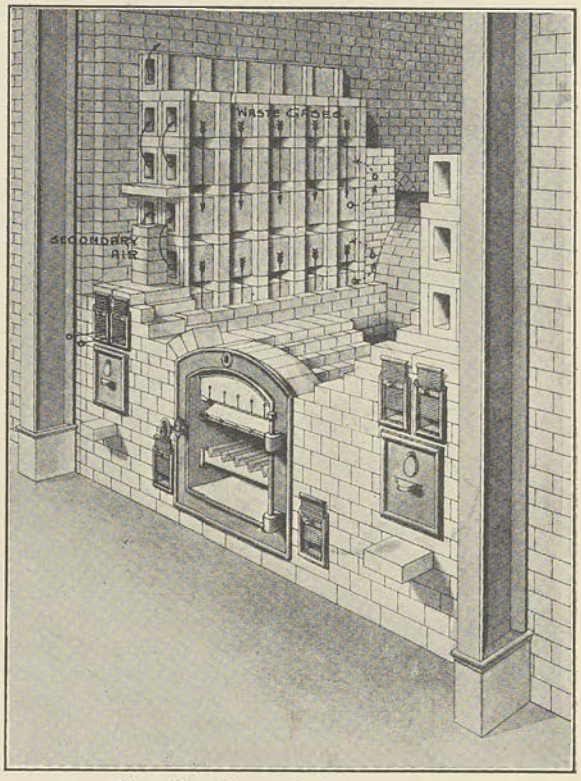


FIG. 48.—BROOKE'S REGENERATOR.

the furnace front, and in four similar places at the back of the bench, so that there are eight inlets in all. The air passing through the various series of horizontal flues is kept entirely distinct from the air travelling in the adjoining series; thus the supply to the various portions of the combustion chamber is under control. The waste gases, after leaving the setting, pass vertically downwards, and are kept in separate streams until they reach the bottom of the regenerator flues, when they enter a common channel. At the bottom of each separate compartment a damper enables any one of the streams to be controlled. In the illustration given, the amount of direct contact surface between the waste-heat and the secondary-air flues is 434 square feet.

An illustration of the Winstanley regenerator is given in Fig. 49. The chief point to notice about this type is that the secondary air is taken in in two distinct streams, one on each side of the waste-gas channel, so that the maximum heat is extracted from the hot products. It will be noticed that the inner stream of secondary air is sandwiched between the waste gases and the producer, whilst primary air is admitted through side channels.

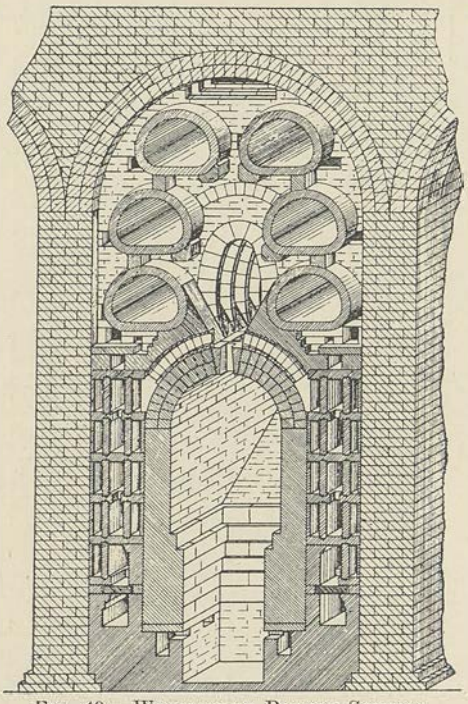


FIG. 49.—WINSTANLEY RETORT SETTING, SHOWING SYSTEM OF REGENERATION.

It is a striking fact that few standard English settings embrace facilities for heating the primary air as well as the secondary. Such systems are more frequently met with on the Continent, where many complicated arrangements are introduced. From an analysis of fuel results, however, it appears that attention to the practical points of design is of greater value than purely theoretical refinements.

The South Metropolitan Gas Company, as is well known, employ generator settings almost exclusively; but at their Old Kent Road works they have adopted a regenerator of their own design. A section of this is shown in Fig. 50. It will be noted that the producer gas, supplied from outside producers, is delivered to the combustion chamber by a series of vertical flues, oval in section, and numbering eight to each setting. At the same time, the secondary air is admitted through vertical Doulton-ware tubes, around the exterior of which the waste gases travel.

(*f*) THE GENERAL ARRANGEMENT OF THE SETTING

This is, in the first instance, entirely dependent upon the capacity of the unit in question. Small works have, of course, to take up the small fluctuations in

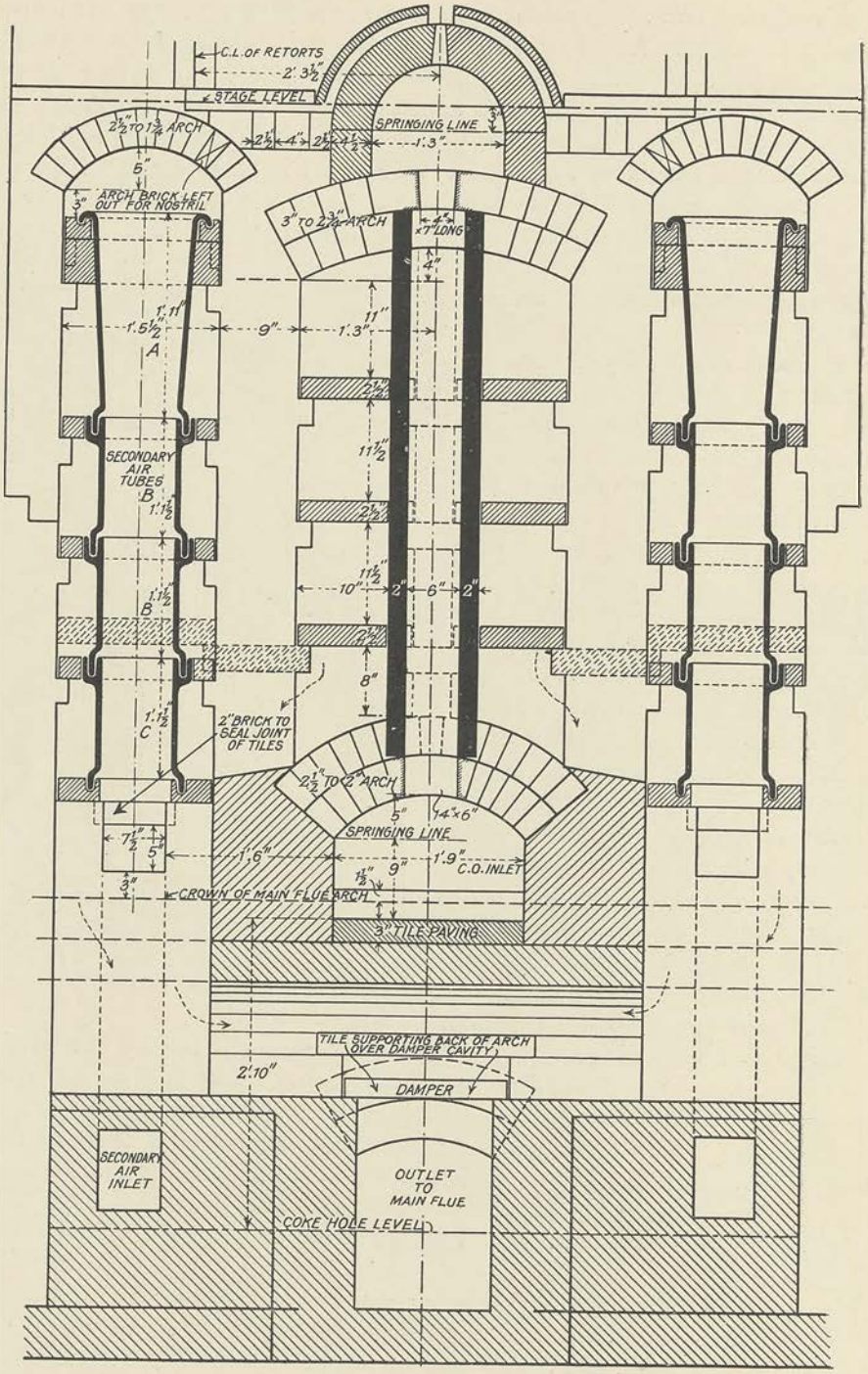


FIG. 50.—THE SOUTH METROPOLITAN SYSTEM OF REGENERATION.

demand by setting down units of varying capacity. Although in rare instances it is done, it is not advisable to work a portion of an arch during slack periods, as fuel consumption is unavoidably increased. If, however, there is no other means of regulating the output, it will be found preferable to work the retorts in one vertical row. The damper on this side of the setting is then opened and that on the opposite side closed, so that the furnace gases are pulled around those retorts in operation. The greater the number of retorts to a bed, the lower (*pro rata*) will be the fuel consumption. Hence settings of twelve have come into fairly extended use. One of the first considerations—of particular moment in cases where land is expensive and the quantity limited—is the productive capacity per square foot of area. The highest yield in this respect is given by the settings of ten retorts in two vertical rows—commonly known as the Bishop of London's bench. The output necessarily varies with the size of retorts, but may be taken, on the average, as 200 to 250 cubic feet per diem per square foot of ground area. This figure is based on the outside dimensions of the retort house and 24 inches × 16 inches through retorts. For a setting of eights in three rows the capacity would be reduced to 150 to 180 cubic feet per diem per square foot. For vertical retorts the figure (according to the system) may be as much as from 350 to 475 cubic feet per square foot, which, again, may be considerably increased by steaming.

The disposition of the retorts in the setting must be such that the heating of each one is as uniform as possible. In settings of two vertical rows this is more easily assured than with three vertical rows, as with the latter, the retort immediately above the combustion chamber has to face the fiercest portions of the flame. In a scientifically constructed setting there is no reason why the average temperature of any of the retorts in that setting should differ by more than 65° C.

Under all circumstances "local heating" must be avoided. This is said to be taking place when certain defined portions of the setting are under considerably greater heat than the remainder. The term really applies to the differing sections of the bench; for instance, we do not speak of a combustion chamber being subjected to local heating merely because its temperature is greater than that of the remainder of the setting. If, however, one section of this chamber were considerably hotter than the remainder, the hotter section would be giving rise to local heating. The effects of this derangement are very often seen when retort doors are opened—rings of dull red colour encircle the retort in contrast to the white heat of the remainder. This is indicative of bad spacing of the "nostrils," or of stoppage of one or more of these; but, beyond choking up by dust or by "drippings" from the upper portion of the bench, the cause of local heating can usually be attributed to constructional defects or to inferior design. The following considerations may be set down as being among the more important items to be kept in mind when designing the upper portions of a setting:—

(1) The combustion chamber should be of ample size, so that sufficient space is allowed for the mixing of the air and gas.

(2) The "nostril holes" must be so spaced out that they come midway between the cross-walls of the setting and the combustion chamber.

(3) The air and producer gas should not come together too closely, and should not meet at right angles. The effect of meeting in this way is that too thorough mixing takes place, and short flames of small volume are the result (*see* Fig. 53).

(4) The shape of the nostrils is of importance ; they should be tapered in section (Fig. 51), the smaller width being at the top. In this way any lumps or dust falling from above will drop through the nostril instead of lodging in it.

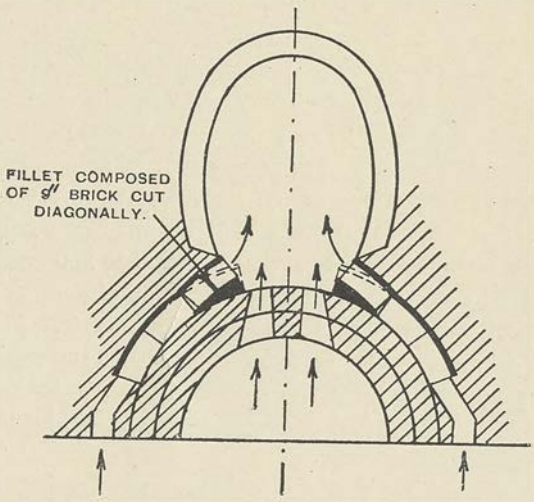


FIG. 51.—DEFLECTING SECONDARY AIR SO THAT FURNACE GASES MEET IN A PARALLEL DIRECTION. DOTTED LINE SHOWS USUAL POSITION OF CHANNEL BLOCK.

(5) The secondary air on both sides of the setting should be under dual control at least, or preferably the supply to each nostril should be capable of regulation. It is frequently found that the air has a tendency to rush towards the centre nostrils of the furnace arch, this giving rise to irregular distribution of heat and dull mouth-pieces.

(6) The "nostrils" should be kept low in comparison with the bottom retorts. If they are above the base of the lowest row of retorts, the latter will be insufficiently heated.

(7) For settings containing two vertical rows of retorts the direction of discharge of the producer gas should be vertical (Figs. 52 and 53). For three rows the "nostrils" should point outwards. In this way more effective distribution of heat is assured, whilst the centre retort is not subjected to a direct cutting heat. In some settings in which three vertical rows of retorts are employed, twin combustion chambers are constructed. In this way the central retort is more effectively protected than is the case when a single chamber is used.

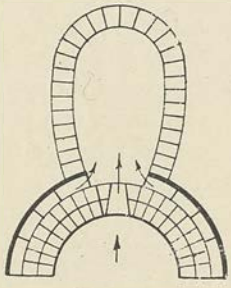


FIG. 52.

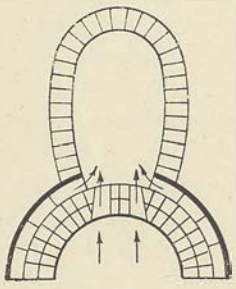


FIG. 53.

(8) Retorts are far less liable to "local heating" when set in tiers of twos. Thus if a setting of eight is decided upon it is preferable to set the retorts in two vertical rows of four rather than in two rows of three and one row of two. In addition, the former arrangement gives a greater yield per square foot of ground area. The chief objection is that if hand charging is in vogue a platform will have to be used for the top tier.

(9) The vertical division walls supporting the retorts need not be of greater width than 4½ inches, provided that 9-inch walls are put in where the retort joint comes. The walls forming the combustion chamber should not be less than 6 inches in width.

(10) The gases should be throttled to a certain extent at the top of the setting. These get away too quickly if excessive room is permitted. The bottom retorts should be no more than 4 inches to 4½ inches from the side of the main arch wall.

Specifications for Horizontal Benches

It would not be possible, owing to the multitude of designs now adopted by individual engineers, to give here a general specification for a horizontal retort bench. The foregoing pages should, however, prove of some assistance to the engineer contemplating extensions or renewals; and, with their aid, there should be little difficulty in compiling specifications for benches of whatever type or capacity. The chief points requiring consideration have been fully dealt with, and in addition it is imperative to ensure that first-class material should be used throughout. Except in certain classes of silica work the joints should be thin, and two to one cement mortar used in all stock brickwork, with fireclay cement for all fireclay work. As regards the types of materials suitable for various portions of the setting, reference should be made to Chapter VI dealing with Refractory Materials.

THE COST OF HORIZONTAL RETORT SETTINGS

Costs of erection must necessarily vary to some considerable extent in accordance with the fluctuations in price of materials and labour, also the design or "stiffness" of the work put down. To attempt to give precise figures at the present time is an unenviable task, and the author suggests, therefore, that the following estimates should only be used as a guide for the purpose of obtaining an approximate idea of the outlay involved. Stage floors, whilst costing on an average about £6 10*s*. per mouthpiece, may rise to as much as £17 10*s*., in cases where exceptionally heavy charging machinery, etc., is allowed for. Other factors affecting the ultimate cost are the distance and ease of access of the point of supply from the site on which the structure is to be erected, also the prevailing railway rates and water freightage. In most cases all the above considerations should not influence the following prices to a greater extent than 10 per cent. in either direction. Owing to competition amongst contractors, a certain amount of "cheeseparing" is inevitable in the preliminary tenders; for this reason the figures given below lean, if anything, towards extravagance—that is to say, they exemplify expenditure where a few extra pounds have not been withheld.

No. I

SETTINGS OF "TENS." Two vertical rows of 5 retorts, 24 inches × 16 inches × 20 feet. Say, 10 beds, carbonizing 120 tons of coal per diem. Capacity, 1½ million cubic feet per diem, straight coal-gas.

	£	s.	d.		
Foundations and excavation, for bench and chimney .	6	6	0	per	mouthpiece.
Arches, spandrils, main flue	31	0	0	„	„
Buckstays and steel bracing	7	0	0	„	„
Chimney: Brickwork, £4 4*s.*; bracing, £1 5*s.* . .	4	9	0	„	„
Mouthpieces, hydraulic mains, ascension pipes (both ends of retort), and all retort ironwork . .	40	0	0	„	„
Tar towers (C.I.) and fittings	2	7	6	„	„
Retort-house governor and connections . . .	1	17	6	„	„
Retort settings, producers, producer ironwork, etc. .	62	0	0	„	„
	£155	0	0	per	mouthpiece.
(Pre-war	£50	10	0	per	mouthpiece.)

i.e., £258 per ton of coal per maximum day. (Pre-war £83.)

Or £20 10*s.* per 1,000 cubic feet of gas per maximum day. (Pre-war £6 15*s.*)

	£	s.	d.		
Bench and fittings as above	155	0	0	per	mouthpiece.
Retort house, including roof and foundations and coal store	85	0	0	„	„
Stage floors: Steelwork, £9; concrete and expanded metal, £4 10*s.*	13	10	0	„	„
Tunnel floors	6	0	0	„	„
Stoking machinery (say, combined discharger-charger coal conveyors, breakers, elevators, hoppers) . .	75	0	0	„	„
Electric generating plant, in duplicate. . . .	15	10	0	„	„
	£350	0	0	per	mouthpiece.

i.e, £583 per ton of coal per maximum day. (Pre-war £210.)

Or £46 10*s.* per 1,000 cubic feet per maximum day. (Pre-war £16 15*s.*)

N.B.—It should be explained that costs for horizontal retorts based on coal used or gas produced per maximum day are liable to be erratic for the reason that by the manipulation of the charges (such as working 10-hour instead of the more common 12-hour charges) more coal can be "through-put" in 24 hours; consequently, more gas than is customary is produced per unit of time. In the above calculations, a normal production of 7,500 cubic feet per mouthpiece per diem has been assumed, this being straight coal-gas with no steaming. Computations are best carried out by considering expenditure per mouthpiece.

No. II

SETTING OF "EIGHTS," in three rows, 22 inches × 16 inches × 20 feet retorts. Say, 10 beds, carbonizing 90 tons of coal per diem. Capacity, 1¼ million cubic feet per diem, straight coal-gas.

	£	s.	d.	
Foundations and excavations for bench and chimney	6	0	0	per mouthpiece.
Arches, spandrils, main flue	37	0	0	,, ,,
Buckstays and steel bracing	7	5	0	,, ,,
Chimney: Brickwork, £4 12s. 6d.; bracing, £2 12s. 6d.	7	5	0	,, ,,
Mouthpieces, hydraulic mains, ascension pipes (both ends of retorts), foul mains	45	0	0	,, ,,
Tar towers and fittings	3	0	0	,, ,,
Retort settings, producers, prodcuer ironwork, etc.	70	10	0	,, ,,
	£176	0	0	per mouthpiece.
(Pre-war	£53	10	0	per mouthpiece.)

i.e., £313 per ton of coal per maximum day. (Pre-war £95.)

Or £22 10s. per 1,000 cubic feet of gas per maximum diem. (Pre-war £7 12s.)

No. III

SETTING OF "SIX," in three rows, 22 inches × 16 inches × 10 feet, stop-ended. Say, three beds, carbonizing 11 tons of coal per diem. Capacity, 130,000 cubic feet per diem, straight coal-gas.

	£	s.	d.	
Foundations and excavations	10	10	0	per mouthpiece.
Arches and spandrils	44	0	0	,, ,,
Buckstays and steel bracing	9	0	0	,, ,,
Chimney	7	10	0	,, ,,
Mouthpieces, hydraulic mains, and all retort ironwork	39	0	0	,, ,,
Retort settings, producer, and producer ironwork	67	0	0	,, ,,
Tar tower and fittings, tar main, etc.	6	10	0	,, ,,
	£183	10	0	per mouthpiece.
(Pre-war	£57	0	0	per mouthpiece.)

i.e., £300 per ton of coal per maximum day. (Pre-war £95.)

Or £25 10s. per 1,000 cubic feet of gas per maximum day. (Pre-war £7 17s. 6d.)

INCLINED RETORT SETTINGS

Little attention need be given to inclined retorts, which, although still employed, can scarcely be considered as appertaining to modern gasworks practice. The originator of the system, M. Coze, designed his settings with the retorts set at an angle of 32° with the horizontal—*i.e.*, the theoretical angle of repose of coal. The chief merits (also largely theoretical) were the absence of charging and discharging machinery and the wear and tear connected with this apparatus, also only one ascension pipe was employed, this being at the lower end of the retort. Other experimenters have worked with the retorts at various angles ranging up to 45°; but it is now generally

recognized that if automatic charging is to be carried out it is best done by placing the retort on end.

Inclined retorts are seldom entirely automatic, and the charge has invariably to be "started on the run" by pricking up at the bottom and pushing from the top. Moreover, the character of the charge is materially affected by the kind, size and degree of dampness of the coal in use. "Creeping" often takes place during the period of distillation, with the result that the upper portions of the retort are completely uncovered. The result is that, to avoid trouble, certain classes of coal have to be selected for use. In G. R. Love's system the retorts were set at 45° and

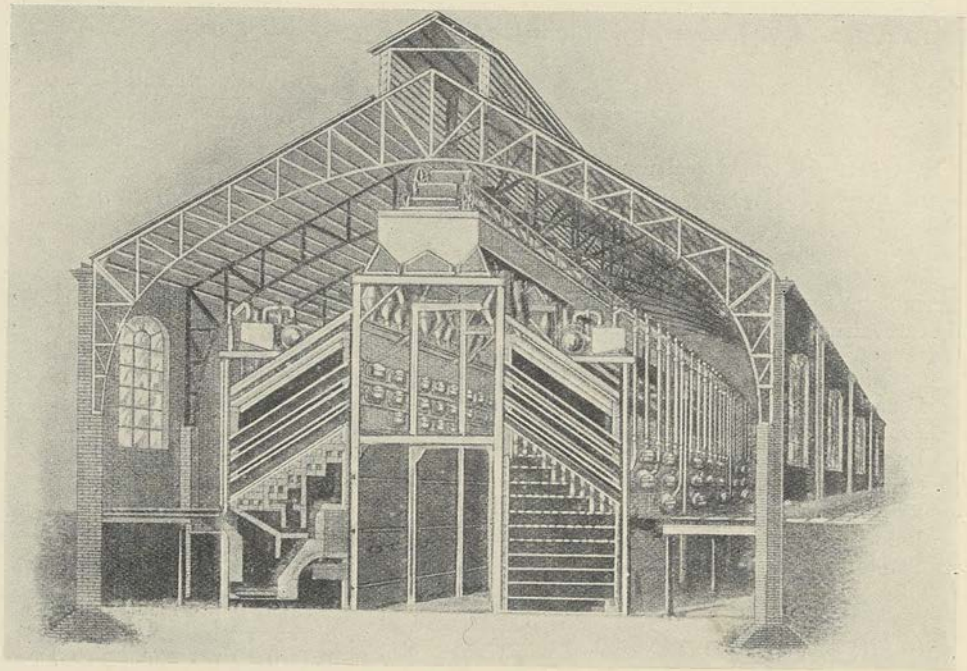


FIG. 54.—DIAGRAMMATIC VIEW OF TWO INCLINED RETORT BENCHES SET BACK TO BACK WITH COMMON CHARGING FLOOR.

received full charges, two ascension pipes being provided. The system has now been abandoned.

With regard to fuel consumption, inclined systems are more extravagant than horizontals, and an average figure of 16 lb. of coke per 100 lb. of coal carbonized (*i.e.*, 22 per cent. of the coke made) may be given.

The intricacy of this type of setting renders it more costly than the horizontal bench ; while the life of the inclined retort is usually less than that of a good quality horizontal type. For the complete setting, inclusive of all ironwork, producers, chimney, foundations, etc., the approximate cost per mouthpiece would now be £145.

It may be mentioned that in the South Metropolitan Company inclined settings

are still employed with satisfactory results. In fact, two of the company's works are solely equipped with inclined retorts.

CONTINUOUS HORIZONTAL RETORTS

A principle has recently been introduced whereby horizontal retorts may be operated continuously on lines approaching the continuous vertical retort. The system is the invention of Messrs. J. West and W. Wild, and the method of operation will be readily understood by reference to the accompanying illustrations.

One of the earliest attempts to render the horizontal retort continuous in action was made about the middle of last century when the principle of the Archimedean screw was employed. A screw conveyor was fitted to the interior of each retort, and as the coal was fed into the inlet end it traversed the hot space and was intended to come out in the form of coke at the opposite end of the retort. At this time the heats employed for carbonization were essentially low and would not necessarily preclude the use of a conveyor of the kind, but in practice the scheme was found impracticable and was ultimately abandoned. In 1889 Yeadon and Adgie came forward with a fairly promising idea which involved the use of a revolving retort. The retort was of conical shape, mounted with its axis horizontal and carried on suitable bearing rollers. The middle length was enclosed in a furnace which, by external heating, maintained the temperature of this portion at about 1,000° C. The coal entered at the smaller end of the cone, being taken through a small cylinder rendered gas-tight by means of a spiral blade device. At the larger end was an ascension pipe through which the gas passed, while at the same end was provided a channel into which the coke fell, passing out by a gas-tight cylinder similar in design to that employed for admitting the coal. The coke obtained, however, was of extremely poor quality, being little better than breeze. Probably, on the latter account the

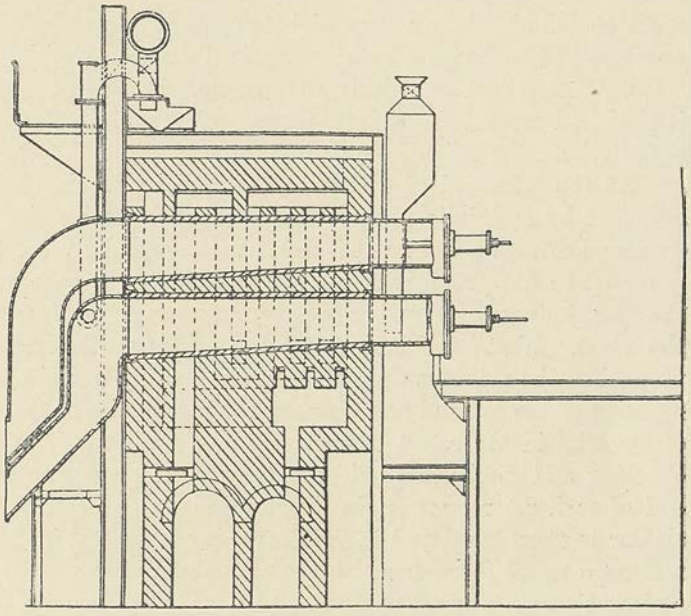


FIG. 55.—WEST AND WILD'S CONTINUOUS HORIZONTAL RETORT SYSTEM. (ORIGINAL DESIGN.)

system was never experimented with on anything approaching a large scale, and to-day it is merely of historical interest.

West and Wild System

J. West and his collaborator have attempted to solve the mechanical difficulties of the continuous method while at the same time providing a high gas yield and a coke of good quality. They have found by investigation and experiment that in order to obtain satisfactory results it is necessary that the retorts should be maintained practically fully charged at the inlet end throughout normal working, that they should be of flattened cross section, approaching that employed in coke-oven construction, and that they should be tapered towards their outlet end. At the same time it has been found that the coal, immediately it enters the hot zone of the retort, must be submitted to a very high temperature in order that the outer portion or envelope of the charge may be carbonized extremely rapidly and taken through the "tacky" condition as quickly as possible. In this manner a carbonized envelope is produced around the charge, which facilitates its passage, with the avoidance of coagulation or cohesion from end to end.

At the inlet end of each retort is attached a chamber in which a plunger is actuated by hydraulic power. Each chamber receives its supply of coal from an overhead storage pouch, and is fitted with a special valve to prevent the escape of gas. When the piston is withdrawn to its extreme outward position coal falls into the space in front of it, and as the piston travels slowly forward the coal is forced into the retort. West has found that by ensuring that the fresh coal charge is brought up against the previous charge before the latter is sufficiently carbonized to prevent cohesion of the old and new charges, the plunger is enabled to force the whole mass of material in the retort towards the discharging end, and to effect simultaneous charging and discharging without the material wedging itself up. At the outlet end of each retort was originally attached a downwardly extending chamber very similar to those employed in the Glover-West vertical installations, and this formed a storage vessel through which the coke was discharged by gravity at intermittent periods through a hermetically sealed door of the usual construction. In the most common practice the horizontal retort is provided with a gas take-off at either end, but in the new system the gas travels along the retort and is removed by an ascension pipe fixed at the top of the coke chamber.

The introduction of the vertical retort, which lends itself to the delicate control of temperatures, has been responsible for the idea of establishing zones of differing temperatures, a practice which is always to be condemned in the ordinary intermittent systems of carbonization. Uniformity of temperature, however, is no longer an essential feature when a continually moving charge is under consideration, and so it is not surprising to find that West arranges in his new system for three zones of different degrees of temperature throughout the retorts. In the first zone, which extends along the inlet length of the retort, the most intense heating is arranged for by bringing about combustion of the producer gas at this point. Then follows a length of intermediate temperature, heated by circulation of the hot products of

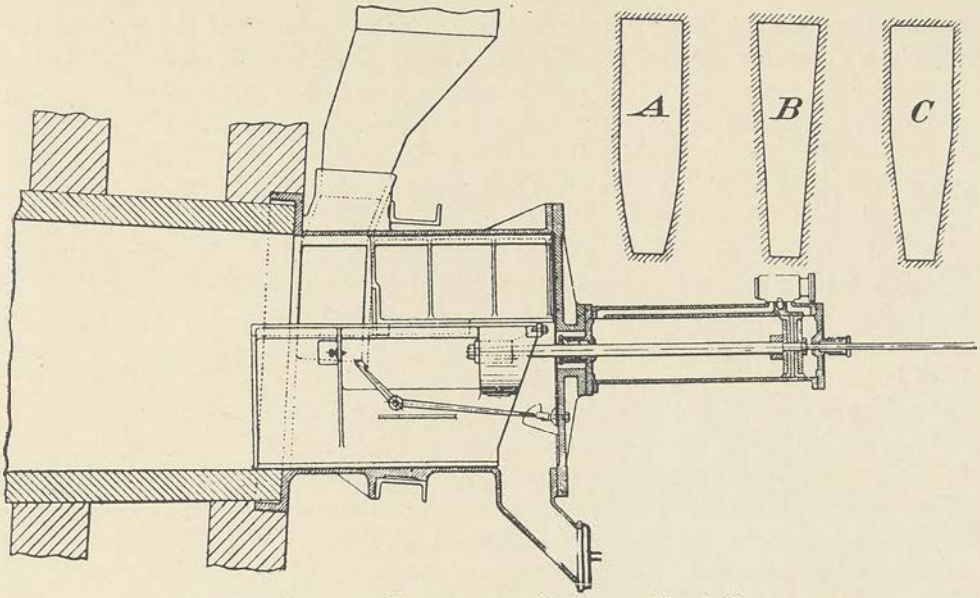


FIG. 56.—CHARGING MECHANISM OF WEST AND WILD'S RETORT.

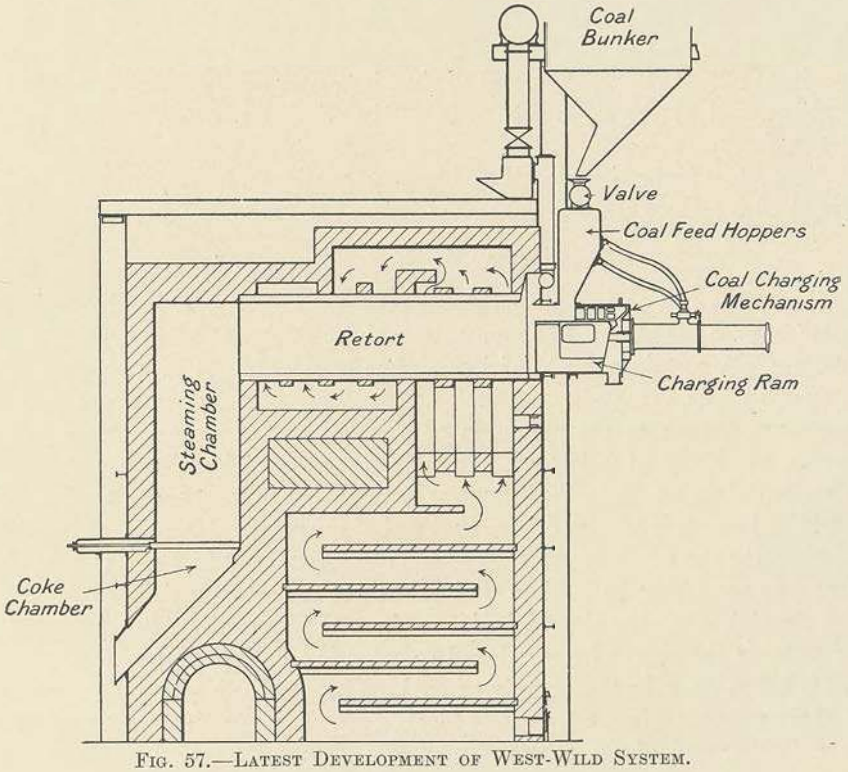


FIG. 57.—LATEST DEVELOPMENT OF WEST-WILD SYSTEM.

combustion; while in the third, or cool, zone, heat may be extracted from the hot travelling charge by carrying round the exterior of the retort the secondary air employed for the combustion of the producer gas. This last-named feature is certainly one which will appeal to that school of fuel economists who are continually pointing to the loss of sensible heat which is an inherent feature of all intermittent horizontal retort systems in which the coke must necessarily be discharged in the incandescent state and ultimately quenched with water.

Later experience with the system indicates that with continuously operating retorts difficulties are encountered owing to the resistance which the material offers to the plunger or propeller. Increase of pressure applied to the mass in the retort may not ensure an efficient feeding and discharging action, for the coal appears to wedge itself in the retort. However, it has been found that if the retort be so shaped that the weight of the coal is distributed fairly evenly over the sides and bottom, instead of being carried practically entirely by the bottom of the retort, the plunger is enabled to effect more efficient propulsion of the charge through the retort with a minimum of pressure, for the resistance to propulsion is more uniform over the whole of the mass, and buckling or wedging of the charge is obviated.

The retorts, therefore, should be made with tapered sides, typical sections being shown at A, B and C in Fig. 56, which also shows in detail the continuous charging apparatus. With the tapered retort it is said that not only is the weight of the charge distributed more evenly over the surface of the retort, but, by reason of the reduced thickness of the coal in the base of the retort, the heat penetrates and completely carbonizes the coal very readily, and so gives it greater power to resist buckling during propulsion, and at the same time reduces the friction between the charge and the retort surface.

The system has quite recently undergone considerable modification, and is now designed with a large steaming chamber (Fig. 57) at the discharge end of the retort.

"STEAMING" IN HORIZONTALS

The success which has attended the process of steaming the charge in vertical retorts (*see* page 424) has led to many attempts to apply the same system to horizontal retorts. A certain amount of success has been obtained in the latter direction, but, on the whole, it may be said that, unless highly superheated steam is employed, derangements, such as the reduction of working heats or the excessive deposition of water, are likely to follow. Favourable results have been obtained by working the horizontal retort on semi-continuous lines. That is to say, one ascension pipe is stopped and steam is admitted from that end of the retort. Instead, as is customary, of discharging the whole of the coke at one operation, only half of it is pushed out at a time (the remaining half filling that portion of the retort which is adjacent to the steam supply), while the cleared half is re-charged with coal. After the usual period of distillation the charge (now reduced to coke) is similarly pushed forward, and its place is taken by a further supply of coal. The ascension pipe on the steam inlet end of the retort is, of course, entirely blocked off, all gas passing out through the pipe at the further end of the retort.

R. J. Rew has adopted the principle of fitting a special duct to the base of the retort and has met with considerable success. The principle will be readily understood by reference to Fig. 58.

Perhaps success is chiefly dependent upon ample recognition being given to the following points :—

(*a*) A retort temperature of approximately 1,100° C. (2,000° F.) should be consistently maintained.

(*b*) Superheated steam must be used.

(*c*) The supply of steam should be carefully regulated so as to avoid anything approaching an excess. Moreover, the pressure should not be too great, as high pressure means high space-velocity throughout the charge, whereas comparatively low time-contact is desirable.

(*d*) In systems where steam is admitted by duct or pipe throughout the length of the retort the precaution should be taken of stopping the first two or three feet of such duct or pipe. This particularly applies to stop-ended retorts with one ascension pipe, for if the steam is allowed to escape in the first few feet it will tend to short-circuit directly up the outlet pipe.

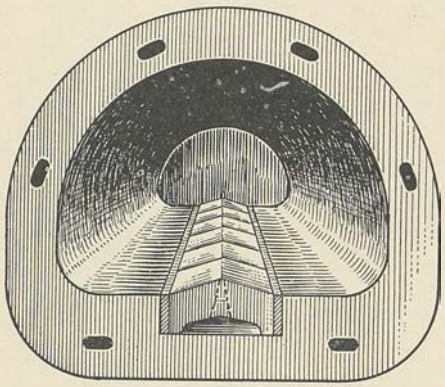


Fig. 58.—Rew's Channel System for Steaming Horizontal Retorts.

(*e*) It has been found advisable to work all steamed retorts under a vacuum of from 2 to 5-tenths, otherwise with retorts in bad repair the gas escapes into the furnace instead of going forward by the ascension pipes.

As regards the effect of steaming horizontal retorts, P. B. Ellacott [1] has given the following figures which were obtained from fairly prolonged working at Newry Gasworks :—

	Without Steam.	With Steam.
Gas made per ton of coal (cubic feet)	12,000	14,200
Coke sold per ton of coal (cwts.)	9	8

Further results obtained by the Devon Gas Association, working with Rew's channel system, were as follows :—

	Without Steam.	With Steam.
Gas made per ton of coal (cubic feet)	11,248	15,030
Coke sold per ton of coal (cwts.)	8·1	7·2

OUTSIDE PRODUCERS

The term "outside" or "external" producer embraces those types which do not form part and parcel of the retort bench ; that is to say, the producer gas is

[1] *Gas World*, LXXI, page 142.

generated at some distance from the point at which it is to be consumed. Outside producers as now employed on gasworks may be classified as follows :—

1. Coke-fired. (*a*) External types. (*b*) Semi-external types.

2. Coal fired (or mixture of coke and coal), with plant for recovery of by-products.

3. High-pressure producers.

External producers of all types are entirely confined to the largest of gasworks. Although they cannot compete with the self-contained furnace on the score of fuel economy, their chief recommendations lie in a somewhat reduced capital outlay, if the producer is of a simple type, comparatively low labour charges, and little wear and tear. The working conditions for the men are also better. A distinct advantage, moreover, is the finer regulation of temperature in the settings owing to the possibility of passing the gas on its way to the settings through metal cocks. The simplest form of coke-fired external producer is very similar in appearance and construction to a water-gas generator, the outer casing being made of mild steel plates, with a lining of firebricks and thin layer of slag wool. In all cases a forced air-blast is provided, consequently a comparatively fine fuel may be made use of. A certain amount of steam is usually admitted below the grate in order to curtail clinker formation. One of the largest installations of outside producers is that laid down at the Provan works of the Glasgow Corporation, some fifteen years ago. These producers designed on the lines of that shown in Fig. 59, are rectangular (not circular) in section, and twelve of them were erected, to be used in conjunction with sixty beds each of twelve retorts. The steel casings are 13 feet 3 inches high by 9 feet 4 inches long and 6 feet 4 inches wide, and are lined with 9 inches of firebrick work, with a 2-inch cavity filled in with slag wool. The gas is led away from each producer by a lined flue casing measuring 2 feet by 3 feet 6 inches, this passing into a round main flue pipe of 4 feet 10 inches diameter. Owing to the forced draught made use of with this type of producer it is essential that an efficient dust chamber should be provided, so that the gas is thoroughly cleansed before reaching the combustion chambers of the settings. In the Provan installation the main flue is intercepted by dust chambers measuring 22 feet high by 11 feet 4 inches long by 6 feet 10 inches wide.

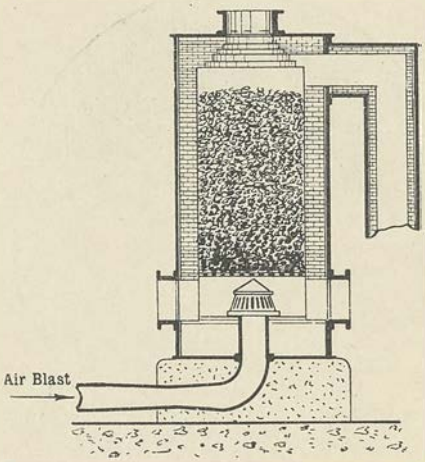


Fig. 59.—Simple Form of Outside Producer.

At the Old Kent Road works there are four retort houses (having a total capacity of 10 million cubic feet of gas per diem) heated by outside producers. There are two producers to each house, having a capacity of 30 tons, the coke used per day being about 35 tons per house. The calorific value of the gas is approximately

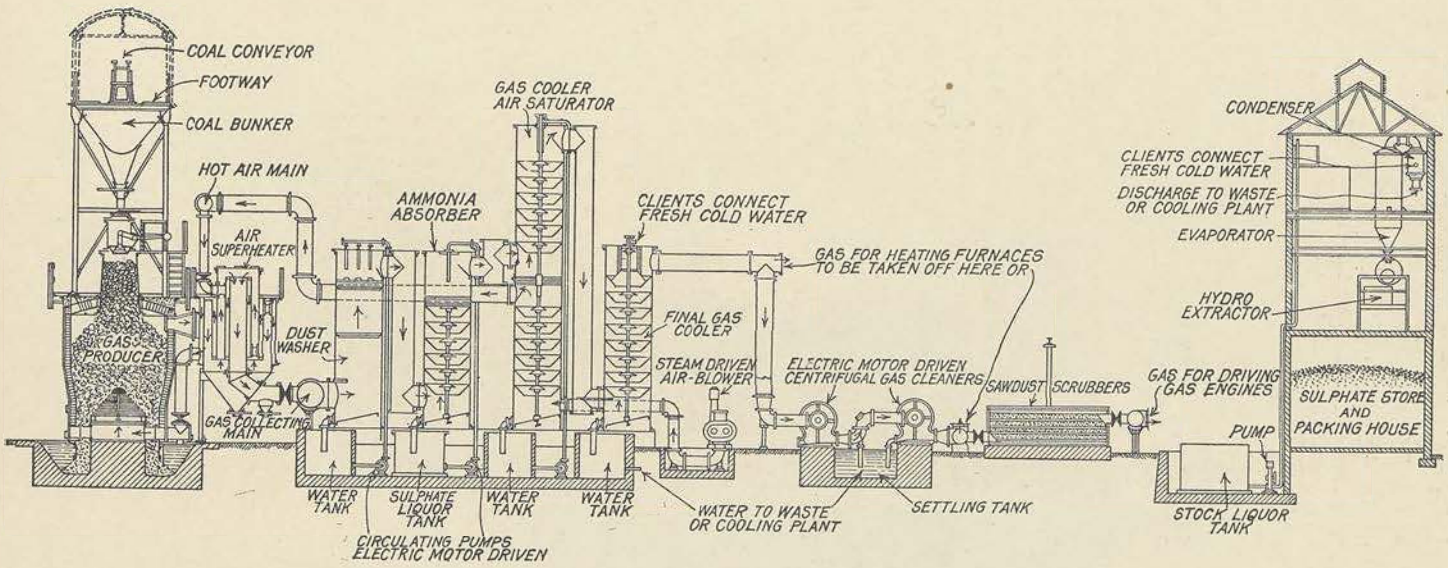


FIG. 60.—DIAGRAMMATIC ELEVATION OF MOND BY-PRODUCT RECOVERY AND GAS PLANT.

120 B.Th.U. gross, and the analysis averages 29 per cent. carbon monoxide, 4 per cent. carbon dioxide and 8 per cent. hydrogen, which gives a waste gas in the shaft containing 19 per cent. carbon dioxide, 0.5 per cent. oxygen. The waste gas on its way to the shaft imparts some of its heat to the incoming producer gas and also to the secondary air, thereby effecting some heat recovery. The average temperature of the combustion chambers is 1,300° C.

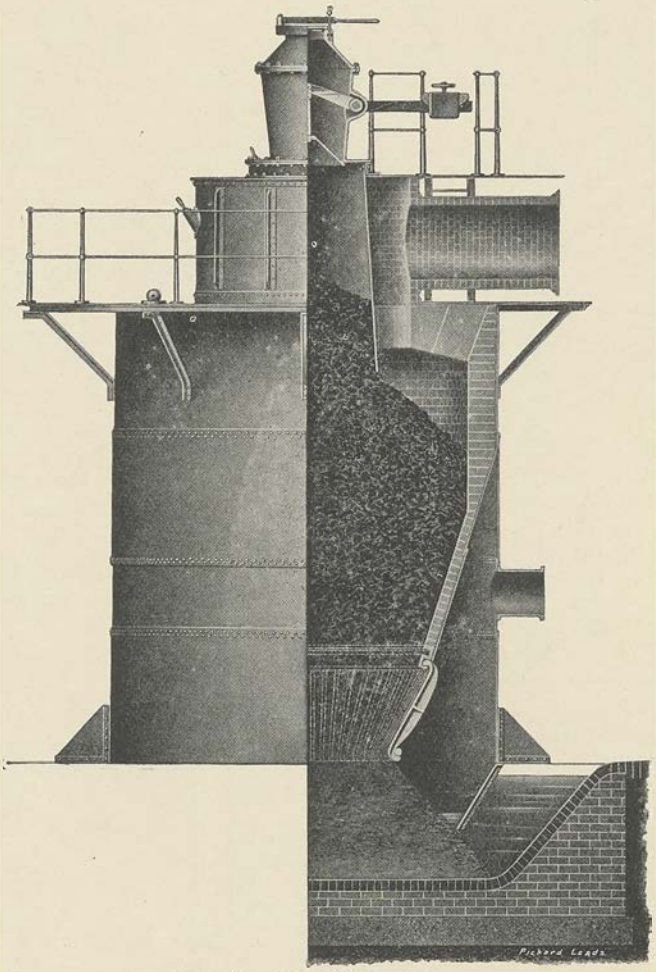


FIG. 61.—MOND PRODUCER.

In the construction of producers of this kind it is most advisable to fit a curtain wall in the producer so as to ensure that the gas passing to the retort settings is taken off well below the upper surface of the fuel. In this way the steam which is evolved from the freshly charged coke is prevented from passing out with the gas before being decomposed.

THE MOND PRODUCER

The Mond producer is probably too well known to need detailed description; but it may be recalled that a complete Mond gas installation was erected at the Saltley works of the Birmingham Corporation in 1912, for the purpose of heating a battery of coke-ovens for the carbonization of coal. A general idea of the producer, complete with apparatus for the recovery of by-products, is shown in Fig. 60, whilst a section of the generator is given in Fig. 61. The producer may be fed with a mixture of coke or breeze and coal slack, and is capable of gasifying about 18 tons of these fuels per 24 hours. The Birmingham plant consists of five producers. The base of each is sealed in water, into which the ash descends, this being periodically removed without interfering with the process of gas-making. The producers can, if desired, be fitted with automatic

ash-removing apparatus. A "wet" air-blast is blown through the fuel-bed by means of Roots' blowers, and in this way the temperature is maintained at a comparatively low point, so that ash alone, and no clinker, is formed. The quantity of steam introduced with the air-blast, when ammonia is recovered, amounts to about 2½ tons for every ton of fuel gasified, the low temperature thus ensured preventing the decomposition of the ammonia, and accounting for nearly four times the yield obtained from the ordinary gasworks process of distillation. The supply of steam and air before entering the producer traverses a regenerator (in which it derives heat from the outflowing producer gas), and afterwards the annular space formed round the inner shell of the producer by the external casing. On leaving the producer and regenerator the gas passes to a mechanical washer, where, by means of a water spray formed by quickly rotating dashers, tar and dust are eliminated.

The gas leaves the top of the producer at a temperature of about 500° C. It may be used direct; or the ammonia may be recovered by passing the gas through weak sulphuric acid in an absorber, in which case the temperature is reduced to that of the atmosphere before it can be finally used for heating purposes. It follows, therefore, that the highest heating efficiency is obtained when the gas is used direct from the producer, and under non-recovery conditions; otherwise there is a loss of sensible heat due to cooling, etc. It is said, however, that when the gas is taken direct from the producer, tar and dust troubles ultimately develop.

W. Chaney, formerly of the Saltley Gasworks, has stated that in the case of large installations of Mond gas plants about 150,000 cubic feet of gas can be obtained from a ton of coal slack, at a pre-war price of ½*d.* per 1,000 cubic feet. The calorific power of the gas is about 140 B.Th.U. per cubic foot. The same authority has also given the following interesting comparison of costs for heating by Mond gas and by means of the ordinary coke-fired regenerator furnace. It should be noted that the costs all refer to pre-war conditions:—

Pre-War Cost of Heating Retorts by Regenerator Furnaces. Based on a Fuel Consumption of 12 per cent. of the Weight of Coal Carbonized

Coke at 14*s.* per ton	20·2*d.* per ton of coal carbonized.
Labour	2·7*d.* „ „
Repairs and depreciation	1·0*d.* „ „
Total cost of heating	23·9*d.* (say 2*s.*) per ton carbonized.

Pre-War Cost of Heating by Mond Gas

(*a*) All coal slack.

Small coal at 10*s.* per ton	18·0*d.* per ton of coal carbonized.
Boiler fuel	2·15*d.* „ „
Labour	3·84*d.* „ „
Repairs and depreciation	8·53*d.* „ „
Oil, etc.	0·34*d.* „ „
Sulphuric acid at 30*s.* per ton	1·95*d.* „ „
Sulphate bags, packing	0·46*d.* „ „
Gross cost	35·27*d.* per ton of coal carbonized.
Less sale of sulphate	18·81*d.* „ „
Net cost of heating	16·46*d.* per ton of coal carbonized.

(*b*) Mixture of half coal slack and half coke dust.

Small coal at 10*s.* per ton	9·0*d.*	per ton of coal carbonized.	
Coke dust at 1*s.* 6*d.* per ton	1·35*d.*	,,	,,
Boiler fuel	2·15*d.*	,,	,,
Labour	3·84*d.*	,,	,,
Repairs and depreciation	8·53*d.*	,,	,,
Oil, etc.	0·34*d.*	,,	,,
Sulphuric acid at 30*s.* per ton	1·30*d.*	,,	,,
Sulphate bags, packing	0·30*d.*	,,	,,
Gross cost	26·81*d.*	per ton of coal carbonized.	
Less sale of sulphate	12·52*d.*	,,	,,
Net cost of heating	14·29*d.*	per ton of coal carbonized.	

More recently Chaney has given particulars which show that the fuel usually employed for producer work is a coal slack containing a proportion of nuts. It generally contains about 13 per cent. of ash; the calorific value of the slack being 12,500 B.Th.U. per pound (dry).

The calorific value of the coke dust is approximately 10,000 B.Th.U. per pound (dry), and the nitrogen content 1 per cent., the actual sulphate of ammonia recoverable being 45 to 50 lbs. per ton. It may safely be assumed that 3 to 4 per cent. of the total coal carbonized for gas-making purposes in this country represents the quantity of coke dust made; so that large quantities of sulphate of ammonia are available, and which at the present moment are neglected. Gasified alone, the coke dust yielded about 95,000 cubic feet per ton; the calorific value of the gas being 114 B.Th.U. per cubic foot. Unfortunately, the through-put per producer diminished to such an extent as to jeopardize the heats of the coke-ovens, and the test had to be discontinued.

By mixing 40 per cent. of coke dust with the producer coal, the heating value of the gas is increased to 130 B.Th.U. per cubic foot; and the average price of the mixture is correspondingly reduced.

	s.	*d.*
Assuming 17*s.* 6*d.* to be the price of the producer coal, 60 per cent. of 17*s.* 6*d.*	10	6
Coke dust, 40 per cent. at (say) 1*s.* per ton	0	5
Average price of mixture	10	11

The additional revenue from the sulphate of ammonia recovered per ton of the mixture would be 69 lbs. at £16 per ton = 9*s.* 10*d.*—reducing the cost of the producer fuel to 1*s.* 1*d.* per ton. To this latter figure has, of course, to be added the increased expenditure of fuel due to heat losses, and to extra manufacturing charges.

As regards increased expenditure of fuel, 12 per cent. for the ordinary internal method of heating retorts would be practically increased to 24 per cent. with outside producers, using 40 per cent. of coke dust and 60 per cent. of producer coal.

The manufacturing costs with outside producers are considerably higher than the ordinary method of heating retort settings; but the large margin between the cost of the producer fuel and the value of the coke displaced, warrants a careful consideration of this system of heating.

Briefly, the advantages of the Mond type of producer are :—

(1) The closing down or reduction of the producer gas when standing off retorts.

(2) The utilization of the coke dust.

(3) The recovery of the sulphate of ammonia.

(4) The generating of cheaper gas.

(5) Regular heating by producer gas as compared with the variable gas constituent of the ordinary generator.

(6) Less combustibles in ashes and clinker.

THE "TEES" PRODUCER

Within the last few years an outside producer, with mechanically operated grate, has been installed in connection with continuous vertical retorts at the Tottenham Gasworks. The installation consists of four Tees producers, each 8 feet 6 inches diameter inside the firebrick lining, and 15 feet high. This type of producer possesses for its special features a combination of steel shell having the lower portion water cooled and the upper part lined with refractory brickwork, with a rotating grate mounted eccentrically on water-luted ash discharge pan. These features are shown in the sectional elevation given in Fig. 62.

At the Tottenham works four producers are erected in a row, with a common operating platform and with gas outlets connected through dust catchers and mushroom type valves, with a common gas collecting main. Two steam

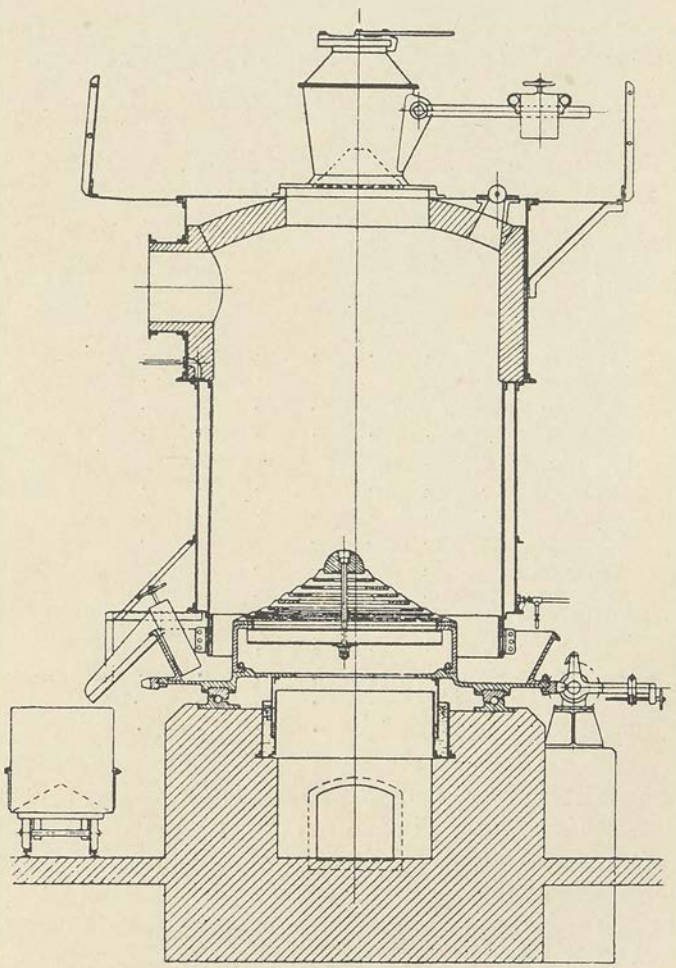


FIG. 62.—THE "TEES" PRODUCER.

turbo blowers, each being capable of meeting the requirements of three producers, provide the blast for the plant, and the rotating grates are operated by electric motors—installed in duplicate, one being spare—driving, by belting, the shaft which actuates through eccentrics and rods the ratchet feed gear of the grates.

The steel cylindrical shell of the producer has the water-cooling jacket so placed as to provide a water-cooled metal surface in that zone of the producer where clinker usually forms. By this provision clinker is prevented from adhering to the walls, and, with the gradual descent of the fuel, the clinker falls to the rotating grate, where it is crushed against the specially prepared grinding surface at bottom of producer, and passes into the luted ash-pan.

The rotating grate is formed of a heavy cylindrical casting surmounted by a stepped cone, the whole being mounted eccentrically on the ash-pan. The pan is rotated by power as below described. The pan is provided with sides forming a water lute, into which the bottom extremity of the producer shell dips. When the producer is operating the pan fills up with mixed crushed clinker and ash, which, as the pan revolves, is forced against a stationary adjustable plough blade, and discharged on to the ground, or, as is generally arranged, into ash trucks alongside the producer.

The water discharged from the cooling jacket provides a supply of hot water, which may be used for boiler feed or other purposes. The following test figures obtained by A. E. Broadberry in connection with the installation are of interest :—

Size of Fuel :—		
Over ½ inch	27·6 per cent.	
Between ¼-inch and ½-inch	33·1 „	
„ ⅛-inch and ¼-inch.	19·3 „	
Below ⅛-inch	20·0 „	
Analysis of Fuel. Vertical Retort Breeze :—		
Moisture	14·29 per cent.	
Ash	22·33 „	On dry basis.
Volatile matter.	5·1 „	On dry basis.
Total carbon	74·45 „	On dry basis.
Calorific value	11,109 B.Th.U. per lb.	On dry basis.
Analysis of Producer Gas :—		
Hydrogen.	14 per cent. by volume.	
Carbon monoxide	25 „ „	
Carbon dioxide	6·4 „ „	
Calorific power (net)	124 B.Th.U. per cubic foot.	

The gas obtained per ton of wet breeze was 110,000 cubic feet, and the temperature at which it left the producer was found to be 197° C.

The gas from each producer, after passing through a " cyclone " dust extractor into a trunk main, is led through the two other dust extractors into steel, firebrick lined, distributing mains running along each side of the retort house. From these, branch mains are taken between the coke-receiving hoppers under the retort benches, and the gas being thereby heated passes to the gas openings in the settings, valves being provided to permit of the necessary regulation of supply. The breeze and very

fine coke from the coke-screens is elevated to a band conveyor and delivered to hoppers above the producers; the hoppers being supplied either with these breeze screenings or with coke direct from the retorts, as may be desired.

THE KERPELY PRODUCER

The Kerpely producer was primarily designed for the gasification of low-grade fuels. It is fitted with a revolving grate of polygonal shape, placed eccentrically on the water-trough. It has a continuous, and not an intermittent action in crushing



FIG. 63.—CHARGING FLOOR OF KERPELY PRODUCER INSTALLATION.

any formation of clinker that may occur. The clinker when entering the ash zone is caught by the numerous edges of the revolving grate and is pressed horizontally sideways against the seal apron, and is, consequently, broken or crushed into small fragments which, dropping into the water-trough, are removed by the ash-scraper. The latter automatically discharges the ash and clinker accumulating in the bottom of the producer, and, being constructed to suit the shape of the ash-trough, the ash is not only pushed aside, but piled up and continually discharged into an ash-shoot. The supply of air and steam to the producer is separately conveyed to the inner and outer sections of the grate, and, being transmitted through spaces between the plates

of the revolving grate, ensures uniform combustion over the whole grate area, the maximum gasification capacity per square foot of grate area, and perfect control of the fuel-bed.

The charging platform of a battery of Kerpely producers is shown in Fig. 63. The gasification capacity of each producer is from 18 to 24 tons of coke per day. The producer is primarily employed on account of its ability to gasify extremely low-grade and dusty fuels—practically waste materials having a calorific power as low as 5,000 B.Th.U. per lb. As in the Mond system, air and steam are supplied to the producer, in this case up to a pressure of 30 inches of water. The lower portion of the shell is water-jacketed, which precludes the adhering of clinker to the side walls.

SEMI-EXTERNAL PRODUCERS

Of the semi-external producers an interesting example is that shown in Fig. 64. The producer differs from the ordinary self-contained retort-bench type in that it is built out from the front face of the setting, thus providing an ample fuel-bed, convenience for charging, and ease of access. It is particularly suited to those retort houses in which hot-coke conveyors are employed, for the coke may be charged directly into the producers from the conveyor, the trough of which is provided with special sliding doors communicating with the producer. From the illustration it will be seen that the gas duct is situated well below the level of the fuel. Accordingly, average variation in the depth of the fuel-bed has no effect upon gas quality. The arrangement does not necessitate the usual frequent charging of the producer, for the upper layers of fuel provide a storage which goes to replenish the fuel consumed in the active zone. It is claimed that the producer possesses the merit of being able to burn low-grade fuels such as breeze and sweepings from the retort-house stage.

Loss of Heat by Radiation

In connection with the loss of heat due to radiation from the conduits of outside producers, Butterfield has pointed out that if the producer stands at some distance from the setting, and the gas has to travel through long pipes before reaching the furnaces, or if it is stored for a short time in a gasholder, then 17 per cent. of the heating value of the fuel will be more or less completely lost. This amount of loss represents the heat which is expended in raising the producer gas to the temperature at which it leaves the furnace. With regard to the methods of insulation employed for maintaining the producer gas at the highest possible temperature, the author believes that the researches of Neumann on the reaction between gases after contact with solid heated carbon have never been considered in conjunction with the working of outside producers of whatever type. Neumann has shown that at the furnace outlet there is a lower percentage of carbonic monoxide and a higher percentage of carbon dioxide in the gas than at the surface of the fuel, and that the total combustibles are less in percentage at the outlet than at a point just above the top of the fuel-bed. It is further pointed out that the change in composition of the gas after leaving the fuel-bed can be avoided by using an outlet pipe which is quickly

cooled by means of a jacket through which cold water is circulated. From these researches it would appear, then, that the gas derived from producers of the outside

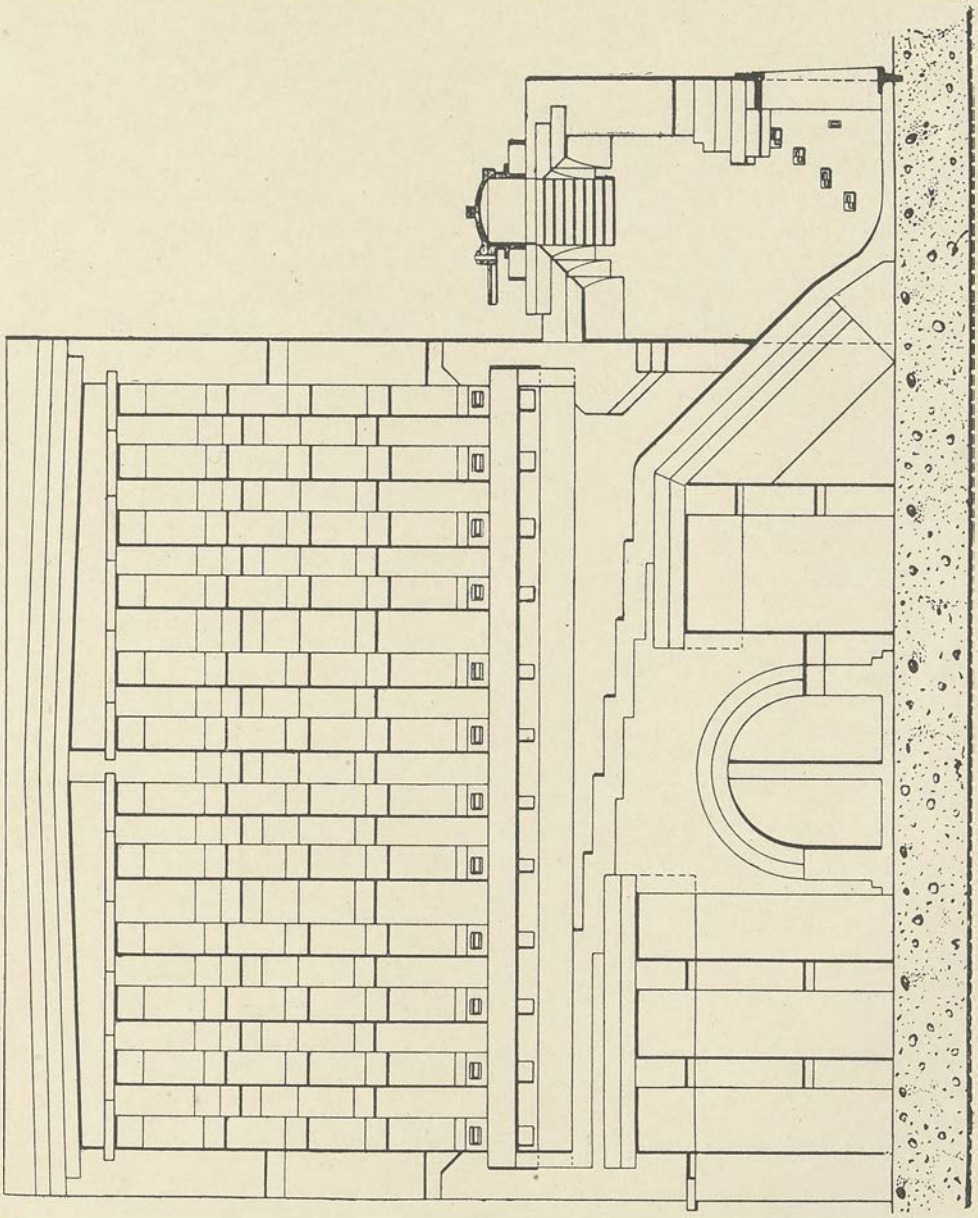


FIG. 64.—THE GIBBONS SEMI-EXTERNAL PRODUCER.

type is extremely likely to deteriorate in quality to some extent during its passage along the comparatively long length of gas pipe ; and, what is more, the deterioration is likely to be augmented by the methods commonly adopted for the prevention of

radiation. The question at issue, however, is as to whether the greatest heat economy would be entailed by cooling the gas immediately it leaves the producer, and thus checking the further oxidation of CO to CO_2, or whether the conservation of sensible heat due to the lagging, etc., is desirable even at the expense of an inferior quality of gas.

Outside producers, with the exception of the semi-external types, are always fed with cold coke, this accounting for additional thermal losses, unless the sensible heat in the coke as it leaves the retort is utilized (as in some vertical retort systems). When the cold coke is charged into the producer it should be as free from moisture as possible, otherwise this will be driven off in the form of steam, which passes on to the settings. As before mentioned, in some forms of external producer the furnace gases are taken off at a point slightly below the average fuel-level, so that any steam formed will be split up by passage through the hot coke.

CHAPTER IV

THE CONTROL OF HORIZONTAL RETORT SETTINGS

THE problem of the starting-up, working, and regulation of retort-bench producers is one with which the gas engineer is continually face to face ; and there are few more trying ordeals than that of warming-up to present-day heats, and afterwards maintaining such heats with regularity. First, it has to be realized that in the case of new work, or settings which have previously been in use, but have been let down, the range of temperature through which they have to be raised is as much as 1,100° C., when considering the retorts, and about 400° C. higher as far as the combustion chamber and its immediate surroundings are concerned. Hence, if damage is to be avoided, more than ordinary care must be given to the procedure known as " slow fires." Rapid temperature rises are the sure forerunners of cracks and opening joints, whilst particular attention is essential with many of the modern forms of regenerators designed on elaborate lines for bringing about an interchange of heat between the waste gases and secondary air.

STARTING-UP RETORT SETTINGS

The working life of a retort bench depends in no small degree upon the manner in which it is dried out and brought up to working temperature. No hard and fast rules as to the length of time which is required for the operation can be laid down, as so much depends upon whether the brickwork of the setting is entirely new or whether it has only been relaid in parts.

As regards the time required for bringing new work into operation, a series of typical conditions are discussed below [1] :—

(1) Entire new bench, including new regenerators, furnace, main arch, etc.

Time for drying—at least four weeks, the fire being gradually increased in size after the first week. After this period another six days should be taken to bring the bench up to working heats.

(2) Bench reconstructed from furnace-arch level, new main arch.

Time for drying—at least three weeks. Six days to bring up to working heats. When the main arches are new it will be found advisable to leave two or three pockets reaching down from the top of the spandril to the crown of the arch. These pockets will then provide an outlet for all the moisture issuing from the spandril brickwork, and they will prevent cracks occurring in the arch rings and in the brickwork above. The pockets may be filled up when working heats have been attained.

[1] Attention may be drawn to the recent practice of the South Metropolitan Gas Company, who have found no ill-effects in picking up working heats in 36 hours.

(3) Bench reconstructed from furnace-arch level in old main arches.

Time for drying—at least two weeks and a half. Four days to bring up to working heats.

(4) Entire old benches. Slow fires for four or five days.

Thirty-six hours for bringing up to working heats.

"SLOW FIRES"

With regard to picking-up benches from cold, there is a prevailing tendency to hurry the work along, which no doubt accounts in no inconsiderable way for reducing the life of retorts, etc. The actual period of "slow fires" varies with the condition of the setting as explained above; that is, whether the brickwork is "green" throughout, or whether the bench has merely been let down for repairs. The procedure adopted for manipulating the various dampers and slides during preliminary heating and picking-up varies in accordance with the taste of the individual; but, speaking generally, the following points are those chiefly requiring attention in connection with the larger types of regenerator settings. First, with "slow fires" it is preferable to isolate the main flue and chimney during the earlier portions of the period, this being done by closing the main dampers between the regenerators and the flue. An outlet for the warm products of combustion is then made by removing a couple of bricks from the front wall of the setting at a point just beneath the crown of the furnace arch. In this way the waste gases circulate in the setting alone. In addition, of course, it must be remembered that the furnace charging hole is left uncovered. With regard to the admission of air to the furnace, most engineers prefer to close the secondary-air ports. The furnace door is left wide open, so that as much warm air as possible may pass through the setting, and carry away the moisture from the brickwork. During this time the fire bars, if of the horizontal type, should be water cooled in the usual way, and clinkering carried out about twice per week. As regards the retorts, the doors of these should be closed, so as to retain as much heat as possible; but they should on no account be tightened up with levers, otherwise the expanded air and steam, being unable to escape (the foul-main valve being closed) will force an exit through some weak spot in the joints, thus giving unnecessary trouble when the retorts are charged up. Particular attention should be given to this point when new work throughout is being dealt with.

"FAST FIRES"

When, after fourteen to twenty-one days, the time comes for working up from "slow" to medium fires certain precautions are necessary. First, the main flue and chimney are brought into play; and to this end the setting dampers may be opened to a small extent (usually about one-quarter of their full working amount), and the outlet made in the front wall of the setting must at the same time be sealed by replacing the bricks which were removed at the outset. In some instances it is usual to open the main dampers to nearly their full working extent for an hour or so, in order to heat up the shaft sufficiently to ensure its creating a good draught. From the point of view of the brickwork, however, this is not to be advised, and the

better practice is to keep a coke bucket burning for some few days at the base of the chimney. A special brick panel or cast-iron door should always be left in the chimney for this purpose. When working medium fires the furnace lid is, of course, sealed up and secondary air admitted. The necessity for exercising a certain amount of vigilance before doing this is dealt with later. When the " fast fires " are com menced, the dampers and air slides may be adjusted to the maximum amount required for working the setting.

GENERAL WORKING POINTS

There is little doubt that the trained eye is by far the most effectual judge as to the manner in which the furnaces are doing their work. Systematic analyses are, no doubt, helpful so far as the prevention of waste is concerned, but their chief drawback is that whilst giving an indication of the quality of the producer gas they entirely neglect the equally important consideration of quantity. This accounts for the somewhat common experience of a scientifically perfect gas giving decidedly indifferent heats. As a preliminary, the most satisfactory method of adjusting the slides is to increase the primary supply until the best results are noticed, thus adopting a trial and effect policy. Having hit upon the correct adjustment, the secondary slides are regulated until the characteristic blue flame of carbonic oxide is seen burning at the ports connecting the regenerators with the waste-gas flue. This indicates that the air entering through the inspection plug is burning the unconsumed CO. Such a state of affairs is, of course, wasteful, and the secondary ports must be further opened until the blue flame just disappears. Sufficient quantities of oxygen for the combustion of the carbon monoxide are now entering the setting; but in order to ensure a slight excess the secondary slides should be further opened to a small extent, say about one-tenth of their amount at the time. In doing this, however, judgment must be exercised; for an additional quantity of secondary air means an increased volume of waste products, hence reduced combustion temperature.

Some interesting figures, showing how the efficiency of the setting may be judged from the analysis of the waste gases, have been given by W. M. Russell.[1] These figures are given in the following table, which provides a very good illustration of the importance of correct air adjustment.

Waste gases per cent.				Efficiency per cent.	Conditions Prevailing.
CO_2.	N_2.	CO.	O_2.		
20	80	—	—	61·7	Complete combustion
17·4	78·2	4·4	—	49·3	Air 10 per cent. deficient
18·2	80·0	—	1·8	58·2	Air 10 per cent. excess
18·0	80·0	—	2·0	57·8	18·0 per cent. CO_2, excess air
18·0	78·7	3·3	—	55·4	18·0 per cent. CO_2, air deficient

[1] *Operation of Gasworks*, p. 30.

WORKING UNDER PRESSURE

Until comparatively recent years the prevailing fashion was to work the retort bench under a slight vacuum throughout the whole of the setting. It is now recognized, however, that more effective results are ensured by maintaining a pressure in certain portions of the bed. Every endeavour should be made to maintain a slight pressure in the combustion chamber, and this will depend to a large extent upon the position of the waste-gas damper. The latter should be opened to the least possible extent, and if adjustment must be made the primary slides should be turned to, when by further opening them matters will be improved, owing to the velocity of air through the fuel-bed being reduced. All producers are, unfortunately, affected to no little extent by the varying conditions of the fire, such as clinkering, "pricking-up," fluctuation in depth of fuel-bed, etc.; but the introduction of the automatic damper slide (such as Brooke's) has gone some way towards remedying this annoyance. The objects of such slides are:—

(*a*) To reduce fuel consumption.

(*b*) To maintain a more regular temperature in furnace and setting.

(*c*) To avoid excessive formation of clinker.

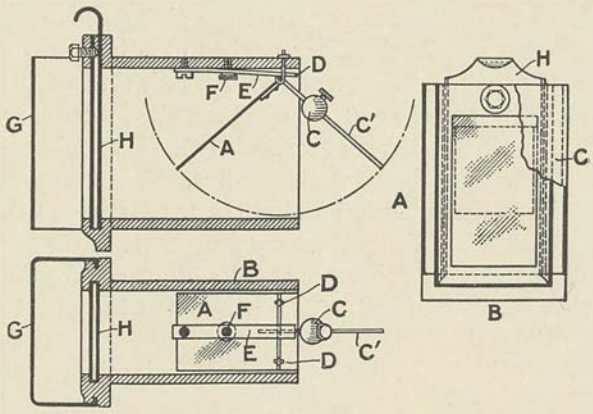


FIG. 65.—BROOKE'S AUTOMATIC DAMPER.

The apparatus (Fig. 65) consists of a vane A attached to a rod on which moves an adjustable balance weight C. The vane is supported from two small hook bolts on which it swings. A flat spring E presses on the spindle, the intensity of the pressure being regulated by the adjustable screw F. There is also provided a damper plate H for use when shutting down, and a shield piece G. The regulators are made to fit into existing secondary-air flues, or to bolt on to the front of clinkering doors for the regulation of primary air. The fuel saving by the introduction of these slides is said in certain cases to be about 3 lb. of coke per 100 lb. of coal carbonized.

A similar type of regulator is also made for use with chimney shafts, which, owing to variations in atmospheric conditions, account for considerable fluctuations in draught. In this case the swing damper is balanced by means of a counterweight until it is just closed, when the desired draught is given. Any alteration of the main damper will then be accompanied by a movement of the regulator, which will open and admit cold air until the draught is reduced to the set amount. Variations due to atmospheric conditions will be similarly counteracted. It must be remembered, however, that devices of the kind are of a comparatively delicate nature, and care

should be taken to see that they are frequently attended to so that the free action of the vanes is maintained.

RELIABLE TESTS

A word is necessary here with regard to the manner in which tests on settings are made. When drawing off samples of waste gases it is advisable not to make use of the bottom or damper section of the regenerator for the purpose, as misleading analyses may be the outcome, owing to the by-passing of the secondary air. In many regenerator settings it is quite common to find that the vacuum in the secondary-air and waste-gas flues is practically equal, which is commendable as far as short-circuiting and by-passing are concerned. When such is the case, however, it rarely occurs to those responsible to analyse the ingoing secondary air at a section near the top of the regenerator.

A point worth noticing with regard to regenerators which show signs of serious short-circuiting is that of isolating the defective sections by transposing the air-box to a position higher up in the tiers of the regenerator. A certain amount of regeneration is, of course, sacrificed ; but usually the loss is more than balanced by the restriction of the short-circuiting. This alternative should only be turned to when repairs to the lower sections are impossible. Here, again, the engineer must be thoroughly conversant with the constructional details of his setting ; for, in more than one type of regenerator, the raising of the secondary-air inlet in this way would completely cut off the secondary supply to many of the nostril holes. In connection with these systems, the advantages accruing from the multiple regulation are undoubtedly significant, for there is frequently a tendency for the rush of air to be greatest towards the centre nostrils of the furnace arch. This entails irregular distribution of heat and dull mouthpieces. With the separate adjustments, however, the mouthpiece temperature is well under control.

As regards the regulation of waste-gas flue draught, it is as well to provide two dampers to each regenerator, as shown in Fig. 66. The upper damper can then be regulated until the best results are given, while during temporary stops or clinkering the lower damper is brought into play. The latter can then be opened again to its fullest extent, and the draught is governed as originally by the upper damper, which has not been moved. Care must be taken, however, to see that the lower damper is properly sealed, otherwise air will be drawn past it, and the chimney draught on the setting correspondingly reduced.

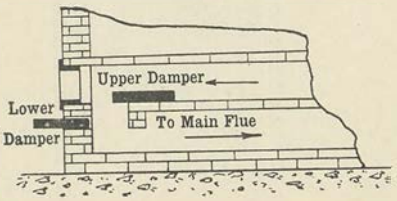


FIG. 66.—DOUBLE DAMPER CONTROL.

It may be mentioned here that in the ordinary way the draught on the chimney of a regenerator setting should not exceed from $\frac{3}{10}$ to $\frac{6}{10}$ inch of water. The actual vacuum is usually measured by a special direct-reading instrument, the connecting pipe of which is thrust into the sight-box at the base of the chimney. It is usual to calibrate these instruments in hundredth parts of an inch, so that for correct working

the indicator points to between 30 and 60. Some engineers prefer to employ a recording gauge, so that a continuous record is taken.

ANALYSIS OF FURNACE GASES AND WASTE GASES

When drawing off samples of gas from different positions in a regenerator setting, care should be taken that the sample is a true and representative one, and the tester should feel assured that there is nothing faulty in the method employed or in the apparatus he may be using. For drawing off a sample of waste gas entering the regenerative portion of a retort setting, it is necessary to consider the temperature which the sampling tube has to withstand. Anything from 700°-1,000° C. may be experienced, and nothing short of porcelain, silica, or a water-cooled iron tube will answer the purpose. Uncooled metal tubes are out of the question by reason of their tendency to convert carbon monoxide into carbon dioxide even at a dull red heat. It has been stated that the composition of a gaseous mixture may be changed from 1·5 to 26·0 per cent. CO_2 by the passage through an iron tube heated to a dull red heat, the carbon monoxide originally present reducing the iron oxide with the formation of carbon dioxide.

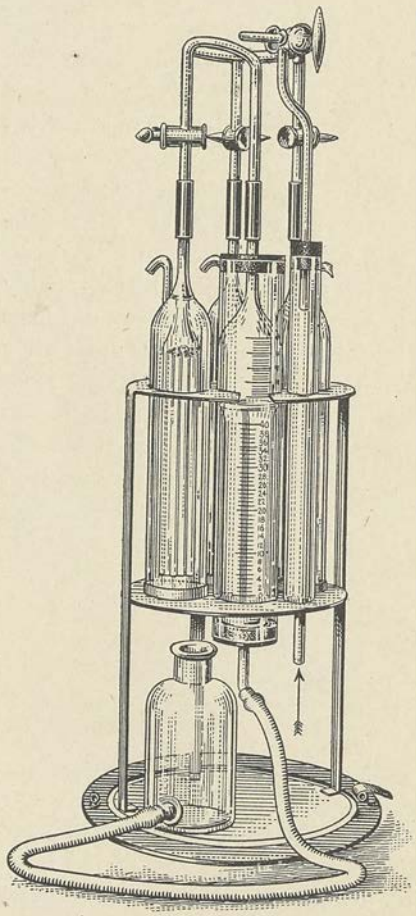


Fig. 67.—The Wright-Orsat Apparatus.

With careful handling a porcelain tube will answer the purpose very well. The tube should not be less than 36 inches in length, and should have a diameter of at least ¾-inch. To preserve the tube against damage it should be wrapped round with asbestos string before being inserted into the flue; and, further, a fireclay tapered brick should be prepared of such dimensions as will allow of its entry, wedge fashion, into the sight-box of the waste-gas flue to be tested—the taper brick having a hole in it sufficiently large to receive the asbestos-jacketed porcelain tube. The joint should be made secure by means of fireclay. The apparatus which is best adapted for the analysis of furnace gas is the modified Orsat as shown in Fig. 67. It is portable, not easily damaged, and is simple to manipulate. It is sufficiently accurate for all technical purposes, and always ready for use.

INSTRUCTIONS FOR USING THE WRIGHT-ORSAT APPARATUS

Preliminary.

1. Fill the water-jacket surrounding the measuring burette with water. This water is simply employed to equalize the temperature of the gas.

2. Fill the aspirator with water, preferably saturated with the gas, to be analysed.

3. The first pipette is half filled with a solution of caustic potash. To do this the burette is filled with water from the aspirator by opening the 3-way cock at the end of the capillary tube connecting to air. The 3-way cock is then closed and the aspirator lowered, thus drawing the potash into the pipette up the inner tube until it reaches the level of the india-rubber connection. When this is done, there should be about $\frac{1}{4}$-inch of liquid sealing the bottom of the inner tube of the potash pipette. The cock on the capillary tube attached to this pipette is now closed.

4. The above manipulation is repeated with the other pipettes on the apparatus, the second one being filled with alkaline solution of pyrogallic acid for absorbing the oxygen, and the third with a solution of cuprous chloride for absorbing the carbon monoxide.

The pipe conveying the gas to be analysed is attached to the bottom of the filter tube containing cotton-wool as shown by the arrow in Fig. 67. The rubber pump is attached to the free end of the 3-way cock at the end of the capillary and the cock is turned so that, by operating the hand pump, the pipes are cleared of the stale gas and a supply of new gas for analysis is brought right up to the instrument. The 3-way cock is then turned the other way and the aspirator lowered so as to draw a supply of gas through the cotton-wool filter tube into the burette.

With a little care it is easy to arrange the liquid surfaces in the burette and the aspirator so that they are level and the volume of gas in the burette is at the bottom graduation 0.

When this has been done, the cock connecting to the first pipette, *i.e.*, the potash pipette, is turned, and the gas is passed to and fro from the burette into the pipette, care being taken not to draw the liquid from the potash pipette higher than the rubber connection.

After performing this manipulation two or three times, the gas is drawn back into the burette until the liquid in the potash pipette just reaches the rubber connection. The liquid surfaces in the aspirator and burette are then levelled as before.

The new reading of the gaseous volume is observed. The contraction gives the amount of carbon dioxide in the gas. This manipulation is repeated with the second and third pipettes, thus obtaining the amount of oxygen and the amount of carbon monoxide.

Carbon dioxide is always the first gas to be removed from a gaseous mixture. It is important to use the reagents in the order given. If, by mistake, the gas is passed into the second pipette, it will absorb not only oxygen, for which it is intended, but also carbon dioxide. Similarly, if the gas be passed into the third pipette, it will absorb not only carbon monoxide, but also oxygen as well. Glass stop-cocks should always be treated with a little vaseline when used in connection with vessels containing caustic potash.

RETORT-BENCH EXPLOSIONS

Though serious damage resulting from the explosion of producer gas in retort settings is, fortunately, rarely met with on gasworks, it is, perhaps, surprising that this is the case, considering the singularly small amount of attention which is often given to the matter. The infrequency of these explosions is partly due to the fact that a large element of luck enters into the question, but chiefly because they are only likely to occur during the period when newly constructed settings are under "slow fires," or when benches are being picked up again for work. Mishaps of the kind, however, are particularly to be guarded against; for, in addition to endangering the limbs of those members of the retort-house staff who may be in the vicinity of the bench at the time, the resulting damage to the structural work of the setting may be considerable, entailing extensive rebuilding, and, consequently, expense.

It is somewhat puzzling to account definitely for the actual source of explosions of this nature, but in the greater number of instances they are the outcome of a mixture of carbon monoxide and oxygen finding its way into the setting at a time when the prevailing temperature is insufficient to bring about ignition. What has to be recognized, of course, is that during the time when a setting is undergoing its preliminary heating up prior to being put into full work, the gaseous firing principle of the furnace is not brought into play, and the fuel is burnt merely as in the old type of "direct" fire. That is to say, primary air is admitted, the object being to burn the fuel to carbon dioxide in the furnace, and not in two steps, as is eventually to be done. If this could be ensured, then an incombustible gas would alone be circulating in the setting; but what usually takes place is that the primary air during its passage through the shallow bed of fuel is only partially converted into CO_2, whilst some CO is afterwards formed. At the same time air may pass through (particularly if the fuel-bed is very uneven) entirely unchanged. Thus we have a mixture of CO and oxygen travelling throughout the setting. The general practice adopted during "slow fires" is to shut off the secondary-air slides completely; but in some cases it is preferred to admit a small supply through these ports, for it is claimed that in this way a better draught is created, which ensures the more thorough removal of steam from new brickwork, etc. If secondary air is admitted, however, it certainly adds to some extent to the possibilities of an explosion in the setting itself.

How Danger is Avoided

Explosions of producer gas, both minor and severe, are usually the outcome of carelessness on the part of the man responsible for the supervision of the settings, or are due to the non-observance of certain practical rules which have come to be recognized as the result of everyday experience. The usual cause to which the trouble can be traced is that of sealing up the producer charging door before the setting has reached a sufficient degree of heat. Some explanation of this is, perhaps, necessary.

First, when the charging hole is uncovered any CO resulting from the combustion of the fuel, instead of travelling onwards through the nostrils and thence

into the setting, will merely pass outwards into the retort house, where it will soon be carried away. If, however, the lid is replaced over the charging aperture, the combustible gas must necessarily find an outlet by travelling through the setting; thus the latter is filled with an explosive mixture. No harm may come of this for a time, but as the temperature of the setting rises the ignition point of the gas is reached, when explosion occurs. The magnitude and force of the explosion depend, of course, upon the volume of the combustible mixture which is circulating in the setting at the time.

Practical experience with the type of setting in question is really the most reliable guide as to when the state of affairs is safe for the producer lid to be put in place. Usually it is merely sufficient to be satisfied that the producer arch is just visibly red-hot, although more careful individuals go so far as to say that the bottom retorts should be at a dull red heat. The latter practice, however, is conducive to extravagance in fuel. But whichever method is adhered to, the chief object is to ensure that any carbon monoxide and oxygen which may be passing through the producer will be ignited on arriving at the producer arch, instead of finding their way into the setting.

Charging with Wet Coke

In addition to the charging-lid danger, other, but less hazardous, risks are run by filling up the producer with decidedly wet coke, or by charging in an excessive quantity of cold coke at a time. In fact, the use of wet fuel should always be avoided; for, lying in a stagnant layer on the surface of the hotter fuel, it permits the passage through the bed of carbon monoxide and oxygen, whilst the actual flames are choked and subdued, and the temperature of the upper portions of the producer is reduced for the time being. The result is that the inflammable gas is not burned in the furnace, and, circulating throughout the setting, it is eventually ignited when the heat of the fuel picks up, and the flames have broken through. Precisely the same argument applies to the use of cold coke, which, if used, should only be introduced in comparatively small quantities at a time. By far the best practice, however, is to use nothing but red-hot fuel from the nearest bench which happens to be in full work.

TEMPORARY STOPS

On the majority of the larger gasworks it is now quite the general practice to discontinue the make of gas for a certain period on Sundays; for by so doing the retort-house hands are assured of a well-earned weekly rest; whilst in many undertakings it is the custom to pay double rates between 6 a.m. and 6 p.m. on this day. Hence the temporary stop entails some fairly considerable saving in carbonizing expenditure.

As a general rule, the staff of a gasworks is not called upon to attend on Sunday, thus the operations of discontinuing carbonization and restarting it are practical problems with which many gas engineers are more or less unfamiliar. On first thoughts, the procedure would not appear to demand any exceptional amount of attention, and this is, perhaps, evidenced by the smooth way and unconcerned manner in which the works foremen carry out the duty week after week. The

modus operandi, however, is by no means as simple as might be supposed, particularly as far as the maintenance of quality is concerned, also the needless "blowing-off" and waste of moderately good gas. The responsibility is, of course, increased owing to the continuity of the process being broken. In some cases vertical retort installations have facilitated matters, as has also the adoption of heavy charges in conjunction with the horizontal retort. Needless to say, the latter practice (that is, twelve-hour or ten-hour charges) has greatly facilitated the work of temporary shutting-down.

Regulation of the Charges

No hard and fast rules can be laid down as to the line of action to be followed during a temporary stop. Much must necessarily depend upon the conditions and facilities prevailing at the works—such as ample storage capacity, the type of retort settings to be dealt with, and whether enrichment by carburetted water-gas or other means is available. The most general practice is to commence the non-gasmaking period at 6 a.m. and to continue it until 6 p.m., but in some instances, under favourable circumstances, a restart is not made until 10 p.m.

It is proposed to describe here a method which will be found satisfactory from every point of view, and which has the primary advantage of being extremely simple. Though the method may be applied in all cases (whatever duration the stopping period may be) it will be assumed, for the sake of simplifying the illustration, that no retort-house work is desired between the hours of 6 a.m. and 6 p.m.

In this case the last row of retorts is charged so as to be completed by 6 a.m.; thus for some time the normal volume of gas is coming away. As this gradually decreases, however, some little precaution is necessary in the regulation of the exhauster and retort-house governor. The method of operating these will be best followed by referring to the two charts shown in Figs. 68 and 69. In fact, the whole idea can readily be grasped by keeping these diagrams in mind. Fig. 68 is a vacuum chart showing the "pull" exerted by the exhauster throughout the twenty-four hours, whilst in Fig. 69 is shown the vacuum on the foul main for the corresponding period.

Regulating the "Draw"

For the first hour and half, *i.e.*, until 7.30 a.m., the quantity of gas driven off will permit the use of the full average "draw." Following this period the volume of gas evolved gradually becomes smaller and smaller, and the "draw" at the exhauster is reduced by degrees, until it is in average cases no more than about 10 per cent. of the normal or, say, half an inch about three hours after the retorts were last charged, *i.e.*, about 9 a.m. Meanwhile, as will be seen from the second chart, the retort-house governor is adjusted so as to give "level gauge" on the hydraulic main; this continuing until 6 p.m. in the evening, when the retorts are charged-up once more. Similarly, the half-inch "draw" is maintained at the exhausters until shortly after 6 p.m., when it is raised gradually to the usual amount. When the exhauster is working at so low a vacuum as half an inch it must necessarily

be running at its lowest possible speed, thus the " pull " is likely to be far from steady. In order to remedy this, and to put the engine under a greater load, it is advisable to open slightly the by-pass between the inlet and the outlet pipes, this having the desired steadying effect.

The advantage of working in this manner, as will be seen, is that there is no actual cessation of gasmaking, and the exhauster is at work during the whole twenty-four hours. In order that this method may be adopted, however, it is essential that heavy charges should be worked. If the old-fashioned light charges are in vogue, then gasmaking must inevitably cease, and a portion of the poor gas should be blown away as described below. With the heavy charges, the make of gas will, of course, diminish by degrees, until, during the final hour before recharging, it will have dropped to about 7 to 10 per cent. of the normal figure. In describing this method the average conditions of $\frac{1}{2}$-inch seal and $\frac{3}{4}$-inch " draw " on the foul main have been assumed. If other conditions prevail the necessary steps will vary accordingly.

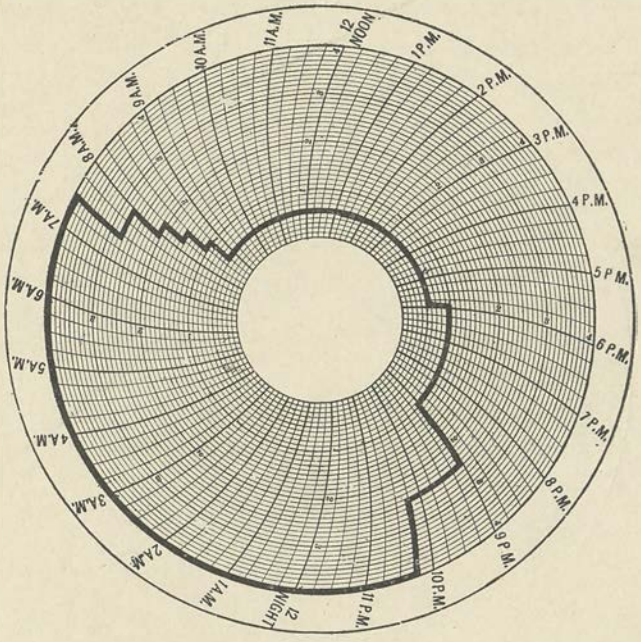


FIG. 68.—CHART SHOWING REGULATION OF VACUUM AT INLET OF EXHAUSTER.

GETTING RID OF INFERIOR GAS

After the final charge of coal has been put in, it is the quality of the gas evolved which really decides the manner in which the " draw " is to be regulated. It is a distinct advantage to have a special recording calorimeter run back from the outlet of the exhauster to the retort house, so that the foreman in charge has some indication of the quality of the gas soon after it has been generated. When the quality is noticed to be dropping, then the " draw " on the hydraulic main must be regulated accordingly. Unfortunately, in some cases, when the inferior coal is being used, the quality drops to such an extent that it is no longer advisable to send the gas forward to the holders. When this occurs, the continuity of the work has to be broken, and the exhauster is stopped while the poor gas is blown away. This is best done as follows: The main valve at the outlet of the condensers is closed and

the exhauster driver (who is standing by waiting the signal) notices the movement of his chart. He then shuts off the steam on the exhauster engine, and immediately afterwards closes the by-pass, which was opened when the "draw" was originally reduced. Gas is still being evolved from the coal in the retorts, and an outlet must, of course, be provided for this, or some considerable pressure will be thrown upon the apparatus between the retorts and the condensers. This should preferably be arranged for by fitting a 4-inch pipe to the inlet of the condensers, the pipe dipping into a seal pot, and being sealed in liquor to a depth of about half an inch. The gas will at first bubble through the seal fairly freely; but as the quantity evolved gradually becomes less and less, precaution is necessary, for after a time no gas whatever will be evolved, and that already in the apparatus will cool and give rise to a vacuum. In consequence, air is liable to be sucked in through the blow-off seal. In order to prevent the possibility of this occurring, the seal on the blow-off pipe is deepened until a pressure of about 1 inch is thrown upon the apparatus.

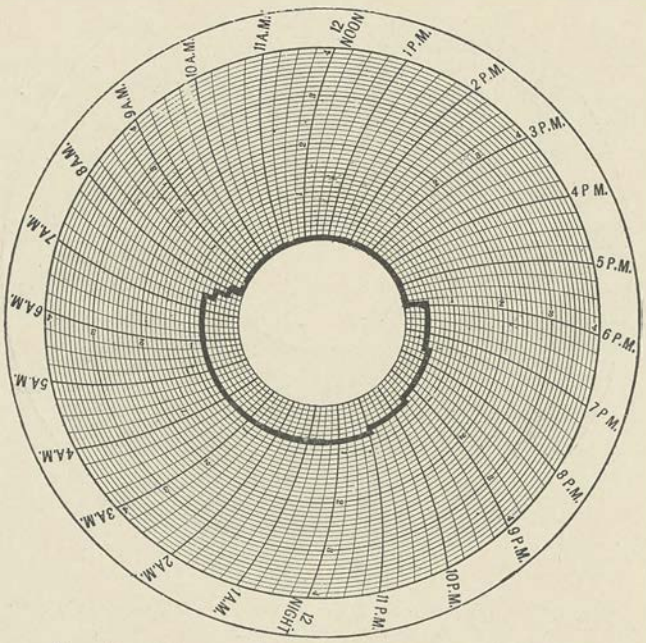


FIG. 69.—CHART SHOWING REGULATION OF VACUUM BY RETORT-HOUSE GOVERNOR.

THE PREVENTION OF A VACUUM

As serious results might follow any intake of air and the probable formation of an explosive mixture in the apparatus, it will be realized that the prevention of this vacuum is one of the outstanding points requiring special attention when temporary stops are made. Some engineers prefer the method of slacking-up the levers of the retort doors, so as to allow the surplus gas to find an outlet in this way. In the method described above, the lids are kept tightly sealed until the retorts are re-charged, and any gas which is expelled goes out into the open air and not directly into the retort house itself.

The late Mr. J. Tysoe drew particular attention to the liability of danger from the formation of this vacuum, and it is as well to recall his methods by quoting his remarks, which were as follows: "It frequently happens that sufficient gas is continuously driven off after the exhauster is stopped to maintain a slight pressure up to starting-time in the evening; but should the pressure entirely disappear before

that time, sufficient gas may be admitted to restore it by means of a 2-inch by-pass at the inlet valve to the washers. On restarting the work, all that is necessary is, after a few retorts have been charged, to open the washer valve and close the safety seal at the condensers. By this method, all risk of explosion in hydraulic mains, of which many of us have probably had experience, is entirely obviated, perfect safety is secured, and very little good gas is lost."

It is interesting to note that previous to the above remarks, Mr. Tysoe had said that " Sunday stoppage means a loss, however it is carried out " ; which recalls the fact that at that time (twenty years ago) heavy charges had not been thought of. Now, of course, given a good coal, there is not the least necessity for any loss whatever.

Controlling the Heats

As retort charging is discontinued during the stopping period, it is quite unnecessary to keep the furnaces up to their full working pitch. The last charges put into each retort are allowed to " stew " during the whole twelve or eighteen hours, hence a considerable amount of heat may be dispensed with and fuel economized. Ideas differ somewhat considerably as to the most effective way of adjusting the producers, but the best and most economical results are, no doubt, obtained by merely using the main-flue damper to make the adjustment (this being closed down to about 75 per cent. of the normal amount) ; whilst, if preferred, the primary- and secondary-air slides may also be closed down by about half. The slides and dampers may then be opened again to their full working extent about 3 p.m., so as to be in readiness for the fresh coal charges at 6 p.m. If the dampers, etc., are regulated in this way, the furnaces should easily outlast the whole period without requiring further charging with fuel. In fact, the latter is one of the features to aim at, in order to dispense entirely with retort-house labour.

The Value of Water-Gas

Perhaps one of the most serious objections to the usual Sunday stop is the possibility of sudden demands arising from such unlooked-for causes as fogs. However short the cessation of gasmaking may have been, it is always followed by some inroads into the gas available, and somewhat depleted stocks are the result. In some cases a works might conceivably find itself in an unenviable position should an abnormal demand arise after the retort-house hands had been dismissed for the day. It is under such circumstances that the value of a water-gas plant is felt ; and, furthermore, should the quality of the coal-gas have suffered from that evolved during the stop, a little further carburation will soon put matters right. Here the question of diffusion, and the value of the holders in this respect, plays some part. It may generally be taken for granted that should any inferior gas go forward to the holder, it will thoroughly intermix with better quality gas therein, with the result that the average quality is quite up to the normal. At times, however, there would appear to be some doubt as to whether complete diffusion does actually take place, and in holders in which the inlet and outlet pipe are side by side it seems possible that the gas (or certainly some portion of it) travels direct from one pipe to the other

without admixture with that already in the holder. The remedy for this is, of course, to avoid working both in and out of the same holder.

FUEL ECONOMY

It is merely necessary to turn to the prevailing figures of a decade or so ago to realize that fuel waste has been curtailed to an even more striking extent than the make of gas per ton has been augmented, so that, instead of having for disposal only about 55 per cent. of the coke made, to-day, with the modern type of producer, it is possible, with careful working, to put on to the market (including sales to other departments of the works) no less than 85 per cent. The true facts of the case are, perhaps, better exemplified by comparing the heat units expended with those obtained for such an outlay in the form of gas; for whereas about 80,000 B.Th.U. used to be necessary to yield 6,000,000 B.Th.U., we now require something less than 26,000 B.Th.U. to give a yield of nearly 7,000,000 B.Th.U. in the gaseous state. That is to say, a reduction of 66 per cent. in the B.Th.U. required has been accompanied by a rise of about 17 per cent. in the B.Th.U. obtained in the gas. Even now it must be remembered that the apparently effective producers of the present day have by no means reached perfection; but, comparatively, the amount of the total heat utilized is a notably small percentage of that contained in the original fuel. For the most efficient producers the loss in heat still amounts to about 40 per cent. of the total contained in the fuel. This figure was in the neighbourhood of 65 per cent. before the introduction of regeneration. Some considerable gain in efficiency results, of course, from the utilization of the sensible heat in the waste gases for the generation of steam.

HEAT BALANCES

The question of the heat balance of a retort setting receives but meagre attention on the ordinary gasworks. Results can never be considered more than very approximate, owing to the difficulties with which the investigator is faced and the assumptions necessary; hence the practical gas engineer finds no great use for them.

Of the total heat due to the combustion of fuel in non-regenerative retort settings the greatest individual portion is accounted for by that passing away with the waste gases—this amounting to nearly 50 per cent. of the whole. By the employment of regeneration, however, the loss from this source has been reduced by almost exactly one-half. The main sources of thermal losses in a setting may be briefly summarized as follows:—

(*a*) Carried away in waste gases.
(*b*) Carbonization of coal, and carried away by evolved gases and vapours, and in hot coke.
(*c*) Radiation and convection from brickwork.
(*d*) Lost in ashes, clinker, etc.
(*e*) Decomposition of water in fuel and moisture in inflowing air. Also vaporization of water in ash-pan and on firebars.
(*f*) Reduction of CO_2 to CO in producer.

The late Vivian B. Lewes has shown that if all the available heat of the fuel could be turned to useful account only 8·6 per cent. of the total weight of coke made would be required for carbonization. Among heat-balance investigators Euchêne has given figures which may be taken as best exemplifying the manner in which the heat is expended. For the ordinary setting in which regeneration is not carried out the following results are given :—

NON-REGENERATIVE SETTING.

Heat supplied—		
From coke		83·6 per cent.
From volatile products		16·4 „
		100.0 per cent.
Heat expended—		
		Per cent.
In setting 60·7 per cent.	Carried up chimney as gases, 34·7 per cent. / Carried up chimney as water vapour, 12·5 per cent.	47·2
	Lost by radiation and convection	12·8
	Lost in ash and clinker	0·7
In retorts 39·3 per cent.	Used in distillation of coal	15·7
	Escaping by ascension pipe, in volatile constituents	10·4
	Escaping in hot coke	13·2
		100·0

The chief point to be noticed is that in this type of setting only 16 per cent. of the total heat supplied actually goes to fulfil the primary function of the setting—*i.e.*, the distillation and decomposition of the coal and its primary products.

REGENERATIVE SETTING.

Heat supplied—		
From coke		77·4 per cent.
From volatile products		22·6 „
		100·0 per cent.
Heat expended—		
		Per cent
In setting 45·9 per cent.	Carried up chimney as gases, 19·9 per cent. / Carried up chimney as water vapour, 5·3 per cent.	25·2
	Lost by radiation and convection	19·9
	Lost in ash and clinker	0·8
In retorts 59·1 per cent.	Used in distillation of coal	21·4
	Escaping by ascension pipe, etc., in volatile constituents	13·8
	Escaping in hot coke	18·9
		100·0

The experiments of D. D. Barnum, of Worcester, Mass., in general corroborate the above figures, except in one important respect. Barnum obtained his figures for a bench in which regeneration was carried out entirely at the expense of the producer. The total loss accounted for by the chimney amounted to 47·6 per cent., and that utilized for distillation and decomposition to 21·6 per cent.

A comparison between Euchêne's figures and those of Barnum is given below. The former are converted from K.C.U. per 100 kilogrammes to B.Th.U. per 100 lb., so that both sets are expressed in similar units.

Regenerative Settings.

	Euchêne.	Barnum.
	B.Th.U. per 100 lb.	
Heat contained in fuel	180,547	215,623
Heat lost—		
In ashes	2,131	—
In flues	58,768	122,377
In volatile matter	32,398	23,333
By radiation	45,550	20,931
Heat in coke	44,253	33,708
Total heat expended	183,100	200,349
Absorbed during distillation	—	15,274
Dispersed during distillation	2,553	—

The chief point to be noticed is that whereas Euchêne finds heat to be liberated, Barnum's results indicate an absorption due to distillation. Undoubtedly both exothermic and endothermic reactions occur simultaneously during carbonization; but more recent authorities disagree as to the ultimate thermal nature of the process, so that its actual nature is still open to question. Research in this direction has been carried out by Cobb and Hollings, who conclude that the exothermic reactions commence at 600° C. and continue until some high temperature is reached; but at 750° C. endothermic reactions commence which mask the exothermic effect above that temperature. Moreover, whilst prolonged heating at 750° C. does not effect a completion of the exothermic reactions, it would appear that it does complete the endothermic reactions, since after heating at 750° C. there is some evidence of exothermic reactions up to 900° C.

In the item "total heat supplied" in Euchêne's figures it should be mentioned that the percentage attributed to "volatile products" indicates the quantity of heat evolved in the retort owing to the supposed nature of the reactions; that is, it is the heat of the formation of the original coal, which is liberated by the process of carbonization. Mahler in his researches observed a loss of $3\frac{1}{2}$ per cent. of the original heat units in coal due to carbonization, which he looked upon as representative of the heat liberated by the process. This figure, however, takes no account of "scurf" deposited in the retorts, or of naphthalene, for both of which some reduction must be made.

Further investigations have been conducted by H. Poole, who finds a balance, due to liberated heat, of 3·05 per cent.

Poole's balance of heat units is as follows :—

In original coal before distillation, 13,260 B.Th.U. per lb.

After distillation, B.Th.U. recovered—

In coke	8,296	B.Th.U.	
In tar	614	,,	
In gas	3,418	,,	
Lost in water, etc.	527	,,	
	12,855	B.Th.U.	
Unaccounted for	405	,,	or 3·05 per cent
	13,260	B.Th.U.	

In recent tests with vertical retorts the Gas Investigation Committee have found that carbonization is endothermic, and the results obtained are in fairly close agreement with those of Barnum. These results show that of the heat value of the coal 1·8 per cent. is absorbed during carbonization.

THE CURTAILMENT OF LOSSES

The economical operation of the modern regenerator depends, perhaps, more upon its structural features than upon any refinements in its working which may subsequently be introduced ; for, more often than not, a producer is designed with but little thought to the many small yet telling items that count, with the result that, however much attention it may afterwards receive, it is never possible to economize beyond a moderate extent. The main point to be kept in view is the most effectual means for abstracting the maximum quantity of heat from the fuel—that is, the greatest possible proportion of its calorific value—and the utilization of this heat with the minimum of loss. On gasworks nowadays the fuels used, almost without exception, are coke and breeze ; although with the price of coal slack lower than that of coke, the Mond and such producers may be a familiar feature of the large gasworks of the future. Tar as an agent for retort or boiler heating may be dismissed from serious notice, as the price it is now commanding has rendered its use unprofitable, although it became quite popular as a fuel some years ago. The price at that time, however, was 1*d.* (or less) per gallon ; now it is about ten times as much, and tar cannot compete with coke when costing more than 3*d.* per gallon.

ITEMS FOR CONSIDERATION

Owing to the different methods of firing now employed on gasworks, that is, whether individual or " outside " producers, generators or regenerators, it is difficult to lay down hard and fast rules of construction and working applicable to all systems ; but the principal heat losses liable to affect all types of producers may be summarized as follows :—

1. Incomplete combustion of carbon to CO.

2. Incomplete combustion of CO to CO_2.
3. Too rapid travel of primary air through fuel-bed.
4. Too rapid travel of hot gases through setting, or too much chimney draught.
5. Losses due to fuel falling through firebars into ashpit or removed with clinker.
6. Radiation and convection losses.
7. Extensive variation in composition of producer gas.
8. Insufficiency of gas.

The main sources which account for loss of heat have been fully dealt with in Chapter III.

With regard to the first two items, these are, of course, avoidable, providing that no faults have been introduced in the design of the producer; and they are best remedied by systematic analysis of both the producer and waste gases. It is necessary, however, to emphasize the fact that satisfactory gas tests do not in any sense ensure good heats; for, although the combustibles may be present in ideal proportions, it is quite possible that they may not be present in sufficient quantities.

The third item in the list lends itself to adjustment, providing, again, that the construction of the producer is not to blame. If this is the case the trouble can usually be traced to an insufficiency of grate area, the importance of providing adequately for this having been somewhat underestimated by designers in the past. Slow travel of the primary air through the fuel-bed is ensured with abundant grate area (*see* Chapter III, p. 82); whilst there will be less "slip" up the sides of the furnace, and a shallower bed of clinker will be formed. Owing to the extended contact of primary air and coke, the quality of the gas will be materially improved.

On no account should the velocity of draught be so great as to draw off the gases from the setting before they have been cooled down in the regenerators by at least 375° C., and the base of the waste-gas channel should be almost devoid of colour. This question of draught may affect the formation of the producer gas in two ways. First, the rate of travel of air through the fuel-bed may be sufficiently slow for the formation of carbon dioxide in the lower portions of the furnace, but the time of contact may not be sufficiently long for the reduction of this gas to carbonic oxide—hence an excessive proportion of incombustibles in the furnace gas may result. So far as the draught is concerned, it is the chimney height and flue area which are of importance in this respect (*see* p. 86).

CLINKER AND ASH

A word is necessary here with regard to the troublesome formation of clinker with some types of producer. When clinker difficulties set in, it is, perhaps, the natural inclination of the man charged with its removal to make disparaging reference to the coke supplied to the producers at the time. A coal with a heavy ash content must necessarily increase the amount of inert matter to be cleaned from the producer; but the secret of long periods without clinkering is due to the physical condition of the non-combustible portions of the fuel after passing through the producer. With a strong draught a large proportion of the ash in the fuel is fluxed, with the consequent formation of clinker; whilst with a slow draught the heat of the fuel-bed is

reduced, with the result that little fluxing takes place, and ash instead of clinker is the outcome. Clinker prevents the admission of air, so that local combustion in the fuel-bed takes place. With ash, on the other hand, furnace cleaning is a small matter ; and it is possible to find works in which clinkering of the fires is practically unknown. The remedy for the excessive formation of clinker is simple, and can be directly traced to the introduction of adequate grate areas and slow travel of gas ; also in some cases to the employment of steam (*see* p. 68).

MAXIMUM COMBUSTION TEMPERATURE

The evil of admitting excessive quantities of air should perhaps receive some mention here ; and it must be borne in mind that the highest temperature which can be obtained by the combustion of fuel is that to which the products are raised on their formation by the heat dispersed. Thus, the larger the volume of gas to be heated the less will the temperature be. It is in this respect that regeneration tells ; for when the air is heated before combustion is allowed to take place, the heat of the air is added to the heat of combustion. Thus the quantity of heat available for raising the temperature of the products is very much greater.

With regard to vertical retort furnaces, it may be pointed out that in the Glover-West type the secondary air is pre-heated by circulating around the coke chamber constituting the bottom three feet of the retort, and in this way the sensible heat is extracted and turned to useful account. In the Woodall-Duckham system the coke is discharged more or less cold, but a device has been made use of by means of which the primary air passes through fireclay tubes adjacent to the base of the retort, thus utilizing heat which was originally lost.

SECONDARY-AIR DIRECTION

In retort settings of nearly every design it is customary to find that the secondary-air channels are arranged round the furnace arch in such a manner that when the heated air emerges it meets the gases from the producer practically at right angles. Until recently the advisability of this method has never been questioned, but opinions now appear to be undergoing some change. Dr. Karl Bunte, in a paper read before the German Association at Strassburg some few years ago, pointed out the shortcomings of this procedure, and stated that in all the more perfect of modern settings such conditions are obviated. The effect of introducing the secondary air in a strong current at right angles to the producer gases is to give rise to too thorough intermixing of the air and gases, with the result that short flames are produced. In order to ensure as uniform heating throughout the setting as possible such short flames should be avoided. To this end the gas and air streams should meet on almost parallel courses, in which case admixture of the two is gradual, and flames of larger volume are produced. The majority of existing settings can be readily adapted to meet this requirement. The method of dealing with a typical case is shown in Fig. 51. In this instance the secondary air is conducted in the ordinary way to the apex of the furnace arch by means of horseshoe channel blocks. As

generally laid, the blocks provide for admixture taking place very nearly at right angles. A simple and effective means of providing for a more parallel flow is to split a 9-inch firebrick diagonally, and to insert it under the final blocks each side as shown, so that the latter are given an upward cant. The method will be clearly followed from the sketch.

It is interesting to recall here that the flame development takes place quite differently in vertical retort firing. In this case the flame follows a spiral course from below upwards (in the Glover-West and Intermittent systems), or from above downwards (in the Woodall-Duckham system). The latter arrangement provides for the heating of the upper third of the retort by a number of burners, whereas the lower portions of the charge are situated in a comparatively cool zone. In the Intermittent system the regulation of the flame development is extremely well effected by means of brattices which ensure the gas streams taking parallel courses, whilst at suitable intervals mixing blocks are inserted which thoroughly churn up the inflowing air and gas.

CHAPTER V

VERTICAL RETORTS AND CHAMBER OVENS

THE present-day popularity of the vertical retort and chamber oven is, no doubt, the natural outcome of the growing preference for carbonization in bulk, and the tendency for the gas engineer to relieve himself as far as possible of the vagaries and expense of manual labour. Although the evolution of the vertical retort in its modern form has taken place within the last decade, the idea is by no means a new one, for so long ago as 1828 Brunton patented an intermittent system having quite a number of features similar to those of the prevailing types of to-day.

The systems of vertical retorts at present in use may be divided into three distinct types :—

(*a*) Continuous types.
(*b*) Intermittent types.
(*c*) Continuous-intermittent types.

Of these the first-named system aims at solving the problem of ideal carbonization ; that is, the continuous admission of relatively small charges of coal accompanied by the continuous extraction of that which has undergone distillation. Hence, undesirable variations in the quantity of gas evolved (inseparable from intermittent charging) are completely avoided. Intermittent types of vertical retorts embrace the principles employed in the horizontal bench, *i.e.*, a definite charge of coal is arranged for at stated periods, the retort being emptied at the end of the distillation spell. Except for the purpose of " scurfing," continuously operated retorts are never emptied. Continuous-intermittent systems are those whose design permits of the retorts being operated on either the continuous or intermittent principle. So far they have not gained much headway in this country ; but as they are of most recent origin, their wide adoption is scarcely to be looked for at present.

It is not proposed to give much attention here to forms of vertical retorts other than those which have been actually employed in this country and are at work at the present time. In addition to the systems described below, many others, originating from America and the Continent, are to be found.

Among the earlier systems was the Settle-Padfield, in which the retort commenced in a vertical plane, but turned off at an angle at the base, so that the coke was discharged through the side of the bench, and not at the bottom. Charging was arranged for on continuous lines, but the coke was withdrawn at definite intervals, so that the amount of free space in the retorts was subject to variation. The system has now been discarded.

It is difficult to draw comparisons between the continuous and intermittent systems. In most cases the engineer must take into consideration the prevailing conditions, and select his system accordingly. In comparison with horizontal systems the following advantages are claimed for vertical retorts :—

(1) Greater yield of gas on a given area. For horizontals the average yield of straight coal-gas is 200 to 250 cubic feet per square foot of ground area. For verticals this figure may be increased to as much as 475 feet per square foot of area—according to the system.

(2) Better conditions in retort house and no very arduous labour. Less clinkering.

(3) Low consumption of fuel (*see* p. 61). This claim, although invariably made for vertical systems of the continuous type, must be viewed with a certain amount of reserve. As yet it is not possible to say definitely that the vertical retort shows any superiority over the latent types of horizontal retort in this direction.

(4) Control of heats as regards various sections of the retort. In the modern horizontal setting the multiple control of secondary air ensures almost as perfect adjustment.

(5) Each particle of coal is subjected to exactly similar treatment. This means that all coal passes in turn through the various temperature zones prevailing in the retort, and there is no trouble with uncarbonized portions of coal, as is often the case near the mouthpieces of horizontal settings.

(6) With continuous systems the gas is certainly produced in more uniform quality.

(7) The heat in the coke is in most systems utilized, and not wasted as in horizontals.

(8) The gas is not subjected to degradation by long contact in a large free space. The gas evolved from the lower portions of the vertical charge travels to the outlet pipe partly through red-hot coke and partly against the sides of the retorts (*see* p. 435).

(9) " Make per ton " may be appreciably increased by steaming the base of the charge, when the coal is sufficiently good to allow of this.

(10) Heavy and complicated charging and discharging machinery is eliminated —thus wear and tear expenditure is reduced.

(11) Labour costs per ton of coal per diem are from one-half to one-third less than with horizontal retorts.

The claims of the horizontal bench may be set down as follows :—

(1) The coke in vertical retorts has occasionally a tendency to " jam " up. This particularly refers to the intermittent types.

(2) The retorts are more difficult to repair during operation, and as the continuous retort is only cleared at long intervals a leak may go undetected for some time.

(3) The capital cost per ton of coal per maximum day is in general higher for the vertical systems. Inclusive of complete bench and foundations, coal-handling plant, power-operating plant, coke-handling plant, but exclusive of retort house, a vertical installation (according to size) will cost from about £450–£600 per ton of coal. The

cost for a horizontal plant would be £250–£320 per ton, and in isolated cases less than the lower limit given.

(4) In continuously operated types any breakdown in machinery usually entails great inconvenience.

So far as the relative merits of the two systems of verticals are concerned, the advocates of the continuous type lay claim to the following advantages over the intermittent :—

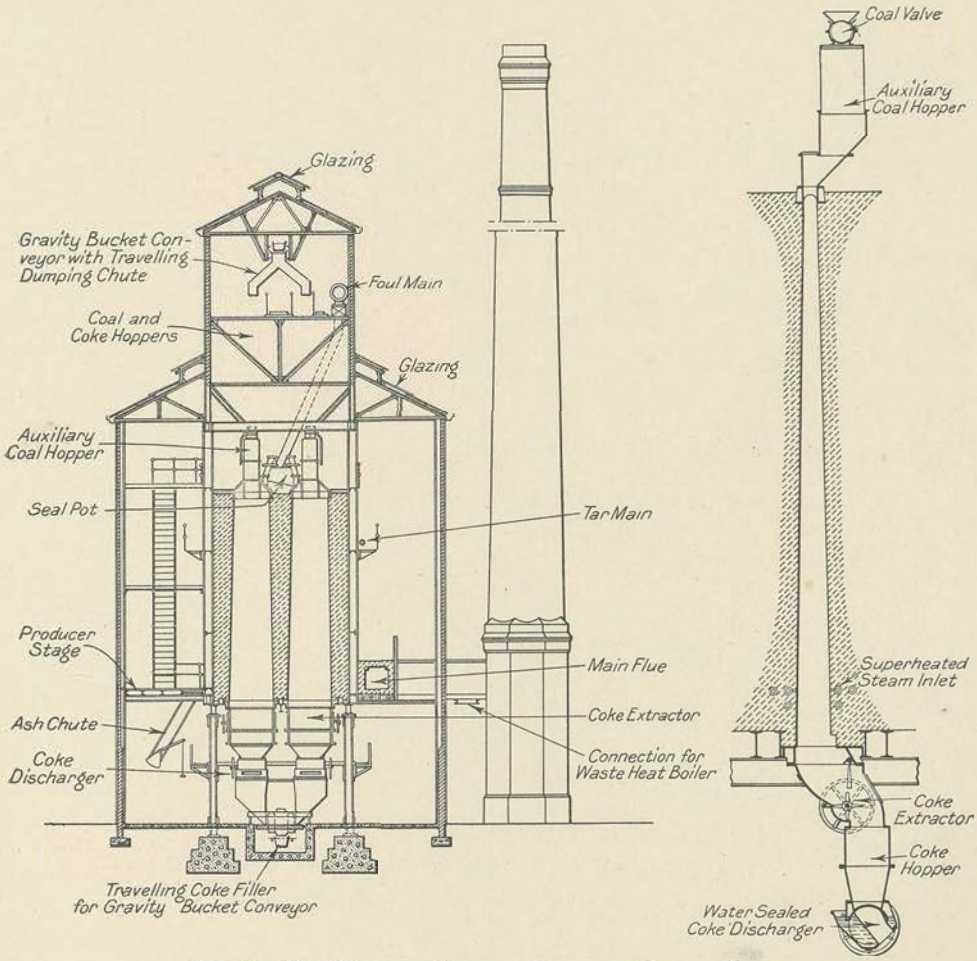


FIG. 70.—THE WOODALL-DUCKHAM VERTICAL RETORT SYSTEM.

(1) No air pulled in, because doors of retort are always closed.

(2) Quality of gas always constant.

(3) Each piece of coal undergoes the same treatment.

As regards the merits of the intermittent systems, the following points are drawn attention to :—

(1) There is no machinery to break down.
(2) The retorts are accessible at any time for repairs, etc.
(3) Wear and tear is less, as there are no continuously working parts.
(4) Retorts are said to last longer, as no abrasion takes place by continuous movement of the coke.

THE WOODALL-DUCKHAM SYSTEM

This system, which, with the Glover-West, has made more headway than any other type in this country, has undergone considerable modification since its introduction in 1903. Continuous charging and discharging was then arranged for; the base of the retort was water-sealed, and the coke, after passing the extractor, was quenched in the seal and removed by means of a short length of conveyor. Five years later the present system of coke extraction was introduced and the water-seal abolished. The amount of coal passing into the retort and the rate at which the charge descends are automatically governed by the speed of the coke extractor. The coal occupies from eight to ten hours in its passage through the retort, the speed depending upon the class and character of the coal employed.

The retorts are about 25 feet in length and of rectangular tapered shape, the three sizes of 3, 5 and 7 tons per day capacity respectively varying practically only in the length of the major axis.

Below are given particulars of the three standard sizes of retorts :—

Size.	No. 1.	No. 2.	No. 3.
Breadth and Width of Retort. Top . .	2 ft. 10½ in. × 7 in.	4 ft. 3 in. × 7 in.	5 ft. 1½ in. × 7 in.
,, ,, Bottom .	4 ft. 3 in. × 1 ft. 7 in.	5 ft. 3 in. × 1 ft. 7 in.	6 ft. 6 in. × 1 ft. 7 in.
Length	25 ft.	25 ft.	25 ft.
Coal carbonized per day (according to class of coal in use).	2½ to 3½ tons	4½ to 5½ tons	6½ to 7½ tons
Average yield of gas per retort per day .	30,000 to 40,000 cu. ft.	60,000 to 70,000 cu. ft.	80,000 to 90,000 cu. ft.
Number of retorts in each setting . .	Three to five	Two or four	One [1]
Grate area of Producers	Approximately 1 sq. ft. per ton of Coal carbonized per day		

The taper of the retort is not uniformly from top to bottom, the greater part of the taper being confined to the upper ten feet where the maximum swelling of the coal takes place. The actual width of the retort on the minor axis increases from 7 inches at the mouthpiece to 1 foot 4 inches at a point 10 feet down. The

[1] Each 7-ton retort is a self-contained unit.

combination of this exaggerated taper with the existence of the high combustion chamber temperatures at the top of the retort enables the most pasty and strongly swelling coals to be successfully carbonized without undue trouble.

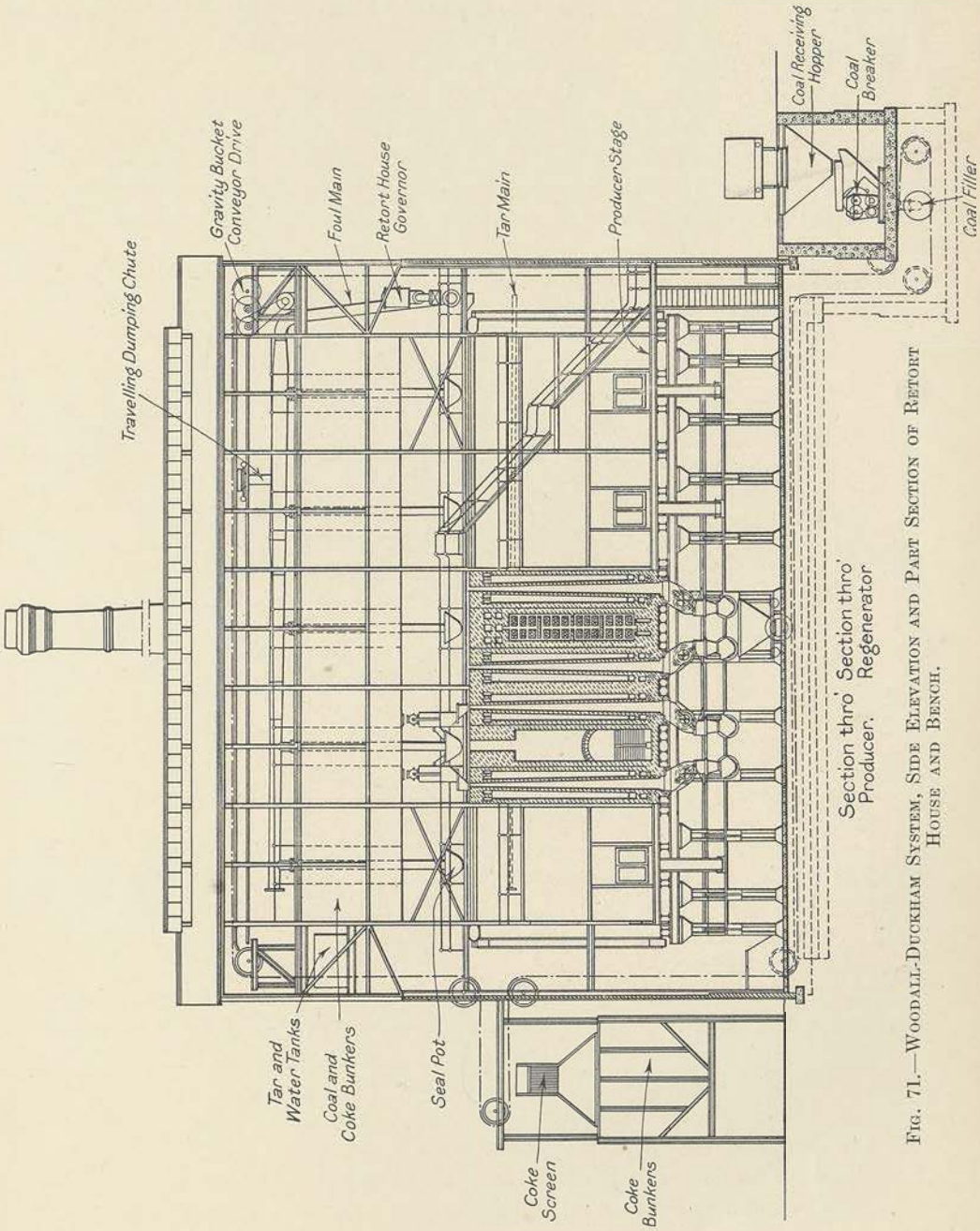


FIG. 71.—WOODALL-DUCKHAM SYSTEM, SIDE ELEVATION AND PART SECTION OF RETORT HOUSE AND BENCH.

The maximum working temperatures in the combustion chambers are usually about 1,290° C. (2,354° F.) at the top and 1,000° C. (1,832° F.) at the bottom.

The walls of the retorts (Fig. 72) are formed of bricks tongued and grooved so that leakage at the joints is prevented, the bricks being panelled out at the back so that the heat can readily pass through the walls to the charge in the retort, a large surface being presented to the heating gases in the flues.

The retort bricks measure 4½ inches from front to back, but owing to the panels the average thickness of fireclay material through which the heat has to travel from the combustion chamber to the coal charge is a little over 3 inches. In this manner a retort wall is formed practically equal in strength to a solid 4½-inch wall but having a heat conductivity to that of an ordinary 3-inch solid retort.

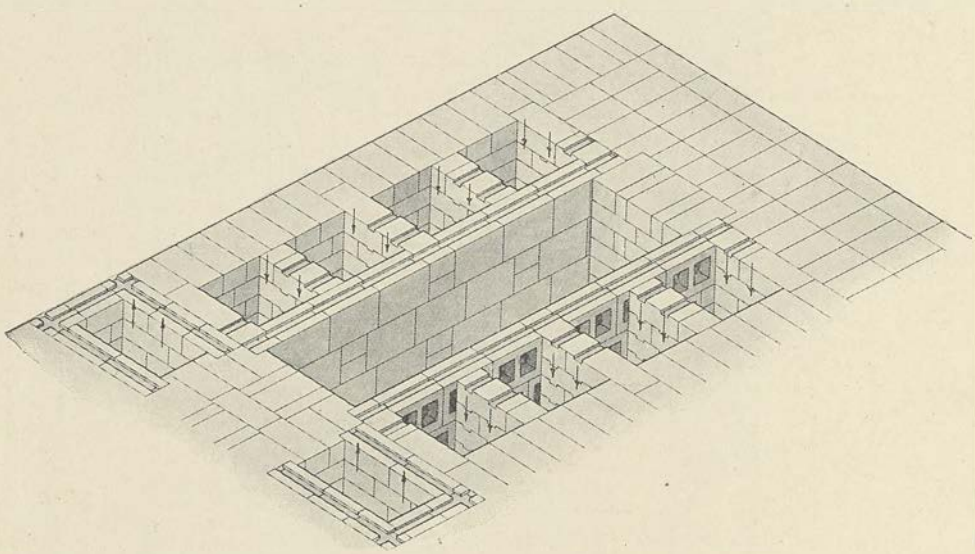


Fig. 72.—Section of Woodall-Duckham Vertical Slot Retort, showing Method of Bonding Special Bricks.

The heating flues are vertical and the division walls separating the flues are constructed of tongued and grooved bricks. The division walls are bonded into the walls of the retorts and into the back walls of the flues, thus forming a very strong and simple construction.

The producer gas and secondary air are brought to the top of the setting and are admitted at the top of the vertical flues, combustion proceeding downwards.

Dampers for producer gas, secondary air, and waste gases are provided for the purpose of maintaining safe and uniform heating of the retorts, the dampers being operated from platforms placed in convenient positions.

The three- and seven-ton sizes of retorts are built in batteries of six and upwards, and are provided with outside producers situated at the end of the retort bench.

Five-ton retorts are arranged in settings of two or four retorts complete with

producer and regenerator in each setting. Each seven-ton retort is a self-contained unit with its own regenerator situated at the lower end of the retort.

Producers of the step-grate type are now installed.

Until about six years ago the five-ton retort was the only size in use in this system, but it was then found that a demand existed for both smaller and larger sizes, consequently the three- and seven-ton retorts were designed to meet the requirements of small and large works respectively.

For small works with a daily output up to about half a million cubic feet of gas retorts of three- and five-ton capacity are installed, for medium sized works up to about two millions per day the retorts are usually of the five-ton size, while for larger outputs the seven-ton size offers many advantages.

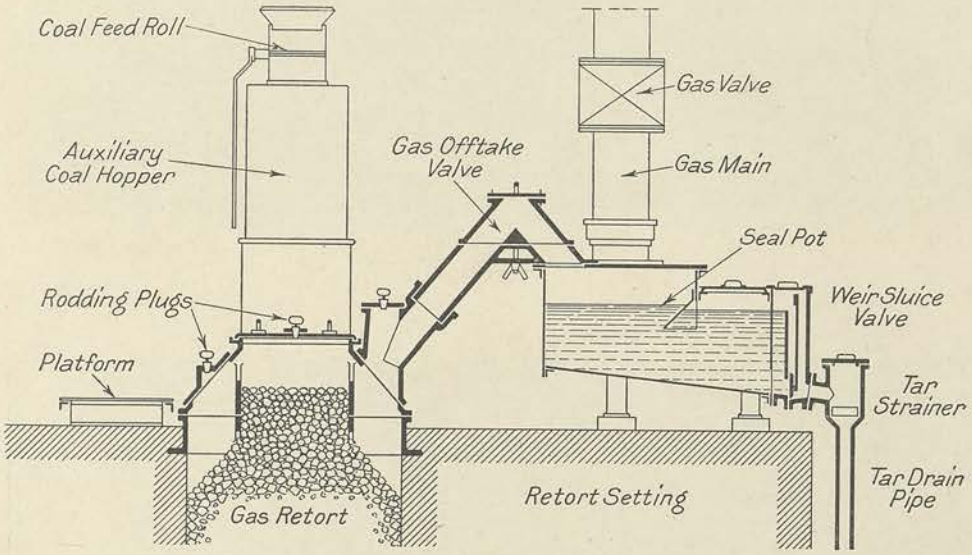


FIG. 73.—GAS OFFTAKE, WOODALL-DUCKHAM SYSTEM.

On the smaller plants, lifts are provided for handling coal and coke to the overhead bunkers and for larger plants bucket elevators or conveyors are installed for this purpose.

DETAILS OF SETTINGS

At the top of each retort is a cast-iron mouthpiece (Fig. 73), to which is attached the coal-feeding device and the gas offtake.

A gastight auxiliary coal hopper constructed of mild steel plate and having a capacity of from two to four hours' coal supply is mounted on a special casting attached to the mouthpiece. The casting is so formed that the hopper in no way obstructs the free access to the retort for inspection, scurfing, or filling with coke.

At the top of the auxiliary hopper is fitted a circular gastight coal valve which is operated by hand every two, three, or four hours. The time required for this

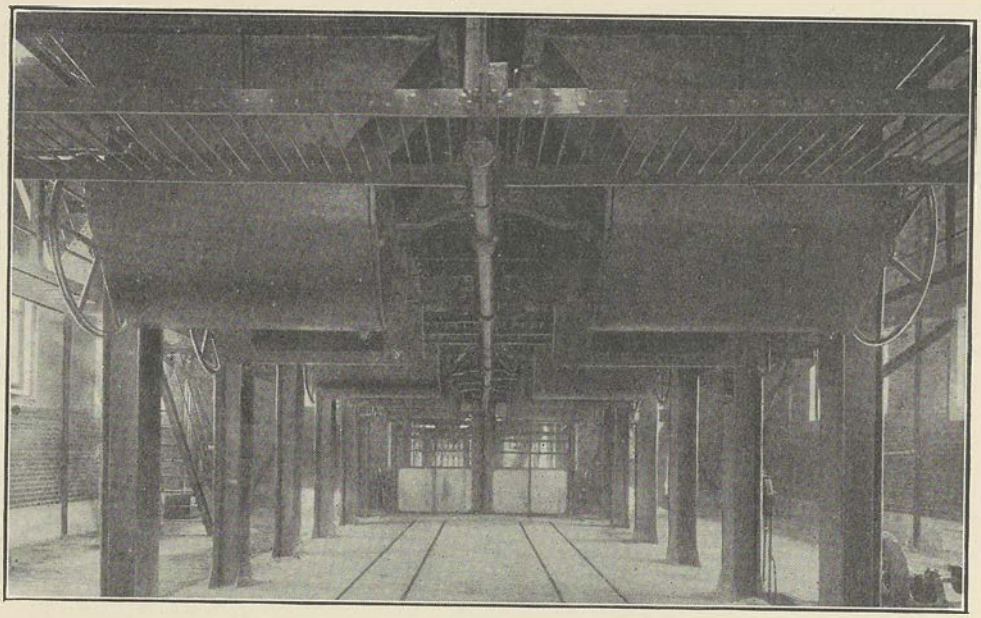


FIG. 74.—BOTTOM RECEIVING HOPPERS. WOODALL-DUCKHAM SYSTEM.

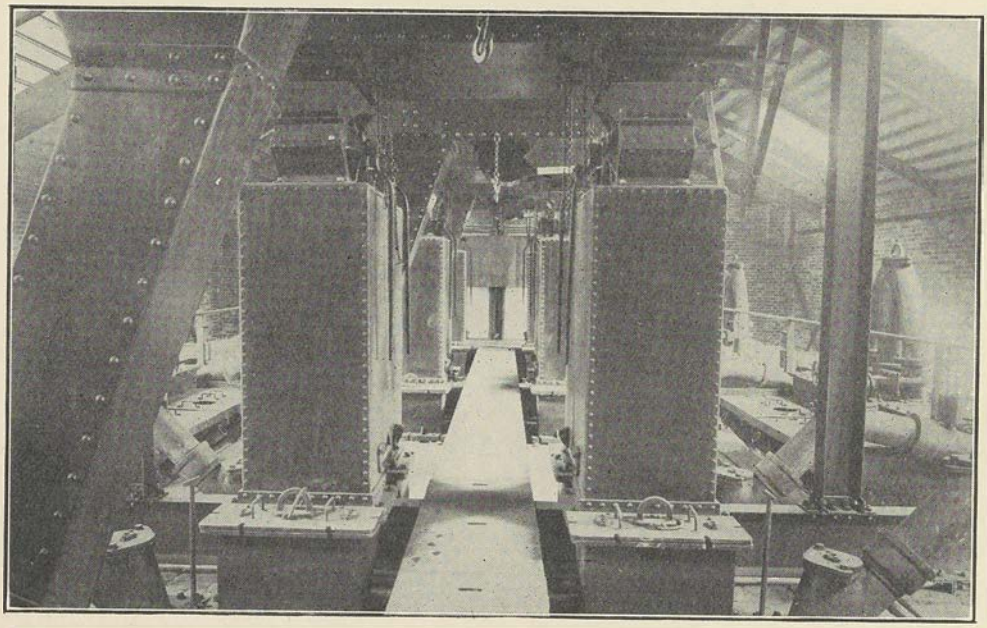


FIG. 75.—COAL CHARGING HOPPERS. WOODALL-DUCKHAM SYSTEM.

operation is about ten seconds. This coal valve is of simple design and practically consists of a cast-iron plug cock with an opening about 9 inches square.

The speed of travel of the coal into the retort is clearly shown by a special form of gastight coal indicator which is operated by a weight resting on the coal in the auxiliary hopper.

Each retort is provided with a special form of disk valve, the surfaces of which under all conditions are kept clean, and which, when closed, cannot leak. This arrangement enables each retort to be shut off for scurfing, when required.

After leaving the retort the gas passes through the offtake pipe and gas valve to the seal pot, where the heavier tars are deposited by fractional condensation before reaching the foul main.

Each setting is provided with a seal pot serving two or more retorts, through

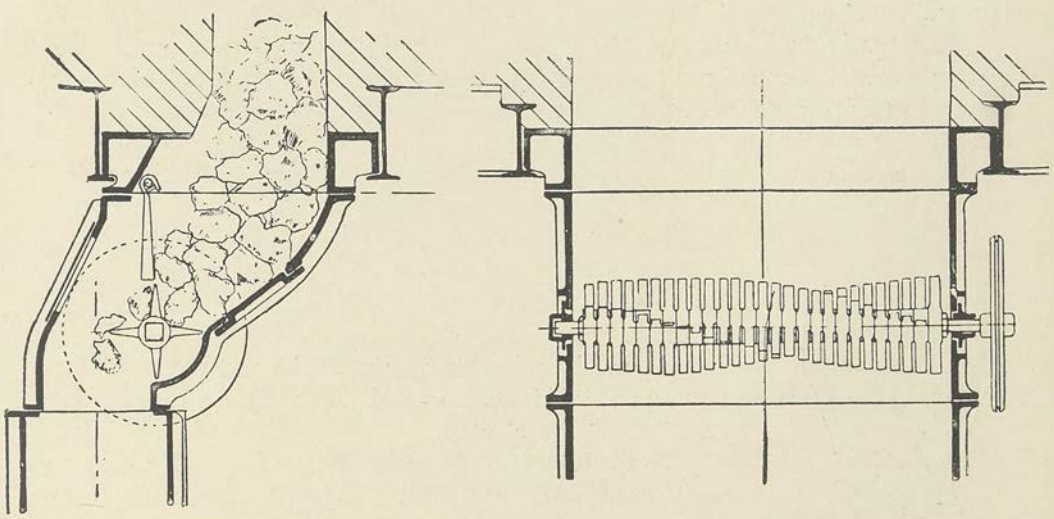


Fig. 76.—The Woodall-Duckham Coke Extractor.

which a stream of tar is passed in order to dissolve the heavier tars ; the gas, however, does not pass through a liquid seal.

This is one of the most important parts of any system of continuous vertical retorts, as the working of the charge through the retort depends to a great extent upon the efficiency of the coke extracting gear.

The coke-extracting device (Fig. 76) is situated along the bottom of a curved plate which forms the back of a cast-iron hopper attached to the bottom of the retort.

The curved plate takes the weight of the charge in the retort and the manhole and inspection holes in it provide free and immediate access to the retort.

As it rotates, the extractor roller does not shear the coke, but merely allows a definite amount to pass over it into the receiving hopper.

Cast-iron hangers are swung from a shaft above the extractor which prevents any coke passing over the extractor unless regulated by the action of same.

The extractor roller is formed of a series of cast-iron cross pieces mounted on a square shaft, each cross piece having a slight lead on its neighbour so that a roller is formed with helical blades. The construction ensures that the discharge of the coke is the same throughout the whole of the revolution of the extractor roller, and, therefore, the travel of the charge through the retort is constant.

The shaft of the extractor roller projects through glands carried by side plates of the bottom castings and on one end is fitted a wheel having a V-shaped groove turned in the rim. In this groove works an eccentric wedge-shaped pawl actuated by a rocking arm, the travel of which is varied by regulating a screw adjustment.

The normal speed of this extractor is one revolution in sixty to seventy minutes, but the screw adjustment allows of considerable variations fast or slow from the normal.

In case of a breakdown of the gas engine or electric motor driving the extractor gear, the extractor can easily be turned by hand. The amount of power required to drive the coke extractors for a plant producing one million cubic feet of gas per day does not exceed one horse power.

The rocking arms previously described are coupled by short connecting rods to a reciprocating bar running the length of the bench settings.

Each reciprocating bar is driven by an adjustable eccentric fixed to the main driving shaft, the speed being about one complete stroke per minute, and the maximum length of the stroke about 4 inches.

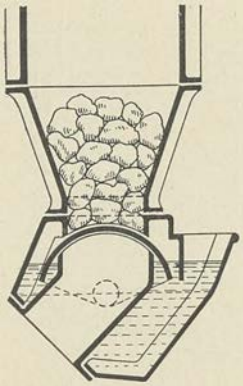


FIG. 77.—WATER-SEALED DISCHARGING DOOR. WOODALL - DUCKHAM SYSTEM.

Below the coke extractor is fitted a cast-iron receiving hopper, which is constructed to contain two or four hours' discharge of coke.

To the bottom of the coke hopper is fixed a water-sealed gas-tight door (Fig. 77). It has been found in practice that any form of faced door rapidly wears away and allows leakage to take place when the machined faces are subjected to the combined action of coke breeze and moisture.

The construction of this water-sealed door consists of two cast-iron boxes, the one fitting inside the other in such a way that an annular space is formed between them. In this space is fitted a segmental door plate constructed with quadrant ends and suitable bearings and operating wheel. The door is sealed in 4 inches of water when closed, consequently it is gas-tight and needs no clamping.

The coke is never in contact with the water, but the latter has the beneficial effect of keeping the castings cool. The time taken in discharging the coke from a retort is about ten seconds.

On leaving the retort proper the coke is finally quenched by means of a small

spray of water playing upon it in the storage hopper. It is, however, discharged dry and practically cold.

On earlier plants, before steaming was in vogue, the heat left in the coke after carbonization was utilized for warming the primary air for the producers. Means are now provided for making use of the heat in the coke for the production of water-gas, and at the same time the temperatures are increased about the bottom lengths of the retort. Steam is superheated by being circulated through flues situated at the lower end of the retort, and is admitted through a number of inlets in the side walls, a short distance above the bottom castings.

The amount of steam introduced to each retort is controlled by means of a metal disk in which is drilled a hole of from $\frac{1}{8}$-inch to $\frac{1}{4}$-inch diameter, depending upon the size of retort and the class of coal to be carbonized.

A constant pressure of from 30 to 40 lb. is maintained in the main steam service, which is made of ample size to ensure that each retort receives the full amount of steam.

The whole of the settings, producers and regenerators, and the various attachments and working parts are usually carried clear of the ground on a steel joist floor supported by stanchions.

The coal and coke hoppers are formed in one continuous line along the settings and are carried by stanchions extending to the floor level. Shoots are provided for feeding the producers, also for filling the retorts after scurfing.

The standard capacity of both coal hoppers and the producer-coke storage hopper for all sizes of plants is forty-eight hours, but larger or small capacities can be arranged to suit special requirements.

Platforms are provided along each side of the top of the settings at the producer-level, and at the level of the top and bottom flues for inspection and cleaning purposes.

Owing to the system of downward heating with the greatest temperature near the top, all repairs are carried out from the top, the lower portions of the settings remaining in good condition for an indefinite period.

THE GLOVER-WEST SYSTEM

This system of vertical retorts was the outcome of patents taken out in 1905 by Young and Glover, and was founded on constructional details and practice in the distillation of shale in vertical retorts in Scotland. In 1907 a patent was taken out by Glover and West for a system of heating the retorts and utilizing the residual coke for heating the secondary air required for the combustion of the producer gas. In 1909, the first installation was completed and put into operation at the St. Helens Gasworks, where very exhaustive tests were made on the plant to demonstrate the advantages of the system for the carbonization of coal in the manufacture of coal-gas.

As in the Woodall-Duckham system, the ideal of continuous carbonization is aimed at, but the methods of arranging for this vary to some considerable extent

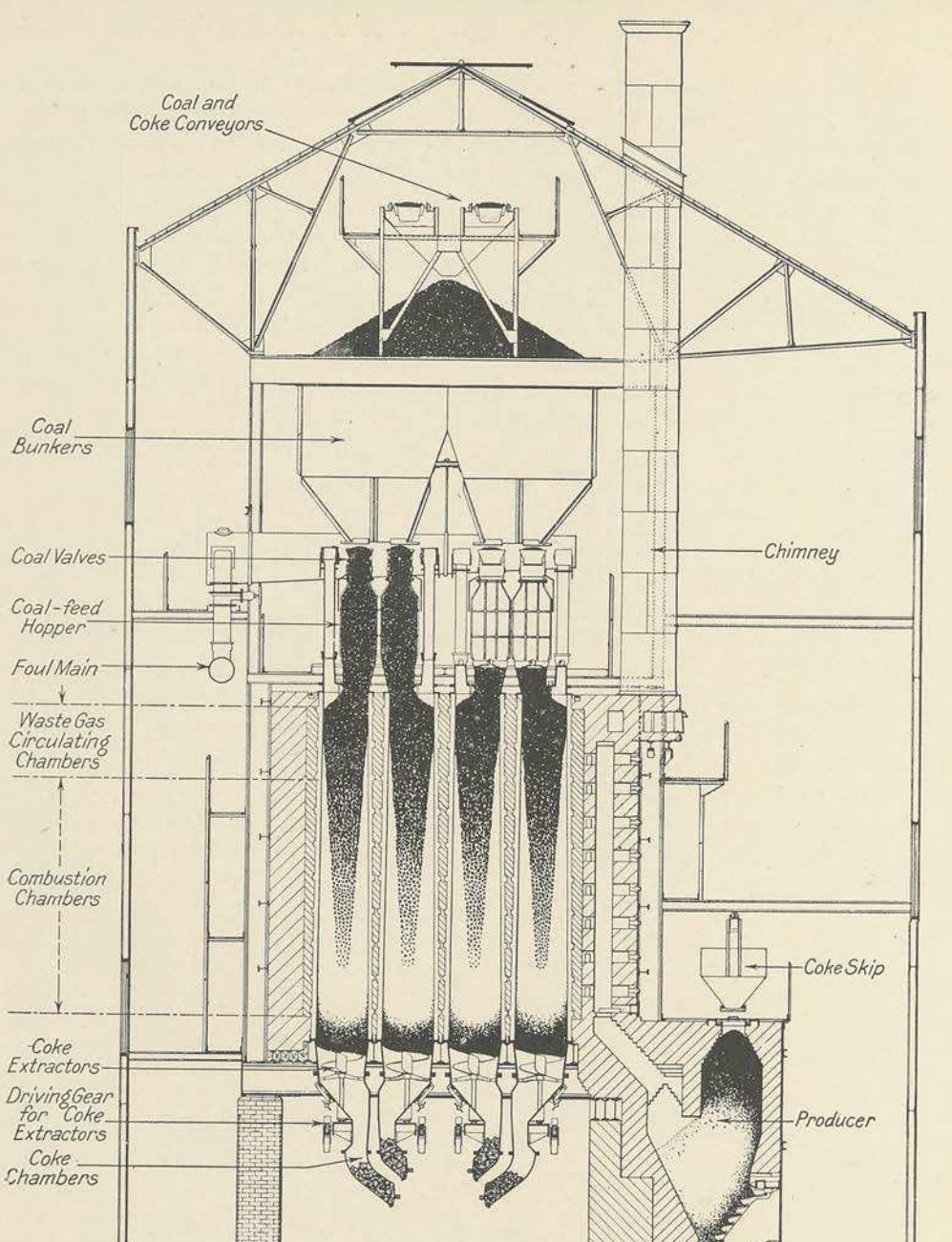


FIG. 78.—CROSS SECTION OF GLOVER-WEST VERTICAL RETORT BENCH, ARRANGED FOR SEPARATE UNITS OF FOUR RETORTS.

in detail. First, the retorts are elliptical in section instead of rectangular, and are built up of concentric rings of silica, the top and bottom of the retorts being of hard burnt fireclay. The bottom portion of the retorts is in the regeneration chamber for the secondary air entering the combustion chamber. The passage of the gas will be readily understood from Fig. 82, an outlet being provided at the base of each coal-feeding hopper, whence the gas is conducted by a 7-inch pipe to a dry main. Each outlet pipe is fitted with a valve, which is brought into use when a retort is out of action for scurfing purposes. Coke extraction is, of course, continuous, and governs the rate at which the coal is delivered. The extractor consists of a slowly revolving vertical worm, driven by gas or electric motor of 3 h.p. for an installation not exceeding twenty retorts, 4½ h.p. for an installation of six settings or forty-eight retorts, and 5 h.p. for an installation of ten settings or eighty retorts. The worm extractor, which makes one revolution in about thirty to forty minutes, is made in two halves, so that it can be opened to permit the retort to be readily inspected. A novel feature enables the speed of the individual extractors to be regulated, so that if different types of coal are in use in the retorts, the speed of each worm can be adjusted to suit the particular class of coal. Dropping from the extractor the coke passes into the chamber fitted with a self-sealing lid (Fig. 81), and is removed from this at intervals of about two hours. The system of heating the retorts differs from that of Woodall and Duckham in that combustion takes place in a number of chambers, and the waste gases (after leaving the combustion chambers) pass around the upper portions of the retorts into horizontal circulating chambers before finding their way to the chimney. On account of the cooling action of the secondary air passing around the base of the retort, no water-quenching is necessary, and the coke is discharged from the lower chambers practically cold. The producers are charged up with this cold coke at intervals of about four hours. The more important details of the system are summarized below :—

	Type 1.	Type 2.	Type 3.
Shape of retorts . .	Elliptical	Elliptical	Elliptical
Breadth and width of retorts	40 in. × 10 in. to 46 in. × 18 in.	33 in. × 10 in. to 39 in. × 18 in.	24 in. × 10 in. to 30 in. × 18 in.
Length of retorts .	21 ft.	21 ft.	16 ft.
Number of retorts in each bed . . .	8 in units of 4	8 in units of 4 or 2	8 in units of 2
Coal throughout per retort per diem (when producing coal-gas) . . .	4 tons	3 tons	2 tons
Grate area (effective) per producer . .	1,600 sq. in.	1,275 sq. in.	850 sq. in.

The several types of retorts and settings designed to fulfil the requirement of both large and small installations.

With the Glover-West settings, the producer furnace openings are not provided with doors or provision for primary-air regulation, as the required production of producer gas is regulated by the draught in the settings, although dampers are

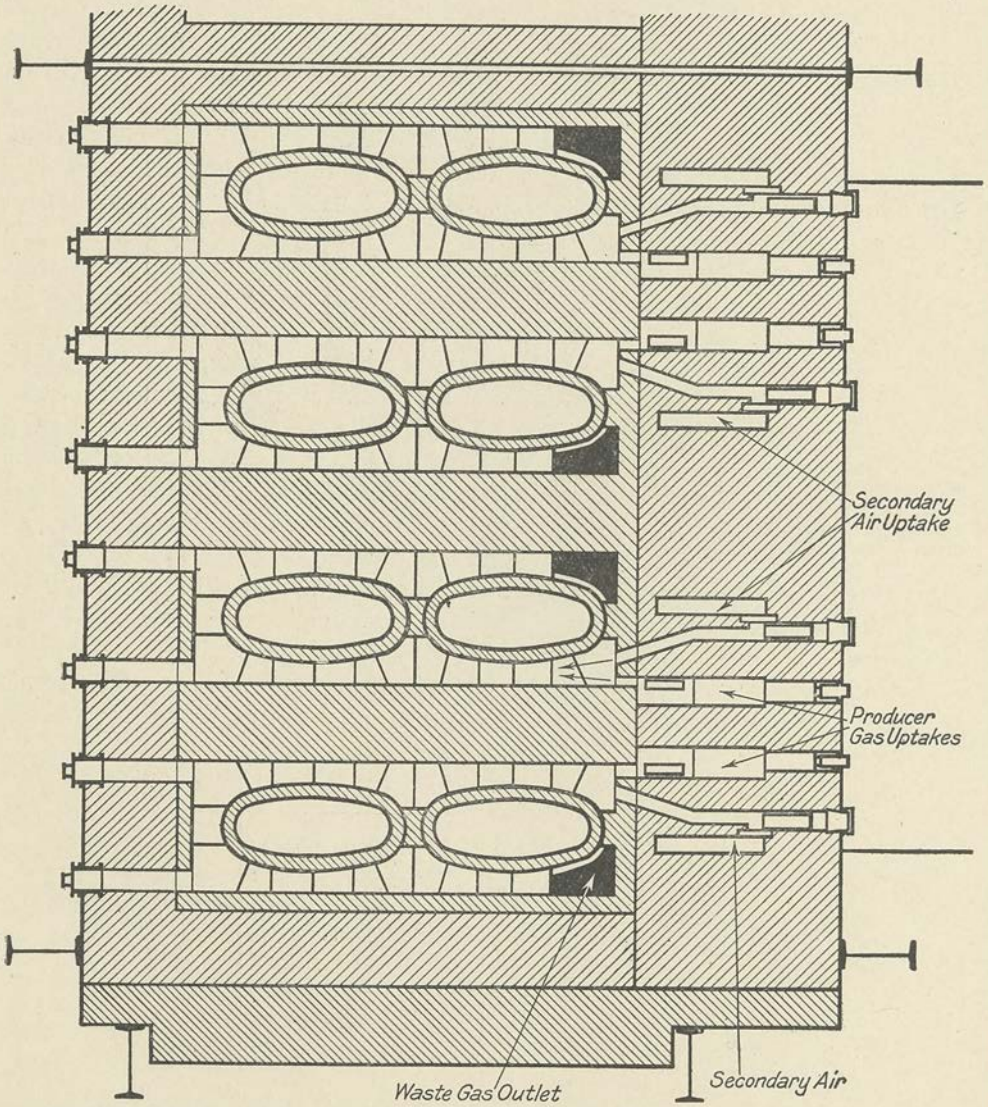


FIG. 79.—SECTIONAL PLAN OF GLOVER-WEST SETTING OF EIGHT RETORTS, ARRANGED IN INDEPENDENT UNITS OF TWO RETORTS.

provided at the base of the producer-gas uptake flues. Consequently, the supply of producer gas is constant and excess is avoided, resulting in economy of fuel. One half of the setting may be isolated when desired.

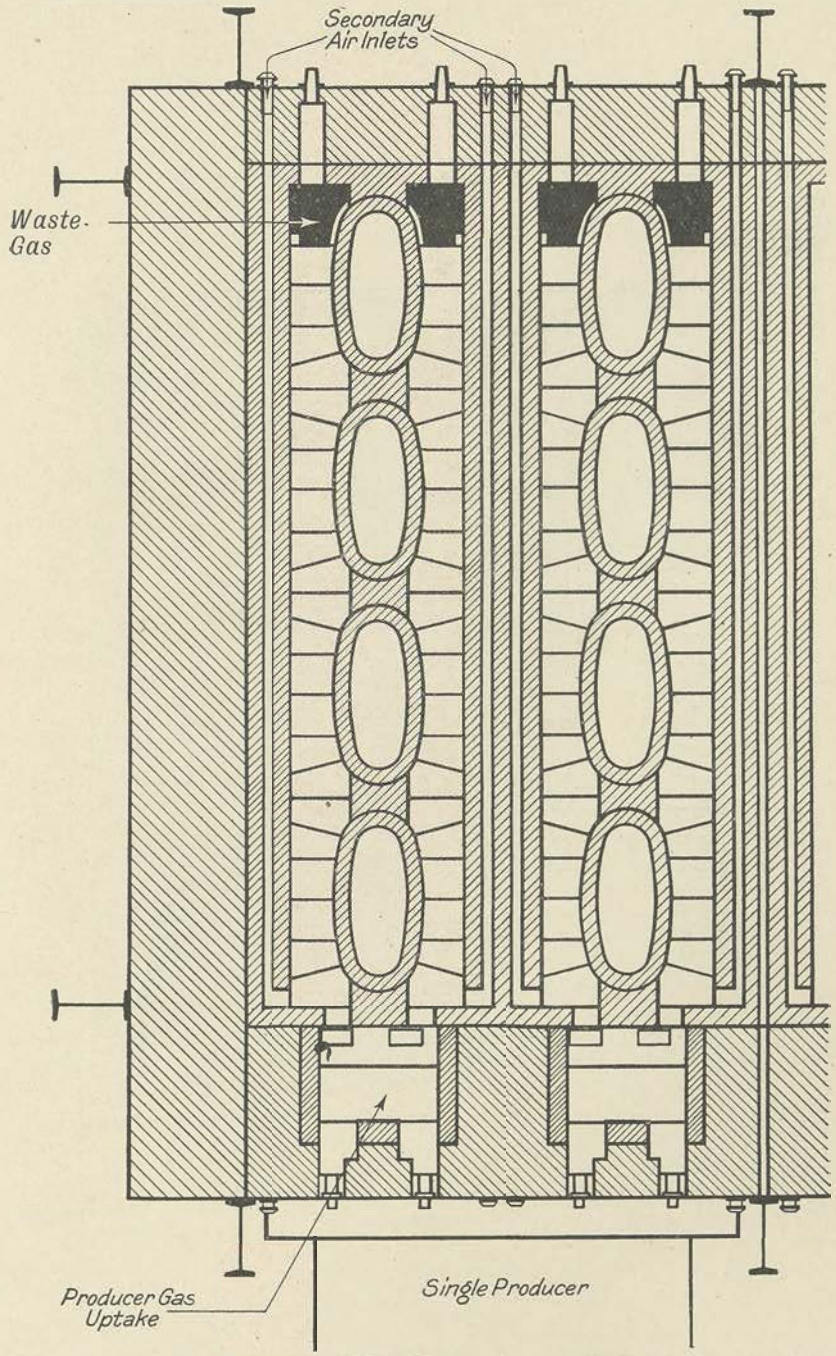


FIG. 80.—SECTIONAL PLAN OF GLOVER-WEST RETORT SETTING OF EIGHT RETORTS, ARRANGED IN INDEPENDENT UNITS OF FOUR RETORTS.

The retorts are heated in a series of superimposed chambers and the heats can be readily controlled. The chambers of the setting are divided into three, the top or waste-gas circulating chambers, the middle or heating chambers, and the bottom or regenerator chambers.

The Glover-West system of heating the retorts readily conforms to the requirements for the continuous production of water-gas by passing steam through the charge during the process of carbonization within the retort; the mixture of coal-gas and water-gas being of suitable proportions to produce the required calorific

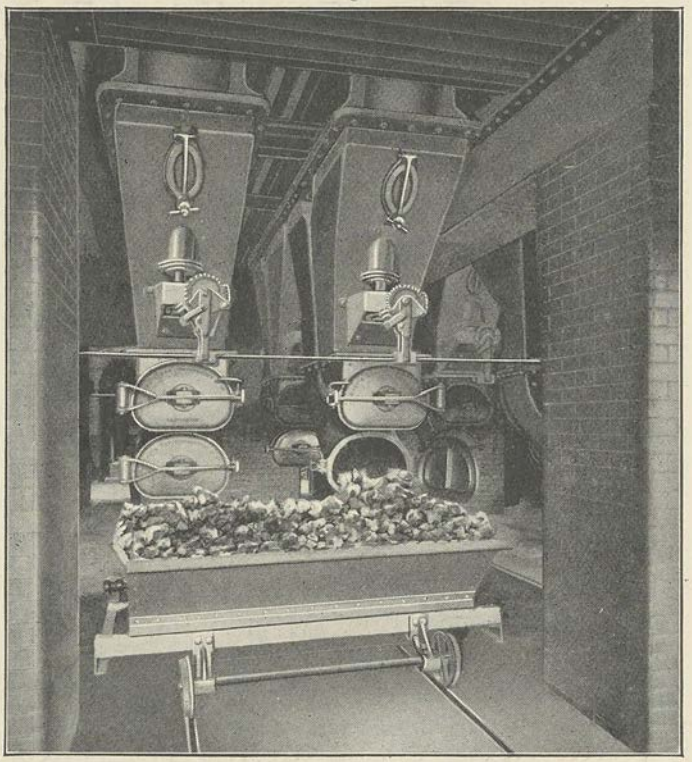


Fig. 81.—Glover-West System. Bottom Discharging Chambers and Extractor Gear.

value of the gas. This combination increases the yield of thermal units of the gas per ton of coal carbonized, with an increase of tar and ammoniacal liquor. Economy is effected by the utilization in some cases of the water-gases for the generation of the steam required for the water-gas manufacture.

THE INTERMITTENT SYSTEM

This system was introduced in 1902, and in its earliest form apertures were introduced for taking off the gas from the side of the retort. Two years later these

side outlets were dispensed with, and the system assumed the form, more or less, in which it exists to-day. In comparison with the two previously mentioned systems, the chief points to notice are that as the retorts are intermittently charged no continuously operating machinery is necessary. The retorts are built in two sizes, having a capacity of 18½ cwts. and 32 cwts. of coal respectively per day.

The top and bottom lids on the retorts are opened or closed as required by a system of hand levers, bottom doors on the large retorts being operated by hydraulic

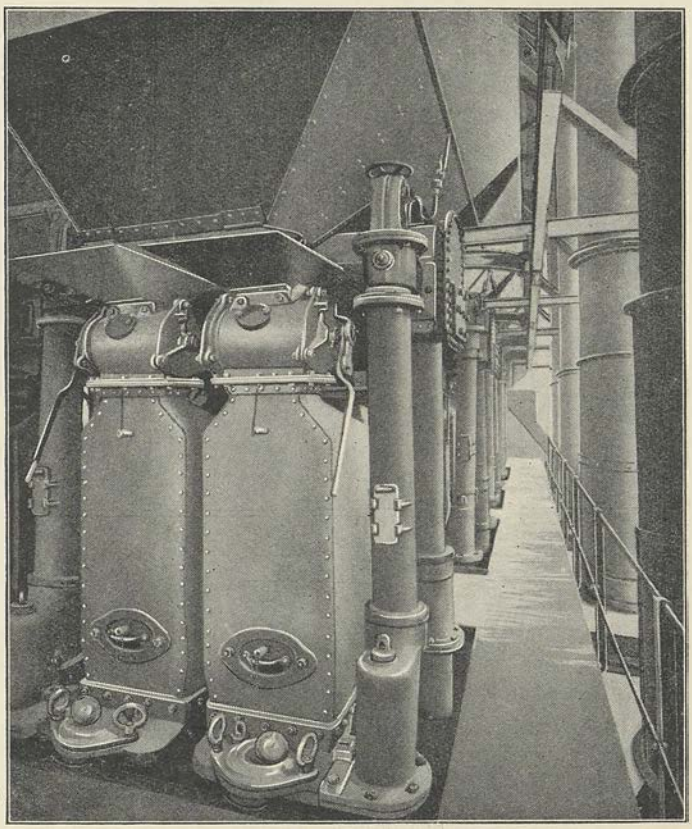


FIG. 82.—GLOVER-WEST SYSTEM. TOP OF RETORT BENCH, SHOWING CHARGING ARRANGEMENTS AND GAS OUTLETS.

power. These are only used at charging times; therefore suffer little wear and tear, and have a long working life. One advantage of the intermittent system of charging is that the retorts are open for inspection every twelve hours.

The coke discharged does not fall heavily, but rather glides steadily from the retorts into its receptacle without shock, which minimizes the wear and tear of apparatus, and avoids depreciation in market value due to crushing or breaking, with formation of small and dirt.

The retorts are arranged in rows of two, and a setting may comprise four, six, eight, ten, or twelve retorts according to the size of plant required, the large installations having several settings combined in one bench.

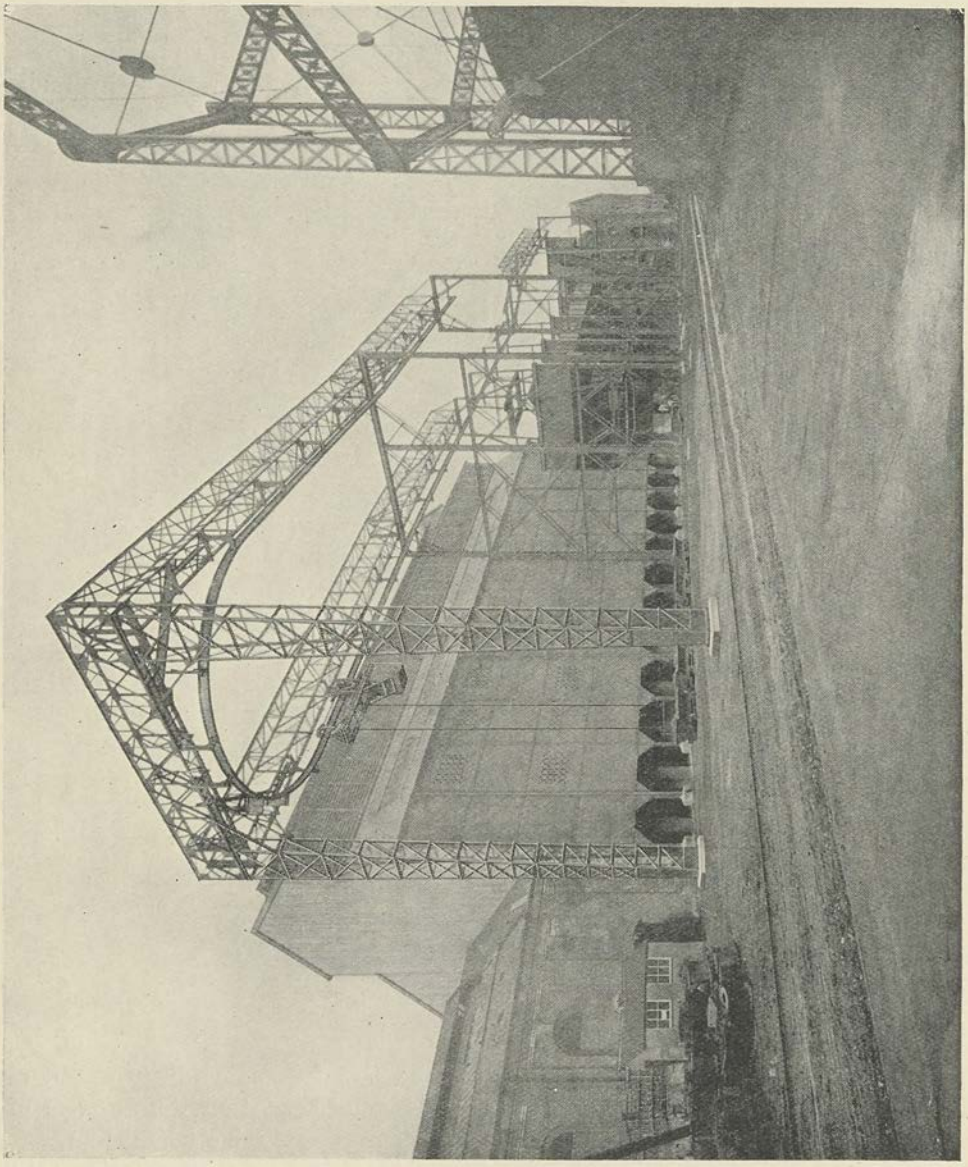


Fig. 83.—Glover-West Vertical Retort House at Cardiff Gasworks.

Each setting has a separate producer, which is built the full height of the bench, having sealed feeding door at the top and a step-bar grate with double clinkering doors at floor-level. Coke is fed to the producers by a travelling shoot filled from

the overhead hoppers. The regenerators are arranged on each side of the producers and are formed of two vertical passages, one for waste gases and one for secondary air, constructed of special tiles to ensure a maximum heating of the secondary air, and the absence of any short-circuiting or by-passing.

The waste gases enter the regenerator at the top, and the secondary air, coming

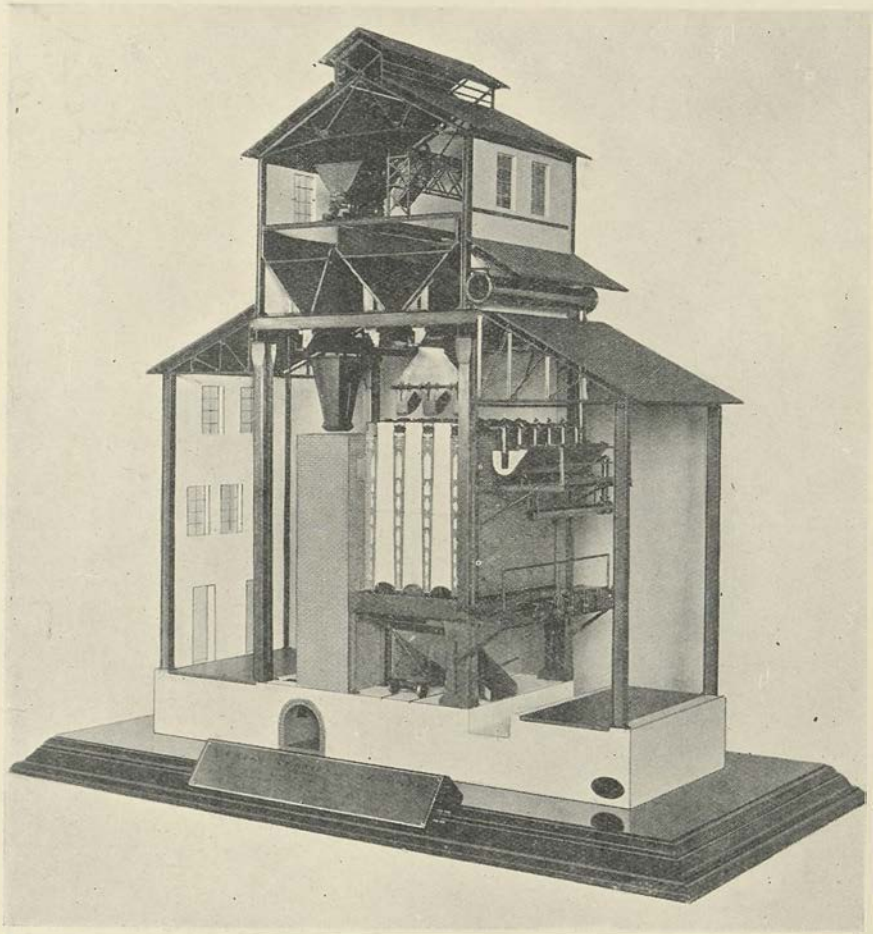


FIG. 84.—SCALE MODEL OF INTERMITTENT SYSTEM.

in at the bottom, passes upwards into a chamber at the top of the setting, where it is split up and conducted to the combustion chambers, which are arranged at the bottom of the retorts.

The combustion chambers are placed between the retorts, and there are control dampers for secondary air, furnace gas and waste gases respectively, so arranged that the supply can be regulated in each combustion chamber. The flame can be extended or set back to suit requirements, and every point in the setting is under

independent control. The temperature of any part of a retort can be adjusted without the slightest interference with the general heating of the setting.

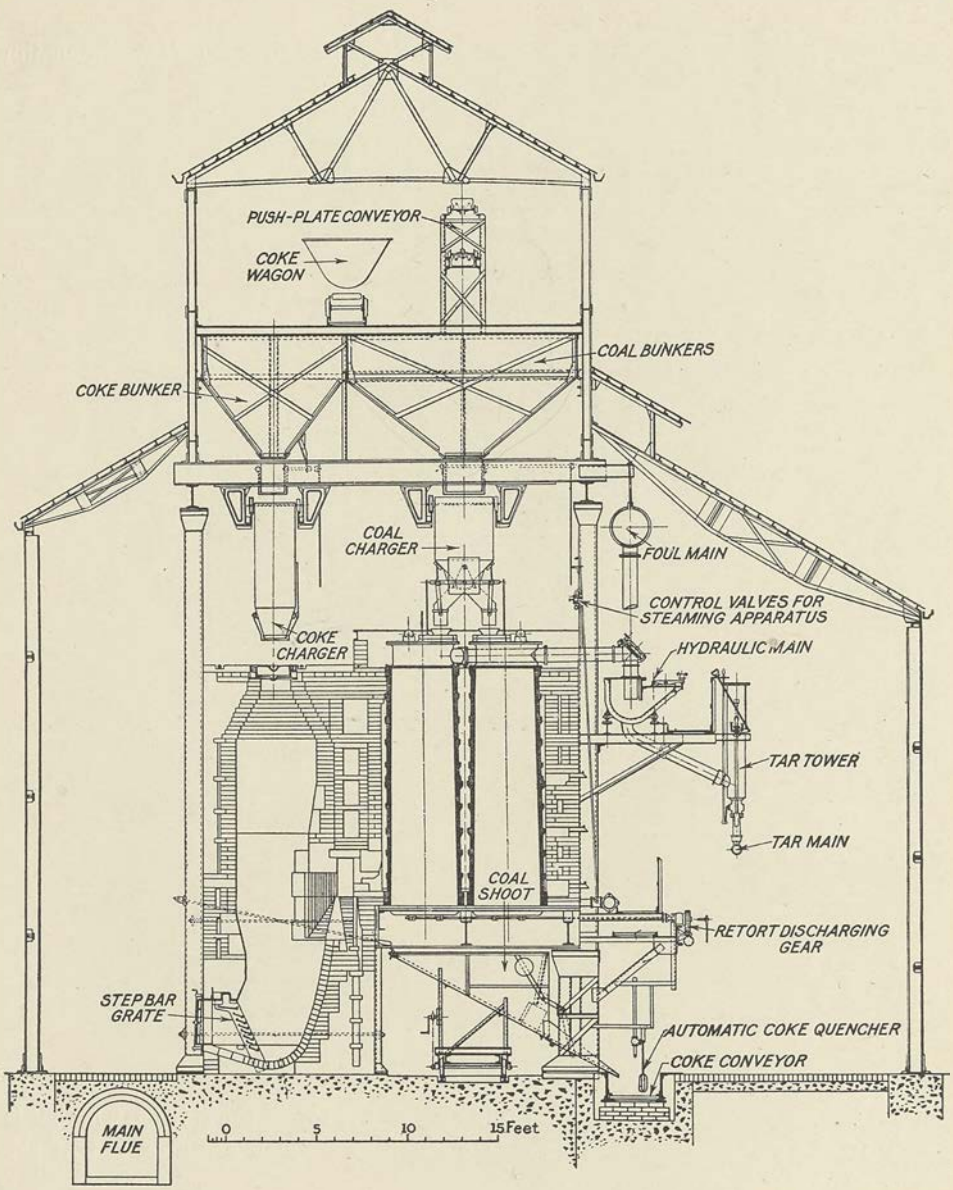


FIG. 85.—INTERMITTENT SYSTEM OF VERTICAL RETORTS.

The retort setting is carried on a platform of cast-iron plates about 10 feet above the floor-level, to allow of the coke being discharged underneath. The retorts

have flanges carrying flooring tiles at different levels to regulate the flow of the gases, which circulate from the combustion chambers at the bottom of the setting to the waste-gas outlets at the top. Dampers are provided in the various floors to control the heat to any retort, each pair of retorts being contained in a separate chamber.

One of the latest additions that have been introduced from time to time, not only as the result of increased experience in construction, but also of intimate

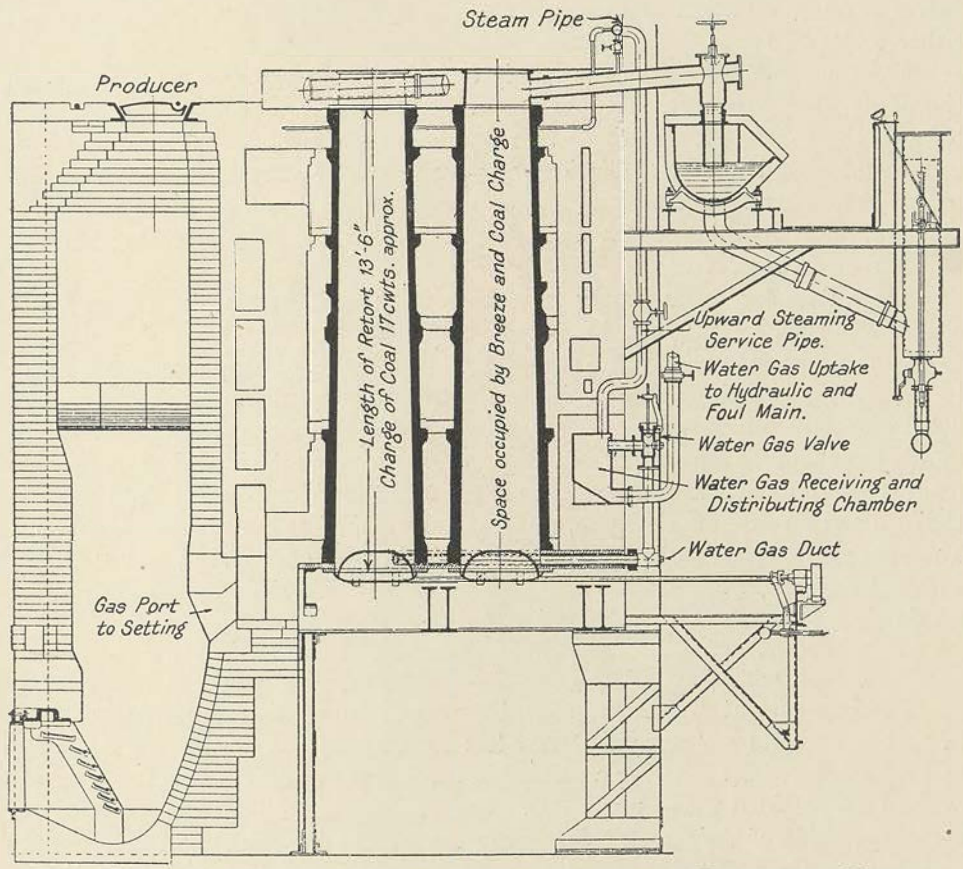


FIG. 86.—SETTLE'S DOWNWARD STEAMING PROCESS, AS APPLIED TO INTERMITTENT VERTICAL RETORTS.

contact with daily working, is Settle's Downward Steaming Process, which is intended to secure a wide range of flexibility in the proportion of water gas manufactured, to reduce the risk of part of the steam passing direct through the outlet and escaping decomposition, and to preclude affecting the carbonizing temperature by the endothermic reaction concerned in the decomposition of steam. An appreciable amount of heat is carried forward from a nearly spent to a new charge. In

this process the flow of gas from the top of the retorts is interrupted during the latter part of the period of carbonization by means of a valve in the offtake pipe, and superheated steam is introduced into the top of the retorts. The steam, being admitted into the open space above the charge, fills the entire area, and moves downwards at slow speed, coming at once into contact with the horizontal section of the charge. The water-gas thus produced passes by way of a common collecting main to the bottom of a freshly charged retort, sweeping the rich gases forward along with it, and protecting them against decomposition. An arrangement of valves permits variation as to the position and number of the retorts subjected either to " down " or " up " current.

The blue water-gas, which is highly heated, dilutes the rich gases formed in the newly charged retort, and greatly accelerates the rate of travel of the gases towards the gas outlet, resulting in a reduction of the secondary action, due both to the protective influence of dilution and to exposure for a shorter time to a decomposing atmosphere. The temperature of the gases in the offtake pipes is remarkably low, rarely reaching 60° C. ; thus deposition of ammonia salts in the hydraulic and foul main is prevented.

The valves for steam supply and those in the offtake pipes are opened and closed from the charging stage by suitable hand gear.

Each retort is provided with a separate offtake pipe of ample area, connected to the hydraulic main by a dip pipe. The hydraulic mains are of special design, fitted with self-sealing inspection doors, so as to permit the pitch pans to be withdrawn during gasmaking, a separate main being provided for each setting. Each hydraulic main is also provided with a separate tar tower, arranged for sealing and unsealing the dips and for flushing the main, which is done each time the retorts are charged. The uptakes from hydraulic mains enter the foul mains on the side, and are fitted with valves, so that they do not become blocked with deposit when the settings are let down.

THE ELLAND INTERMITTENT SYSTEM

The intermittent system (Fig. 87) differs from the continuously operated type in that the retorts are of considerably less total length. A special feature is the method employed for ensuring a partly porous charge so that the gases as they are evolved are provided with a ready exit. Unscreened coal is charged in a thin stream against one side of the retort, this causing the nuts to accumulate on the one side and the slack along that side at which charging takes place. In addition to ensuring a porous charge, it is claimed that a less dense coke is produced ; whilst the coal is permitted to shrink freely from the walls of the retort, and in this way facilitates discharge. On charging, the flow of coal from the hopper ceases automatically when the required level is reached. The shoot is then withdrawn, and its contents drop into the retort. The self-sealing lids are of special construction, a toggle system of levers being used instead of eccentrics ; and a single pull by the attendant suffices to raise and seal the lids. The regenerators are of the tubular type, and the setting is subdivided in a manner to give a maximum control of the heats. The retorts

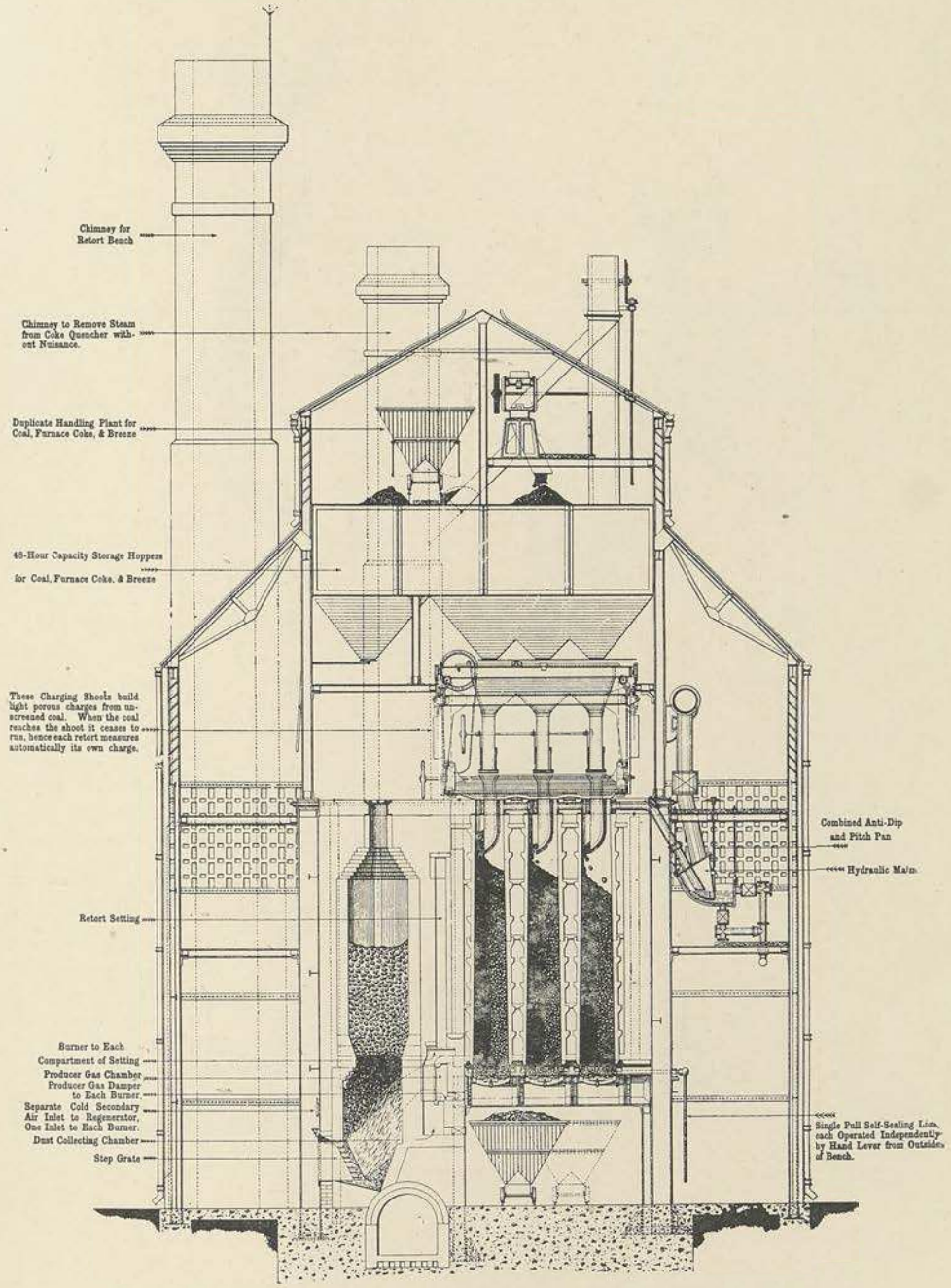


FIG. 87.—THE ELLAND SYSTEM OF INTERMITTENT VERTICAL RETORTS.

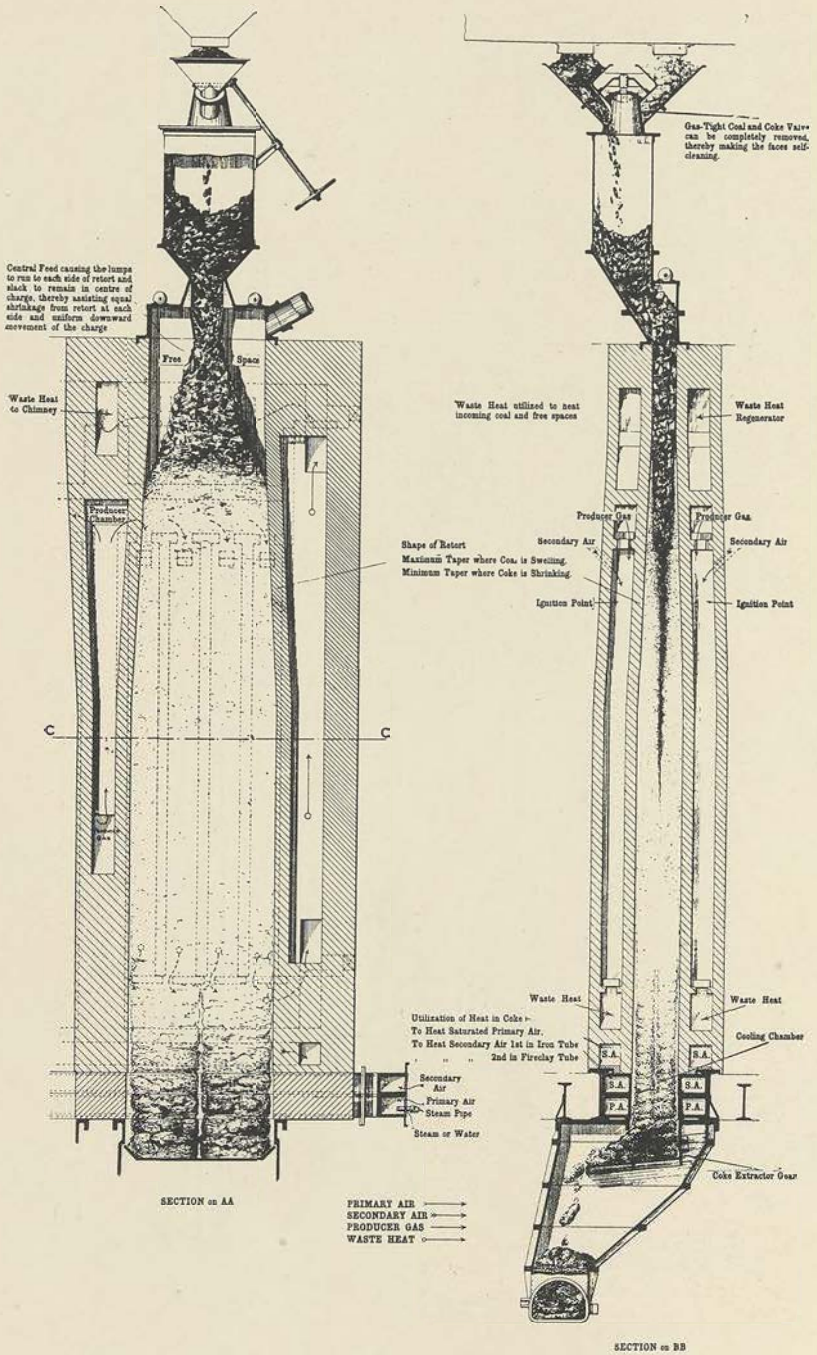


FIG. 88.—THE DEMPSTER-TOOGOOD SYSTEM OF CONTINUOUS VERTICAL RETORTS.

are usually set fifteen to a bed, are 16 feet 6 inches long and each carbonizes 25 cwts. of coal per diem.

THE DEMPSTER-TOOGOOD SYSTEM

The retorts in this system are 25 feet in length, and are charged by means of a gastight valve arranged with two inlets. One of these inlets is for the ordinary purpose of charging in coal, the other is for use in the case of those retorts which have undergone scurfing, and which first receive a charge of coke. As will be seen from Fig. 88, the coal is fed on the centre line of the retort. The taper of the retort is greater at the top than at the bottom ; this is to accommodate for expansion of the coal on first heating. There are no stationary inclines or curved parts to support the charge, which during its downward travel meets successively larger cross-sections, until the extractor gear is reached. This actually supports the maximum cross-section of the charge, hence bridging or hanging-up is prevented. At the base of the retort is an inclined plate supporting the whole charge at the natural angle of repose, and the coke is gradually pushed off by the reciprocating motion of the plate, which makes one complete stroke in about seven minutes. The coke is cooled by circulating primary and secondary air around the base of the retorts, which are heated on their broad sides only.

Each retort is provided with an independent secondary-air supply, producer-gas and waste-gas dampers, and with separate supply of superheated steam for steaming the charge. Thus every facility is provided for individual control of the heats. The retorts are built up from special moulded blocks to form round-cornered retorts, each of which is rated to carbonize 5 tons of coal per day. Four retorts are laid in each bed. The retorts are approximately 5 feet wide by 18 inches broad at the bottom, this being reduced to 4 feet by 7 inches at the top. A consideration of importance in this system is that the active combustion zone is neither at the top nor at the bottom. This, it is claimed, has some considerable effect on the life of the refractories, which are most liable to corrosive influences in the upper and lower portions of the retort.

THE GLASGOW SYSTEM

This system, designed by Mr. Alexander Wilson, was introduced for the purpose of dealing with the non-caking or semi-caking Scotch coals, which under ordinary circumstances give a particularly small and friable coke.

In order that the charge may have ample time to consolidate, the coke is not drawn out continuously, but at intervals of about four hours. In this way a fairly large coke of good appearance is obtained. The quantity of coke extracted at each period of discharging is governed by the size of the wagon or shoot into which it is delivered ; this is due to the fact that as the receiving wagon fills up it supports the whole weight of the charge in the retort, the bottom mouthpiece when being closed cutting through the coke column and sealing the base of the retort. No constantly moving machinery is required, and the coke is cooled in the bottom cast-iron

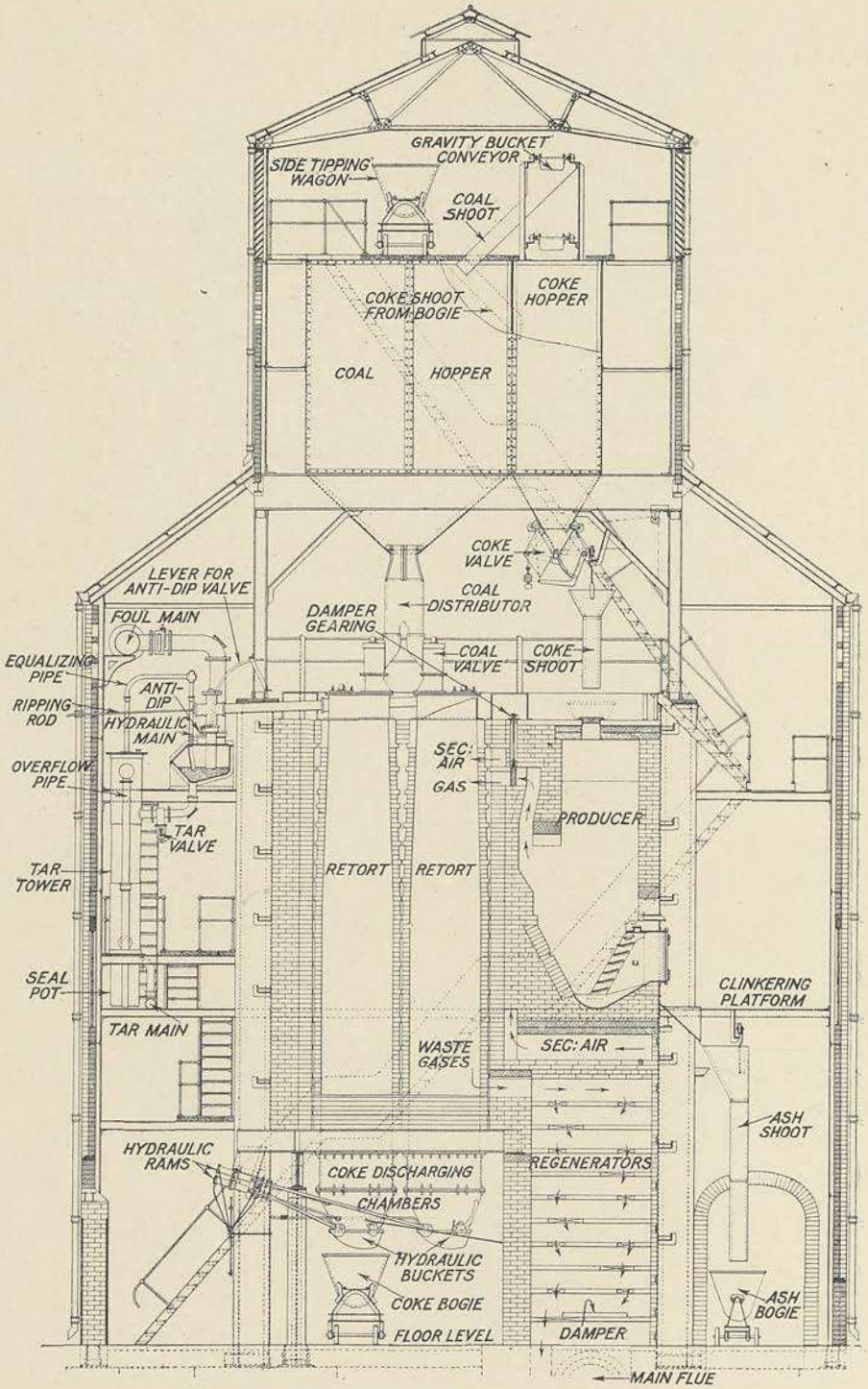


FIG. 89.—GLASGOW SYSTEM OF VERTICAL RETORTS.

chambers, to which are attached movable buckets for holding the water seals. These buckets are actuated by a small hydraulic ram, so that the movement of the handle of the water cock serves to push back the bucket, allowing the requisite quantity of coke to fall into the receiving wagon. Another movement of the handle then closes the bucket, which is sealed in water to render it gastight. The retorts, which

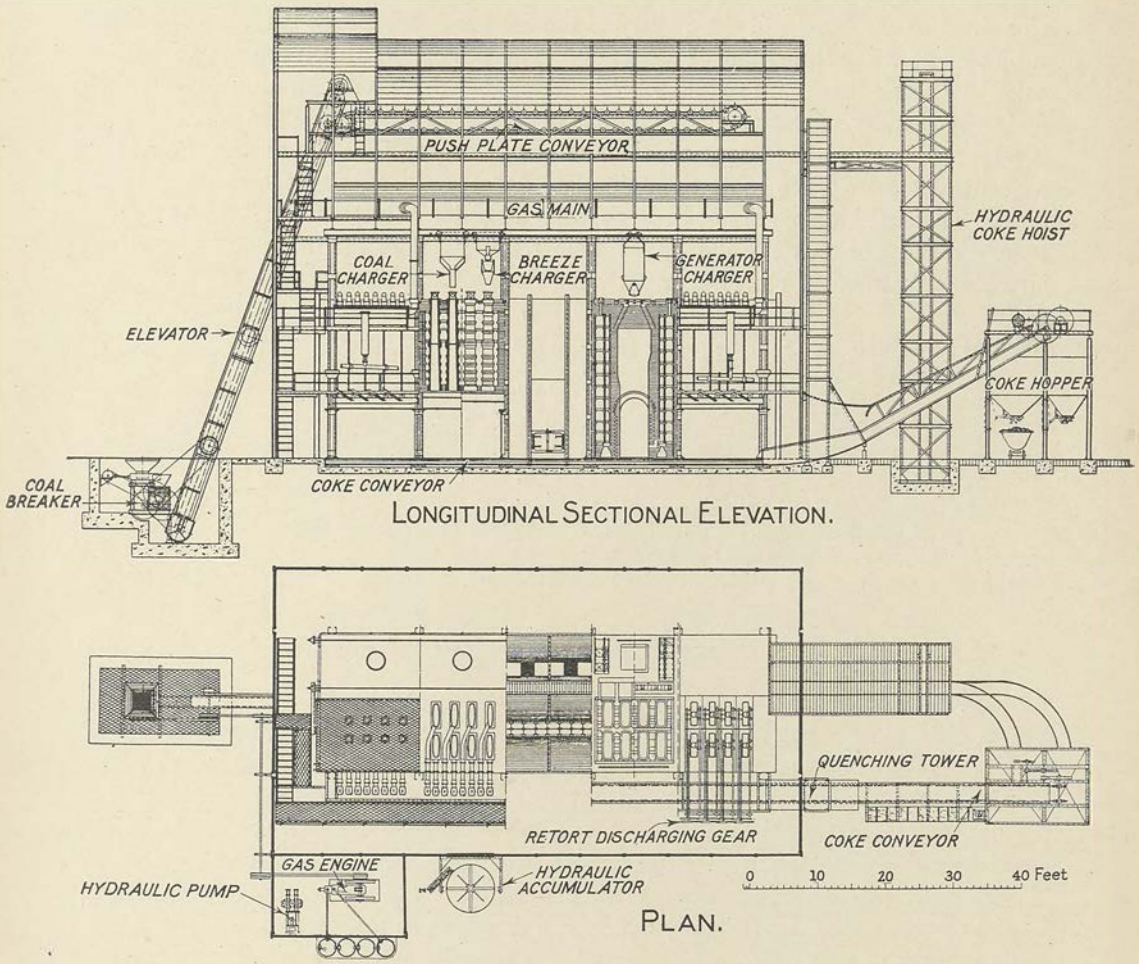


FIG. 90.—GLASGOW SYSTEM OF VERTICAL RETORTS.

are rectangular in section, are built up of tongued and grooved bricks, and vary in length according to the size of the installation. They are built with the whole of the taper at the top third of the length, the bottom two-thirds being parallel, but when English coals are used the taper extends from top to bottom. For this construction it is claimed that unless the deposit of " scurf " is allowed to get very heavy there is no trouble with the holding-up of the charge when the retorts are drawn. The

charging of the coal into the retort is effected by opening a large cock or valve having an upright plug, the lower opening of which connects with the retort and the upper opening with the coal hopper. The amount of free space in the retort (usually about 3 per cent. of the total volume) is regulated by a rod which projects into the top of the retort for the required distance. The movement of this rod indicates when the proper quantity of coal has been delivered, and the charging cock is then closed. For the benefit of the quality of the coke the coal charge may, if desired, be subjected to a small amount of steaming. The producers, which are fed with cold coke, are carried right up to the top of the setting, this giving an ample reserve of fuel, and thereby minimizing the amount of attention required. The producer gas is admitted around the upper portions of the retort, so that the maximum heat is concentrated here; the gases then circulate downwards, leaving the setting at the base. The coal hoppers are of large capacity in order to allow for sufficient storage to carry the work over Sundays without refilling. The following are the more important features in connection with the design of the system :—

Retorts: Length	23 feet.
Breadth and width. At top.	40 inches by 10 inches.
At base	48 inches by 18 inches.
Coal carbonized per retort per 24 hours	3 to 5 tons.
Average yield per retort per diem	31,500 to 55,000 cubic feet, according to class of coal.
Number of retorts in each setting	4, 6, or 10.
Grate area of producer	4 square feet per retort per bed.
Approximate time taken by coal in travelling from entrance into and exit from retort	18 hours.

HERRING'S SYSTEM

Mr. W. R. Herring's system of vertical retorts, erected some years ago at Edinburgh, differed from the majority of installations at work in this country in that the retorts were fired by means of outside producers. The system was designed to work on either the continuous or intermittent principle. When working continuously the coke extractor was devised to act as a cutter, wherewith the size of the coke could be reduced as required. The retorts were built up of tongued and grooved bricks, they were of rectangular shape, and received their coal charge through a special closure apparatus (Fig. 91) which was designed to maintain a gastight joint while permitting the passage of the coal. The coal finds its way into the retort through an upper cylindrical pouch, to which the gas outlet is also affixed. The coke extractor (Fig. 92) is varied in speed in accordance with the class of coal undergoing carbonization, and the coke on passing this is confined in special chambers, where it is slowly quenched. The outlet of the coke hopper is closed by a special gastight device similar to that through which the coal is admitted to the retort. Heating of the retorts takes place from the top downwards, so that the newly charged coal passes at once into the highest temperature zone. Pyrometric tests conducted by Mr. Herring showed that the temperature varied from 1,130° C. towards

the top to 850° C. at the base. The following are the more important particulars connected with the installation :—

Shape of retorts	Rectangular.
Total length	25 feet.
Breadth and width : Top	39 inches by 11 inches.
Base	48 inches by 20 inches.
Coal carbonized per retort per 24 hours	70 cwts. Scotch common coal.
Average yield per retort per 24 hours	38,000–39,000 cubic feet.
Number of retorts set in each bed	6.
Capital cost for complete bench, exclusive of foundations, but inclusive of coal-handling plant, coke-handling plant, etc. (house not included)	£148 per ton of coal per max. diem. (Pre-war.)
Make per square foot of ground area	370 cubic feet per diem.

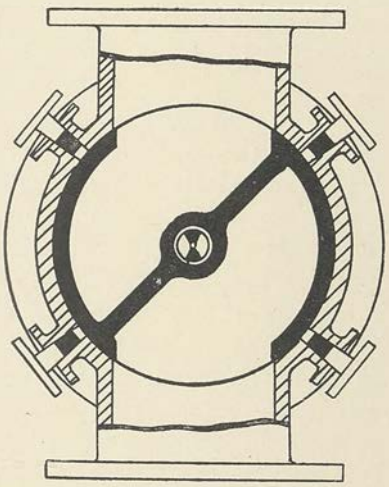


Fig. 91.—Herring's Coal-Feeding Device.

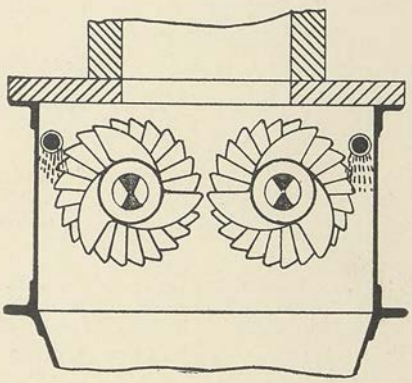


Fig. 92.—Herring's Coke Extractor.

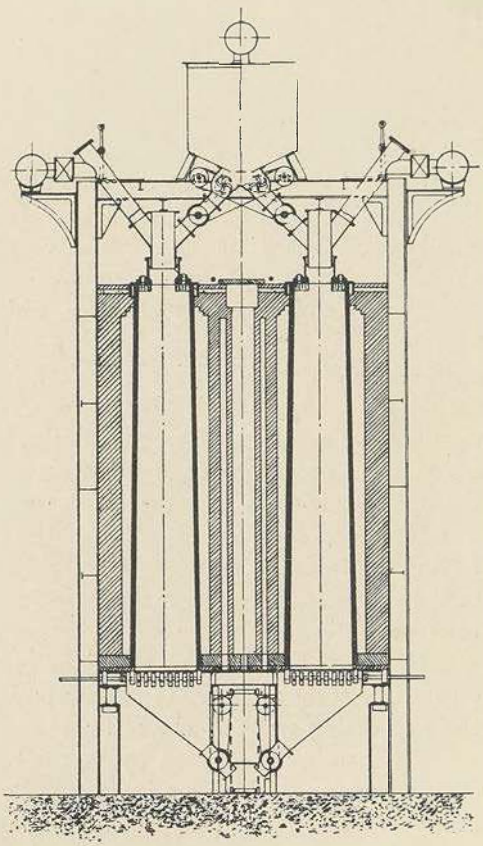


Fig. 92A.—Herring's System of Vertical Retorts.

The outside producers were, of course, fed with cold coke and were subjected to steaming. The free space in the retort was adjustable at will by regulation of the coal feed; and the gas was taken off to a dry main. The approximate time occupied by the coal in travelling from the top to the base of the retort was twenty-four hours.

THE HOLMES-WINSTANLEY SEMI-CONTINUOUS SYSTEM

This system consists of retorts rectangular in section, set vertically, and grouped in pairs. A coal hopper is provided at the upper end of each retort capable of containing twenty-four hours' supply of coal, the latter being in direct communication with the retort, no intermediate valve or feeding device being provided.

The base of the retort consists of a casting set at an angle of 45° and terminating in a mouthpiece, enabling the coke to be discharged at the side of the structure and, when required, direct into the producer. Fig. 93 shows a cross-section of the setting through the retorts, and Fig. 94 gives a general outline of an installation of ten retorts. Each retort is designed for a throughput of 3 to 3½ tons of coal per twenty-four hours.

The coal is supplied to the hoppers by means of a travelling bogie fitted with a bottom discharging door. A feeding door is provided in the top of the hopper which engages automatically with the travelling bogie on the latter being brought into position over it. Thus coal is admitted without loss of gas (*see* Fig. 95).

It will be seen that the contents of the retort are under constant pressure from the column of coal in the hopper, the "free space" being practically confined to a small pocket formed at the gas outlet. The coal in the hoppers may be replenished at convenient intervals, or the hoppers may be filled every twenty-four hours.

The coke outlet, or mouthpiece, which is attached to the casting forming the bottom of the retort, is fitted with a self-sealing lid. As no mechanical means of extracting the coke is provided, a safety door is fitted inside the discharging chamber, actuated by a hand lever. By means of this the flow from the mouthpiece may be regulated as required. The coke outlet is fixed at such a height above the retort-house floor as to discharge direct into a tipping wagon or telpher skip and to enable the operator to manipulate with ease the mouthpiece lid and safety door.

It will be seen that the producer is situated immediately under the retorts, having the feeding shoot so constructed so as to admit of its aperture being placed in the sidewalls of the retort bench and immediately under the coke outlet of one of each pair of retorts.

By means of a movable shoot the furnaces are charged direct from the retorts on one side of the setting. Clinkering is effected at the inner side in the space between the supporting walls of the setting.

The heating is effected by means of a series of three horizontal combustion chambers arranged between the side walls of the retorts. The gases rising from the producer meet the secondary air which may be admitted to any or all of the chambers and, passing upwards in a zigzag direction, are finally controlled by a damper before admission to the finishing flue connected to the chimney, there being one chimney to

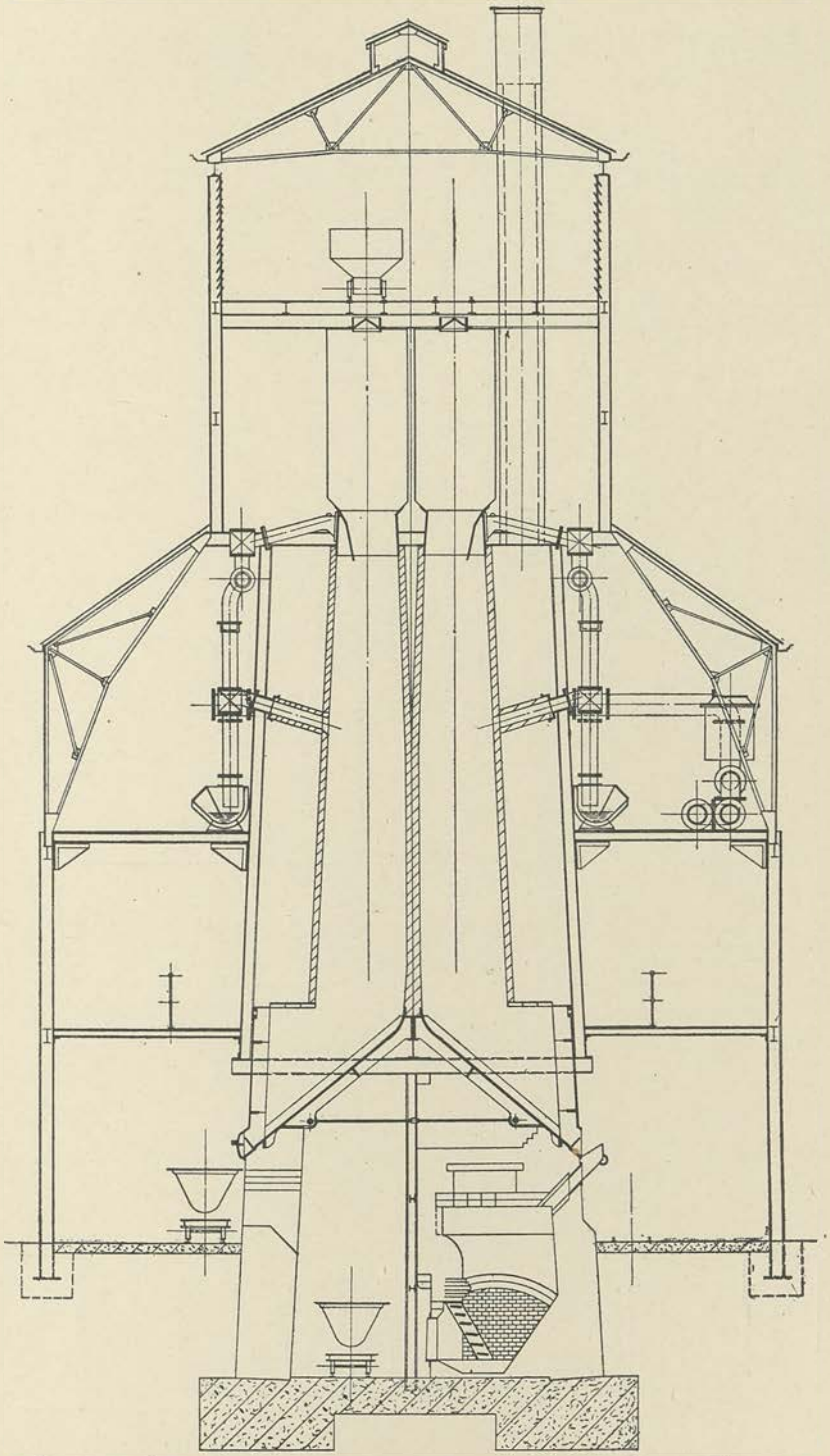


FIG. 93.—HOLMES-WINSTANLEY SYSTEM. SECTION THROUGH RETORT SETTING.

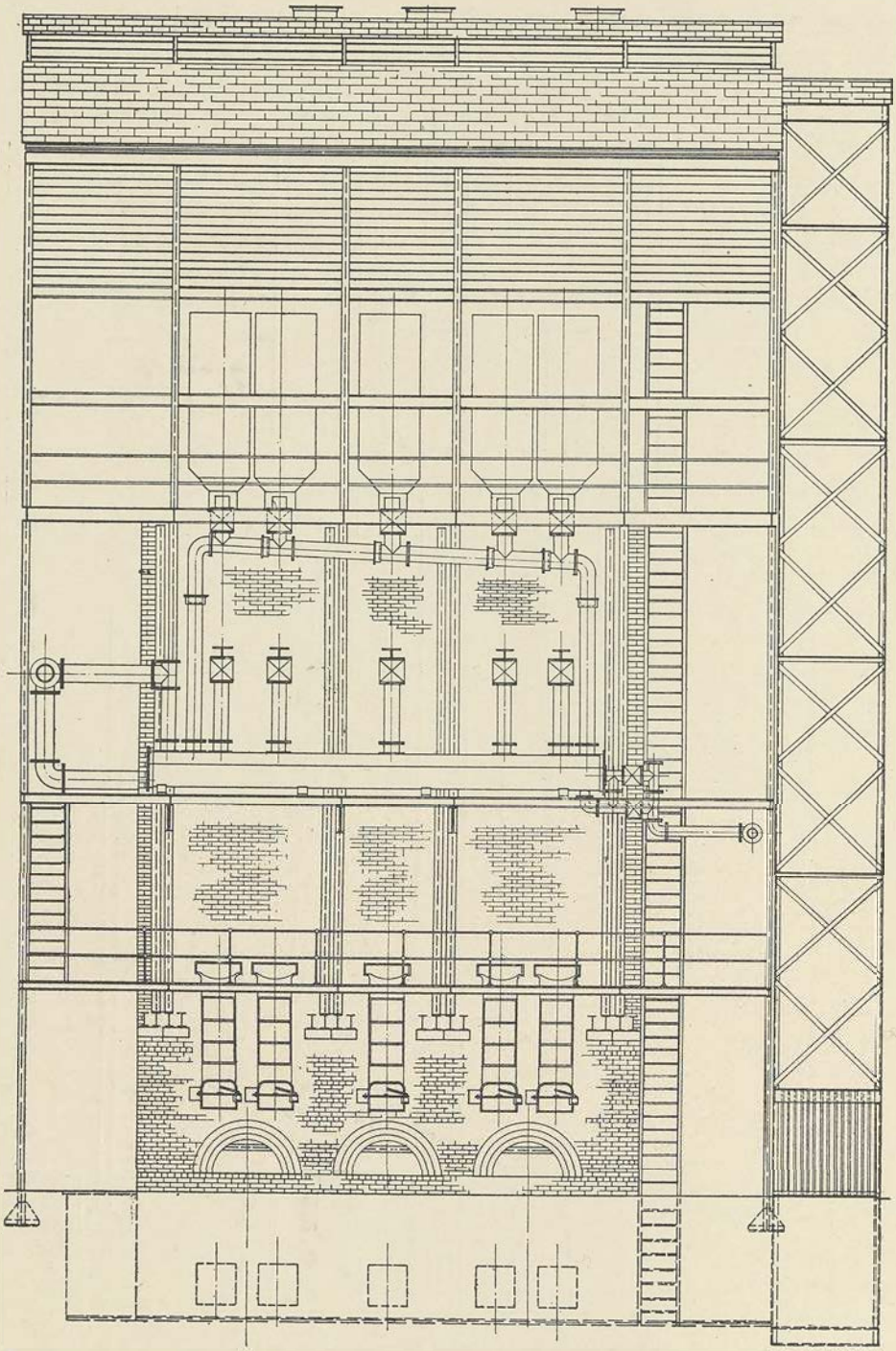


FIG. 94.—HOLMES-WINSTANLEY SYSTEM. SIDE ELEVATION OF RETORT BENCH.

each bed. The temperature of the retort is thus adjustable, enabling top or bottom heating to be obtained as desired. A stream of air is circulated round the casting at the base of the retort, thus cooling the coke and providing heated secondary air.

Tongued and grooved bricks are used for building up the retorts, which are rectangular in section, taping from 21 inches by 4 feet 9 inches at the bottom to 15 inches by 3 feet 4 inches at the top.

Coal bogies holding one ton of coal running on a narrow-gauge track are filled at the ground level direct from railway wagons, storage bunkers or coal dumps, and by means of a hoist, electrically or steam operated, they are raised to the charging floor. These bogies are fitted with a grid, on which any large lumps of coal are broken.

The main gas offtake from the retort is placed at the top, and forms part of the casting connecting the coal hopper to the retort. The gas passes under a deflector plate, provided to prevent the coal entering the gasway, and thence by means of an 8-inch pipe to the collecting main at the side of the setting. A screw-down disk valve is provided to enable the retort to be isolated when necessary.

An auxiliary or relief offtake is also provided in the end wall of the retort, which is used to relieve the pressure when starting up and if swelling coals or coal containing a high percentage of dust are used.

The collecting main is provided with a seal curtain plate and clean-

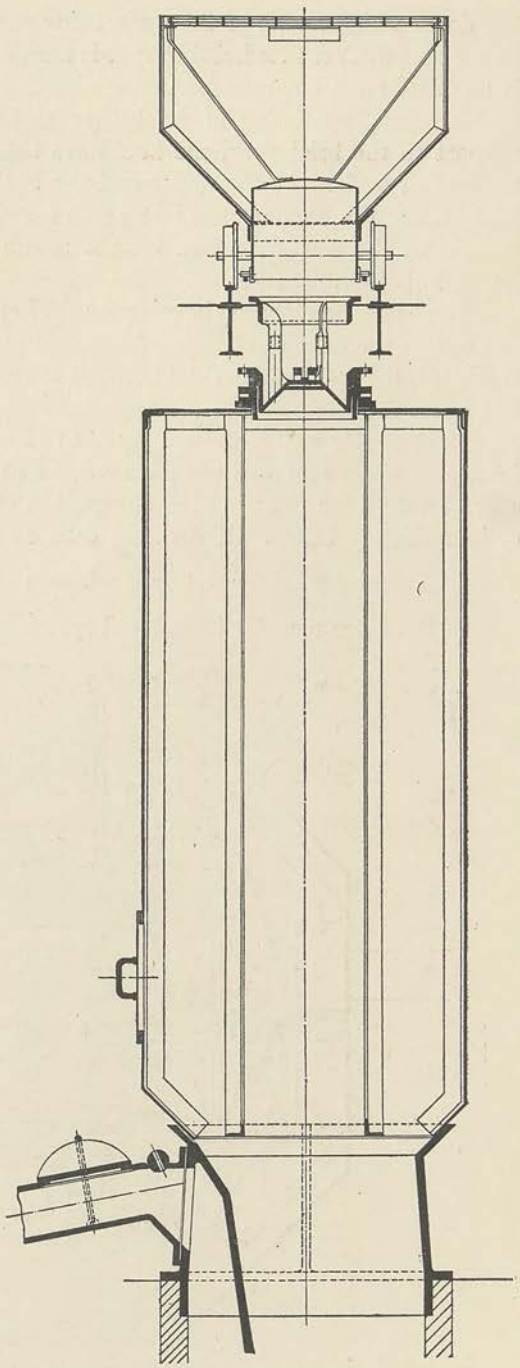


Fig. 95.—Coal-Feeding Chamber and Gas Offtake.—Holmes-Winstanley System.

ing doors which admit of the main being cleaned whilst in use. Separate tar and liquor take-offs are fitted, and the gas is passed through a retort-house governor which is mounted on a common platform with the collecting mains.

Bracings, consisting of buckstays and tie-rods, are provided to give ample support to the brickwork, the buckstays being supported on a joist built into the supporting walls. At the upper end the buckstays are attached to the framework surrounding the hoppers, the latter also forming the support for the charging floor.

As will be seen from Fig. 93, the retort house consists virtually of two steel-frame buildings.

The upper one forms a housing for the hoppers and charging floor, and the lower one covers the coke discharging floors and platforms carrying the collecting mains. If desired, the space at the sides between the floor-level and the charging floor may be left open.

In the outer wall of the setting at the base of each retort a manhole is provided for access when renewals are required. At this point are also fitted nozzles with control valves for steaming the charge, the steaming being carried on continuously or immediately before withdrawing coke as may be required.

THE CENTRAL SYSTEM

Of the more recently introduced systems of vertical retorts the Central System

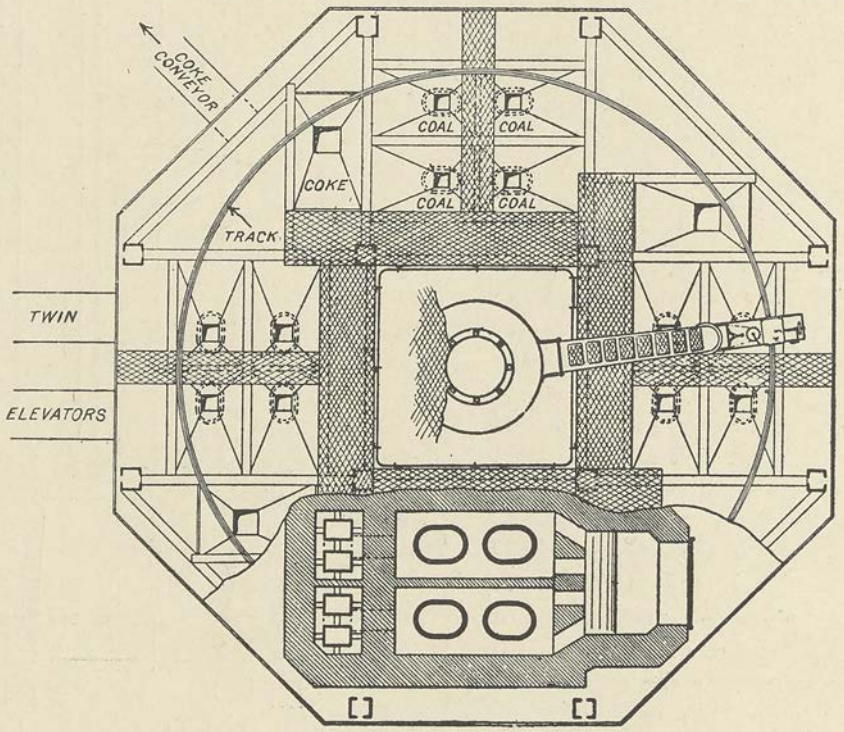


FIG. 96.—THE CENTRAL SYSTEM. PLAN.

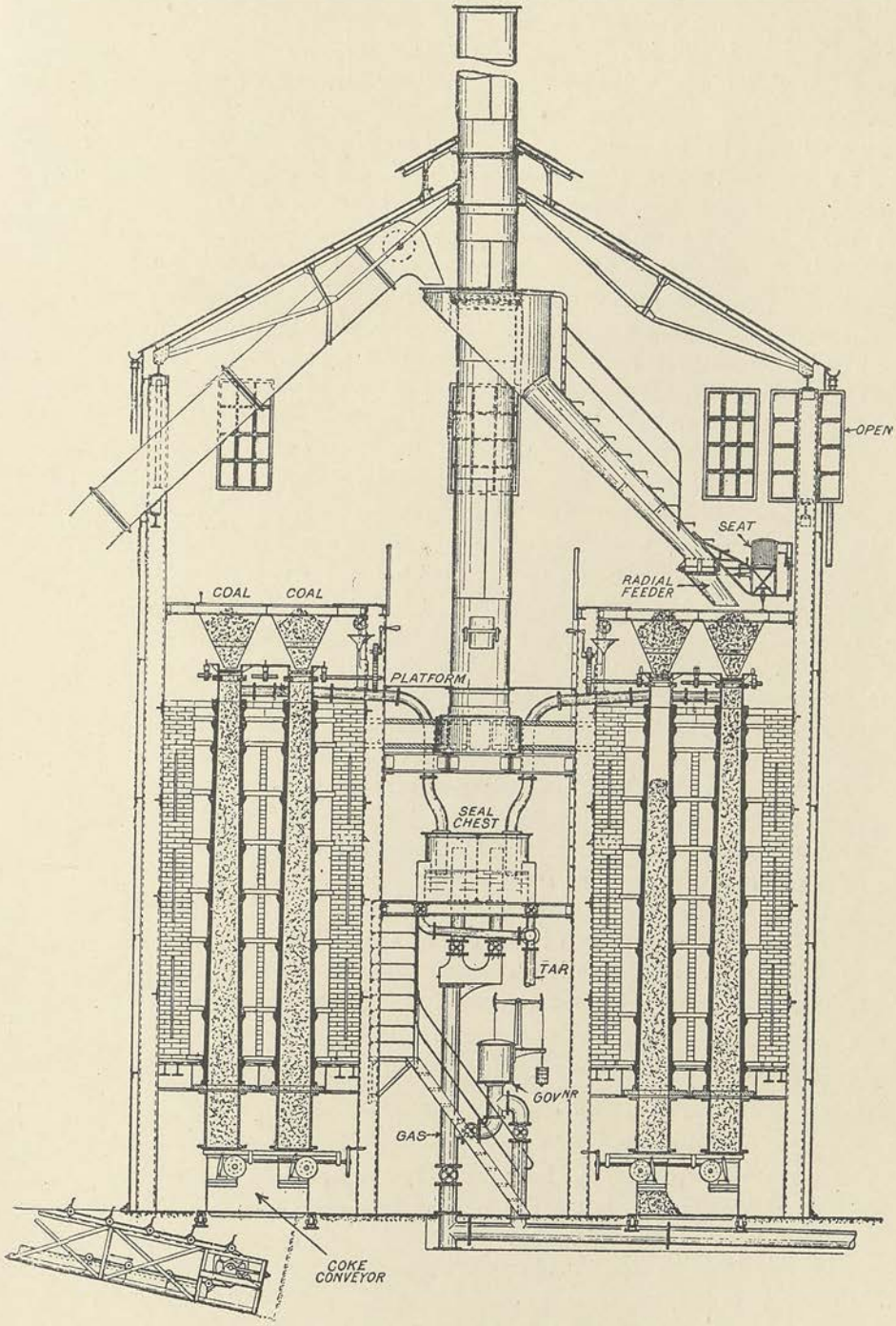


FIG. 97.—THE CENTRAL VERTICAL RETORT SYSTEM.

is certainly of interest owing to the unique arrangement of the plant. From the illustrations given it will be observed that the retorts are arranged round a circle, the centre of which is occupied by the chimney, around which travels a radial coal feeder.

Figs. 96 and 97 show a sectional elevation and plan of four beds, each of four retorts ; the sixteen retorts being capable of an output of over half a million cubic feet of gas per twenty-four hours. The system shown is of the semi-continuous type ; but it is also designed for intermittent working.

The coal for the retorts and the coke for the producers is deposited into the measuring hoppers by means of an elevator, which may be in duplicate, through the intermediary means of a radial shoot or feeder. The feeder is of taper shape, carried on ball bearings or runners around the upper part of chimney, with a shoot leading to the hoppers. At the lower end of the shoot is provided a swivel extension, which can be worked radially to enable the material to be guided into the hoppers as required. The main inclined shoot is also provided at its lower extremity with a driver's seat on a runner carriage. This runs on a circular track over the top of the hoppers ; and all the movements for travelling over the track and working the radial shoot extension are controlled from the driver's seat.

The measuring hoppers above the retorts are capable of holding sufficient coal for a single charge on the continuous system, which can be reduced or increased at will. At the bottom of the retorts a special arrangement is provided, enabling a measured quantity of coke to be discharged upon a slowly revolving table conveyor, which, by means of a deflecting plate, deposits the coke into a drag link or other conveyor, which carries it to the outside hoppers and screening plant. When the furnaces are clinkered, the clinker and ashes may be removed in a similar manner by the revolving conveyor, and deflected in another direction. No coke quenching is required, the coke being cooled sufficiently in the extension piece below the bottom retorts. This extension piece can be air-jacketed if found advisable ; the hot air being utilized for the primary or secondary-air supply.

The design illustrated is for four beds of retorts. It will, however, readily be understood that a larger number of beds can be adopted, these being placed to form a regular polygon in plan. The triangular spaces between the beds are utilized for the producers and regenerators—a separate one being provided for each.

Vertical Retort with Internal Heating Flue

Walker and Bates [1] have introduced a vertical retort (Fig. 98) in which a central heating zone is provided. It is, of course, a fact that before the coal around the axis of a retort can be carbonized the heat has to travel through a comparatively thick layer, although the difficulty is usually overcome by employing a retort of moderately small breadth (*see* Fig. 72). Attempts have been made to provide the retort with a central heating flue, so that the charge is heated from within as well as from without. Such retorts are, therefore, of annular construction ; but trouble in the way

[1] Eng. Pat. 116,458.

of the charge holding up usually results from any arrangement of the kind. Walker and Bates have contrived to overcome this disadvantage by providing an annular plunger which exerts pressure on the coal charge and thus assists the downward travel. The central flue is the main flue for the products of combustion, the hot

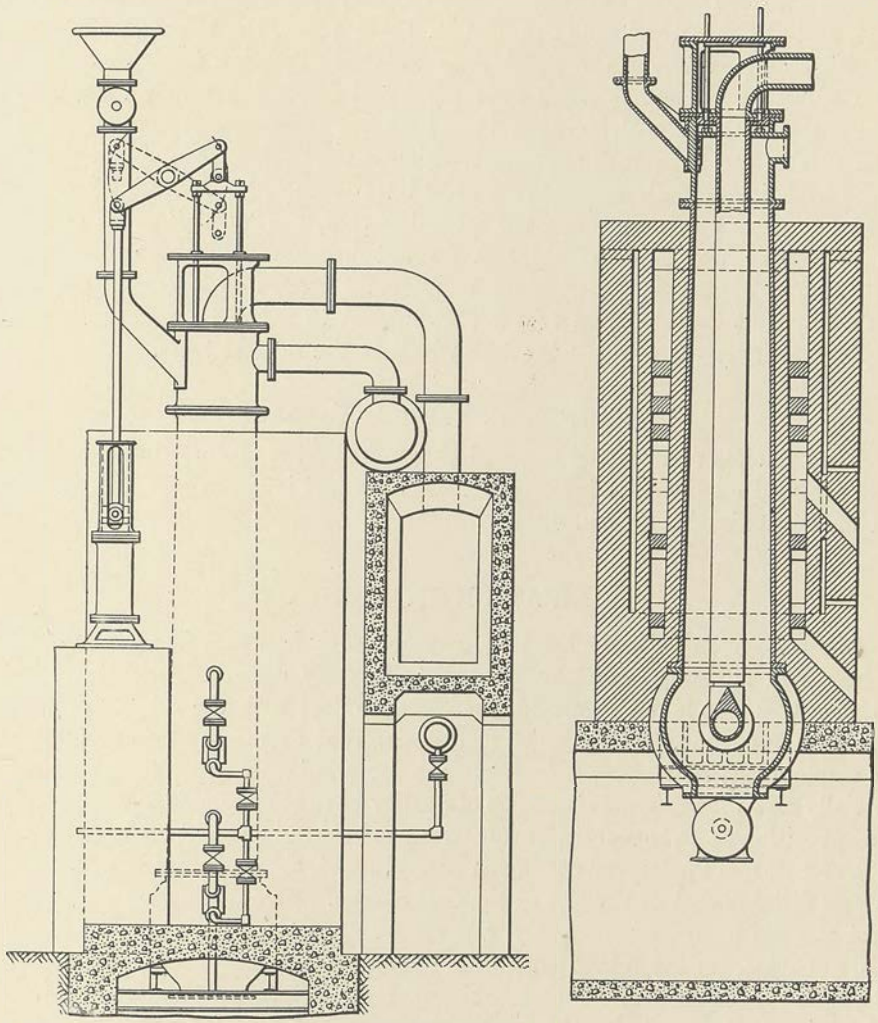


FIG. 98.—WALKER & BATES' VERTICAL RETORT.

gases passing into it after having traversed the flues around the exterior of the retort. The illustration shows the plunger operated by a hydraulic cylinder.

BOTTOM GAS OFF-TAKE

Bancroft and Hansford [1] have designed a system whereby the coal is charged

[1] Eng. Pat. 126,121.

into the lower end of a chamber, and the gas is removed at the base of the chamber, which is the coolest part. In this way it is claimed that it is possible to obtain high gas, tar, tar oils, and by-product yields, and provide a coke of good quality. Definite quantities of oxygen or air, and steam or water are introduced into the top of the retort. The oxygen, or air, and steam pass down the retort, and at the hottest zone combustion takes place, the temperature considerably increasing, whereby the well-known water-gas reaction takes place from the steam admitted. The hot gases thus generated descend through the retort and through the incoming coal, giving up their heat and assisting carbonization, and pass to an exit in the bottom of the retort, which is the coldest zone within the retort. As the heat is gradually applied (from the base of the retort upwards) and owing to the hot gases passing through the incoming coal, the "rich" gases evolved do not pass over any hot surfaces and do not become subject to deterioration. The retort is heated in a customary manner by means of producer gas and in such a way that the incoming coal is first subject to a low temperature; and the temperature increases towards the top, which is the hottest zone.

Steaming in Vertical Retorts

The principle of steaming the coal charge in vertical retorts has within recent years assumed considerable importance. The subject is fully dealt with in Chapter XII on Carbonization (*see* p. 424).

CARBONIZATION IN COKE OVENS

The coke-oven industry has now assumed such immense importance that the methods and apparatus employed would, to be fully described, demand a volume to themselves. It is not proposed, therefore, to deal with the subject in anything more than in outline. There can be no question that there is a considerable field for the employment of surplus coke-oven gas for admixture with town's gas, more especially now that thermal standards of quality have at last come to be appreciated. In composition there is practically no difference between straight coal-gas as yielded by the retort and unstripped coke-oven gas. In fact, the one point in which the two systems differ is that of the size of the coal charge. This distinction does certainly affect the gas composition slightly, but essentially the product remains the same. It is, of course, for the future generation of engineers to decide whether it is preferable, from the economic standpoint, to segregate the carbonization of coal in industrial and mining centres and pipe the gas for long distances, or whether it is more feasible to operate on the present system of local gasworks and distribute the coal over a considerable area. From the point of view of transport the super-carbonizing station has its merits; but it must not be forgotten that such a principle entails segregation of coke supplies, and coke is a fuel which is in constant demand in all parts of the country. Thus, what is gained in one direction is partly lost in another.

There are those, too, who argue that efficiency will best be obtained not only by segregation of plant, but by effecting carbonization entirely on the mass principle

by deleting the retort altogether and substituting for it the super coke oven. The prospect, perhaps, is alluring in these days of high-priced labour, but the fact must always be borne in mind that distinct grades of coke are required to conform with the different applications to which it is put. For example, while coke-oven coke might prove ideal for the industrial consumer it would scarcely be tolerated for domestic purposes.

One of the most notable instances of the application of coke-oven gas to town's purposes is to be found at Sheffield. During the past few years the Sheffield Gas Company has augmented its supplies in increasing quantities by piping gas from the Tinsley Park Colliery Company. The quantity of gas taken per annum approximates to 400 million cubic feet, and represents nearly 50 per cent. of the total gas generated in the ovens. It is interesting to note that in America the super-coking plant is to be given a trial on an immense scale. The Carnegie Steel Company are erecting a plant which provides for twenty-four batteries of sixty-four ovens each, *i.e.*, a total of 1,536 ovens. It has been estimated that the surplus gas from this installation will approach 60,000 million cubic feet per annum, or sufficient to supply a population of six millions.

A. H. Middleton [1] in contrasting the relative merits of producing town's gas in ordinary retorts, or by means of coke ovens, has put forward the following advantages which, in his opinion, the coke oven presents :—

(1) The gas made in coke ovens is equal to, if not superior to that made in any form of retort, whilst their flexibility as gasmaking apparatus is greater than that of any other type of plant.

(2) The labour is less arduous and unpleasant as most of the heavy and hot work which used to be performed manually is now done by machinery.

(3) The carbonizing costs would be reduced to about half those now prevailing in up-to-date undertakings working with the systems at present in vogue in gas-works.

(4) The cost of maintenance and renewals in the retort house would be reduced.

(5) The coke made is of greater value where there is a market for metallurgical coke either for local use or for export. The very best foundry coke can be made in a by-product oven at the same time as a high yield of good gas, provided that suitable coal is used.

The above conclusions, though largely theoretical, are certainly deserving of the consideration of gas engineers ; but much turns on the quality of the coal employed. So far as the characteristics of coke are concerned, it may be noted that the majority of coke-oven engineers ridicule the suggestion that coke ovens are incapable of yielding a domestic coke. Unfortunately, practical experience of what coke ovens can do in this respect is limited, for as yet they have existed solely for the purpose of providing for industrial requirements. General experience would indicate, however, that mass carbonization carried out on the coke-oven scale could scarcely be expected to produce a product bearing the physical characteristics of the coke such as is obtained from the modern continuous vertical retort.

[1] *Gas World*, Coking Supplement, Vol. LXXII, p. 9.

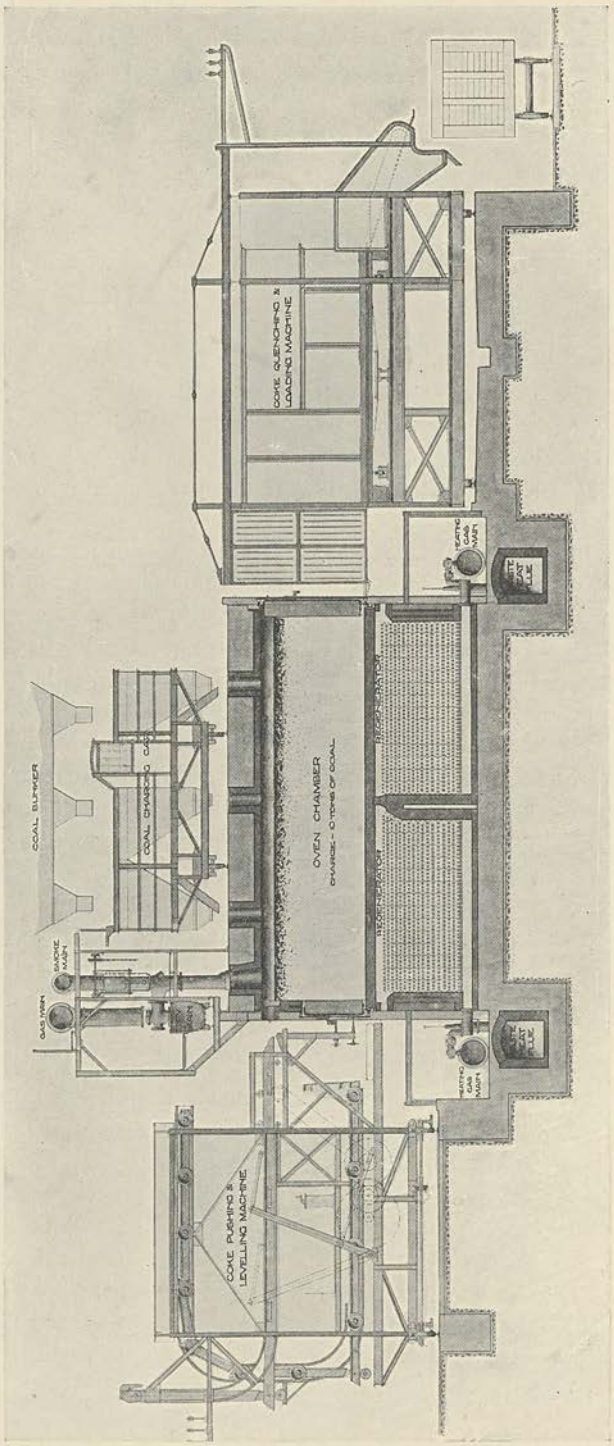


FIG. 99.—KOPPERS' CHAMBER-OVEN SYSTEM.

Birmingham Corporation Coke Ovens

The Birmingham Corporation gas undertaking was the first to experiment in this country with the installation of coke ovens on gasworks. The installation is on the Koppers principle, the ovens themselves being 35 feet long, 8 feet 10 inches high, and tapering in width from 19½ inches to 18 inches. Each is capable of taking a charge of from eight to ten tons of coal, the average period of carbonization being twenty-four hours. The arrangement of regenerators is shown in Fig. 100, each oven being supplied with its separate system, consisting of a chamber (C) divided

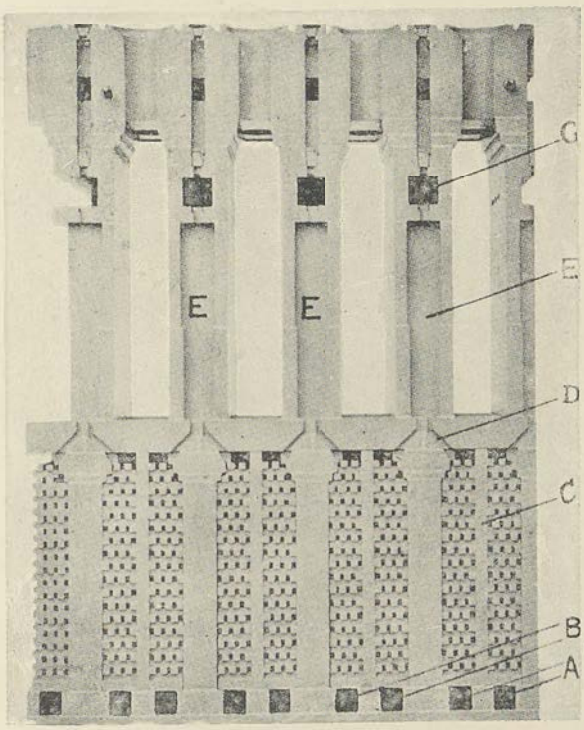


Fig. 100.—Koppers' Regenerator System.

vertically into two compartments. The secondary air flows through one of these chambers and the gas through the next, and so on ; the two meeting at the bottom of a vertical combustion chamber (E) extending to very nearly the same height as the oven. The products of combustion then pass into a common horizontal flue (G), over a parting wall, and down vertical flues similar to the combustion chambers, thence to the regenerators and main flue. By means of a special change-over gear an interchange is effected between the pre-heating chambers of producer gas and secondary air ; that is to say, the air is admitted to those chambers previously taking gas, and *vice versa*. In this way the pre-heating of both air and gas is arranged for, the change-over taking place about every half-hour. In the majority of these

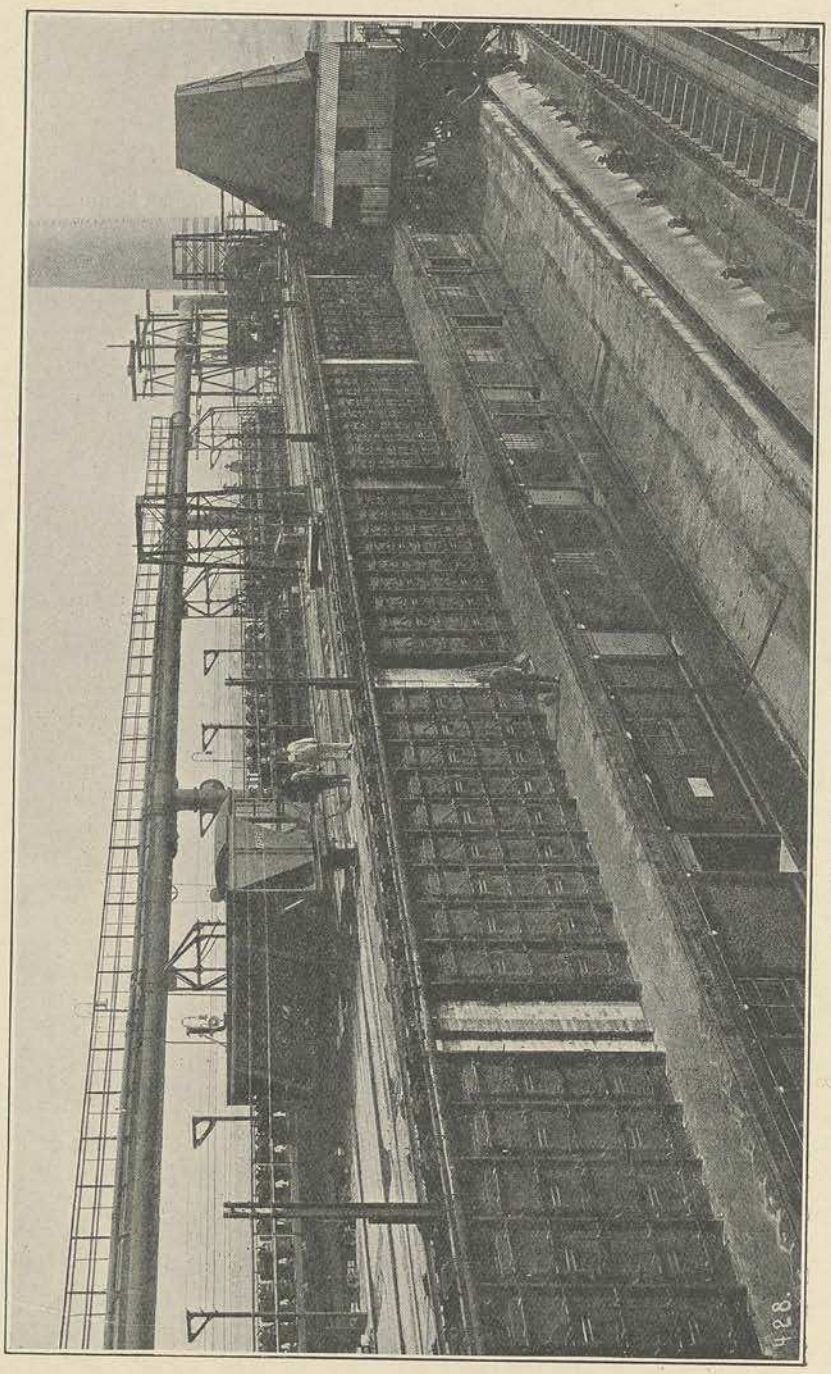


FIG. 101.—A BENCH OF KOPPERS' CHAMBER OVENS.

plants the gas from the ovens themselves is used for maintaining the working heats; but in the Birmingham installation, as before explained, the heating is carried out by means of low-grade gas from a Mond producer. The regulation of the gas to each chamber is arranged for by means of adjustable metal cocks, and the quantity passing forward is also dependent upon the pressure from the Mond producers. For the production of a dense metallurgical coke the coal is first ground in a special

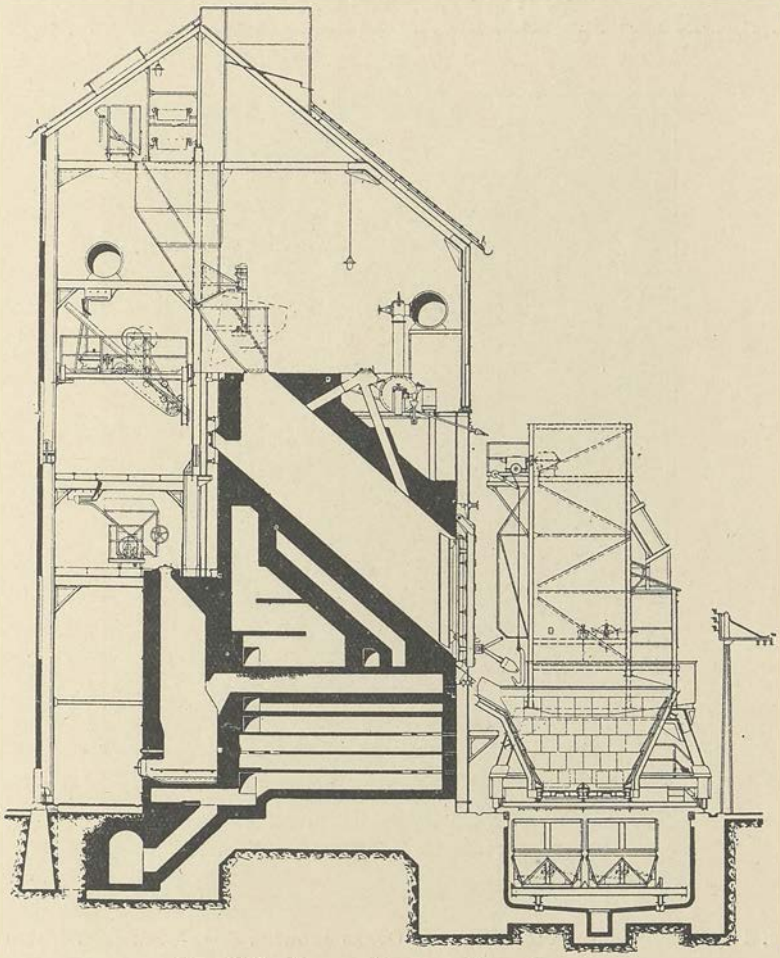


FIG. 102.—MUNICH CHAMBER-OVEN SYSTEM.

form of disintegrator to a fine dust, and is then delivered to the stamping machine, where it is compressed into a solid cake of practically the same dimensions as the oven, and introduced through the end door. For many purposes unstamped coal may be made use of, in which case charging takes place by means of a machine running along the top of the settings and discharging through hoppers into three openings in the roofs of the chambers. The coal is afterwards levelled by a machine

travelling alongside the setting, the latter machine being also provided with a ram for the purpose of discharging the coke at the end of the carbonization period. The operation of discharging usually takes about five minutes. The self-sealing oven doors are cooled by a water circulating arrangement round the frame of the door.

Munich Chambers

A system of carbonization in bulk which in a modified form has found its way into this country is the chamber-oven plant designed by Herr Ries, of the Munich

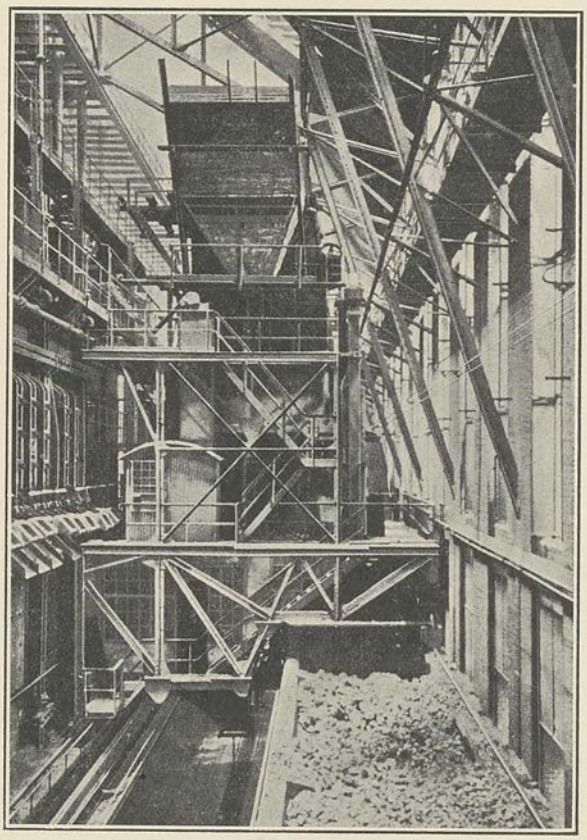


Fig. 103.—Bench of Munich Chamber Ovens showing Coke-quenching Machine.

Gasworks. The chamber consists of a tapered inclined coke oven. There are three or more of these in each setting, set at angles varying from 40°–42° with the horizontal. They are constructed from special keyed bricks and charged from an opening on the top of the beds. Coal is elevated to continuous overhead hoppers and directed into the ovens by means of a special shoot. Some idea of the rapidity of charging can be gained from the fact that in the most recent installations only twenty-five seconds is required for the complete filling of a chamber taking from seven and a half to eight

tons. Owing to the moderately sharp incline at which the chambers are set, the coke will in many cases discharge itself without any outside assistance, but in order that any tendency to hang up may be avoided, a light starting-ram is provided to set the carbonized charge in motion. The discharger consists of a "link-coiling" ram geared to an electric motor; and the pusher, by means of suitable guides, is constrained to move in a straight line, following the angle of the oven which it enters. As a general rule the complete charge is dispatched in about forty seconds. The oven doors, which are extremely massive, are raised by an electric hoisting motor, and the incandescent coke runs direct into a specially designed coke-quenching machine. The chamber door is then lowered, and automatically engages itself in a special fastener for ensuring a hermetical seal. In the Munich installation the coke-quencher consists of a mild-steel receiving hopper surmounted by a ferro-concrete shaft of square section for the purpose of conducting the steam to a considerable height before its escape into the air is permitted. After quenching has been partly carried out by means of a spray at the head of the hopper the coke goes into a swing-boat conveyor, cased with steel plates, which scrapes it through a bath of water and delivers it, fully quenched, to a de Brouwer conveyor. The coke is then carried on to a screening and sorting plant. Outside producers have in some instances been employed for heating the ovens; but, in general, each bench of three is provided with a self-contained producer, the fuel consumption averaging from 14 to 15 per cent. of the coal carbonized. A feature of the producer is the water-cooled grate. Any class of coal can be charged into the ovens so long as the lumps do not exceed 10 × 15 inches in size. Much depends, however, on the type of coke required. For a semi-coke the temperature of carbonization is kept down to 600° C.; whilst for furnace coke the coal is ground extremely fine, carbonized at 1,100° C., and steamed in the bunkers with exhaust steam so as to add the requisite 10 per cent. of moisture. At the Tegel works, Berlin, there are eighty-one of these ovens at work, carbonizing 567 tons of coal per diem. An idea of the labour entailed can be gleaned from the fact that eighteen men are required for an output of 7,000,000 cubic feet in twenty-four hours. At the Moosah Gasworks, Munich, there are nearly a hundred ovens at work.

The salient features of the Munich chamber system are given below:—

Shape of chamber	Rectangular tapered.
Slope	40–42° with horizontal.
Length	26 feet (actual length of sloping floor line).
Mean width	1 foot 9 inches.
Height	9 feet 10 inches.
Coal carbonized per chamber per 24 hours	2½ to 8 tons, as desired.
Average yield of chamber per 24 hours	100,000 cubic feet.
Number of chambers set in a bed	2, 3, 4, or 5.
Duration of charge	24 hours.
Grate area of setting	8 to 16 square feet.

Darwen Chamber Ovens

These ovens (Fig. 104) are of fairly recent introduction in this country, and in

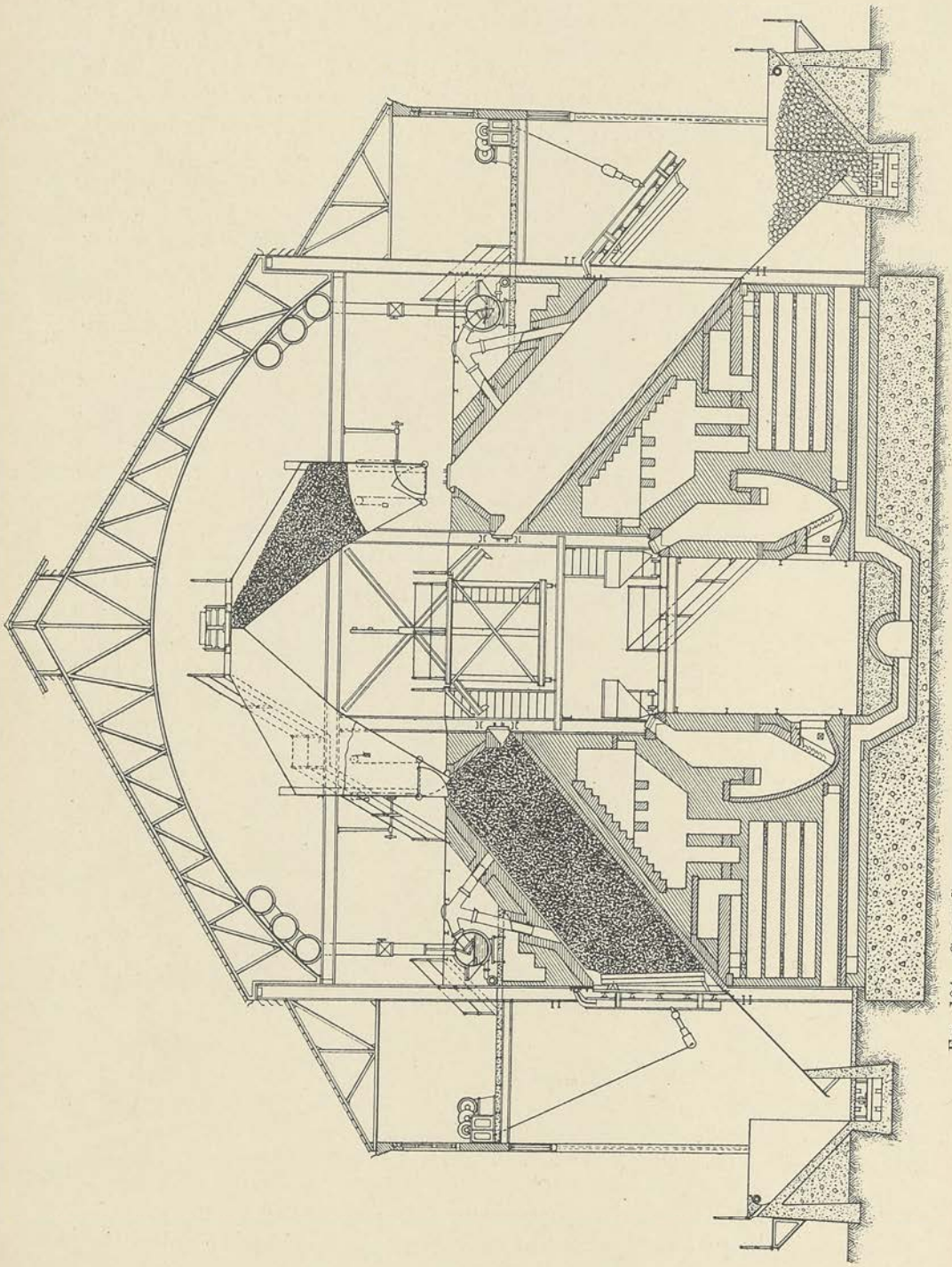


FIG. 104.—CROSS-SECTION SHOWING GENERAL ARRANGEMENT OF DARWEN CHAMBERS.

many ways bear a resemblance to the Munich chambers. Coal, crushed or screened to any size under 6 inches, is delivered to the scraper conveyor situated immediately under the centre line of the roof principals, and the conveyor automatically fills each hopper in turn to the required volume of coal. Each oven is provided with its own coal hopper, and the charge can be regulated at will; thereby fixing the volume of coal delivered to the oven.

The Darwen ovens are constructed of special fireclay material in such a manner that angular thrust is entirely avoided. They are usually 12 inches to 18 inches in width, 8 feet to 11 feet in height, and from 20 feet to 30 feet in length, inside dimensions. The angle of inclination is about 42 degrees from the horizontal, thus affording ample slope for rapid discharge. The chamber content varies from three to eight tons of coal, according to desire, and the carbonizing period is generally twelve or twenty-four hours. The heating flues are angulated in vertical series of five or more, depending upon the vertical height of the chamber, and each heating flue is controlled by its own damper, thereby securing a most effective control of the heating system.

Two 10-inch diameter offtakes are provided for each chamber when over five tons capacity, and they are so placed as to remove the gas evolved at the most advantageous position. Both the 10-inch pipes converge to a common "octopus" header, which also embraces the main delivery pipe to the hydraulic main, thereby necessitating the opening and closing of only one manlid for cleaning all three pipes with augers.

The discharge door consists of a heavy swing type door, having faced joints, sealing dry on a faced frame, and securely fastened by means of eccentric balanced hook gear, working on five pin pressed springs operating over two steel pressure joists. The leverage effects a distributed pressure of close on 20 tons, which is found to give a perfect fitting door. The door frame is fastened to the oven front by means of pressure pins transferring thrust on to the heavy buckstays, four in number, and 18 inches $\times$ 8 inches $\times$ $\frac{3}{4}$-inch. The joint is made with asbestos rope and special fireclay material, reposing in concave joints contained in the oven construction. The opening and closing of the door is merely a matter of a lifting hook, which automatically engages a cross bar, and by lifting on this bar the door releases itself; and, by lowering, automatically closes and locks itself. No hand labour is required. So soon as the door is lifted the charge of incandescent coke rushes out of the oven on to the conveyor quencher.

In case a charge of coke hangs up, by reason of non-scurfing, a small ram machine is provided to traverse between the twin chambers. This machine carries two rams working as illustrated, and which are electrically operated by means of a motor taking current from leads and a trolley arrangement concealed and fool-proof. In some cases the ram framing carries a coke or breeze hopper feed for gas producers on the stage below, thus avoiding separate feed hoppers for coke for producers.

Charging an oven occupies twenty-eight seconds for eight tons, the entire operation of discharging and charging occupying only one and a half minutes.

Norwich Chambers

At a time before the merits of the fully charged horizontal retort were realized, Mr. Thos. Glover introduced at Norwich a special form of semi-chamber horizontal retort. These chambers, which were 21 feet long, 3 feet high, and 1 foot wide, were fully charged by means of a de Brouwer projector. The average coal charge amounted to 21 cwts., and was distilled for a period of twelve hours. Compared with partly filled horizontals the results were a decided improvement, but it was eventually found that heavily charged horizontal retorts of the normal size gave equally satisfactory yields, and the system was ultimately abandoned.

CHAPTER VI

REFRACTORIES FOR GASWORKS PURPOSES

Only within comparatively recent years has the study of various types of fireclays and their relative merits for retort-bench and other purposes received its full measure of attention from the gas engineer. In years gone by there was not only a lack of knowledge as to home resources in raw materials for refractories, but an absence of co-operation between manufacturers and users. The result was that little or no attempt was made to organize the industry, and manufacturers were in many cases producing materials without precise knowledge of the duties they were intended to fulfil. It may be said that gas engineers took a lead in the direction of improvement, and in many other trades their example has now been followed, so that the aid of all the component workers has been enlisted for the purpose of carrying out a definite policy.

Recently, the science has developed to an amazing extent as a result of the co-operation between producer, consumer, and research laboratories. The mass of information now available makes it impossible to deal thoroughly with the scientific aspects of the whole subject within a single chapter. It is proposed, therefore, to consider the question in a more or less practical manner, with special reference to those features which should influence the gas engineer when the selection and purchase of refractories is in view. For more detailed information the reader cannot do better than study the proceedings of the Ceramic Society, in which all the more important developments are noted, while attention should be given to the annual reports of the Refractory Materials Committee of the Institution of Gas Engineers.

The word "refractory" in reality is merely a comparative term, and in the literal sense means "unable to melt." A wide range of substances is included under the classification of refractory materials; among these, in addition to the more common types of fireclays, being carborundum, alundum, diamantin, quartz, etc. No material is completely refractory; that is to say, all so-called refractory substances are capable of fusion, but their respective yielding points are abnormal in comparison with prevailing working temperatures.

Stated in brief, fireclays are the result of the decomposition of the feldspathic constituents of particular rocks subjected for untold years to the destructive influence of weathering. Differing degrees of the process of weathering account for modifications in the type of clay produced, and only in rare instances is the process so complete that the final stage (*i.e.*, reduction to true clay substance, kaolin or china clay) is reached. The evolution of the true clay substance from the feldspars

in the presence of carbonic acid and water may be chemically expressed as follows :—

$$Al_2O_3.K_2O.2(3SiO_2) + 2H_2O + CO_2 = 4SiO_2 + K_2CO_3 + Al_2O_3.2SiO_2.2H_2O \text{ (kaolin)}$$

These kaolin clays are highly refractory but are practically devoid of plasticity ; they exist, however, in relatively small quantities, and the larger deposits of fireclays of service to the gas engineer are the result of incomplete or intermittent weathering. It should be stated here that although, as a general rule, the refractoriness of a substance may be gauged by the proportion of silica it contains, this proposition is by no means beyond question, and definite combinations of silica and alumina are more highly infusible than when the latter gives way to silica. In fact, certain experimenters have shown that alumina is rather more refractory than silica, and that by admixing the two so as to give the composition $Al_2O_3.2SiO_2$ the most infusible product is obtained. Ordinary fireclays may in general be denoted by the formula—

$$Al_2O_3.6SiO_2$$

but in addition to the silica and alumina they contain varying quantities of impurities, such as oxides of calcium, magnesium, titanium, potassium, sodium and iron. These impurities, owing to their low fusibility, exert a most harmful influence on the ultimate refractoriness of the clay, and in most cases their total content should be limited to 4 or 5 per cent. Much depends, however, on the type of clay in question, and some highly refractory materials now used contain as much as 8 per cent. of iron alone. Chief objection to impurities lies in the fact that once they themselves have set up fusion by the formation of fusible silicates the remainder of the material may fall a victim to their influence, even though the prevailing temperature is considerably below the normal fusing point.

Many recent investigators into the refractoriness of clays have emphasized the fact that ultimate chemical analysis cannot be taken as a final indication of serviceability ; in fact, instances have been quoted where clays having chemically a model composition have been known to give defective articles. For this reason it has been suggested that the analysis should be directed towards the presence of the various mineralogical constituents on a subdivision such as the following :—

(*a*) True clay substance.
(*b*) Quartz.
(*c*) Remnants of the original mother rocks.

The last-named component, containing the original alkaline impurities, is, perhaps, of chief importance, and for effective results should be in the neighbourhood of 2½ per cent. In the less siliceous clays the desirable kaolin will average about 72 per cent., the remainder being accounted for by quartz, which has a varying influence, chiefly dependent upon the quantity of impurities present. If the impurities are on the low side the tendency of the quartz will be to aid infusibility. An im-

portant feature in connection with impurities is that their influence is usually more marked in the presence of silica than of alumina ; hence deletion, as far as possible, from the highly siliceous clays is desirable. Calcium compounds are particularly to be guarded against, owing to their tendency to act as an extremely rapid and powerful flux. The ability of the various compounds classified as impurities to act as fluxes is in direct ratio to their equivalent combining weights. The most desirable means of determining the suitability of a material for high-temperature work is undoubtedly by a combination of the ultimate, rational, and mechanical analyses.

THE WINNING AND WORKING-UP OF FIRECLAYS

By far the largest deposits of aluminous [1] fireclays in this country occur in the Stourbridge, Yorkshire, and Newcastle districts. The clay is generally found at a considerable distance below the surface, and shafts are frequently sunk to depths of 500 or 600 feet, or more. In winning the clay, care has to be taken to avoid mixing the products from distinct seams ; for although the seams occur in close proximity to one another, their chemical constituents and properties are by no means similar. Thus a highly desirable substance may be found adjacent to one containing an abnormal proportion of deleterious salts. After being brought to the surface the majority of clays undergo treatment known as " weathering," which has an important influence on their suitability for future use. This process is essential, in that the clay (stacked in shallow heaps for some considerable period) is subjected to thorough lixiviation, with consequent reduction of the harmful alkalis, which are usually decreased by at least 40 per cent. Once " weathering " is complete the requisite quantity of " green " clay is made up by thoroughly grinding together definite proportions of the varying types ; that is to say, the clay from one particular seam is frequently not used by itself, but, if of the " strong " or siliceous type, it is mixed with a certain proportion of the " mild " quality until the desired material is obtained. The material having been moulded and dried would then be ready for burning in the kilns but for the fact that the " green " clay treated in this manner is subject to considerable shrinkage, and would in addition provide a finished article of too fine a grain for high-temperature purposes. In consequence, not the least important consideration in the manufacture of fireclay articles is the preparation and admixture of " chamotte "—a substance known in manufacturing circles as " grog,"—which reduces the shrinkage to reasonable limits and opens out the texture of the material, rendering it of greater porosity. It is because contraction takes place on burning that fireclay goods are rarely absolutely consistent as regards size, for it is impossible to foretell with perfect accuracy what the shrinkage, or " sink," will amount to. For ordinary Stourbridge firebricks the contraction on burning usually amounts to 1 inch to 1½ inches per foot, the length of a 9-inch brick being 9¾ inches before burning ; whereas with gas retorts, the amount is about ¾ inch per

[1] Exception is frequently taken to the use of the term " aluminous clays." The author employs it merely as a convenient means of distinguishing between such clays as the well-known Stourbridge variety in contrast with silica or siliceous materials containing less than 72 per cent. of silica.

foot, and a finished retort measuring 24 inches by 16 inches would be moulded before burning to 25½ inches by 17 inches.

The selection and preparation of " grog " has to be carried out with great care, since a superior clay may be completely ruined by the careless introduction of an inferior " grog." " Grog " is usually prepared from a clay which originated in the same seam as the fireclay with which it is to be mixed. This clay, in the form of lumps, is burnt in a kiln out of contact with the fuel; and the firing temperature should be greater, or at least as great, as that to which the finished article will be subjected. The lumps are then ground to the desired size. The quantity of " grog " added varies, of course, with the material required and the kind of clay made use of. For firebricks and smaller articles, however, it is usually added in a proportion of from 15 to 20 per cent., while for larger articles, such as retorts, the amount is increased to from 30 to 40 per cent.

On the Continent the preparation of chamotte is an industry in itself, and lumps of selected burnt clay are dispatched long distances for the use of manufacturers. In some Continental fireclays ordinary " grog " is dispensed with, and in its stead a special china clay is employed, the shrinkage of which is so small that it may be used without previous burning.

THE CLASSIFICATION OF REFRACTORY MATERIALS

Refractory materials are, in general, classified in accordance with the percentage of silica they contain. " Aluminous " clays are those of the Stourbridge type, containing about 65 per cent. of silica, " siliceous " those containing from 80 to 92 per cent. of silica, whilst those containing upwards of 92 per cent. are known as " silica " materials. It is the two last-named materials which are assuming great importance in present-day gasworks practice. Typical highly siliceous clays are the Dinas, Ewell, Ganister, and some Scotch varieties. Analyses of the various materials as now used on gasworks are given below.

1. Aluminous Clays. (*See* also under " Scotch Clays.")

Stourbridge Type.

Silica	64·62 per cent.
Alumina	21·65 ,,
Ferric oxide	1·48 ,,
Lime	1·88 ,,
Magnesia	0·62 ,,
Moisture	9·62 ,,

2. Siliceous Clays. (Bywater.)

(*a*) *Ganister. Oughtibridge* (*Type A*).

Silica	90·2 per cent.
Alumina	7·06 ,,
Titanic oxide	0·36 ,,
Ferric oxide	1·03 ,,
Magnesia	0·05 ,,
Lime	0·40 ,,
Potash	0·56 ,,
Soda	0·30 ,,

(*b*) *Ewell Type.*

Silica	87·57 per cent.
Alumina	3·60 ,,
Ferric oxide	4·80 ,,
Lime	0·74 ,,
Magnesia	0·41 ,,
Potash	0·69 ,,
Soda	0·10 ,,
Water of combination	2·09 ,,

3. Silica Clays.

(*a*) *Dinas.*

Silica	97·6 per cent.
Alumina	0·5 ,,
Ferric oxide	1·5 ,,
Lime	0·2 ,,
Potash	0·09 ,,
Soda	0·03 ,,

(*b*) *Black Ganister.* (Bywater.)

Silica	98·5 per cent.
Alumina	0·3 ,,
Ferric oxide	1·3 ,,
Lime	0·2 ,,
Potash	Traces.
Soda	Traces.

(*c*) *Oughtibridge* (*Type B*).

Silica	94·78 per cent.
Titanic oxide	0·20 ,,
Alumina	1·65 ,,
Ferric oxide	0·62 ,,
Lime	1·51 ,,
Magnesia	0·01 ,,
Potash	0·54 ,,
Soda	0·34 ,,

This material is of very similar nature to the Oughtibridge type given under siliceous clays, with the exception that this variety is manufactured with the lime bond, whereas that previously mentioned is not.

(*d*) *Bonnybridge* (*Type A*).

Silica	95·03 per cent.
Alumina	2·73 ,,
Ferric oxide	0·45 ,,
Lime	1·80 ,,
Magnesia	0·11 ,,

4. Scotch Clays (Aluminous).

(*a*) *Glenboig.*

Silica	53·26 per cent.
Alumina	42·10 ,,
Ferric oxide	2·08 ,,
Titanic oxide	1·50 ,,
Lime	Trace.
Magnesia	Trace.
Sulphates	1·06 per cent.

The iron content is frequently higher than shown above.

(*b*) *Bonnybridge* (*Type B*).

Silica	61·10 per cent.
Alumina	33·64 ,,
Ferric oxide	2·40 ,,
Lime	0·72 ,,
Titanic oxide	0·89 ,,
Magnesia	0·80 ,,
Alkalis	0·45 ,,

The following is an analysis of typical German retort material :—

Silica	71·48 per cent.
Alumina	24·79 ,,
Oxide of iron	2·08 ,,
Lime	0·28 ,,
Magnesia	0·61 ,,
Alkalis	0·76 ,,

SILICA AS A REFRACTORY

A valuable report indicating the character and extent of refractory material deposits in the United Kingdom has been issued by the Geological Survey.

The Yorkshire deposits yield the best varieties of ganisters, and there are not only ample reserves in the areas at present worked near Sheffield, but other deposits which are still untouched. Sheffield may indeed be regarded as the centre of the silica brick industry, and Leeds, Huddersfield, and Halifax of firebricks. Ganister is also obtained from the fireclays of the millstone grit of Lanarkshire and Stirlingshire, and it seems likely that new deposits which have been opened up near the base of the limestone series along the borders of Edinburghshire may also yield refractory materials of high quality, although it is doubtful whether any of these are likely to prove equal to the best English ganister.

Other materials have been investigated, including quartzites, sands, and siliceous clays. All occur as beds in the series of sedimentary formations and exist in great quantity and variety, several of them in one part or another of the carboniferous system. With the exception of dolomite they all fall within the class of acid refractories.

At the present time in the gas industry the tendency towards the use of silica or siliceous materials is gradually asserting itself, and it is to be noted that in American gas undertakings silica is almost universally used in the construction of retort settings.

THE INVERSIONS OF SILICA

In studying the use and vagaries of silica it is important to note that it is presumed to exist in, probably, seven crystalline modifications. The most important of these are α-quartz and β-quartz, various forms of tridymite, and cristobalite. The ability of the material to transform at different temperatures into one or other of the above modifications is closely associated with its behaviour in practice. The ordinary silica material is generally understood to contain a proportion of silica amounting to over 92 per cent., although many of the well-known varieties such as Dinas and

Oughtibridge contain considerably more. The material from which silica brick is made is a rock very rich in α-quartz, and during burning in the kiln this changes to the β modification and partly to tridymite ; on cooling again, however, the β-quartz reverts to the α form. It has been shown that during the time the brick is in the furnace the quartz gradually undergoes conversion, so that the material ultimately consists of tridymite or cristobalite. The chief point of interest is, however, the actual temperatures at which the various inversions from one modification to another take place, and here, it would appear, there is room for considerable further research ; for, from the point of view of actual working conditions, the inversions are accompanied by changes in volume. For instance, it is generally understood that as tridymite has the lowest co-efficient of expansion of the various forms, it is a most desirable constituent ; but, as Scott has found, few silica bricks made in this country contain much tridymite at the end of the kiln-burning.

The total expansion of a brick when subjected to heating may be classified under three distinct headings, in each case a different factor coming into play. For instance, there is first the ordinary thermal expansion, which is unavoidable and also reversible. This involves not only the ordinary thermal expansion, but also the volume changes due to $\alpha - \beta$ transformations, which, again, are reversible. Secondly, there is the permanent expansion, that is, the volume change during the inversion of the original quartz to the ultimate tridymite. According to Scott, this, by sufficiently prolonged firing before use, could be overcome, but the question of the feasibility of the operation is mainly an economic one. The third factor is the increase of bulk, which is in excess of that calculated from the increase of the specific gravity of the finely ground material. In America, D. W. Ross has found that on heating a silica brick to 1,400° C. the volume expansion on an average amounts to 2·8 per cent. ; at the same time the diminution in specific gravity is slightly under 2 per cent., while on heating up to 1,500° the corresponding figures are 9·7 and 2·8 per cent. respectively.

Acquaintance with the technical modifications associated with silica which have been briefly discussed above will permit the ordinary practical engineer to appreciate the part they play when refractories are actually at work. Fearnsides[1] has stated that little is really known about the inwardness of the texture of the various materials utilized. Quartz is a mineral found everywhere, and represents the survival of the least soluble portions of granite. It can be obtained in millions of tons together, and in great pieces having a purity up to 98 per cent. With a rise of temperature it expands—though not so rapidly as many other minerals—until, when a temperature of 575° C. is reached, it quite suddenly changes from the α to the β variety. The chief point to consider, then, in dealing with the texture of bricks is the fact that there is present a constituent which in five minutes can come up from the β to the α variety, or *vice versa*. If, in the ordinary works, a silica brick were doing this it might look quite clean at one moment and immediately afterwards be covered with dust, owing to electrical disturbances. Every time a retort or coke-

[1] *Proc. Midland Assocn. Coke Oven Managers*, 1918.

oven wall containing silica is taken past 575° there is danger of this change, and arrangements must be made to meet the inversion.

Another important constituent of fireclays is the true clay substance or kaolin. Very little is known of this substance, beyond the fact that it always occurs in particles which are too small to be individualized, even in a high-power microscope. Kaolin, in fact, is not amenable to the theoretical study such as is applicable in the case of quartz. The reason for admixing kaolin with quartz is that the one may grip the other, but there is still a good deal of argument as to whether the material should be made up in large or small pieces. As regards the ultimate behaviour of refractories, it is generally understood that no harm will result from the presence of quartz so long as the impure remnants of the original mother rocks are eliminated as completely as possible. An important feature in connection with impurities (*i.e.*, lime, magnesia, iron, etc.) is that their influence is more marked in the presence of silica than of alumina ; hence deletion, as far as possible, from the highly siliceous clays is imperative. As Fearnsides says, experimental evidence shows that quartz can live quite happily with kaolin at temperatures far higher than those employed in the distillation of coal, for up to 1,500° probably no reaction takes place. Undoubtedly a pure material forms the ideal, but the employment of such a material is not in all probability commercially practicable.

It is generally known that there is some substance in fireclays which when associated with two solid materials of high melting point causes its neighbours to react and form a low melting point mixture. This reaction appears to begin just above 900° C. For instance, if alkaline impurities are present the tridymite expansion may be expected to take place quickly and on each occasion when variation in temperature occurs. Evidence points to the fact that iron compounds may possess a similar influence. Iron is present in either the ferrous or the ferric form. The latter form is inert so far as it is possible to judge, but it has been stated that in the presence of the gases the ferric salt cannot remain owing to reducing reactions which will be set up. Thus fireclay users must chiefly be concerned with the ferrous salt which, in conjunction with the alkaline impurities, has the effect of causing the silica to "grow." In this direction texture is of importance, for if large pieces of silica are employed the portions of each piece which are in contact with the fireclay (and it is the fireclay and not the silica which contains the impurities) form a small portion of the whole. Accordingly, large pieces are much more likely to survive protracted contact with the impurities present than if a very fine silica is utilized. On the other hand, certain difficulties are found in practice when a coarse material is employed. Very much must depend upon the proportion of impurities present in the clay, and if a practically pure kaolin admixed with a high-class silica is obtainable, better results will follow the use of a fine grain, whereas it is advisable to turn to a coarse texture when the clay is such as to be chemically active with respect to silica. Fearnsides suggests that the period during which the shattering of the material takes place, and when pieces an inch or so in thickness come away, is when the quartz is passing from the α to the β stage at 575° C. In this connection it must be remembered that

tridymite does not change at this temperature, so that so far as immunity from trouble is concerned, the condition to be aimed at is that of obtaining a brick in which the fireclay, by reacting, has converted all the silica present in the mass into tridymite.

Experience with silica retorts tends to show that when new material is employed some appreciable outward diffusion of gas takes place, although the formation of "scurf," a fairly speedy operation, will soon act as a check. When demolishing old retort benches, it is customary to find a black vein running completely round the section of the retort. This vein (Fig. 105), starting about a quarter of an inch from the inner surface of the material, will usually run to about an inch in width, and on analysis the portion of the refractory at this point shows a free carbon content of 10 per cent.



Fig. 105.—Section of Used Retort showing Carbon Vein.

THE TEXTURE OF FIREBRICKS

It has been pointed out previously that the service which a refractory article is likely to give cannot finally be judged from the composition and refractoriness of the material from which it has been made. Texture is a property of equivalent importance, and largely determines the suitability of the article for any special purpose. In general, it may be said that vitrification of a clay is favoured the closer the particles are to one another. Accordingly, the coarser the grain, the more highly refractory will the article be. A limit as to coarseness is, however, imposed by considerations of physical strength. Mellor[1] has stated that when clays are heated on a gradually rising temperature the surfaces of the more fusible granules melt first. Hence again, quite independently of the action of the fluxes, a fine-grained clay with its augmented internal surface will vitrify faster and at a lower temperature than a coarser grained clay of the same composition. There is therefore a cumulative action in favour of coarse-grainedness for highly refractory bricks.

On the other hand, Mellor states that a fine-grained texture gives the property of resisting abrasion and attack from fluxes, slags, flue dust, and salt vapours. Thus, bricks which have to resist the corrosive action of slag should have a close texture and be of uniform size, with joints as small as is practicable. The jointing clay should also be chosen so that it quickly vitrifies without cracking, and welds the

[1] *Proc. Faraday Society*, November, 1916.

bricks together when the plant is fired for the first time. So far as texture is concerned, the main point to emphasize is that, whether the grain be open or close, uniformity is essential.

THE TESTING OF REFRACTORY MATERIALS

In addition to the ordinary laboratory tests for the determination of ultimate analysis, refractory materials should be subjected to certain practical tests in order to determine their suitability for retort-bench purposes. The tests usually applied, and specified by the Refractory Materials Committee of the Institution of Gas Engineers, are as follows :—

(*a*) Refractoriness.
(*b*) Apparent porosity.
(*c*) Contraction or expansion.
(*d*) Crushing strength.
(*e*) Refractoriness under load.

It must be mentioned at the outset that refractoriness is not merely dependent upon the maximum temperature which the material is capable of withstanding before fusion takes place. The rate of change of temperature has also some considerable influence, and for this reason it is specified that for tests for refractoriness the temperature of the experimental furnace shall be increased at the rate of 50° C. (122° F.) during five minutes. There are various furnaces suitable for the purpose, but the electrical apparatus of Hirsch, or the Méker air-gas type, are to be preferred.

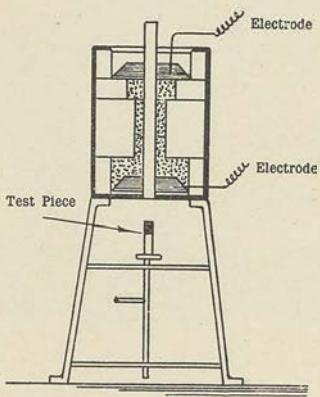


FIG. 106.—HIRSCH'S ELECTRIC FURNACE.

The Hirsch furnace (Fig. 106) is of the resistance type, the resistance material used being chiefly carbon. The current is led into the furnace by means of the two electrodes shown, these being of iron and embedded in a large area of carbon, which tends to keep them cool. The volume of carbon in the centre of the furnace is made smaller, so that the heat is concentrated here. To attain the maximum temperature the furnace requires a current of 130 amperes at 70 to 80 volts. The clay to be tested is mounted on the top of the cylindrical support and introduced into the centre tube of the furnace, this tube having an internal diameter of $2\frac{1}{2}$ inches. The appearance of the sample undergoing test can be watched by looking down the centre tube from the top. A weak current of air constantly passes through the centre tube, the object of this being to overcome the reducing atmosphere always associated with carbon resistance furnaces.

The Méker furnace (Fig. 107) is capable of giving a temperature up to 1,850° C.

(3,360° F.). The main feature of the apparatus is the special type of Méker burner, requiring compressed air under a pressure of from 10 to 30 lb. per square inch ; whilst, for effective results, the gas pressure should not be below $1\frac{3}{8}$ inches.

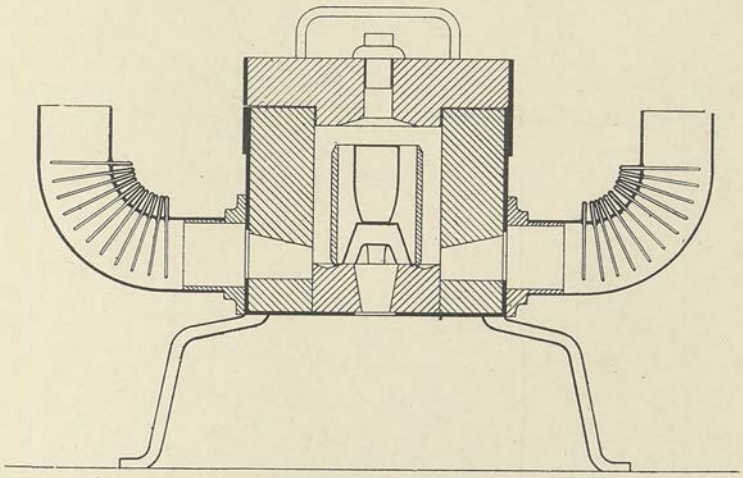


Fig. 107.—The Méker Air-Gas Furnace.

A crucible of special refractory material is mounted on a support, and the flame from the burner, passing through the base of the support, surrounds the crucible, and is then turned downwards to its outlets.

Seger cones (Fig. 108), which partially fuse, or " squat," at predetermined temperatures, are found to provide the most convenient means of recording the approximate yielding points of the samples under test. The Refractory Materials Committee state that two or more tests are generally required when an unknown material is being dealt with. " A preliminary trial is first made with a piece of the material chipped into the approximate form of a cone. This should be cemented on to the refractory slab of the test furnace with a mixture of alumina and best china clay, together with Seger cones 28, 30 and 32 (small size). Best china clay fuses between cones 35 and 36 ; and all British fireclays fall below this point. If cones 28 and 30 fall, the furnace should be cooled, and the material under investigation examined. If it exhibits no sign of fusion, the trial should be repeated with cones 30, 31 and 32. By this method of approximation it is possible to decide whether the piece vitrified between cones 30 and 31 or between cones 31 and 32. The cones should, in all cases, be placed relative to the sample so that both are subjected to the same temperature. It should be

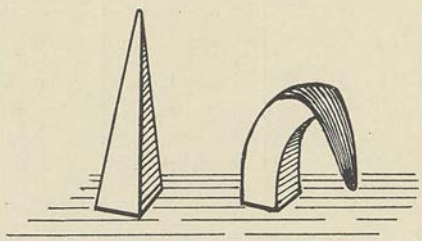


Fig. 108.—Seger Cones.

noted that clays and related materials have no sharply defined melting points, and the definition of refractoriness adopted refers to the temperature at which the angular edges of the material begin to lose their angularity when heated under the conditions stated."

SOFTENING POINTS OF SEGER CONES

Cone No.	Cent.	Fahr.	Cone No.	Cent.	Fahr.
022	600	1112	9	1280	2336
021	650	1202	10	1300	2372
020	670	1238	11	1320	2408
019	690	1274	12	1350	2462
018	710	1310	13	1380	2516
017	730	1346	14	1410	2570
016	750	1382	15	1435	2615
015a	790	1454	16	1460	2660
014a	815	1499	17	1480	2696
013a	835	1535	18	1500	2732
012a	855	1571	19	1520	2768
011a	880	1616	20	1530	2786
010a	900	1652	26	1580	2876
09a	920	1688	27	1610	2930
08a	940	1724	28	1630	2966
07a	960	1760	29	1650	3002
06a	980	1796	30	1670	3038
05a	1000	1832	31	1690	3074
04a	1020	1868	32	1710	3110
03a	1040	1904	33	1730	3146
02a	1060	1940	34	1750	3182
01a	1080	1976	35	1770	3218
1a	1100	2012	36	1790	3254
2a	1120	2048	37	1825	3317
3a	1140	2084	38	1850	3362
4a	1160	2120	39	1880	3416
5a	1180	2156	40	1920	3488
6a	1200	2192	41	1960	3560
7	1230	2246	42	2000	3632
8	1250	2282	—	—	—

TESTING UNDER STRESS

Although the conditions of testing in furnaces such as described above coincide with those prevailing in a retort setting in respect of temperature, it must not be forgotten that the fireclay material forms part of a structure, and is, in consequence, subjected to varying degrees of stress (chiefly compressive) according to its function in the setting. In this respect a series of tests have been carried out by J. W. Mellor [1] to determine the effect of stress upon ultimate refractoriness.

[1] Report of Refractory Materials Committee, 1918.

Two important empirical facts have been established, namely :—

(*a*) The refractoriness of a fireclay under load diminishes as the load increases in accordance with a definite law.

(*b*) The sensitiveness of a fireclay to load is greater the greater the alumina content of the clay, and the sensitiveness is less the greater the silica content of the clay.

In carrying out his tests Mellor employed a furnace as illustrated in Fig. 109, loading of the test piece being arranged for by means of a lever system.

The refractoriness under load is determined in the following manner: The test piece is cut from the brick and ground to a rectangular block $3\frac{1}{2}$ inches long and 2 inches cross-section. This presents a surface of 4 square inches to the load. The final measurements of the piece are taken with micrometer slide gauge. Much depends upon the careful preparation of this block. If the ends are not parallel, the weight will not act in a true vertical direction, but tend to thrust sideways.

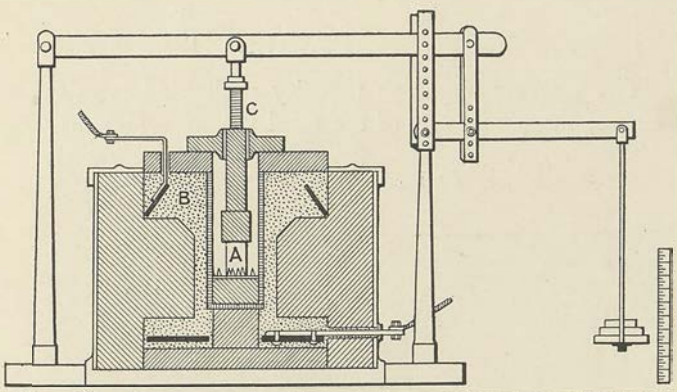


Fig. 109.—Apparatus for Testing Refractories under Load.

A solid refractory support is bedded at the bottom of the inner tube of the furnace. A thin layer of powdered carborundum is spread over the top of this basal support to prevent the sticking of the test piece. Small Seger cones, arranged in series of four, are fixed on the basal support round the test piece. A cube $2\frac{1}{4}$ inches square, made of similar material to the bottom support, is placed on top of the test piece. This is followed by a cylinder, say, magnesite—and finally a carbon rod mounted on an iron ring. The rate of heating is controlled by means of variable transformers and resistances. The current used varies from 8 to 10 k.w. As the temperature of the furnace rises, the thermal expansion of the brick causes the lever arm at first to rise, and later on the lever begins to fall. The rate at which the deformation proceeds depends on the character of the test piece. When the squatting has reached the limit decided upon, the current is switched off, the weights, lever, and supports removed, and the cones observed. The test piece is left in the furnace until its temperature has dropped.

As a result of a number of tests, Mellor concludes that in general silica bricks stand up under load very much better than firebricks made from fireclays ; but the finer grained silica bricks do not stand under load so well as the coarser grained silica bricks. Indeed, very fine grained silica bricks show as large a difference between the normal refractoriness and the refractoriness under load as bricks made from fireclays.

Firebricks under load seem to break down in one of two ways. In one type of collapse (fusion collapse) the firebricks gradually give way as the temperature rises, until finally the piece collapses. This behaviour is typical of aluminous and zirconia bricks. In the second type of collapse (mechanical collapse) the firebrick may show symptoms of a gradual deformation; but the characteristic feature is a more or less abrupt collapse. This is typical of silica and siliceous bricks, and, to a less degree, of magnesite and chromite bricks, although a sufficient number of varieties of the latter have not been determined to give the same confidence in making general statements.

The effects produced are exceedingly complex; and they are affected by many factors other than composition, texture being one of the most important. In all cases the experiments were conducted under a load of 50 lb. per square inch.

APPARENT POROSITY

The test for apparent porosity really indicates the density of the material and gives the percentage of the total volume which is occupied by air spaces.

$$\text{Percentage porosity} = \frac{\text{Volume of air spaces}}{\text{Total volume of test piece}} \times 100.$$

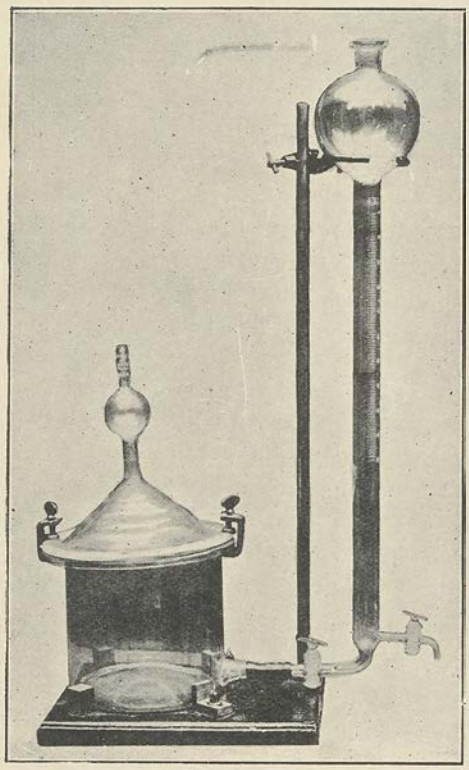


Fig. 110.—Mellor's Porosometer.

Porosity is one of the most important properties of present-day fireclay articles and is determined by means of some forms of "voluminometer" or "porosometer," as shown in Fig. 110. The piece to be tested should be of the size of half a brick, having a volume of about 700 c.c. The principle of the test is based on the absorption by the brick of a suitable liquid (usually paraffin) until the air spaces and cavities are completely filled. The volume of liquid required for this purpose can be measured in the burette, this being identical with the volume of the air spaces, hence the porosity may be determined. The test piece, dried at 100° C., is placed in the glass jar; the paraffin from the latter having been previously sucked up into the burette by means of a water pump. Another water pump is then connected to the lid of the jar containing the test piece, and as much air as possible is sucked out. With the pump still working, the paraffin is then allowed to enter the jar slowly until the brick is

completely covered, the pump sucking away the air from the interstices of the brick, paraffin taking its place. By levelling and reading the burette, the volume of liquid displaced by the solid portion of the test piece will be given. The volume of the soaked brick is then found by displacement in a similar manner, thus giving the total volume of the test piece, and the percentage porosity calculated as above.

AFTER CONTRACTION AND EXPANSION

When fireclay articles are burned in the kilns a certain amount of contraction occurs ; but usually such contraction is not wholly completed during this operation, with the result that further contraction takes place when the articles are in use. The secondary change in volume is generally known as " after-contraction " or " after-expansion," and it will be appreciated that, if the stability of a construction such as a retort setting is to be ensured, effects of the kinds must be eliminated as far as possible. Mellor [1] states that when firebricks are kilned the fluxes melt and dissolve the less fusible materials, binding the whole more or less together.

It is well known that ferrous iron has a far greater fluxing action than ferric iron, so that the contraction of a brick fired under reducing conditions will probably be greater than when fired under oxidizing conditions, providing no bloating occurs. Nearly all firebricks are burned under oxidizing conditions. It therefore appeared of interest to find the difference in the results obtained in the specification contraction test when conducted under oxidizing and under reducing conditions. Some measurements are given in the following table [2] :—

Type of Brick.	Percentage after Expansion or Contraction (Means of Duplicates).			
	Oxidizing Atmosphere.		Reducing Atmosphere.	
Silica brick, unusually fine grained	0·44	C	0·77	C
Silica brick, high in " iron "	0·58	E	0·48	E
Firebrick	0·21	E	Nil	—
Firebrick	Nil	—	0·33	C
Firebrick	1·12	C	1·27	C
Silica brick	0·20	E	0·13	E
Silica brick	0·13	E	0·12	E

C signifies contraction ; E, expansion.

These results show a general tendency for silica bricks to give a less expansion in a reducing atmosphere than in an oxidizing atmosphere ; and for " aluminous " firebricks to give a greater contraction in a reducing than in an oxidizing atmosphere.

[1] *Proc. Faraday Society*, November, 1916.
[2] Inst. Gas Eng. Refractory Materials Committee, 1917.

Whereas with "aluminous" firebricks there is usually an after-contraction the reverse is the case with silica bricks.

The Refractory Materials Committee specify the following limits for various materials so far as contraction or expansion is concerned :—

Retort Material.—A test piece heated to a temperature of cone 14 (1,410° C.) for two hours shall not show, when cold, more than $1\frac{1}{4}$ per cent. contraction or expansion. The test piece is to be $4\frac{1}{2}$ inches long by $4\frac{1}{2}$ inches wide, with the ends ground flat. Readings as to length are to be taken by means of Vernier callipers reading to 0·1 mm.

Firebricks, Blocks and Tiles.—A test piece when heated under the above conditions shall not show more than 1 per cent. or $1\frac{1}{4}$ per cent. contraction or expansion, according to the grade of material.

Silica Articles.—A test-piece when heated for two hours to a temperature of cone 12 (1,350° C.) shall not show, when cold, more than 0·75 per cent. linear contraction or expansion.

CRUSHING STRENGTH

The crushing strength of a firebrick gives an indication of the internal strength of the brick, and the manner in which the binding materials are performing their duty.

The compressive strength of fireclay articles may be determined by means of one of the forms of apparatus made for the testing of materials. With regard to ordinary Stourbridge articles, these should be capable of withstanding a crushing stress of not less than 1,800 lb. per square inch.

Emery and Mellor [1] have carried out a series of tests with materials of varying composition and porosity. The results show that the crushing strength is reduced by increasing the grain-size of the grog when the proportion of grog is constant ; and also by increasing the proportion of grog when the grain-size is constant. The investigators state that there are not yet sufficient data available to enable any conclusion to be drawn respecting a possible relation between the so-called fusion temperature of the clay and the crushing strength of the cold bricks. There is probably a close connection between the temperature coefficient of the vitrification and the crushing strength ; and it is further probable that the crushing strength reaches a maximum during the firing of the brick, and that the strength gradually deteriorates when the bricks are in use. It does not follow that the crushing strength of the newly fired brick is at its maximum.

THE RELATION OF REFRACTORY MATERIALS TO THE VARIOUS PORTIONS OF A RETORT SETTING

In dealing with fireclay articles and their relation to the various portions of a retort bench, it is proposed to consider the matter from the purely practical standpoint of the gas engineer, and to avoid, so far as possible, the inclusion of the more

[1] Refractory Materials Committee (Inst. Gas Eng.), 1919.

abstruse technical details, which are of chief concern to the scientist and investigator. Errors of judgment in the selection of fireclays are only too common, even in the present age; and, undoubtedly, considerable trouble and expense could be avoided if, in the first place, the purchaser studied his requirements on methodical lines. To this end, it is suggested that the conditions which any particular material may be called upon to withstand should be subjected to a preliminary investigation on lines such as the following:—

1. Is the temperature high or moderate? "Moderate" may be considered up to 1,000° C. "High," up to 1,500° C. As a matter of fact, the latter temperature should seldom be necessary in the modern combustion chamber; the figure being usually in the neighbourhood of 1,400° C.

2. Will there be fluctuations of temperature? This is one of the most trying conditions which the material can be called upon to withstand. If the setting is worked correctly there should be nothing in the way of violent fluctuations, except, perhaps, in the retorts. It must be remembered that there may be so great a fall in temperature as 500° C. when a retort is freshly charged.

3. Will the material come into direct contact with the flame, or will there be "cutting heat"? By a "cutting heat" is usually understood a fierce, localized flame, the effect of which is exaggerated by the presence of flue dust in the gases. This dust may contain upwards of 50 per cent. of injurious iron compounds.

4. Is mechanical strength required? Various portions of the retort bench take their place in ensuring the stability of the structure; hence, in addition to withstanding high temperatures, they are called upon to withstand working stresses.

5. Is heat to be conducted or retained? This is a point which arises chiefly when deciding upon material for regenerators and the external walls of settings. In order to prove a good conductor of heat, the material should be dense, and manufactured with as close a grain as possible.

6. Is the material likely to be affected by external fluxes? The small percentage of low-fusing constituents present in the fireclay is more or less harmless when left to itself; but if incipient "slagging" is set up by other fusible substances introduced from outside, there is no telling where the trouble may end. Iron dust in the producer gases and clinker adhering to the sides of the furnace walls are the chief offenders in this direction. This effect is considered more fully on page 215.

7. Will the material be subjected to an oxidizing or to a reducing atmosphere? A reducing atmosphere (*i.e.*, an atmosphere of carbon monoxide) is more trying than oxidizing conditions; but if a retort bench is being correctly operated, the only possible point at which a reducing atmosphere could continuously prevail, would be above the fuel in the furnace and below the nostril arch. If carbon monoxide is found at a point beyond this, it is certainly indicative of a shortage of secondary air. Mellor says that the magnitude of the fluxing effect induced by the reducing atmosphere depends upon a number of factors. For example: (1) It depends upon the strength of the reducing atmosphere; that is, on the proportion (and kind) of reducing gases in the given atmosphere; (2) it will also depend upon the rate the gases penetrate into the interior of the brick, and this in turn depends upon the

character of the superficial skin, and on the porosity of the brick; and (3) on the time and temperature the brick is bathed in the reducing atmosphere.

Horizontal Retorts

It is not within the power of the retort manufacturers to alter materially the chemical composition of the clay occurring in their districts; hence it is by modification of the texture of the finished article and attention to the details of manufacture that greatly increased refractoriness has been obtained. Not only do retorts now have to withstand high heats, but in addition, as discharging and charging take place, they are exposed to considerable fluctuations in temperature. Moreover, they must be of a certain mechanical or physical strength in order to carry the loads to which they are subjected and to resist the strains put upon them by modern stoking machinery. In the case of the full coal charge and "pusher," the retort has to withstand some considerable bursting pressure in the event of a charge jamming-up and refusing to move. For high temperature, a highly refractory material is required; and to obtain this, high porosity and a fairly open grain are desirable. This is chiefly due to the fact that an open grain means larger individual particles, and the heat and flame have greater difficulty in penetrating to the interior of these than in the case of smaller dust-like particles. One function of porosity, however, is that of imparting to the material the ability to withstand fluctuation in temperature. For mechanical strength, on the other hand, a close-grained material of high density gives the best results, whilst diffusion of coal-gas outwards or furnace-gas inwards through the walls of the retorts is more effectively restricted, and better thermal conductivity is obtained. In the manufacture of the retort, therefore, these contrary requirements have to be reconciled as far as possible, although greater attention is usually paid to refractoriness. It is in this way that porosity plays so important a part; and no doubt the success of the German-made retort (which even now has a higher porosity than the average English type) can, in all probability, be greatly attributed to this fact. Porosity, however, as will be realized, is a somewhat dangerous property to interfere with, unless considerable care is exercised to keep it within the prescribed limits. It cannot be denied that any increase in porosity may be accompanied by a corresponding decrease in the capacity of the material to withstand working stresses; hence too much zeal in the open-grain doctrine is likely to tell somewhat seriously when the working life of a retort comes to be reckoned up. Evidence of this is seen in a certain number of retorts having a porosity up to as much as 30 per cent. which at one time found their way into gasworks with decidedly unhappy results. In this connection it is particularly interesting to note that, whilst the Refractory Materials Committee specify a minimum porosity of 18 per cent., the German-made retort has an average in the neighbourhood of 25 per cent. It has been shown, too, that in this country the German horizontal retorts, with due care, are capable of surviving about 2,100 days. A comparison between working life and porosity in this way is striking, in that it shows that even with a comparatively open texture a high degree of mechanical strength is obtainable. With regard to conductivity, it has been shown that if an ordinary

fireclay retort is burnt at 1,040° C., and the final substance is taken as giving a standard coefficient of conductivity (*i.e.*, 1), the figure will be increased to 1·6 if burning takes place at 1,300° C. It is for this reason that a retort will give a greater conductivity after having been in use for some time.

The practice of coating the inner surfaces of the retort with a glaze, which is prevalent in Germany, has never gained much favour here, and is usually carried out only when specified by the purchaser, the additional charge being about 1*s.* 6*d.* per foot length. The glaze is primarily intended to act as an impervious coating to prevent diffusion of gas through the retort walls. The friction of the stoking machinery disposes of the greater part of it; but by this time "scurf" will have formed, and will take up the duty of the glaze. Experiments have recently been conducted in connection with the problem of the outward diffusion of gas through the retort walls during the early stages of the charge, when the retorts may be subjected to some pressure, and it is a question whether the increased porosity of the material is not an offender in this direction. When perfectly new retorts are in use, there is little doubt that some gas must be lost in this way, although the formation of "scurf" will soon act as a check (*see* Fig. 105).

Retorts in this country are made by two distinct methods, *i.e.*, hand-moulding and machine-pressed. The former method is still employed in many yards to-day, and consists in plastering the clay to a certain thickness round a "plug" of the required shape. The whole length of the retort is not plastered on in one operation, but is formed in stages of about 18 inches to 2 feet in length at a time. The mandril is placed in a vertical position, and after the first stage has been moulded it is permitted to stand aside for a day or two until sufficiently dry to bear the weight of the next stage. In some instances, chiefly on the Continent, a different method is used. An outer casing is fitted with a core so as to form an annular space corresponding to the shape of the retort. The clay substance is then rammed into the space by means of long-handled punners provided with spiked ends. The object of the spikes is to release air bubbles which would affect the porosity of the finished article.

Machine presses for retort making (Fig. 111) are chiefly operated by steam power, and consist of a large cast-iron cylinder in which the piston or "presshead" works. The cylinder is filled up with a certain quantity of clay, depending upon the capacity of the machine, and as the piston goes down the clay is compressed and forced through a die at the base of the cylinder. The die is fashioned in accordance with the shape of the retort required, and as the moulded clay passes through, it is supported by a movable table, which descends at the same rate as the compressing cylinder. The moulded retort issuing from the die and resting on the movable table is shown in Fig. 112. Machines of this description are capable of making 400 to 500 feet of retort per day.

Cast Retorts

The process of casting gas retorts has not been generally favoured in this country, but recent experiments have shown that, so far as physical properties are concerned,

a high-quality article is obtained by the method. In the experiments [1] conducted the casting slip was prepared from Stourbridge fireclay and grog, the latter being used in various sizes. Sodium carbonate or silicate is added to the slip in sufficient quantity to produce a smoothly flowing mixture without reducing the consistency to such an extent as to allow the grog to settle. The amount required is determined in each particular case by trial; it varies with the nature of the clay, the size of the grog, and the proportion in which the clay and grog are mixed. With some clays the best results are obtained by using a mixture of equal parts of silicate and soda-

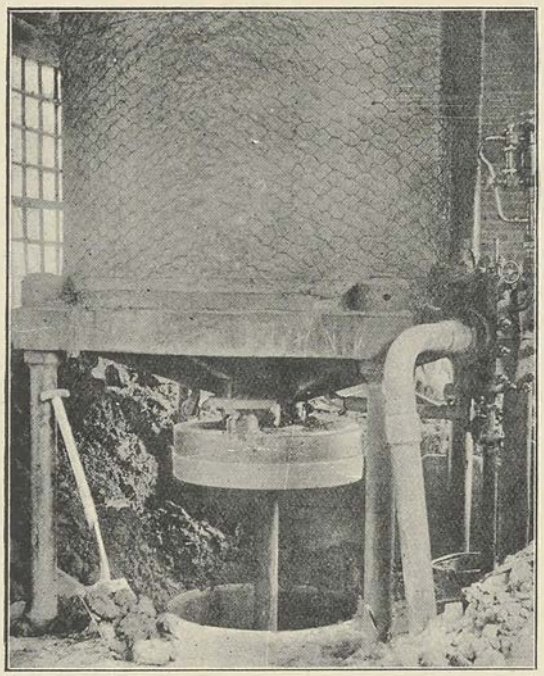


FIG. 111.—A STEAM-DRIVEN RETORT-MOULDING MACHINE SHOWING LOWER PORTION OF STEAM CYLINDER AND UPPER PART OF CLAY CYLINDER, THE LATTER WITH PISTON UP SO THAT IT MAY BE CHARGED WITH CLAY.

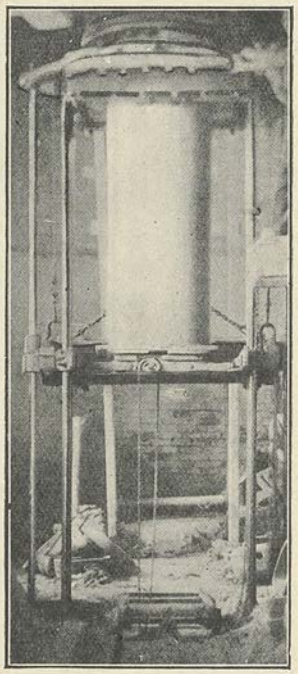


FIG. 112.—RETORT PASSING THROUGH MOULDING DIE.

ash; others give better results with a larger proportion of silicate. This mixture is usually referred to as the "alkali mixture," and on an average the quantity used amounts to 0·3 per cent. of the weight of the dry clay used. A sketch of the plant employed is given in Fig. 113. The mixture of clay and grog passes from the conveyor to the elevator, thence to the primary mixer, or "blunger." The blunged mixture then passes to the agitator, from which it runs direct to the mould. The time occupied in casting a retort is about fifteen minutes; the core is removed in about twenty-four hours; and the retort is removed from the mould in another twenty-four hours. A typical mould is shown in Fig. 114.

[1] Report of Refractory Materials Committee, Inst. Gas Eng., 1920.

As yet, the casting process has not been sufficiently developed for any definite opinion to be given as to the likelihood of its more general adoption. Very much must depend upon operating costs, and it would appear that the cast retort will necessarily be more expensive than those made by more common methods. It is stated that a denser retort with less tendency to crack is given by the casting process as compared with other methods, the reason for this being that the great homogeneity of the retort lessens the tendency to set up local strains which are the main cause of cracking.

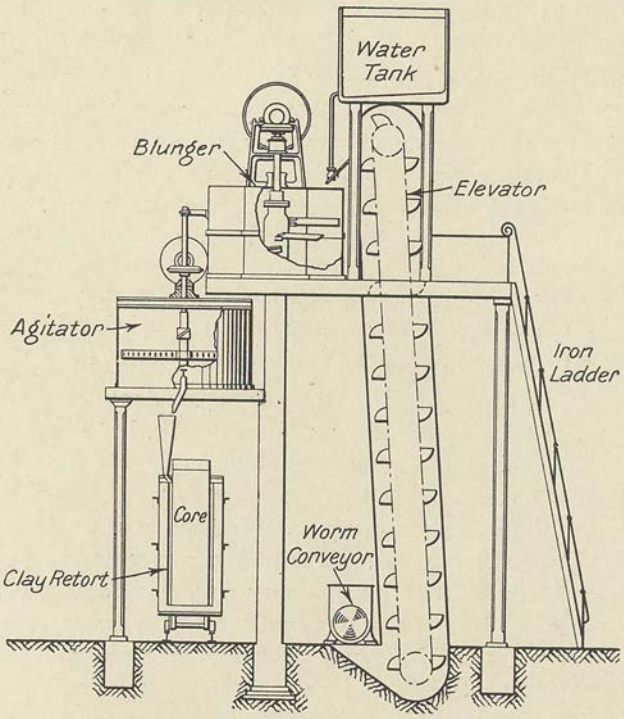


FIG. 113.—PLANT FOR CASTING GAS RETORTS.

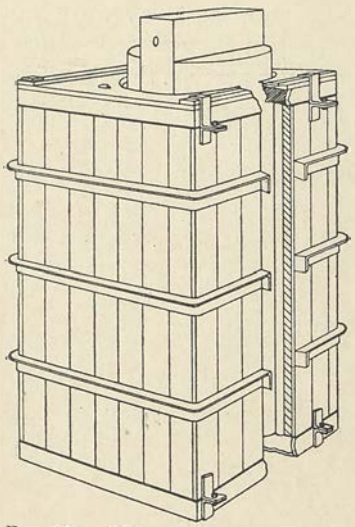


FIG. 114.—MOULD AND CORE FOR CASTING RETORTS.

THE QUALITIES OF HAND-MADE AND MACHINE-PRESSED RETORTS

With regard to manufacturing costs, there is little to choose between the two types of retort, but from the point of view of working life the hand-made article is usually preferred. The fact that the machine type is made in a single operation may account for somewhat greater homogeneity, but the gradual building up in distinct lifts ensures slower drying, which is desirable. Machine-made retorts are denser and heavier, but an excess of density can be avoided by the addition of sawdust or coarser grogram. Owing to the high working pressure of the machines the prepared clay must of necessity be stiff, otherwise warping and sagging will occur after the material has passed the die. Stiff material put together by

pressure is not so effective for most purposes—particularly retort work—as a more plastic clay which is put together by hand. When the clay is plastic, the additional amount of water is afforded an opportunity of carrying out its function of knitting and binding up the particles. Moreover, when the ram under heavy pressure squeezes or drives the clay out of a retort machine, there is a tendency to destroy the best setting of the grog and to drive the coarse particle into a more or less regular formation. On the other hand, the machine-made retort, prepared with due care, is far cleaner, more regular, and straighter than that made in successive lifts by hand.

There is a good deal of controversy as to the relative merits of machine-made and hand-made firebricks, the latter usually being preferred although the reasons for this are not quite clear. Mellor [1] says that the subject is one which requires careful re-examination, and that the prejudice to machine-made bricks is probably the result of an unfair comparison. Evidence shows that the essential difference is not that of machinery *versus* handwork, but depends rather on the difference in the time the clay is allowed to stand in contact with water. Hahn [2] says that the internal cohesion of a brick appears to be better with well-made machine bricks than with hand-made bricks. Mellor points to the fact that there is also a tendency for the machine-made body to be less uniform in texture. Pug-mills are not really good mixers. With pugs mixing, say, clay and grog, the eject from the pug has a tendency to be more or less laminated into poor patches and patches rich in grog. The preparation of the clay for hand and machine working usually differs in a way which materially affects its working properties and texture. If the texture of the brick be not uniform, it is highly probable that strains will set up when the brick is being heated, owing to a difference in the rates of expansion of the different parts. This will lead to the formation of fissures and cracks, and, probably, also to spalling. A prime desideratum with machine or hand-made bricks is uniformity of texture. Other things being equal, that process of manufacture which is least liable to yield bricks with an irregular texture will give the best results. In the dry or semi-dry processes of machine-making, films of air between the granules prevent their packing together so well as in bricks made by plastic processes, and this again has a tendency to make machine-made bricks less sound than hand-made bricks.

Emery and Bradshaw,[3] as a result of a series of tests carried out with hand-made and machine-made silica bricks, have come to the following conclusions :—

1. The prevailing objections to machine-made silica bricks appear to be due to prejudice arising from early failures to produce good bricks from improperly graded mixtures, and with unsuitable machines.

2. Of recent years the quality of machine-made silica bricks has been greatly improved.

3. Bricks made from the same materials moulded by hand and by machine were submitted to a series of comparative laboratory tests. In none of these were the machine-made bricks found to be inferior to the hand-made, while in several

[1] *Proc. Faraday Society*, November, 1916.
[2] *Ber. Ver. deut. Fab. feuerfester Prod.*, 33 (1912) and 34 (1913).
[3] Refractory Materials Committee, Inst. Gas Eng., 1920.

important respects, viz., mechanical strength, resistance to spalling and abrasion, and accuracy of shape, they were superior.

The Effect of Slags

Refractories employed in certain portions of gasworks plant, such as the retort-bench producers and water-gas generators, are particularly liable to be damaged by the action of low-melting fluxes or slags. The chemical composition of ashes derived from coke fuel is decidedly variable, the iron content ranging between 5 and 40 per cent., while lime compounds may be anything between 2 and 10 per cent. In addition to the action of slags, portions of the plant have to withstand the corrosive action of the dust suspended in the travelling flue gases. Mellor and Emery [1] have shown that the deep red-coloured dust collected from the top of the retort bench has the following composition :—

Silica	20·40 per cent.
Alumina	10·07 „
Ferric oxide	55·86 „
Lime	2·25 „

with smaller proportions of titanic oxide, magnesia, potash, soda and sulphur trioxide. At temperatures below 1,300° C. the action of the dust is mechanical rather than chemical, and it begins to act chemically at some temperature exceeding 1,300° C. At temperatures of 1,400° C., with the above dust, it was found that the surface of the brick becomes glazed and is corroded to some extent. Considerable cracking was also found, the dust having penetrated completely through the brick. On the other hand, the grog particles had suffered but little, although the bond was permeated with dust.

It may be said as a general rule that the finer the texture of the brick the less will be the penetration, and that "aluminous" bricks are more susceptible to corrosion than are silica bricks. Much, of course, depends upon the prevailing conditions of atmosphere, whether oxidizing or reducing. Texture, however, is of chief importance in the way of effecting mechanical resistance, and where flue-dust corrosion is suspected a high-quality close-grained brick should be utilized.

Raymond Howe,[2] in conducting experiments in connection with the rate of penetration of slag, found that in all cases the slag penetrated more deeply at higher temperatures. In many cases an increase of 10 per cent. in temperature resulted in nearly doubling the penetration. This increased penetration has several effects in practice. One effect concerns the strength of the brick itself, for it is known that bricks when saturated with slag are not so strong at high temperatures as when they are free from slag. This decreases their ability to sustain the weight of the superimposed parts of the structure.

Some interesting points in connection with the choice of refractories for water-gas plant have been raised by Fulweiler and Taussig,[3] who state that in water-gas

[1] *Proc. Ceramic Society*, XVIII, 234.
[2] American Refractories Manufacturers' Assocn., November, 1918.
[3] *J. Eng. and Ind. Chemistry*, 1919, 11, p. 1153

plants the generator linings are subjected at the top to abrasion by the descending fuel, and by the small particles whirled about by the blast, and also to the effect of tools used for removing clinkers. The central combustion zone is very hot, owing to the preliminary combustion of the fuel. There is slagging action due to the ash of the fuel, some abrasion due to the fuel, and, with various kinds of fuel, serious abrasion caused in the removal of clinker. The lower portion of the generator, though not so hot, is subject to the effects of steam on the up-run, the hot gases on the down-run, and the effect of tools in removing the clinker periodically. The connections between the generator and the carburettor are subjected to high temperature, erosion due to fuel particles passing through quickly, and some slagging action from the ash. The lining bricks of the carburettor are subjected to only moderate temperature; but the chequer-bricks and the crown are exposed to a temperature of perhaps 1,200° C. during the blasting, and are then deluged with a spray of cold oil during the gasmaking period. This results in an accelerated spalling action on the chequer-bricks.

The two important points in the selection of materials are the generator lining and the chequer-bricks. In the selection of material for the generator lining, the relatively high temperature (due to the combustion of fuel), and the action of the clinker as a slag, have to be considered.

The fusing-points of the same ashes ranged from 1,090° to 1,660° C. The very great variation results in the development of three distinct classes of clinker. The ashes with high fusing-points tend to build-out on the sides of the generator, thus considerably reducing the working area. This type of clinker does not seriously deteriorate the lining in a chemical sense; but the abrasion in barring-down the deposit is very destructive. The ashes with moderate fusing temperature for the most part collect on the grate, forming a compact mass which can be removed without much difficulty. The ashes with a low fusing-point—generally high in iron and rather low in alumina—seriously attack the linings, and also collect on the grate to form a hard compact mass, which is difficult to remove when cold. In extreme cases they may even melt, and form stalactites in the ash-pit.

The usual lining block is of fireclay. Silica materials have not been generally successful, because of extreme and very frequent changes in temperature during use. Experimental trials with magnesite have not been very successful, because of spalling. Recently, magnesite blocks enclosed in a thin iron casing seem to have been somewhat more successful. Chrome bricks have been tried; but sufficient data are not as yet available. Zirconia bricks are very expensive; but their special properties may, perhaps, warrant more extensive trials. Carborundum materials have been tried as solid bricks and as veneered bricks. The solid brick is much stronger; and its extra cost will probably be compensated by a longer life. With all these neutral materials the adhesion of the slags to the sides is eliminated, along with possible corrosive action; and consequently less time is required for cleaning the sets.

For chequer-bricks to resist spalling action (due to alternate heating and cooling), it has been found that bricks with rather coarse grog and a minimum amount of

plastic clay, are generally better than others. A dense brick that would not absorb the oil should apparently be more satisfactory; but such bricks do not generally resist spalling action. The fireclay linings of the connections between the different shells are often nearly cut away by the abrasive action of coke particles in the gaseous current, and by the slagging action of the ash.

It is believed that many failures attributed to the refractory material have really been due to the use of improper cements. The average mason likes cement which works easily under the trowel; and there is a tendency to add plastic clay, or some similar material, to the more refractory cements. The use of such material reduces the refractory qualities of the cement, and the resulting jointing material fuses. This deterioration may even extend to the bricks. In general, better results are obtained on construction work by using a cement consisting chiefly of ground material similar in quality to the grog in the bricks, and a minimum amount of material of lower fusibility. In using silica shapes, cementing material is often omitted—the bricks or shapes being separated by corrugated cardboard of such thickness that at the proper temperature the expansion will form a sufficiently tight joint.

Salt Corrosion

The corrosion of refractories by salt is a problem which mainly concerns the coke-oven engineer. In gasworks the coal carbonized is comparatively dry, whereas for coking purposes the coal is invariably washed before use. The saline matter in coals consists principally of sodium and potassium chlorides and sulphates, and the process of washing, instead of removing these compounds, may, if the washing water is not frequently changed, actually add to the original amount in the coal owing to the high proportion of dissolved salts which the circulated water contains. W. J. Rees [1] has given the following figures in connection with the water used in coal washeries:—

Water in Circulation in Washery

Sodium chloride	1·529	grammes	per litre.
Sodium sulphate	0·524	,,	,,
Potassium sulphate	0·062	,,	,,
Calcium sulphate	0·168	,,	,,
Magnesium sulphate	0·264	,,	,,
Calcium carbonate	0·057	,,	,,
Magnesium carbonate	0·041	,,	,,

Proportion of Salt in Coal

	Sodium chloride	Sodium sulphate
(*a*) Unwashed slack	0·37 per cent.	0·19 per cent.
(*b*) Washed slack	0·18 ,,	0·08 ,,

In the above instance it is evident that the saline compounds have been partly removed by the washing process. The rate of flow of the water through the washery is of importance, as the concentration of salts will be reduced as the rate is increased.

[1] *Proc. Ceramic Society*, XVIII, p. 432.

The decomposition of the salts in coals commences at about 900° C., the acid radicle usually combining with the ammonia in the gas to give ammonium chloride, etc. The salt vapour appears to penetrate into the body of the brick, passing from the cooler face at the interior of the oven to the hotter external face, when it reaches a zone where the temperature is sufficiently high for interaction to take place with the refractory. The result is the formation of a spongy layer, which, as it disintegrates, opens the way for an attack on the remainder of the wall. The decomposition of the original salts is followed by the formation of alkaline alumino silicates, which may appear at first as a glaze on the surface of the brick. Cobb [1] has pointed out that the refractory is destroyed, not by the removal of successive thin layers by fusion, but a much more drastic process of breaking off of layers of considerable dimensions. As a consequence of chemical alterations in that part of the refractory into which the salt has penetrated, there is an accompanying physical change in the coefficient of expansion which may have considerable influence.

As to the means of preventing or curtailing corrosion, there are two directions from which the problem can be attacked, namely :—

(*a*) By attention to the coal before carbonization, particularly the process of washing. In general, too, the drier coals appear to be followed by far less serious effects than result from the employment of coals containing from 10 to 15 per cent. of moisture.

(*b*) By attention to the chemical and physical properties of the refractories employed.

As regards the latter consideration, it may be said in general that aluminous refractories are far less prone to attack than are those made of silica. Of primary importance, however, is the question of texture, for with an open-grained surface the vapours are afforded ample opportunity for penetration, thus from the salt stand-point a perfectly non-porous body would provide the ideal. Joints between the bricks are again of importance, and as these provide facilities for penetration, they should be as few as possible in number and as fine as it is practicable to make them. Coating the interior surfaces with an impermeable glaze has been suggested as a remedy, but in practice many difficulties arise ; firstly, owing to the fact that the glaze is quickly removed by the abrasion of the moving charge and ram-head during discharging ; and, secondly, owing to the fact that cohesion of the glaze is rendered doubtful by reason of the alternate contraction and expansion of the face of the oven.

Observations made at a coke-oven works showed that a proportion of 0·143 per cent. of salt in the water employed for washing coals ruins a retort in three years, while one-quarter of this amount renders a refractory substance of little value after five years' work.

Fortunately, the majority of coals in general use in gasworks contain only small quantities of saline impurities, and the corrosive effect, accordingly, is not particularly marked.

[1] Coke-Oven Managers' Assocn., March, 1916.

Segmental Retorts

From the point of view of working life, segmental or built-up retorts are far superior to the common moulded type, but, chiefly owing to the preliminary expense incurred, they have not been very generally adopted in this country. Built-up retorts may be classified under two headings, namely, those composed of large segments and those constructed from special small blocks about the size of an ordinary brick. It has been said that retorts built up from small tongued and grooved segments can be worked continuously for five years without requiring repairs, the explanation being that the flexible units give and take with the expansion and contraction caused by the variation of temperature in the setting. In the case of a brick retort, the line of fracture necessarily follows along the joint-lines, whereas in the case of a moulded retort the line of cleavage is indefinite, and cross-stresses are set up. Under local heating, it is impossible to expect perfectly uniform movement; thus, when the retort is composed of one single piece, cracks and fissures result. In these days of the "pusher," moreover, distortion must be avoided if the charge is not to jam up. In this respect, the built-up retorts composed of small units are probably to be preferred to those in which large sections are employed, although opinion in this respect differs considerably.

The retort built up of small units is extremely flexible, and yet (owing to the tongued and grooved joint) little or no leakage takes place. A difficulty, however, arises when "scurfing" is considered, for, owing to their delicate adjustment, the separate units are liable to be damaged with the heavy tool employed and the rough handling they receive. Furthermore, there is the possibility of the carbon getting into the joints and opening out the bricks in this way. Segmental retorts require, of course, substantial and at the same time flexible supports, this being another factor which adds to the expense. With regard to the relative "gastightness" of the two types of retort, there appears to be some divergence of opinion. It may be generally taken, however, that, so long as the segments are carefully made and laid together, the gas leakage will, in the long run, be less than with the moulded retort, in spite of the number of joints necessitated. Some authorities attribute the tightness of the segmental retort to the fact that when a line of cleavage occurs, it runs along the joints and is quickly sealed by the formation of scurf. With the moulded retort, on the other hand, the cracks may be anything from $\frac{1}{8}$ inch to 1 inch, or even greater. The built-up retort, moreover, lends itself to effective repair.

A typical brick-built retort with tiled bottom, of a somewhat old-fashioned type, is shown in Fig. 115, whilst the more common forms of segmented retorts are illustrated in Fig.

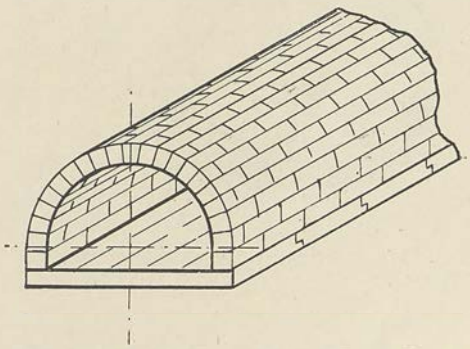


Fig. 115.—Brick Retort with Tiled Base.

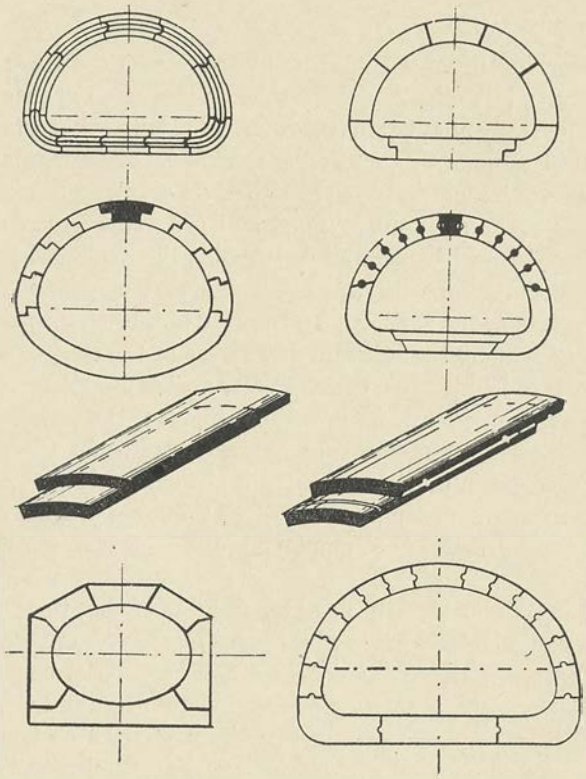


FIG. 116.—TYPES OF BUILT-UP RETORTS.

116. In all cases where the latter types are used, the modern tendency is to employ a highly refractory material of a silica nature ; but experience has shown that this clay is not altogether capable of withstanding the erosion caused by friction of the coke. Accordingly, while the arch of the retort is composed of silica material, the shoulders and base are made from an aluminous clay of a Stourbridge nature, as shown in Fig. 117. With occasional repairs, retorts of this description have, in some instances, recorded a working life of 3,000 days. Some idea of the longevity of the segmental chamber retort may be gathered from the fact that the ovens employed in the Munich chamber installations have, in many cases, been in use for nine consecutive years.

To overcome the inability of the silica ware to withstand friction, A. Cliff has suggested the adoption of a composite retort as shown in Fig. 118.

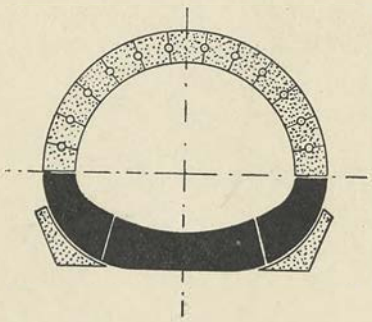


FIG. 117.—SEGMENTAL RETORT WITH SILICA ARCH AND ALUMINOUS BASE.

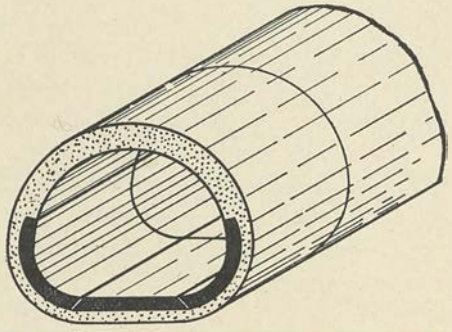


FIG. 118.—COMPOSITE RETORT WITH ALUMINOUS BOTTOM.

In some instances the segments composing a rebated retort are carried right up to both ends, and cast-iron sheaths (similar to that shown in Fig. 147, p. 245) are

used for attaching the mouthpiece. The more modern and satisfactory method, however, is to form the last couple of feet from a short length of moulded retort as seen in Fig. 119. This is, as in the ordinary way, composed of Stourbridge clay, which possesses the advantage that it is not injured by the condensed alkaline vapour falling back from the ascension pipe. Silica material, on the other hand, is quickly reduced to a powder in this way.

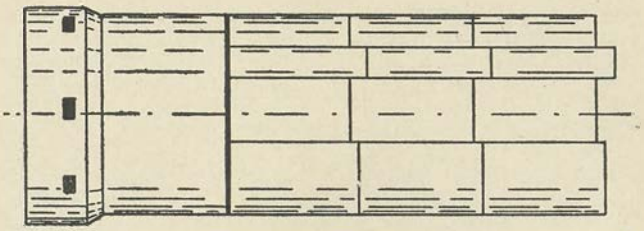


FIG. 119.—SEGMENTAL RETORT WITH MOULDED MOUTHPIECES.

Present-day vertical retorts are, of course, almost exclusively built up from rebated silica bricks or segments.

THE COST OF RETORTS

At the present time, prices for retorts must be given with caution, as there are obvious indications that the figures are unlikely to remain stationary. At the same time, much depends upon the locality, also the size of the works, the larger gasworks with big demands naturally being supplied at a lower figure than a smaller concern requiring an identical article. Taking London delivery as an average instance, however, the following figures may be given :—

Standard specification retorts	15*s.* to 16*s.* 6*d.*	per foot run,	delivered.
Good quality (not to specification)	13*s.* 6*d.* to 14*s.* 6*d.*	,,	,,
Segmental retorts :			
1. All aluminous material	16*s.* 6*d.* to 18*s.*	,,	,,
2. Silica tops, aluminous base	17*s.* 6*d.* to 19*s.* 6*d.*	,,	,,

These prices are all for average sizes. The very large patterns would be slightly more costly, whilst very small sizes would be rather less. Special shapes are, of course, extra.

With regard to the actual laying of segmental retorts, an additional cost (compared with moulded types) of from 2*s.* 6*d.* to 3*s.* per foot should be allowed.

PROTECTION FOR RETORTS

Owing to the expansion of the siliceous material employed in the cross-walls and other portions of the setting, the retorts often suffer damage from the increased stresses put upon them. A method for overcoming this effect, which has been employed with some considerable success, is that shown in Fig. 120. The idea, as will be seen from the sketch, consists in placing a shuttering of wooden strips completely around the sides and top of the retort, the strips being built into each cross-wall as it goes up. As the temperature of the setting is gradually raised, the wood chars, and finally burns completely away when the working heats are obtained, thus providing a small space for expansion, and preventing undue pressure on the retort.

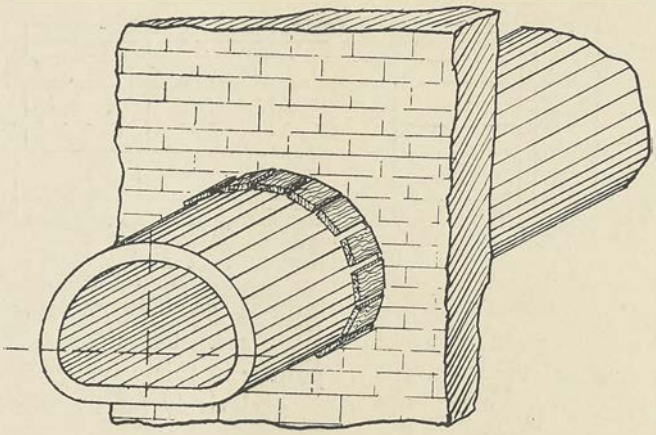


FIG. 120.—THE WOODEN STRIP METHOD.

Owing to the liability of retorts immediately surrounding the combustion chamber to suffer from the severe and sometimes local heating at this point, it has for sometime been the practice to insert special silica protection shields (as shown in Fig. 121) around the bottom corners. At the same time the silica material is liable to be affected by the slagging action of the dust carried forward by the furnace gases; and, for this reason, the block illustrated in Fig. 122 has in some cases been adopted. This shield is made wholly from Stourbridge clay, of the same material as the retorts, and will frequently be found to out-last the retorts themselves. The main body of the block is 3 inches in thickness, and it is made of such a length as to run from centre to centre of the cross division walls from which it is supported.

Another successful idea, which has been introduced with a view both to economy and the protection of the retort, is that shown in Fig. 123. In the majority of cases of "through" retort settings it is customary to insert a 9-inch cross-wall here and there in the setting, and particularly where the retort joints occur. By adopting the arrangement shown in the sketch, the expense of the heavier wall is obviated, and 4½-inch brickwork (or certainly 6-inch) can be run up instead. A 9-inch ring of brickwork (usually silica or siliceous) is carried completely round the retort, and the 4½-inch wall carried direct from this. In

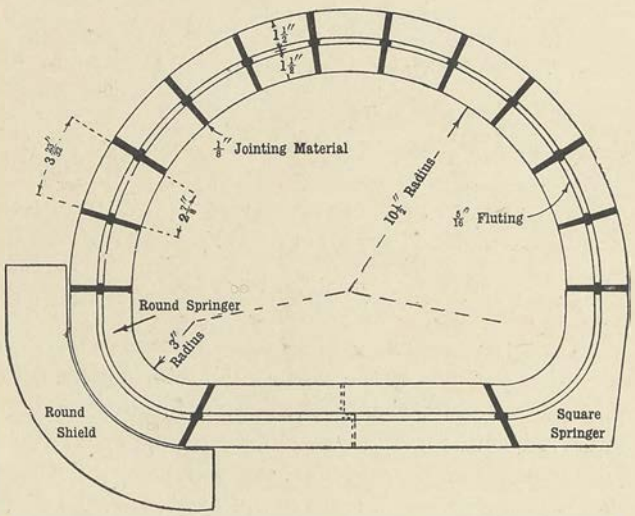


FIG. 121.—SEGMENTAL RETORT, 21 INCHES × 15 INCHES, WITH ROUND SPRINGER AND SHIELD ON COMBUSTION CHAMBER, SIDE AND SQUARE SPRINGER ON EXTERNAL SIDE. THE LENGTH OF THE SEGMENTS VARIES FROM 1 FOOT 3 INCHES TO 2 FEET.

the case of those retorts surrounding the combustion chamber, the brickwork makes an admirable substitute for special protection blocks.

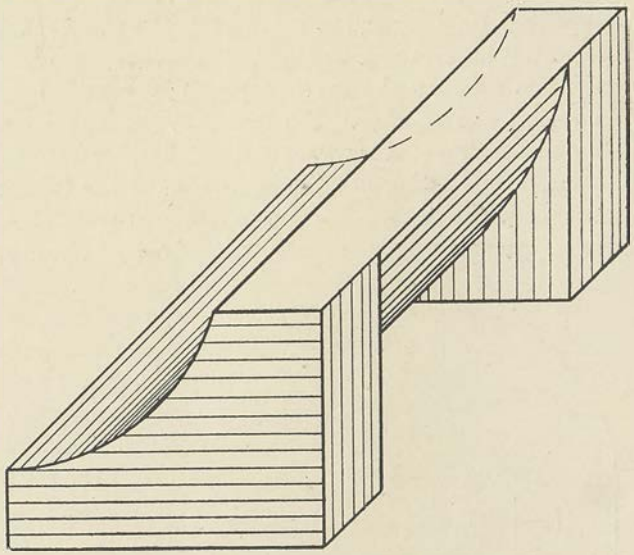


FIG. 122.—FIRECLAY SHIELD BLOCK.

COMBUSTION CHAMBER AND CROSS-WALLS

The greatest intensity of heat which is produced in a retort setting is in the combustion chamber and its immediate neighbourhood; hence a material of high refractory qualities is essential. In this respect the siliceous or silica materials are to be preferred, and those containing upwards of 96 per cent. of silica are now coming into fairly general use for the purpose. In this connection it is always well to bear in mind that while fireclay of the aluminous or Stourbridge type shows some tendency to contract when under working heats, the silica clays invariably expand; and, as a general rule, the higher the silica content the greater will this tendency be. Bricks of the siliceous type, however, being intermediate so far as silica content is concerned (87 to 89 per cent.), remain practically stationary, although at the more intense heats there may be some slight tendency towards expansion. Owing to this property, also to their high refractoriness, siliceous bricks are largely used for combustion chambers and cross-walls in modern settings.

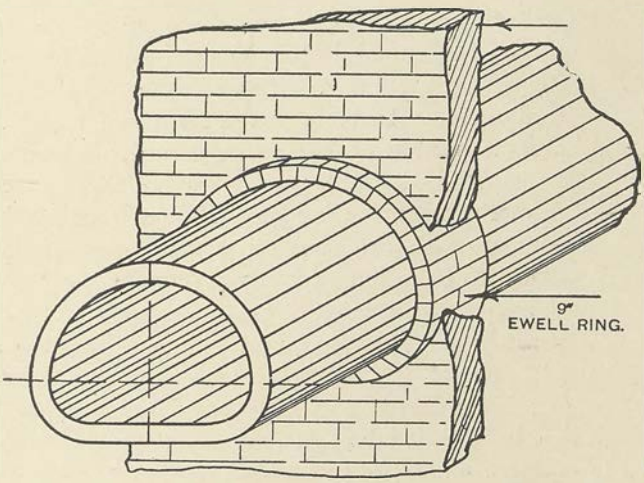


FIG. 123.—4½-INCH DIVISION WALL WITH 9-INCH EWELL RING.

The characteristic of certain bricks to diminish or increase in size is rather

liable to upset the calculations of those responsible for the design of settings, one of the chief consequences being that the retorts, after a short time, fall slightly out of level. In order to avoid this, an arrangement has been introduced by some engineers whereby the varying properties of the two types of material are made to neutralize one another. For instance, the furnace arch and combustion chamber may be built up of silica ware and the division walls of material having a contracting nature. On heating up, the expansion of the former is counteracted by the contraction of the latter—hence everything is maintained on an even keel. A setting built up in this way is diagrammatically shown in Fig. 124.

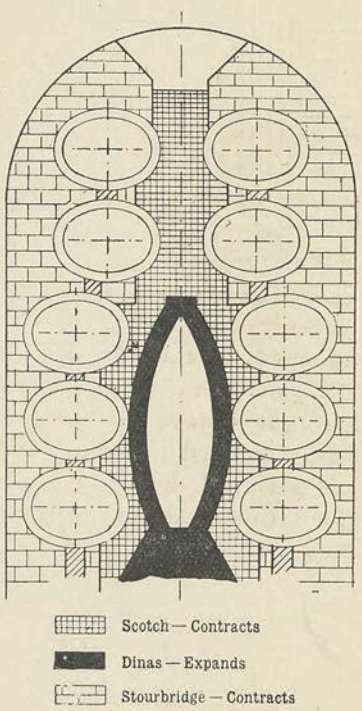


FIG. 124.—COMPENSATION ARRANGEMENT FOR EXPANSION AND CONTRACTION.

Attention must be drawn to the practice of running up the cross-walls between the retorts and above the combustion arch of siliceous material, while on the outer side of the setting, where the heat is less, the same walls are continued in aluminous work. In such cases it is frequently found that the retorts tend to overturn in an outward direction (particularly if the joints in the wall have been made fine), this being due to the pushing upwards and outwards of the silica material, whereas the aluminous material on the outside will have undergone a certain amount of shrinkage, thus allowing the movement to take place. In the construction of all types of division walls, it will be found an excellent policy to leave a big joint here and there to take up the crowding out, if necessary. With regard to these cross-walls, it must be remembered that, so far as the greater portion of them is concerned, mechanical strength is desirable rather than extreme refractoriness, for the material merely comes in contact with the circulating gases, and is not likely to be affected by any severe cutting heat. Consequently, a brick of greater density and less porosity may be used, and ordinary aluminous firebricks of the best quality usually give every satisfaction. Speaking of "cutting heats," it is as well to point out that small combustion chambers, although they have their advocates, are decidedly conducive to these, and also prevent the effective mixing of the gases.

It is essential to employ bricks for the cross-walls which are of sufficient refractoriness to withstand the working temperature, as drippings resulting from the fusion, or partial fusion, of these often cause trouble.

The disastrous effect which a small proportion of alkaline impurities may have on the remainder of the setting has already been emphasized. It is well known, of course, that in the case of the ordinary stock building brick the original clay

contains a comparatively high proportion of impurities, and these are actually caused to flux during burning, so as to firmly bind the remainder of the material together. A point to remember is that extremely high temperatures and "cutting heats" are not alone responsible for "running." Considerable damage from this cause may often be found at the relatively cool zone of the producer linings, and also at the base of water-gas generators. Such occurrences are, of course, due to the adhesion of clinker (having an extremely low fusion-point) to the walls, and its subsequent "slagging" action on the impurities of the lining material. The chief precaution is to ensure that the bricks or blocks made use of contain a low proportion of fusible constituents. The unwelcome results of "running" are very well illustrated in Fig. 125. This photograph shows the consequences of using an unsuitable jointing material, and the manner in which incipient slagging has

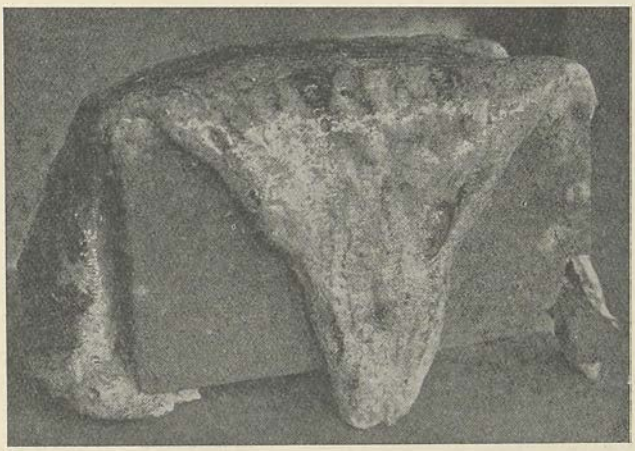


Fig. 125.—The Effects of "Running."

been set up in the brick can be clearly noticed. The brick in this case was taken from a combustion chamber working at a temperature of about 1,400° C.

With regard to fireclays for the making of cement for use in retort benches, before making a definite purchase it is advisable to apply a rough test in order to ascertain their suitability. An excellent rough method for determining their refractoriness is to mix up the cement in the usual way, afterwards plastering it on one side of a brick to the depth of about an inch. The brick should then be pushed into the combustion chamber of a retort setting and allowed to remain for about a week. If at the end of that time there is no sign of fusion, the material may be safely relied on. The test is, no doubt, severe—particularly in view of the rapid rate at which the temperature of the sample is increased.

PRODUCERS AND REGENERATORS

As pointed out above, the material employed for the lining of the producer must possess the ability to withstand the slagging action of the low fusing-point

impurities associated with the fuel. It is a recognized rule of retort-house practice that the furnaces must not be too hot; therefore there is theoretically no need for very high refractoriness. If, however, an inferior brick was made use of, the results would undoubtedly be very far from pleasing, for the heat in the producer —chiefly owing to fluctuation in the depth of the fuel-bed—undergoes severe changes.

With regard to the construction of the regenerator flues for the circulation of secondary air and waste gases, it must be borne in mind that the arrangement is employed with a view to abstracting the maximum of heat from the waste gases and conducting it to the secondary air. Accordingly, as the heat to be withstood is comparatively low, the bricks or blocks should be made with an eye to high thermal conductivity and mechanical strength rather than to high refractoriness.

WORKING REPAIRS

When retorts have been in operation for some time they should be carefully examined when discharged. When holes and cracks begin to make their appearance they should be dealt with at once, as the cutting action of the furnace gases passing through them tends to enlarge them. This is particularly the case in the modern regenerative setting in which a pressure prevails in the combustion chamber and gas flues. Many excellent proprietary patching cements are now to be obtained, and experience with the various kinds is the best guide. For cold patching and "crawling" the author finds that the best method is to clean thoroughly all of the cracks, and then to wash them out with a solution of silicate of soda made by dissolving 1 lb. of the silicate in a gallon of water. For pugging up the cracks the above silicate solution should be intermixed with as much of a good quality silica clay as gives a consistency suitable to work with. After the crack has been stopped, the surface should be washed over with the silicate solution. In this way the material forming the repair tends to flux slightly, with the result that it forms a close bond with the original refractory, and seldom works out when the retort bench is put under heat again.

R. L. Fletcher [1] has introduced a method in America whereby the repairs are effected by spraying into the cracks by means of a hand-pump a mixture of fireclay, silica cement, and a small proportion of common salt. The mixture is diluted with water, so as to form a solution which will freely pass the spray, and it is applied at a pressure of 50 lb. per square inch.

MATERIALS FOR HEAT RETENTION

The chief qualities required of the material of which the outside or front walls of the setting are composed are moderate refractoriness, but, more especially, a low ability to conduct heat. By far the most common practice is still that of building up these walls of 9-inch or 13½-inch work in aluminous fireclay, but within the last few years some attempt has been made to reduce the thermal losses by radiation

[1] *Gas Record*, July, 1919.

from these walls to a minimum. Chief among these methods is that of building up a cavity wall (a clear 2-inch space usually being left, whilst for the sake of stability the two walls are tied together at intervals by a brick), the cavity being left clear, or filled in with some type of non-conducting material, such as asbestos composition. A more recent means is to fill in the cavity or to build up a separate interior wall from one of the special types of insulating bricks. These bricks are extremely light, thus indicating high porosity and low conductivity.

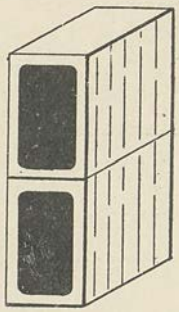


Fig. 126.—Special Air-blocks for Outside Wall of Setting.

Another practice is to construct the whole of the outside wall of large hollow blocks as shown in Fig. 126.

In the case where a screening wall of some type of insulating material is employed, there seems little reason why the face wall of the setting should not be built up entirely from ordinary stock brickwork. Such bricks, owing to their relatively high porosity, would ensure the retention of a further amount of heat.

The extremely light and porous insulating bricks which have sprung into favour at the present day are mainly composed of diatomaceous or infusorial earth (Kieselguhr). This material is composed of the siliceous remains of minute aquatic

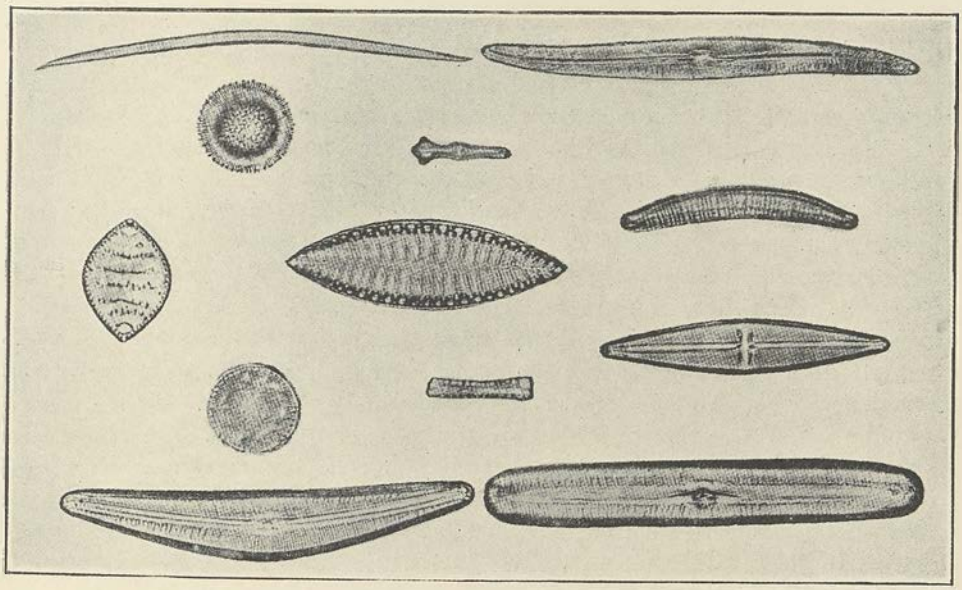


Fig. 127.—Microphotographs of Diatoms (Diatomite Company).

plants known as diatoms, which originally secreted silica in the process of building their shells. The raw product, therefore, consists almost entirely of the silica shells of diatoms, the finished article containing about 92 per cent. of silica. The efficiency of diatomaceous bricks depends almost solely upon the air spaces enclosed by the

cells. Accordingly, care is required during manufacture in order to ensure that the cell structures are not broken during crushing or mixing. E. Griffiths [1] states that the material has an extremely low thermal conductivity, and its refractory nature permits of its use at high temperatures if it is protected from the cutting action of flames and abrasion. From a series of investigations on the insulating property of diatomaceous tiles Griffiths obtained the following results :—

Temperature. Hot face. (° C.)	Temperature. Cold face. (° C.)	Conductivity in C.G.S. units.
186	24	·000310
287	25	·000331
505	28	·000359
622	32	·000387
939	64	·000461

It is interesting to note that although it is generally accepted that the thermal conductivity of insulation materials is greater the less porous the material, some authorities are opposed to the view that a porous substance forms the best insulator, pointing out that the transmission of heat by radiation and convection has not been taken into account. Millard and Lichty,[2] as a result of investigations in America, particularly point to the fact that though air-space construction is of decided value at low temperatures it is not so at high temperatures. In all cases the heat transmission across an air space will rapidly increase with an increase in temperature of the enclosing walls, and also with the same difference of temperature if the absolute values of the wall temperatures are increased.

Mellor [3] holds the opinion that at ordinary temperatures the quantity of heat travelling through porous bricks by conduction is much greater than the amount travelling by radiation across the pore spaces. By making a calculation for material with pores $\frac{1}{10}$ cm. across, with a temperature of 1,400° C., it works out that the amount of heat carried per second across the air space and through the solid material is the same. Smaller pores would make the temperature higher, and larger pores would make it lower. With pores $\frac{1}{2}$ cm. across, the insulating properties begin to break down above 730° C.—that is, within ordinary kiln temperatures.

Mellor [4] clearly states, however, that his opinion is one which may be refuted by facts when definite proof is available. The difficulty with the measurement of high temperature thermal conductivity is that of finding a method sufficiently sensitive to show differences in the conductivity of bricks of different porosity. From several indications it appears that there may be a reversal in conductivity at about 1,000° C. in the sense that the more porous bricks become better conductors than the same bricks of less porosity. The considerable amount of literature which has been published on thermal conductivity is indecisive.

[1] *Proc. Faraday Society*, November, 1916.
[2] University of Illinois, Bulletin No. 102.
[3] *Proc. Ceramic Society*, April, 1919.
[4] In a letter to the author, June, 1920.

CHAPTER VII

THE MEASUREMENT OF HIGH TEMPERATURES IN GASWORKS

In the majority of gasworks during the past century too much dependence was placed upon the human eye and its ability to judge roughly between the difference in temperature of heated objects. In the matter of retort benches and the like, the accuracy with which the trained individual can discern between correct and incorrect working heats is remarkable; but, to say the least of it, the method is crude and unworthy of the scientific procedure which is a feature of the modern gasmaking establishment. The pyrometer, accordingly, is now recognized as an instrument essential to the proper conduct of many of the everyday gasworks processes. Needless to say, the choice of a pyrometer depends essentially upon the purpose for which it is required. For instance, if it is to be employed in the laboratory or for research work very much greater accuracy is needed than is the case with the operations of the retort-house or water-gas plant, where an error of some 50° is of no great importance. In the latter case, therefore, it is usually advisable to sacrifice a certain amount of accuracy for portability and capability to withstand the somewhat trying conditions. In the matter of temperature recording appliances, the engineer has a large selection from which to choose, and it has been thought advisable to enumerate the various methods employed, followed by a brief description of the principle upon which each is operated.

Appliances for recording medium and high temperature may, in general, be classified as follows:—

(1) Prepared clay substances or alloys, *e.g.*, Seger Cones, the Watkin Heat Recorder, etc.

(2) Special Mercury Thermometers.

(3) Optical Pyrometers.

(4) Resistance Pyrometers.

(5) Expansion Pyrometers.

(6) Thermo-electric Pyrometers.

Reference is made to the use of Seger Cones in the chapter on Refractory Materials (*see* page 203). This method of determining temperature is, of course, necessarily only approximate, and while it forms a useful and handy means when dealing with such cases as refractories under test, it is scarcely applicable to the working processes associated with gasworks. Temperature recorders of this kind

consist of fusible mixtures—generally clay, sand, and special fluxes—of known melting-points. The fluxes used mainly consist of soda or lead oxide.

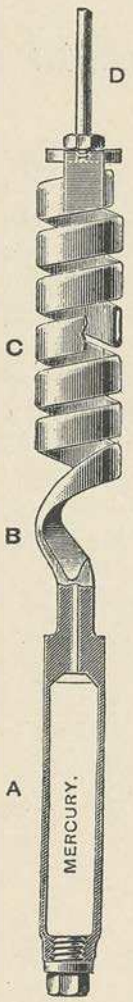


FIG. 128.—SPIRAL OF STEINLE THERMOMETER.

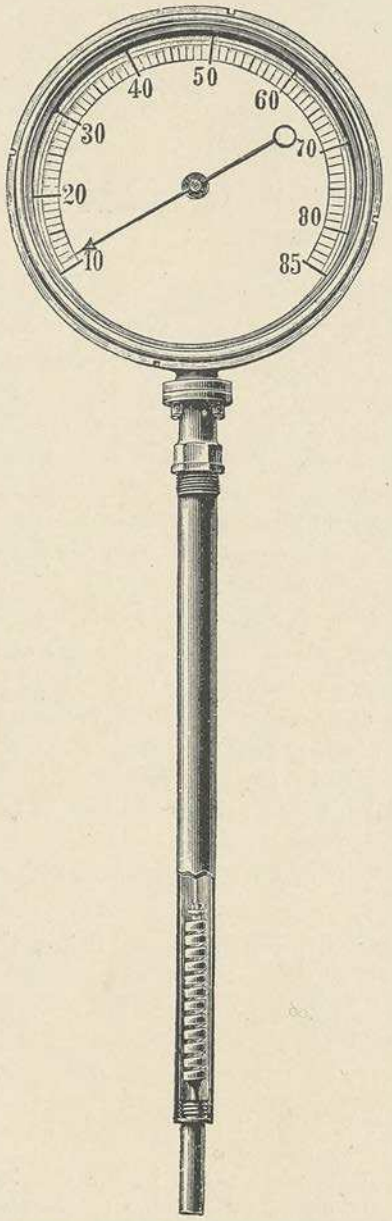


FIG. 129.—THE STEINLE THERMOMETER.

As regards special mercury thermometers, it is well known, of course, that mercury under atmospheric pressure boils at 360°,[1] and above about 260° its reliability is uncertain. If, however, the mercury is maintained under pressure its boiling-point is raised, so that thermometers on this principle have been constructed to measure temperatures up to 540° (1,000° F.). One such instrument is the Steinle, shown in Fig. 128. It consists of a strong, mild steel cylinder A, which is closed at one end and tapers off at the other end to a very fine bore which connects at B with a steel spiral spring C. The spiral is made from a solid drawn steel tube with thin walls rolled flat until the sides meet within $\frac{1}{100}$ inch. The container and spiral spring are entirely filled with mercury, after which the upper end of the spring is hermetically sealed. When, owing to a rise in temperature, the mercury expands, the pressure causes the spiral partly to uncoil, and conversely. The rotary motion of the spring may, therefore, be transferred by means of suitable gearing to a dial hand working over a specially calibrated scale. The spiral of average size is about 21-inch long before coiling, and is rolled into nine coils. One form of the complete instrument is shown in Fig. 129.

[1] All temperatures are in degrees Centigrade unless otherwise stated.

One of the latest forms of the special mercury thermometer for reading temperatures up to 540° is the Hohmann and Maurer instrument as made by the Cambridge Scientific Instrument Company. The author has found this type of thermometer particularly suitable for recording the temperatures of benzol stills and similar apparatus, and it is accurate to about 1 per cent. The principle of its operation will be readily understood by reference to Fig. 130. A is a steel bulb, connected by means of a steel capillary tube B, to a special form of steel Bourdon spiral C. The whole system is filled with mercury, and changes of temperature of the bulb give rise to corresponding changes of pressure in the system which are magnified and

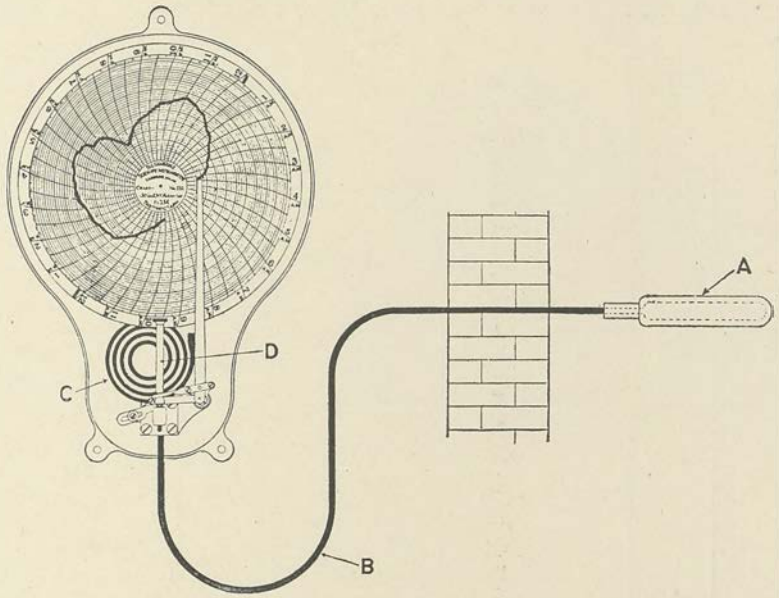


FIG. 130.—HOHMANN AND MAURER RECORDING THERMOMETER.

recorded or indicated by means of a simple pen or pointer mechanism in connection with the Bourdon spiral.

OPTICAL PYROMETERS

Within recent years a number of optical pyrometers have been developed which compare different colours with that of the heated object. These, however, would appear to depend largely upon the individual in whose hands they are placed, for it is seldom that two operators obtain exactly similar results. Another form of instrument is that in which a glass prism graduated in depth of colour is employed, differing depths of colour being required to eclipse the light emitted by bodies in differing degrees of temperature. For retort-house and similar operations the author has found this type of instrument particularly suitable in spite of the fact that it is, to some extent, dependent upon the human element. When extreme accuracy

is not desired, however, the portability of the instrument and the fact that retort-house conditions are not liable to cause derangement make it one of the most convenient for the purpose. One such instrument is that known as the " Wedge," which is shown in Fig. 131. The instrument consists of a rectangular brass tube 9 inches long, across which at right angles there is fitted a small telescope of which A is the eye-piece and B the objective, while C is a rack and pinion for focusing the telescope on the heated body of which the temperature is to be measured. Inside the rectangular brass tube is a carrier D, which can be moved up and down by means of the rack and pinion E. Attached to the carrier, so as to move across the field of vision of the telescope, are two glass wedges F, of which one, the essential one, is of dark red glass, while the other is of plain glass, being introduced to correct the

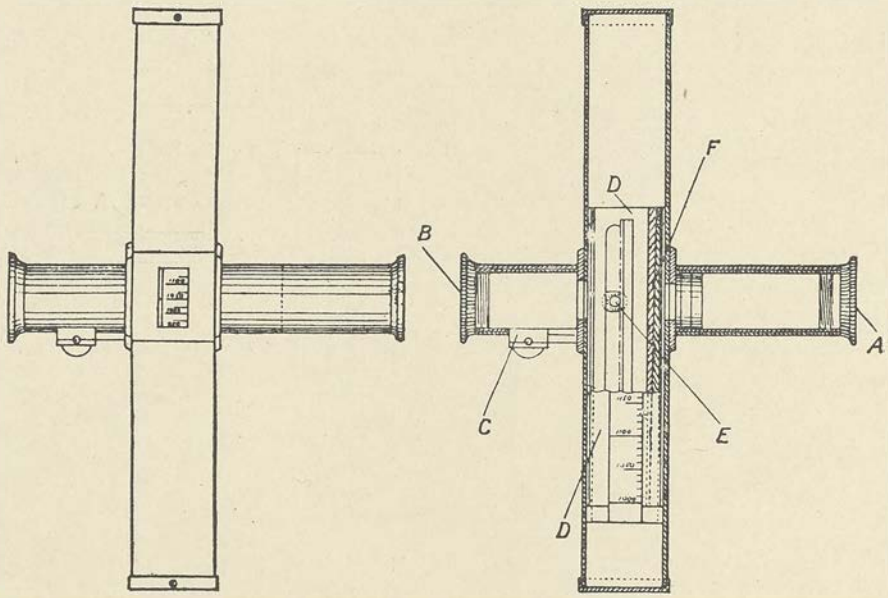


Fig. 131.—The Wedge Optical Pyrometer.

effects of refraction. In use, the telescope is pointed at the heated body or furnace aperture, and the image is viewed as focused on the wedge of dark red glass. The wedge is then moved so as to increase the thickness of coloured glass between the hot body and the eye. As it is moved the image gradually fades, and at the point of extinction the scale on the side of the instrument is read for the temperature. The " Wedge " Pyrometer is calibrated to cover any range of temperature desired, between the limits of 500 and 2,100° C. The average instrument is made to cover a range of 400°, the scale being divided into intervals of 20°.

The optical pyrometers of the Wanner type employ the principle of comparing the intensity of light emitted from a hot body with that of a standard source of light, and their action may be compared with ordinary forms of photometers. The draw-

back to pyrometers of this description is the uncertainty of always obtaining the same degree of intensity from the standard light, although the latest Wanner instrument is provided with electric lamp, galvanometer, and regulating resistance by means of which it is claimed that intensity can always be maintained at the prescribed standard.

THE CAMBRIDGE OPTICAL PYROMETER

This pyrometer (Fig. 132) is a convenient and accurate instrument which utilizes the relationship between the intensity of the red rays emitted by heated bodies and their temperatures. Into the enlarged part in the front of the pyrometer is fitted an electric lamp, and a screen at the back end of this portion contains two holes. Light from the object under observation passes through one hole, and light from the lamp through the other. These beams of light then pass through a system of lenses and prisms, are polarized in different planes, and are rendered monochromatic. Finally, the two beams of light pass through to single eye-piece, and the observer sees an illuminated circular field divided into two semicircles. One semicircle is filled by an image of the hot body under observation, and the other is uniformly illuminated by the electric lamp. The two semicircles are brought to an equal intensity of illumination by turning the eye-piece, to which the scale pointer is directly attached. In this manner the unknown rays are compared with those of known intensity from the electric lamp. Means are introduced to ensure that, whatever the voltage of the lamp battery may be, the current passing through the lamp is constant. Thus constant candle-power of the standard is maintained.

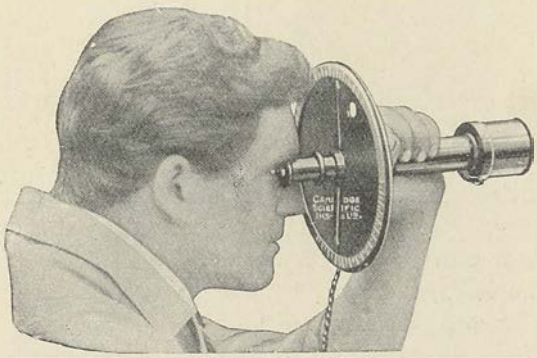


Fig. 132.—The Cambridge Optical Pyrometer.

RESISTANCE PYROMETERS

The electrical resistance of a metallic wire varies with its temperature; consequently, this property presents a method of measuring temperature. Sir W. Siemens was the first to endeavour to construct a platinum resistance pyrometer. It consisted of a platinum wire wound round a fireclay cylinder, the whole being protected by a stout wrought-iron tube. The instrument, however, was not altogether satisfactory, and the question was ultimately taken up by Professor Callendar, who pointed out that if a coil of pure annealed platinum wire be wound on a mica framework, and thoroughly protected from the action of gases, then the temperature as deduced from an observation of the resistance of the wire will seldom be in error by more than

$\frac{1}{100}°$. The principle of the resistance thermometer may be simply explained by the diagram, Fig. 133. The coil of platinum wire is shown at A, and this is connected with a Wheatstone's bridge by means of platinum wires from A to B, and of copper wires from B to C. In order to eliminate errors introduced by these leads a set of compensation leads is placed beside the primary leads. The resistance of the platinum coil is, therefore, read direct on the Wheatstone's bridge, and the temperature may be taken from the temperature-resistance curve for platinum. In the modern form of instrument a special indicator is employed from which the temperature can be read direct. A complete resistance pyrometer, suitable for furnace use, is shown in section in Fig. 134. With this instrument four-way copper leads are connected to one side of the Wheatstone bridge and the other two to the other side. The leads, therefore, counterbalance each other, and alterations in resistance due to changes in temperature or length are eliminated.

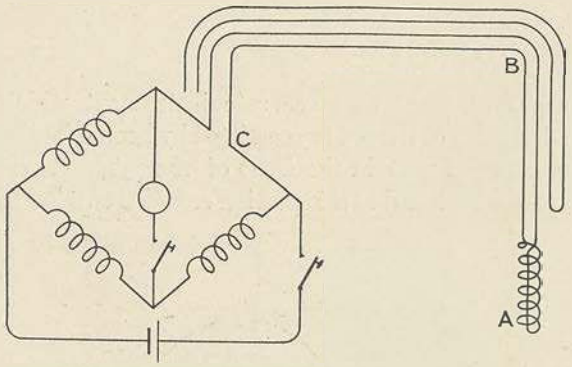


FIG. 133.—DIAGRAM OF WHEATSTONE'S BRIDGE.

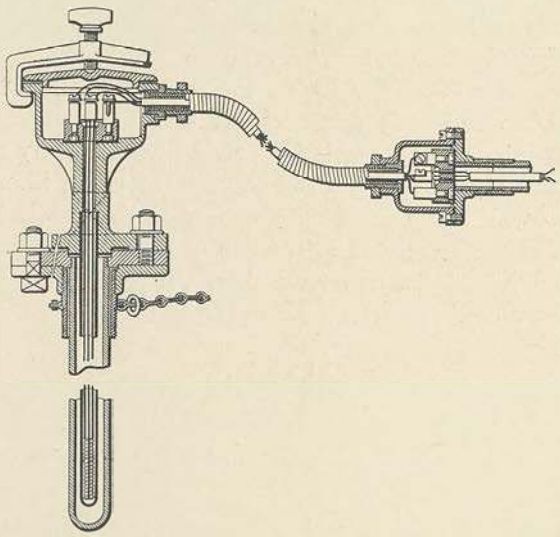


FIG. 134.—COMPLETE RESISTANCE PYROMETER.

CALLENDAR RECORDING PYROMETER

This instrument (Fig. 135) is based on the Wheatstone bridge principle, but instead of the bridge having to be balanced by hand, this is done automatically by the recorder mechanism. The pen arm is attached to the contact which slides to and fro on the bridge wire. The movement of the pen is governed by a clock, which, in turn, is controlled by two electro-magnets. The galvanometer pointer carries two insulated wires which can make contact on one side or the other of a platinum-rimmed contact wheel. When the pen is registering the correct temperature these wires do not touch the wheel. Any change in the temperature of the thermo-

meter, however, throws the bridge out of balance. The resulting deflection of the galvanometer pointer causes one of the wires to make contact with the moving wheel, and this in turn energizes one of the electro-magnets and so releases the clock. The pen arm is then drawn along the bridge wire until the balanced condition is restored, when the contact of the galvanometer pointer is broken. In this way a continuous record of the variations in temperature of the thermometer is obtained. A 4-volt accumulator is necessary to operate the recorder. The drum of the recorder rotates once in twenty-five hours, giving a time scale of ½-inch per hour, but a simple change-speed gear is fitted, by means of which the speed may be increased to one revolution in about two hours.

The resistance pyrometer is of a very accurate order, being extremely sensitive and responsive to the slightest changes of temperature. For work up to 1,200°, in which accuracy is of the first importance, the platinum resistance instrument is to be preferred to all others. As compared with the thermo-electric pyrometer, it has the advantage of a more pronounced effect for a given temperature, and, consequently, greater sensitiveness. On the whole it may be said, however, that whereas the resistance instrument is of special value for laboratory and research work in which accuracy is essential, the thermo-electric pyrometer is preferable for ordinary industrial work. For continuous use the resistance pyrometer should not be taken much above 900°.

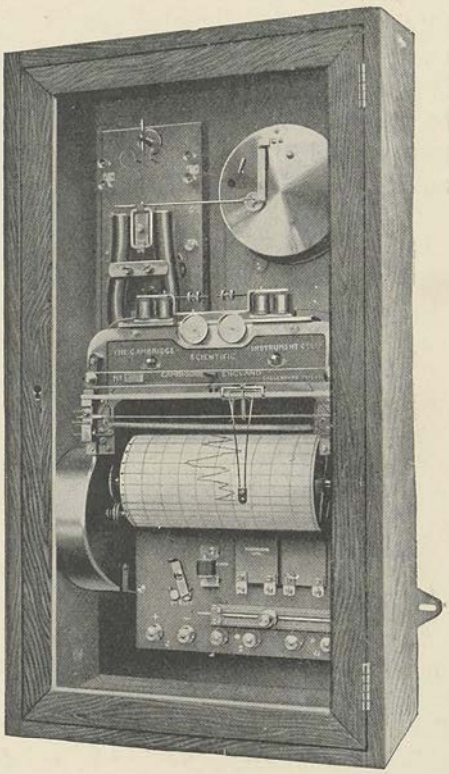


Fig. 135.—Callendar Recording Pyrometer.

THERMO-ELECTRIC PYROMETERS

If a closed circuit is formed of two different metals, and one of the junctions is heated, a current will flow round the circuit. For a given circuit, the current produced will depend upon the difference of temperature between the hot and cold junctions. This gives a means of measuring very high or very low temperatures.

Let ABC and ADC be two pieces of wire of different materials, fused or soldered together at A and C; then if the junction at A is maintained at a higher temperature than that at C, a current will be produced which may flow round the circuit in either direction, according to the temperature of A. The two wires are said to constitute a thermo-couple. For measurements of very high or very low temperatures a thermo-

couple, comprising two wires—one of which is composed of a pure metal and the other of an alloy—is generally used. For high temperature work it is further necessary that both the metal and the alloy should be infusible.

In some of the best-known modern pyrometers—particularly among those used on gasworks—the sensitive element employed is merely a thermo-couple constructed from special metals.

As regards the direction of the current, this undergoes reversal when the temperature of the hot junction rises above 550°. This is known as thermo-electric inversion, and it has been found that certain metals do not exhibit the phenomenon of reversal. It is those metals which are invariably employed in the construction of thermo-couples made use of in the practical pyrometer. The electro-motive force set up is proportional to the difference in temperature between the hot and cold junctions, and as the cold junction is maintained at a constant temperature the E.M.F. is proportional to the increase in temperature of the hot junction. This E.M.F. is measured by introducing into the circuit a sensitive galvanometer or millivoltmeter calibrated to read directly in degrees of temperature. At 1,100° C., a couple formed of iron and copper-nickel wires will generate 50 millivolts. For measuring temperatures up to 95° C., a thermo-couple of bismuth and antimony is best; for temperatures up to 500° C., a satisfactory thermo-couple consists of one iron wire and one 60 per cent. nickel and 40 per cent. copper; for temperatures as high as 1,000° C., a very satisfactory base-metal thermo-couple is one wire of 90 per cent. nickel and 10 per cent. chromium, and the other wire of 98 per cent. nickel and 2 per cent. aluminium. For constant service above this, a thermo-couple, one wire of which is chemically pure platinum and the other 90 per cent. platinum and 10 per cent. rhodium, is recommended.

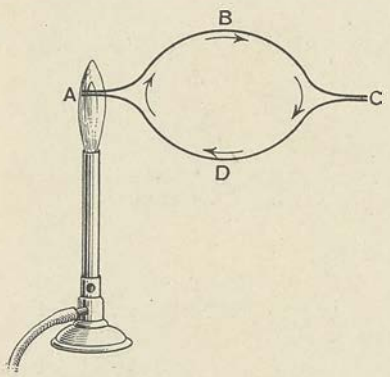


Fig. 136.

The thermo-couple instrument is found, broadly speaking, in two distinct forms. The " direct-insertion " instrument is very similar to that shown in Fig. 134, with the exception that a thermo-couple, fitted with the necessary leads, is substituted for the resistance coil. Probably, however, the most familiar instrument on gasworks is that in which the optical and thermo-couple principles are combined. These pyrometers possess the advantage that they are operated at a distance from the hot body through the action of radiant heat, and as no part actually comes in contact with the heated object, there is no harmful influence upon the life of the instrument. With careful operation they will read within 1 or 2 per cent. of accuracy.

RADIATION PYROMETERS

The Féry radiation pyrometer is made in three patterns; for portable use, for continuously indicating, and for graphically recording temperatures. Each pattern has a telescope which is focused on the hot body, the heat rays being received on a concave mirror and brought to a focus on a small thermo-couple. The electromotive force produced by the consequent heating at one junction of the thermo-couple is measured on an indicating or recording galvanometer calibrated to give direct readings in temperature.

Fig. 137 illustrates the portable pattern. The outfit consists of a telescope, indicator, tripod, leads, and travelling case. The indicator, which is fitted with a double-pivoted moving coil, has a high sensitivity, but is at the same time of robust construction.

The indicator may be calibrated to cover any particular range of temperature desired from 500° C., but the standard ranges which will be found to meet most requirements are as follows :—

500-1,100° C.
600-1,400° C.
800-1,700° C.



Fig. 137.

The optical arrangement of the telescope is illustrated in section in Fig. 138. The heat rays A from the furnace are received on the concave mirror C and are brought to a focus at N. Looking through the eye-piece E, the observer sees an image of the heated body in the small mirror M, and is able to direct the telescope on the exact spot of which the temperature is required. The small sensitive thermo-couple is situated just behind a small hole in the mirror M, and becomes heated by the rays passing through this hole.

An ingenious device is fitted on all telescopes to make the operation of focusing the instruments as simple as possible. The mirror M, in which the observer sees the image of the heated body, consists of two small semicircular wedge-shaped mirrors fixed together. If the instrument is correctly focused, the appearance is as shown in the centre diagram of Fig. 139, in which the outer circle represents the mirror, the shaded portion the reflected image of the hot body, while the black centre is the sensitive element of the pyrometer. If the focus is too short, the image appears split in two parts, as in the left-hand diagram, whilst if it is too long, the appearance

is similar but reversed, as in the right-hand diagram. Turning the knurled head attached to the pinion F causes the upper and lower half-images to slide on one another, so that it is comparatively easy to arrive at the correct focus.

The size of the body focused on, and the distance of the telescope from it, do not, within wide limits, affect the readings. It is, in fact, only necessary for the body sighted on to be of such a size that its image will overlap the sensitive element on all sides.

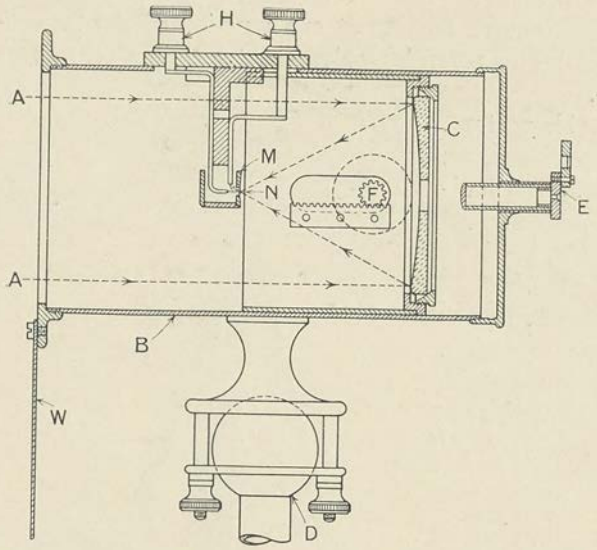


FIG. 138.—THE FÉRY RADIATION THERMO-COUPLE PYROMETER.

With the Féry radiation pyrometer the size of the object sighted on must be at least 1 inch in diameter for every 2 feet of distance between the telescope and the object.

The thermo-couples supplied with these instruments are of three different types, namely :—

(*a*) Silver and constantan, for temperatures up to 800° C.

(*b*) Platinum and platinum-iridium, for temperatures up to 1,000° C.

(*c*) Platinum and platinum-rhodium, for temperatures up to 1,400° C.

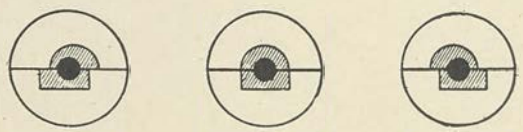


FIG. 139.

THE FOSTER RADIATION PYROMETER

Of the newer radiation pyrometers the Foster instrument (Fig. 140) presents some novel features. In the first instance, it is of the fixed focus type and, therefore, requires no adjustment. The receiving tube is pointed at the hot body and receives a portion of the radiant heat therefrom. The radiated heat received is focused, by means of a special mirror, on the junction of a minute thermo-couple. The E.M.F. generated at the thermo-couple is carried by leads to a separate recorder. The operation of the pyrometer is independent of the distance from the object, within certain fairly wide limits. However, a sighting device is incorporated in the tube,

whereby the user can verify accurately if he is within the requisite working distance.

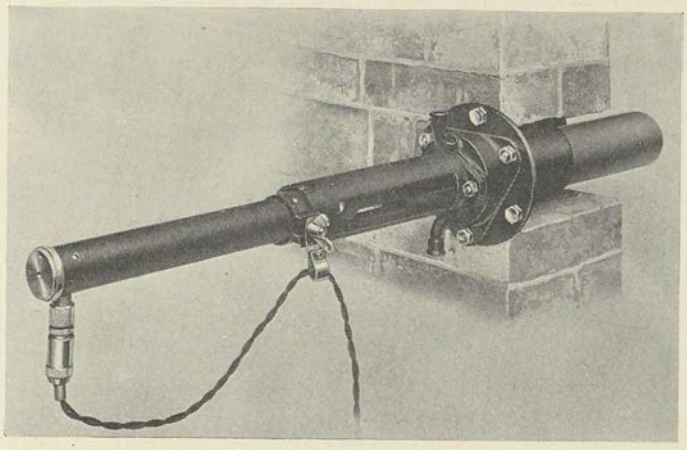


FIG. 140.—FOSTER RADIATION PYROMETER.

THEORETICAL CONSIDERATIONS

It is well known that the hotter a body is the more heat it radiates. When the body is of sufficient heat (*i.e.*, above about 500°) a portion of the energy issuing from it is visible as light. The intensity of brightness of a luminous body is measured by the rate of emission of luminous radiance per unit of area, and depends, therefore, upon temperature. It must be borne in mind, however, that in addition to the energy radiated as visible light there is another form of radiated energy, the wave lengths of which are too long to be seen by the eye. It so happens that in those instances met with in practice the invisible radiated energy is much greater than the energy derived from visible light, but in the modern form of radiation pyrometer radiated energy of all frequencies—whether visible or invisible—is almost entirely absorbed and converted into heat. It is in this respect that the thermo-electric instrument differs from the optical type, for the latter is dependent solely upon the visible radiations. Again, in the optical instrument it is customary to bring the visible radiations to a focus by means of a convex lens or a concave mirror, and exactly the same principle may be applied in the thermo-electric pyrometer with the invisible energy.

The Stefan-Boltzmann law states the relation between the temperature of a hot body and the energy which it emits. From this law it may be seen that the energy radiated is proportional to the fourth power of the difference in temperature :—

$$E_R = K\ (T_1^4 - T_2^4)$$

Where E_R = the radiated energy emitted.
,, K = a known constant.
,, T_1 = the temperature of the hot body (absolute).
,, T_2 = the temperature of the instrument (absolute).

Under ordinary conditions the temperature of the instrument becomes a negligible

factor ; so that, put briefly, it may be said that 1 per cent. increase in the temperature of the radiating body is followed by an increase of 4 per cent. in the energy received by the pyrometer. The rapid increase in energy at the higher temperatures accounts for the open nature of the scale calibrations at these temperatures as compared with the smaller divisions found at lower temperatures. An advantage which has also been pointed out is that a change in sensibility of 1 per cent. in the apparatus would only result in a change of 0·25 per cent. in the temperature reading.

Within fairly wide limits, the distance at which a radiation instrument is set up from the source of heat is immaterial. This consideration renders the radiation pyrometer particularly convenient for making quick observations during the brief period for which the retort doors are open. For the purpose of recording the temperatures prevailing in water-gas apparatus the radiation pyrometer is unsuitable owing to the impossibility of focusing any portion of the enclosed vessels. In such cases it is customary to employ the thermo-electric instrument having a thermo-couple enclosed in a protecting tube. The tube may then be built in through the sides of the vessel and left permanently in position.

DIRECT INSERTION INSTRUMENTS

Direct insertion thermo-couple instruments for supplying intermittent readings or a continuous record are made in several forms, and the decision as to which type should be employed depends upon the conditions to which it will be subjected and the accuracy required.

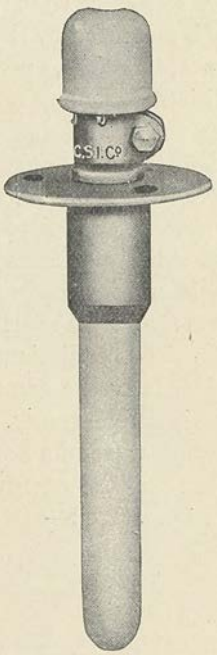


FIG. 141.—DIRECT INSERTION INSTRUMENT.

In general, the two main types as employed in this country may be classified as follows :—

(*a*) Thermo-couples consisting of platinum and platinum-rhodium for temperatures not exceeding 1,400° C.

(*b*) Base metal thermo-couples for temperatures not exceeding 1,000° C.

It is essential that rare metal couples should be protected by either quartz or porcelain tubes, and for temperatures exceeding 800° C. it is advisable that base metal couples should be similarly protected. A simple form of rare metal thermometer is shown in Fig. 141, in which the protecting porcelain tube is inserted in a socket supporting the porcelain head on which the terminal screws are mounted. If desired, a steel protecting sheath, not shown in the illustration, can be fitted. A pyrometer of this kind is useful for general testing work when it is not desired to instal it permanently. In oxidizing atmospheres, or where the couple is likely to come in contact with flame, a fireclay protecting tube and steel socket is used instead of the steel sheath.

The Cambridge Scientific Instrument Company have introduced three types of base metal thermo-couples, namely :—

(*a*) Titan couples for temperatures up to 1,000° C.
(*b*) Iron-Constantan rod thermo-couples for temperatures up to 800° C.
(*c*) Iron-Constantan wire thermo-couples for temperatures up to 600° C.

With a thermo-electric pyrometer the electro-motive force indicated by the galvanometer is proportional to the difference in temperature between the hot and cold junctions of the thermo-electric circuit. Hence, in order to obtain correct indications, it is important for the temperature of the cold junction to be known. To get over the difficulty of keeping the pyrometer head cooled by water or other devices, compensating leads are supplied which have the effect of transferring the cold junction to a position of known temperature, *i.e.*, to the indicator or recorder (or junction box if the connecting leads are of great length), and thus the temperature of the pyrometer head itself does not affect the readings.

Where a still closer accuracy is required, or in places where the instrument or junction box cannot be erected in a steady temperature, the cold junction may be placed in a thermos flask filled with oil, or in a steam vessel or hypsometer, through which steam at atmospheric pressure is passing.

The success of a pyrometric installation depends largely on the care taken in installing the pyrometers. Care should be taken in the method of protecting the leads used for connecting the pyrometer to the junction box or indicator. It will usually be found advisable to run the leads through flexible metallic sheathing either to the galvanometer or to the junction box. Where the leads are subjected to a high temperature they should be protected by asbestos before being placed in the steel sheathing. If the temperature is not high, then cotton braided leads may be used.

EXPANSION PYROMETERS

The Féry spiral pyrometer is a more compact and cheaper instrument than the Féry thermo-electric type, but it is less accurate. The methods of receiving the radiant heat and of focusing are exactly the same, but instead of using a thermo-couple which must be connected to a galvanometer outside the instrument, a very small bi-metallic spiral is used, and this controls the movement of a pointer which swings across a scale calibrated in degrees of temperature. The instrument is, therefore, entirely self-contained. Fig. 142 is a diagram showing the metallic spiral (much enlarged).

The action of the spiral when heated will be understood from the following consideration. If two strips of metal having different coefficients of expansion with temperature be soldered together to form one strip of double thickness, then, if the temperature be changed, the two sides of the strip will expand or contract by different amounts, thus causing the strip to bend. In the Féry spiral pyrometer the strip built up of two dissimilar metals is rolled flat and very thin and coiled into a spiral shape, so that as its temperature is raised the spiral uncoils. This spiral is very small, actually measuring less than $\frac{1}{8}$-inch (3 mm.) in diameter, and $\frac{5}{64}$-inch (2 mm.) wide. It is fixed at the centre, and its free end carries a light aluminium

pointer which moves across a dial. The instrument is calibrated so that the reading of the pointer on the dial indicates directly the temperature of the body on which the instrument is sighted. Focusing is effected in the same way as with the Féry thermo-electric instrument already described.

The three standard ranges for this pyrometer are 500–1,100° C., 600–1,400° C., and 800–1,700° C.

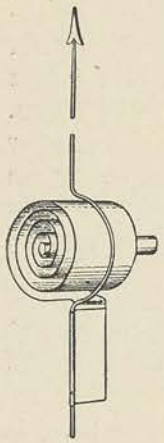


Fig. 142.—The Féry Spiral (4 times actual size).

GENERAL CONSIDERATIONS

It will be generally agreed that in point of convenience and scope of utility no types of pyrometer have attained so high a position as the resistance and thermo-couple instruments. The main consideration to be borne in mind is that the extent of accuracy which is required in the measurement of temperatures varies considerably with the purpose in view. The gas engineer for his general works purposes does not need a pyrometer such as would be essential to the research chemist. He can well afford to sacrifice 2 or 3 per cent. of accuracy for more tangible considerations, such as ability to withstand rough usage and bad conditions. In fact, it will not be considered uncomplimentary to say that the first care should be that of selecting an instrument which is "fool-proof."

One of the most notable features in the progress of industrial pyrometry during the last decade has been the widespread introduction of base metal thermo-electric pyrometers. This is mainly the result of the enormous increase in cost of platinum and other rare substances; but partly to the fact that base metal couples possess certain distinct advantages. One of these is the development of a large E.M.F., which enables more robust indicators and recorders to be used, and another is that the pyrometer itself may be strongly constructed and thus made less liable to injury in workshop use.

Although they are limited as regards temperature range—the upper limit being about 1,000° C. for continuous use—base metal pyrometers are suitable for a multitude of industrial purposes. The couples commonly employed are iron-constantan, two iron-nickel alloys of different composition, or two different nickel-chrome alloys. Attempts are now being made to devise a base metal couple for use at higher temperatures, the method which has been tried being to utilize the E.M.F. developed by a junction in which one or both of the metals may be in the liquid state. This is rendered possible by the fact that tin, aluminium, copper, and certain other metals may be used up to temperatures approaching the boiling-point, which ranges from 1,800° in the case of aluminium to 2,310° for copper, if the junction can be maintained.

A concise statement of the advantages to be derived from the use of pyrometers has been given by R. P. Brown,[1] who says that the extensive use of pyrometers to measure or record high temperatures will serve (1) to eliminate guesswork as to

[1] *Proc. Faraday Society*, November, 1917.

the temperature; (2) to reduce fuel consumption through the maintenance of the correct temperature and not excessively high temperatures; (3) to reduce time for heating of the product due to the maintenance of the correct temperature; (4) to increase generally the efficiency of operation.

Probably the gas engineer may yet live to see the day when he will be provided with instruments which will automatically control the temperatures of his various pieces of apparatus, and which will entirely eliminate the personal factor.

CHAPTER VIII

RETORT-BENCH APPURTENANCES

THE retort-bench fittings employed with modern horizontal settings do not vary in character to any marked extent. Various engineers employ different means for arriving at the same end; but the distinction in most cases is generally a matter of detail. In the first place, the chief items requiring consideration are :—

1. (*a*) The primary staying-up of the bench (*i.e.*, by longitudinal and transverse buckstays and ties).
   (*b*) The secondary staying-up of the individual setting, such as cross-bracing between the buckstays to prevent protrusion of the regenerators and the producer front. Also the bracing of the front walls above the producer, and the retention and support of retort mouthpieces in their correct position.
2. In addition, consideration has to be given to the various features in the design and erection of the retort mouthpieces, ascension pipes, bridge pipes, hydraulic mains, etc., so that the process of gasmaking may proceed with the regularity essential to the best results.

RETORT MOUTHPIECES

The self-sealing metal-to-metal retort door is now in almost universal use, except in the smallest of works making less than about 6 to 8 million cubic feet of gas per annum, which, for the sake of convenience, still adhere to the detached door with spent lime luting and central-tightening hand-screw. For small stop-ended retorts this method is advisable, particularly in cases where no facilities exist for readjusting the self-acting type. As the means wherewith hermetical sealing is obtained in the common type of door are not always fully understood, a diagram (Fig. 143) is given showing the principle employed. First, the tightening handle is forged with two eccentrics, as shown in Fig. 144, and the cross-bar passing in front of the lid turns on these eccentrics. At the same time, when the tightening handle is turned it revolves about the centre of rotation shown. It is thus seen that the eccentrics force the cross-bar towards the lid, and the bar—turning on the fulcrum formed by the clip B—transmits pressure to the centre of the door at A. By means of an eccentric bolt, with which the cross-bar is attached to the rib of the door at A, wear can be taken up and the pressure regulated. With the ⌂-shaped door the pressure is not applied at the true centre, hence it is greater at certain portions

of the faced rim than at others, this being an objectionable but unavoidable feature of the appliance.

The means employed for attaching the mouthpiece to the retort is of considerable importance, as an insecure joint soon gives way under the stresses of the stoking

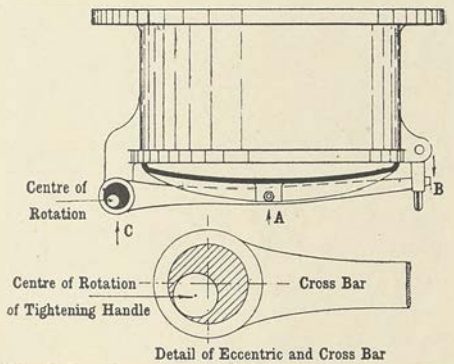


FIG. 143.—SELF-SEALING RETORT LID, SHOWING PRINCIPLE OF ACTION.

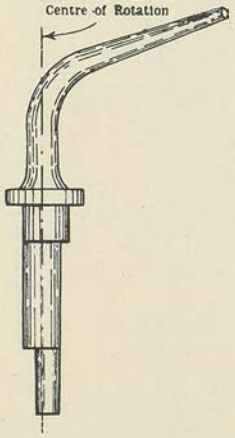


FIG. 144.—DETAIL OF TIGHTENING HANDLE, SHOWING ECCENTRICS.

machinery and pipe augering. There are three distinct methods now made use of for affixing the mouthpiece. The most common method (Fig. 145) is to cast the mouthpiece with a plain back flange, the flange being drilled at intervals for bolts, which are secured in slots in the thickened end of the retort. In this case some form of jointing material must be used between the flange and fireclay end of the retort, for which purpose the following usually gives the best results: One part of cast-iron borings to 2½ parts of fireclay, the mixture being just damped with a solution of sal ammoniac. The amount of sal ammoniac required is about 1 lb. to every hundredweight of the fireclay and borings. For this purpose sal ammoniac is to be preferred to ammoniacal liquor, as a more complete rusting action is set up.

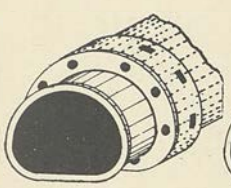


FIG. 145.—COMMON BOLT ATTACHMENT.

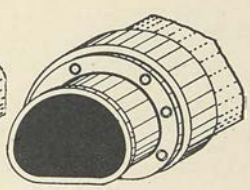


FIG. 146.—SHEATH ATTACHMENT.

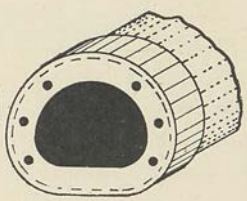


FIG. 147.—C.I. SHEATH.

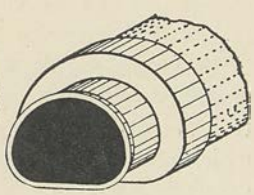


FIG. 148.—SHEATH AND MOUTHPIECE COMBINED.

METHODS OF ATTACHING MOUTHPIECES TO RETORTS.

A comparatively recent method of attachment is that shown in Fig. 146, in which a distinct sheath or socket is employed. The socket (Fig. 147) is made from cast-iron, usually ¾-inch thick throughout, and is passed completely over the end of

the retort, extending about 8 inches backwards. In this case the end of the retort is not thickened up, the lengths as laid having 3-inch walls throughout; and as a fairly tight fit is arranged for (slight chipping of the fireclay end often being necessary), no rust joint is employed, but the retort is given a wash of fireclay before the socket is fitted. Bolts, countersunk on the inside of the socket, form the attachment for the ordinary mouthpiece flange. The chief merits of the method are that the retort mouthpiece can be easily removed for repairs, the holding bolts are far less liable to burn or break away than with the common type of attachment, and, if properly fitted, a tighter, and at the same time more elastic, joint is obtained.

The third method (Fig. 148) is comparatively rare in this country, but possesses the advantage that no retort bolts whatever are required. It is really another means of carrying out the socket principle described above, with the difference that some initial expense is saved by casting the socket and mouthpiece in one. Its disadvantage, however, lies in the fact that the security of the mouthpiece is entirely dependent upon the cross bracing employed (although the latter can be made more effective owing to the absence of protruding bolts) and the socket portion has a tendency to crack. Once such a crack develops it is difficult to prevent a certain amount of gas leakage when the retort is under pressure.

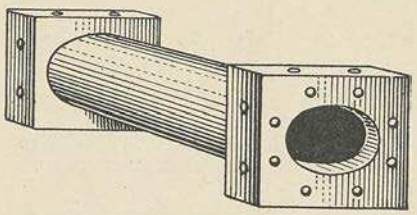


Fig. 149.

Figs. 149 and 150 show a method of fastening which has been adopted in Continental gasworks. The retort is made up in two parts, the heads, and the retort proper. With the more common types of fastening it is occasionally found that a rupture occurs in the retort adjacent to the mouthpiece, particularly during the starting up of the bench. This is due to the fact that the body of the retort, being directly above the producer arch, is exposed to the full effect of the heat, whereas the ends are still moderately cold. As a result, interior stresses are set up, which are followed by cracking, and it is claimed that in the system shown this defect is eliminated.

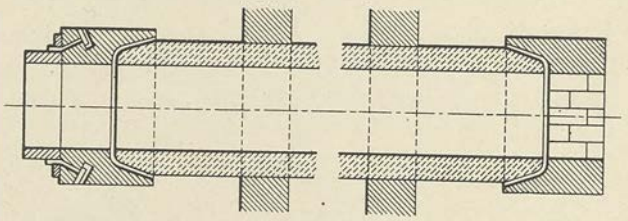


Fig. 150.

In addition to the bolt attachment, all retort mouthpieces must be stayed up by means of bracing attached to the main buckstays, and passing outside the front wall of the setting across the flanges of the mouthpieces. There are several means of attaching such bracing, the most common being shown in Figs. 151 and 152. In Fig. 151 a double bull-headed rail is carried in cast-iron brackets attached to the buckstays as shown. In many cases the rail is carried across vertically (as shown

dotted), so that an ample bearing on the lower portion of the flange of one mouthpiece and the upper portion of the flange of the mouthpiece just below may be obtained. The arrangement given in Fig. 153, although frequently seen, is not to be

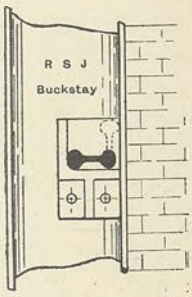


FIG. 151.—C. I. BRACKET FOR SUPPORTING BRACING RAIL FOR RETORT MOUTHPIECES.

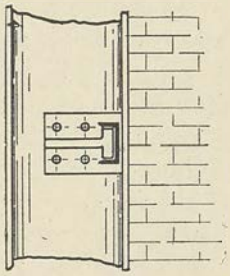


FIG. 152.—C. I. BRACKET FOR CHANNEL IRON MOUTHPIECE BRACING.

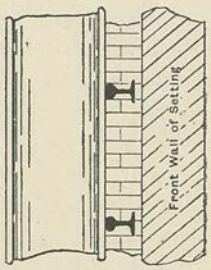


FIG. 153.—SINGLE BULL-HEAD RAIL SUPPORT.

recommended, particularly in view of the fact that the main buckstays do not bear direct upon the brickwork of the bench, an intervening space being left which is filled in with a false wall.

ASCENSION PIPES, BRIDGE PIPES, AND DIP PIPES

The point of chief importance with regard to the ascension pipe is, perhaps, its size. Present-day practice in this respect is towards ample area, so much so that in many cases the pipes in modern installations provide practically double the cross-sectional area considered sufficient a decade ago. In general, however, design may be considered on safe lines if carried out in accordance with the following :—

SIZE OF ASCENSION PIPES

Works making under 10 million cubic feet per annum . . .	5-inch pipe.
Works making between 10 million and 200 million cubic feet per annum	6 „ „
Works making above 200 million cubic feet per annum . . .	7 „ „

This rule refers, of course, to retorts having an ascension pipe at each end, in the case of "through" settings. In some recent horizontal benches, ascension pipes of 8-inch diameter have been fitted at each end of the retort. The chief difficulty with the larger pipes lies in inducing the attendants to clear them properly. For 7-inch pipes a 5½- or 6-inch auger is generally used, but above this size the augers become somewhat unwieldy and difficult to handle, so that there is some temptation to make use of them as little as possible. In the arrangement of ascension pipes it is necessary to keep them as far as possible from the centre of the setting, so that they are unaffected by the heat of the combustion chamber. There is also the question of curvature, for the purpose of working round the upper mouthpieces. All abrupt bends must be rigidly avoided, otherwise endless trouble in cleaning the pipes and in

the prevention of stoppage will ensue. Further, precaution must be taken to see that the jointing material used in the pipe sockets is not allowed to get past the spigot end, and thus be responsible for projections which partly stop the pipe and provide a lodgment for the formation of pitchy deposits. It is a good practice to make all ascension pipes slightly bell-mouthed at the spigot end so that there is no possibility of a ridge forming on which the auger may catch. So far as the general arrangement is concerned, as many of the pipes as conveniently possible should be carried up on the sides of the main arch nearest its springings, and it is necessary to avoid running up two pipes between any two mouthpieces, otherwise the retorts will have to be spaced wider apart in order to give sufficient room, this tending to spoil the heating arrangements of the interior.

The joints in ascension pipes must on no account be made with lead. Although rust joints of iron borings are not essential, they are to be preferred to any other material, in spite of the additional labour entailed in cutting them out during dismantling. For ascension-pipe, bridge-pipe, and dip-pipe joints the following material may be used :—

Cast-iron borings damped down with gas liquor, rammed well into the joint, and left. When the bench is got to work, the heat from the setting quickly hardens off the joint.

Many engineers prefer not to use gas liquor, and in cases where a particularly durable joint is required it should be made up as follows :—

To 2 cwt. of iron borings add 2¼ lb. of sal ammoniac, and 1 lb. 2 oz. of flowers of sulphur. This should be mixed to a stiff paste with water, and should preferably be kept for two days before use. If kept under water the material may be stored for several months.

Where borings are only obtained with difficulty, or to save expense, a very serviceable joint can be made from the following mixture :—

Ewell brick dust	1 part.
Slaked lime	2 parts.

This is rammed into the joint dry, no moistening whatever (beyond the slaking of the lime) being necessary. In cases where a cast-iron foul main is used, lead joints may safely be used in the sockets, and are desirable.

STOPPED PIPES

The introduction into the larger works of the mass system of carbonization has proved the most effective deterrent to the old-time trouble of continually stopped ascension pipes. The absence of deposits may be chiefly attributed to the lower temperature of the escaping gases and the increased velocity with which they travel through the pipe. In addition, the elimination of an excessive "free space" in the retort accounts for less degradation of the hydrocarbons, with the result that a minimum quantity of free carbon is carried forward in suspension by the gas. It is such solid particles (also those drawn up from the cloud of coal dust inseparable

from some types of charging machines) which, by adhering to the tarry surfaces of the interior of the pipe, promote obstruction. Once started, such obstruction grows apace.

When the temperature of the issuing gases is high—such as with light charges or layer carbonization—the escaping tarry vapours undergo distillation and redistillation in the pipe until a pitchy mass capable of no further volatilization remains. The most satisfactory means to avoid stoppage is to ensure that every pipe is augered each time the retort is opened for charging, whether there is any apparent obstruction or not. Some engineers prefer to arrange for an auger gang to pass right through a definite row of pipes an hour or so before the charges are withdrawn. In this way the work of charging and drawing is not delayed, and it is claimed that the time is favourable for the operation owing to the condition of the tarry mass.

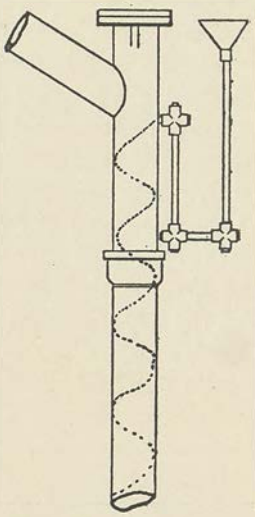


FIG. 154.—WATER-FEED FOR ASCENSION PIPE.

Many ideas have been introduced with the object of avoiding trouble from stopped pipes, and one of the earliest of these was the admission of a small trickle of water to the apex of the ascension pipe by means of a gooseneck (Fig. 154), or by the Darwen pipe (Fig. 155). In this way the temperature of the pipe is lowered, whilst the steam produced aids in carrying away a portion of the tarry vapours before their distillation can take place. Another means of arriving at the same result is to add a small proportion of water to the coals before carbonization, but this is not to be recommended. In some cases a small steam supply has been admitted direct to the base of the pipe, but its use appears to be attended with mixed results, although the process of steaming on orthodox principles appears to be followed by decidedly beneficial results. A precaution, however, which calls for attention is the avoidance of cutting draughts around the pipes, and local cooling. Where the latter occurs in any degree, trouble will nearly always be experienced; and in some works provision has been made for ensuring uniform temperatures by jacketing the pipes with non-conducting material. This would certainly seem unnecessary in any but very exceptional cases; but care should be given in the design of the house so that draughts are avoided, whilst ample room should be left around the ascension pipes for the effective circulation of air.

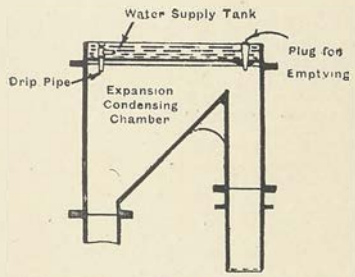


FIG. 155.—THE DARWEN PIPE.

Some interesting work in connection with stoppages in ascension pipes has been carried out by M. Coudelou [1] in France. This investigator found that the

[1] *Proc. Société Technique du Gaz*, July, 1919. *See also* Gas J., CXLVI, p. 243.

deposits taken from the pipes contained on an average 6·75 per cent. of volatile matter, 91·75 per cent. of fixed carbon, and 1·5 per cent. of ash. It having been suggested by some that these deposits were due to the formation of pitch by the distillation of tar in the ascension pipes, Coudelou made several tests to disprove the theory by raising the temperatures in them. The maximum deposit was found at 280° C. (536° F.), which is too low a temperature to produce pitch.

If the diameter of the ascension pipes is insufficient in proportion to the gas production, the speed of the gas in them is increased until the dust from the retorts is no longer deposited in them, but carried forward and left in the hydraulic mains, where a thickening of the tar takes place. Coudelou verified this by a comparison on five different gasworks. In those where the gas travelled in the ascension pipes at the low speed of 5·5 inches to 6·1 inches, the dehydrated tar from the hydraulic mains contained only 2·4 per cent. of carbon, as against 27·9 to 29·6 per cent. where the speed of the gas was 8·9 to 9·4 inches. The tar in the first instance was fluid, and the hydraulic mains needed no watching, whereas in the second case they needed cleaning daily—the tar quickly becoming thick. The following table shows the results obtained at the works in question :—

	A	B	C	D	E
Length of retorts, feet	9	9	18	18	18
Diameter of ascension pipes, inches	4·9	6·1	7·1	7·1	7·1
Length „ „ feet	13·9	15·3	14·4	15·3	13·8
Period of carbonization, hours	6	6	8	8	8
Charge per retort, cwt.	2·4	3·3	10·6	10·6	10·6
Average quantity of gas in an ascension pipe, cubic feet	5·5	5·0	8·1	8·4	8·4
Mean hourly make per retort, cubic feet	240	339	738	777	777
Mean period during which gas remains in ascension pipe, seconds	27	32	19	19	17
Analysis of tar from hydraulic mains :					
Water incorporated, per cent.	6·4	4·6	9·5	..	10·6
Carbon, per cent., crude tar	22·4	23·3	25·3	..	26·5
Carbon, per cent., dehydrated tar	23·9	24·4	27·9	..	29·6

The thickening of the tar in the hydraulic mains, Coudelou says, could only result from the mixture of carboniferous dust with it. The theory of a distillation of the tar must be put aside, the temperature being too low for the formation of pitch.

The conclusions are that the diameter and length of the ascension pipes should be such as to allow readily of condensation, and to prevent the gas passing through them too rapidly. They must be kept as clean as possible ; and variations in their sectional area, and sudden changes of direction of the gas in its passage, must be avoided.

THE SINGLE ASCENSION PIPE

In recent years there has been some tendency to work with only one ascension pipe for the removal of the gas from a through retort, instead of providing a pipe at each end, as is the more common practice. When the single pipe is used it should, for the standard sizes of through retorts, never be less than 8 inches in diameter. The following are the advantages which may be claimed for the single-pipe system :—

(*a*) Owing to the necessity of providing only one set of ascension pipes, dip pipes, hydraulic main, tar towers, foul main, etc., to each retort setting, the saving in initial cost is considerable. It must be remembered, however, that two hydraulic mains should be used when there are ten or more retorts to the setting, also with settings of " eight " in two rows. This is owing to the limitations imposed by the width of the arch.

(*b*) There are fewer pipes to keep clear. At the same time the pipes are larger, and the labour, therefore, is more arduous. When the pipes are all on one side, the men can keep away from the stoking machinery, and are thus out of the way, whilst there is less liability of coal dust being carried up the pipe.

(*c*) There is said to be greater immunity from stopped pipes.

(*d*) The system lends itself admirably to steaming.

With regard to statement (*c*), it must be taken with a certain amount of reserve, as experience with single pipes has hardly been such as to definitely establish this fact. The disadvantages of the system are :—

(*a*) It cannot be satisfactorily employed when the retorts are fully charged, for although a vacuum may obtain in the end of the retort nearer the pipe, there may be a heavy pressure at the other end, owing to the gas way being choked by swelling of the coal, uneven charging, etc.

(*b*) With light charges the gas travelling from the farther end of the retort is in contact with the hot walls for a considerably longer period than is the case when two pipes are employed. Hence the effect of degradation will be more noticeable.

(*c*) If the single pipe becomes choked there is no alternative outlet for the gas ; but, as previously noted, no well-managed works should have a completely choked pipe.

BRIDGE PIPES

The change of direction of flow of the gas from the ascension pipe to the dip pipe is effected by means of the bridge, arch, or saddle pipe. When direction has to be altered in this manner a certain amount of friction is inevitable. The change must be effected as gradually and smoothly as possible, so as to avoid mechanical deposition of the tarry vapours and suspended particles. To this end sharp angles must be avoided. An equally important feature in connection with the bridge pipe is that of ensuring easy access to all sections of the pipe way. Various types of bridge pipes are illustrated (Figs. 156 to 161). Fig. 156 is chiefly found in the smaller works. The design shown in Fig. 158 should be avoided, for, in spite of easy access to all sections, the change of direction is far too abrupt. The " Bournemouth "

type embraces many advantages, chief among these being the means of cleaning, both branches being accessible by the removal of a single flange, and that not a cumbersome one. The joints of bridge pipes should be made of similar material

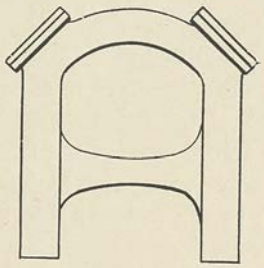


Fig. 156.

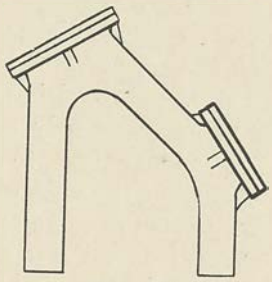


Fig. 157.

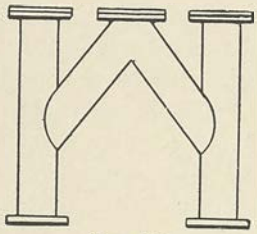


Fig. 158.

to that employed for ascension pipes. In the "Darwen" pipe (Fig. 155) a large expansion and cooling chamber is provided at the top of the ascension pipe, whilst

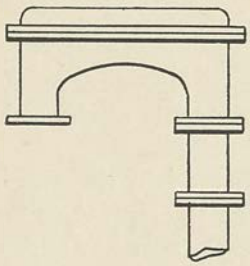


Fig. 159.

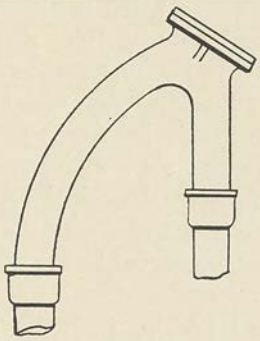


Fig. 160.
The Bournemouth Type.

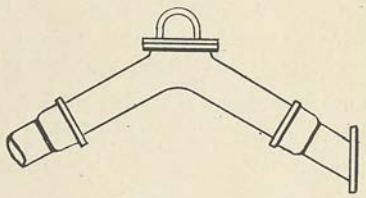


Fig. 161.
For Vertical Retorts.

the top of the bridge forms a water-supply tank which feeds a drip cock immediately above the rising pipe.

DIP PIPES

Dip pipes may be connected to the bridge pipe by means of either flange or socket joints ; the latter are the more common. The pipe is always connected to the hydraulic main by a flange. Although in many cases the seal end of the dip pipe is left square, it is now generally recognized that more effective working ensues if it is turned to a knife edge, as seen in Fig. 162. By this means less oscillation of the liquor takes place, the gas spreads more effectively, and suspended tar vesicles are more easily removed. For the last-named reason some engineers prefer the serrated end as in Fig. 163.

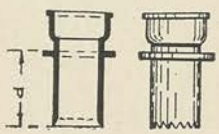


Fig. 162. Fig. 163.

Some care is necessary during the erection of dip pipes in order to ensure that the seal on each will be the same. Providing the hydraulic mains have been laid

on a perfectly even keel, a uniform seal may be best obtained by machining a small portion of the upper face of the dip-pipe flange. When turning up the dip edges the distance (*d*), Fig. 162, can be made constant for all pipes. When the pipes are in position, ready to be permanently tightened down, a straight edge can be run along the turned portion of all flanges. So long as the straight edge remains level the dip pipes will then all be level at the lower edges, and any flanges not complying with the line of level can be there and then adjusted. This method is preferable to running a straight edge underneath the dips and inside the hydraulic main; and, if necessary, the dips throughout the whole house can be brought to a common level with ease.

When a retort bench is picked-up from cold, some means must be provided for permitting any slight movement of the ascension and bridge pipes. This may be allowed for by making one of the socket joints (preferably that where the bridge pipe and dip pipe meet) of slag wool to a depth of about 2 inches in the socket. This will permit movement; and when the heats are fully raised, the remainder of the joint may be made with borings in the usual way.

The Bergmann expansion bell-joint (Fig. 164) has been introduced in order to provide for expansion. An annular packing of asbestos is placed between the pipe and the socket so as to make a gastight joint. Moreover, the lower portion of the socket forms an annular recess which serves as a seal when the liquid accumulates there.

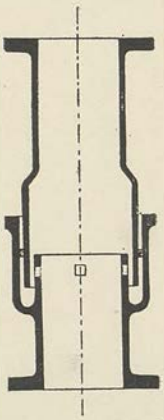


FIG. 164.—THE BERGMANN EXPANSION JOINT.

THE HYDRAULIC MAIN

Although there are still many cast-iron hydraulic mains in use, they are now never erected where renewals or extensions are carried out. Mild steel plates put together with the aid of angle sections are the modern practice, the plates being from $\frac{5}{16}$-inch to $\frac{7}{16}$-inch thick, the usual being $\frac{3}{8}$-inch. With regard to covers, cast-iron is still in many cases employed with the steel main, the reason being that owing to the numerous holes for dip pipes and bolts for flanges the steel cover is somewhat more costly, and is apt to spring unless stiffened. The steel hydraulic main is rarely made square in section, favourite designs being those of a ⊔-shape or with semi-circular bottom as at A in Fig. 165. From every point of view, however, the type shown in Fig. 167 may be looked upon as the most effectual. The base is given a decided fall to the tar outlet pipe connecting with the tar main or tower; and, in addition, the main is sloped longitudinally to the same pipe, so that in elevation it is V-shaped. One of the most important features is the apron plate, as seen, which permits of the thorough cleaning away of pitch or other deposits which may tend to block the tar-outlet pipe. A cock, as shown, should always be fitted to the tar pipe from each box, so that in the event of the cast-iron pipe breaking, the cocks may be shut and the unsealing of the dip pipes prevented. If a weir valve is employed, so that gas and liquor pass out of the box together, a tar shield, as shown

in Fig. 168, should be attached to the front of the overflow. The heavier liquor and tar from towards the bottom of the hydraulic main will then flow away first.

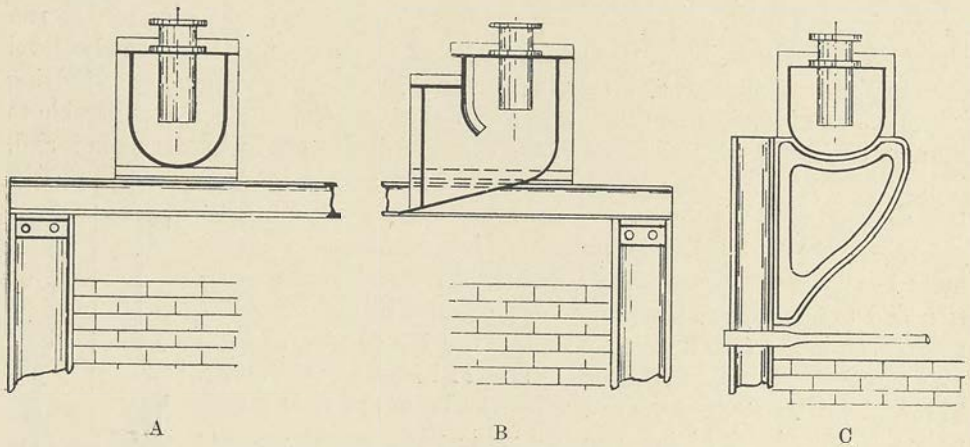


FIG. 165.—METHODS OF FIXING HYDRAULIC MAINS.

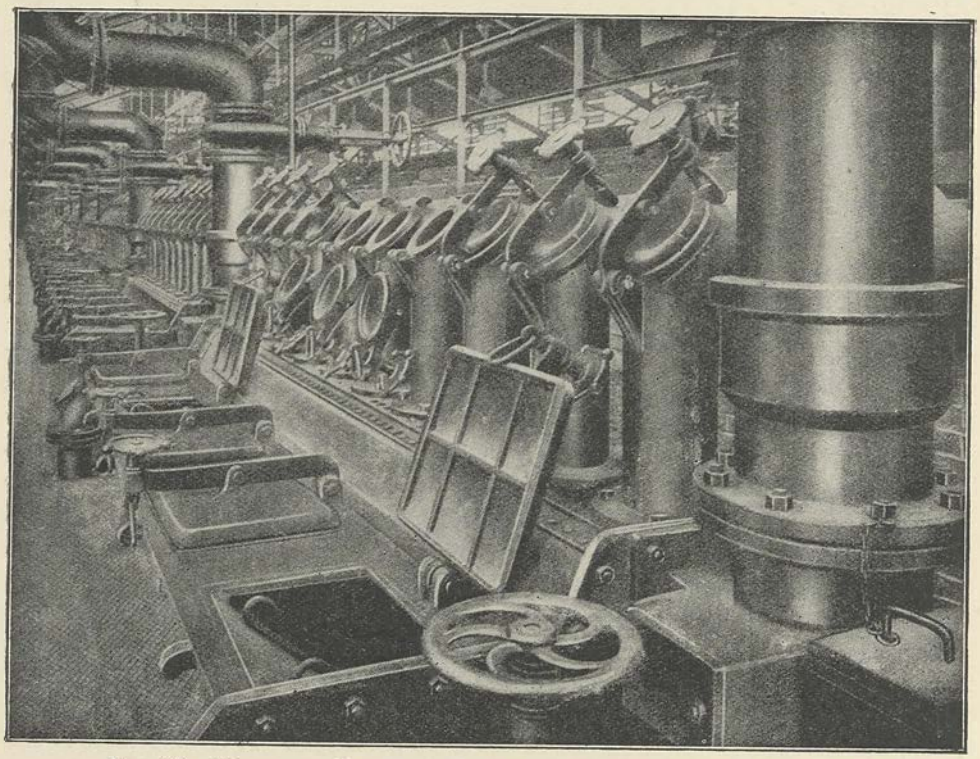


FIG. 166.—HYDRAULIC MAINS FOR VERTICAL RETORTS. COLOGNE GASWORKS.

A Continental type of hydraulic main with weir valve is illustrated in Fig. 169. The main is provided with cleaning boxes fitted with automatic sealing devices having hand-wheel, screw, and locking bow. The special design of tar shield, in reality performing the duty of a tar box, will also be noticed.

Hydraulic mains as now erected are either :—

(*a*) Distinct mains, *i.e.*, one to every retort bench, on either or both sides ; or

(*b*) Continuous mains, *i.e.*, one uninterrupted main extending over a number of (usually six) retort benches.

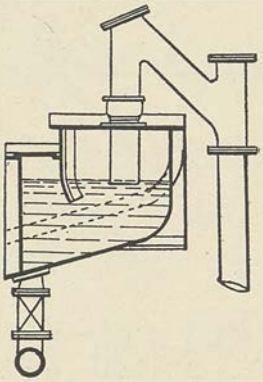


FIG. 167.—MODERN FORM OF HYDRAULIC MAIN.

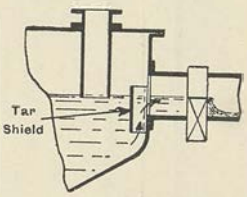


FIG. 168.—TAR SHIELD FOR HYDRAULIC MAIN.

Although the latter type is somewhat less expensive as regards first cost, the advantages lie on the side of the distinct main, which is more easily adjusted. In addition, a single setting can be readily isolated, and easier control is assured. In many of the continuous mains it is customary to avoid the use and expense of long foul mains by arranging the gas take-off (or gas and liquor take-off over a weir valve) at the extreme end of one of the sections. This method has, of course, its advantages ; but one of the chief troubles with hydraulic mains is the oscillation of the liquor therein, so that the dips are alternately lightly and heavily sealed as the crests and depressions of the waves pass around them. As the " draw " on the hydraulic remains constant, the pressure or vacuum in the pipes connecting with the retort is accordingly affected by considerable fluctuation. When, however, the gas take-off is arranged at the end of a length of continuous main, the " draw " from the exhauster appears to exert an influence on the surface of the long stream of liquor and to give rise to pronounced wave-motion.

Such is the effect of liquor oscillation that various means have been devised to restrict it. Among these are Meunier's floats (Fig. 171). The floats, made from wood, are placed in the hydraulic main at, or partially below, the surface of the liquor, and, by means of a series of holes about 1 inch in diameter, free egress is provided for the gas. It is stated that a far more uniform level of liquid is maintained in the hydraulic, there is thorough contact between the gas and liquid, and retort pressures are more constant. Attached to the floats are dip-pipe sleeves (Fig. 172), wherewith the seal of the pipes can be either mechanically or automatically controlled by means of rods passing through stuffing boxes, as shown. The inventor states that with the application of the floats he has found an increase in gas make of from 10 to 12 per cent., whilst the trouble from naphthalene is consider-

ably curtailed. The latter result is said to be due to the floats retaining the gas in longer contact with the hot liquid in the hydraulic main than is the case in ordinary working.

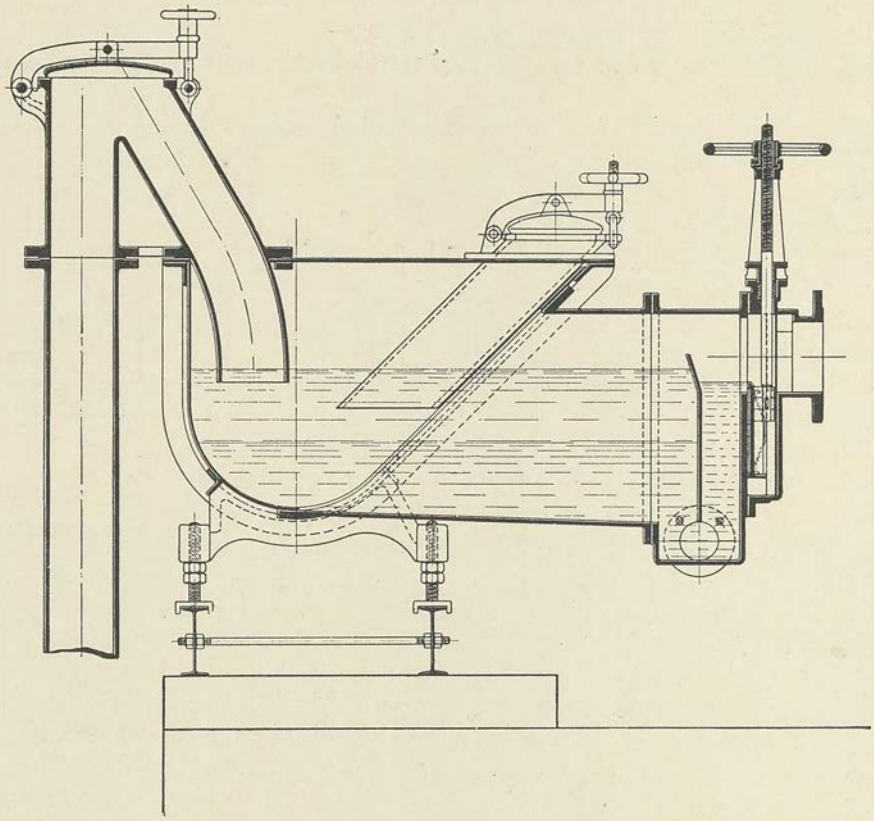


FIG. 169.—HYDRAULIC MAIN WITH ASCENSION AND DIP PIPES, CLEANING HOLE, AND COMMON GAS AND TAR DISCHARGE. DRORY SYSTEM.

H. E. Bloor and J. B. Fenwick have introduced a hydraulic main of a new type, the chief object of which is to avoid the necessity for tar mains, and to permit of the easy removal of deposits of thick tar.

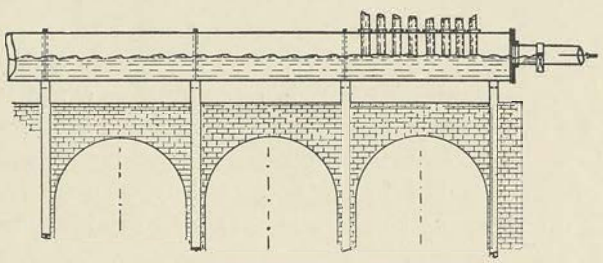


FIG. 170.—CONTINUOUS HYDRAULIC MAIN WITH END GAS AND LIQUOR TAKE-OFF, SHOWING EFFECT OF OSCILLATION DUE TO EXHAUSTER PULL.

The main is in one continuous length of 60 feet; and it slopes 2½-inches per setting to the tar tower. Division plates between each setting allow any setting or settings to be left-off; and the main can be carried over the end of the bench

with a connection taken direct to the tower. The cover plates for the open side of the main are dished, and are sealed in shallow lutes, so as to reduce to a minimum the loss of ammonia. There is only one main per bench, on the machine side. All the ascension pipes are 8 inches in diameter.

A recent attempt has been made to construct hydraulic mains from reinforced concrete. As an emergency measure during the late war, Martineau constructed ten of such mains for use at a French gasworks.

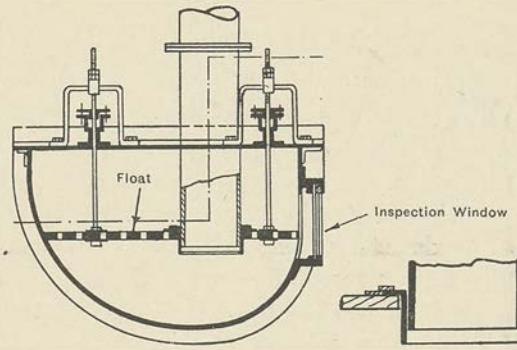


FIG. 171. FIG. 172.

MEUNIER'S FLOATS.

The metallic reinforcement consisted of a network of $\frac{1}{4}$-inch round iron wire formed in squares 4 inches by 4 inches. The concrete walls had a thickness of $2\frac{3}{8}$ inches, and the valve of the tar-outlet was let into the cement. A rebate along the upper part of the main received the cover, formed of a slab of cement into which were set the inspection and cleaning boxes. Before being put into use, the interior surface of the main, as also the lower side of the cover, was given three coats of hot tar. This was done in order to close up the capillary passages in the cement, and thus prevent any action of ammonia upon the metallic reinforcement—the continuous flow of tar during the working maintaining this protective coating. The main was put into use without any mishap in the way of expansion or leakage. Test pieces of cement placed in it at the time of commencing operations, and examined six months afterwards, showed no sign of any action on the cement by the ammoniacal liquor. Martineau expressed himself as wholly satisfied with the result of the measure imposed upon him by circumstances. The ten mains were constructed in six weeks at a cost of 60 per cent. less than the prevailing prices for steel mains.

With regard to the gas take-off from the hydraulic mains, this should be arranged from the cover of the box, rather than from the side, as is so frequently found.

The method by which the hydraulic main is supported in its position above the retort bench requires careful consideration. As the chief function of the main is to provide a seal, it is essential that it should be maintained on a perfectly even keel; hence the supports must be such that they are entirely uninfluenced by any movement of the bench which may take place when heating-up occurs. In the past it was a favourite practice to bed the main on brick piers or cast-iron standards erected immediately on top of the retort bench; thus when any movement of the latter occurred the mains were thrown out of level. Modern fixings for hydraulic mains which render them entirely independent of the bench movements are shown in Figs. 165 and 169. That shown at C, Fig. 169, is, perhaps, not so desirable as the other methods, as if tightening of the main tie rods is necessary, the upper portion

of the buckstays is slightly canted over, with the result that the main may develop a slight twist. All the methods are, however, subject to this effect in some degree. A very fine adjustment can be obtained by the screwed supports shown in Fig. 169.

THE FUNCTIONS OF THE HYDRAULIC MAIN

The principal functions of the hydraulic main are :—

(*a*) To act as a seal so as to prevent air being drawn up the ascension pipe when the retort doors are open.

(*b*) To act as a safety seal in the event of sudden heavy back-pressure being thrown by the apparatus following, particularly in the event of the exhauster pulling up.

(*c*) To form a receptacle for the tar and aqueous vapour condensed from the gas at the early stages of manufacture.

(*d*) To act as a primary washer.

The seal on the dip pipes is, therefore, liable to be overcome—

(*a*) by the vacuum induced by exhausting ;

(*b*) by the stoppage of the exhauster (or from some other cause) and the consequent back-pressure thrown on the hydraulic main, in which case the liquor in the main is forced up the dip pipes.

The conditions of retaining the seal are, therefore, dependent upon the relative areas of the hydraulic main and dip pipes. Theoretically, if—

x = the combined cross-sectional area of all dip pipes leading into the main,

y = the total cross-sectional area of the main, and

d = the extent to which the dips are sealed when the box is open to the atmosphere,

then the total back-pressure which the pipes will withstand before letting back gas (neglecting any variation in density of the liquid)

$$= d + \left(\frac{y - x}{x} \times d\right)$$

Thus with a $\frac{1}{2}$-inch seal, which is frequently found with modern methods of obtaining high gas "makes," the back-pressure which would be withstood is 6 inches, on the assumption that the respective areas x and y are as 1 to 12, or 10 inches if the ratio is 1 to 20. At the time when this function of the hydraulic main was conceived seals were commonly so much as 3 inches in depth, and capable of withstanding a back-pressure of 30 inches.

On the other hand, the amount of "draw" which can be applied to the main before the seal is broken forwards is given by the following :—

"Draw" must not exceed—

$$d + \left(\frac{x}{y - x} \times d\right)$$

providing that no overflow for the liquor is employed. That is to say, with a 1-inch seal the vacuum before the seal is overcome may equal $1\frac{1}{11}$ inch, or with a $\frac{1}{2}$-inch

seal 0·54 inch, again assuming a ratio of areas of 12 to 1. But on all systems of hydraulic mains some form of liquor overflow, whether it be by weir valve or tar tower, is imperative; accordingly the above formula has little bearing on the conditions of seal in the hydraulic main. If a permanent overflow is provided, then the liquor outside the dip pipe can never rise above a certain level; consequently, the difference in level of the liquid in and outside the pipe during the application of a vacuum will be brought about solely by the fall in level of the liquid inside the pipe. Hence, if a vacuum of 1-inch is applied to the hydraulic, the liquid in the dip pipe will fall 1 inch. Consequently, before the seal is broken a "draw" equivalent to the original seal can be applied.

ANTI-DIPS AND DRY MAINS

Since with modern methods of carbonization there is frequently a vacuum in the ascension pipe, so that air is drawn forward when the retort doors are open, and, furthermore, it has been shown that the safety-seal function of the hydraulic is, with light seals, practically valueless, there is strong reason to suppose that the liquor seal could be dispensed with altogether. In order, however, that the in-drawing of air, with its consequent deteriorating effect upon the quality of the gas, may be precluded, the device known as the anti-dip has been introduced. Primarily, it consists of a receptacle similar to the hydraulic main, but without the permanent liquor seal, means being provided for closing the inlet to the main during the time when the retort doors are open.

The chief claims which can be made for the dry main are the following:—

(*a*) The liquor (or tar) seal is abolished, consequently any deterioration which the gas may suffer, due to the bubbling, is avoided.

(*b*) There is no continuous fluctuation of pressure or vacuum in the ascension pipe, and consequently in the retort. In fact, oscillation is absent.

(*c*) No air is pulled in during the time the retort doors are open, as is often the case with the hydraulic seal.

(*d*) Little, if any, pressure in hydraulic main and retort, therefore less scurf formed.

(*e*) If the main gets out of level the consequences are not very serious.

On the other hand, the appliance for making and breaking the seal entails the use of fairly costly apparatus, which increases the original expenditure and the wear and tear.

Anti-dips now in use may be classified under three distinct heads, namely:—

(*a*) Those where, by means of some form of plug or valve, the free-way in the ascension pipe is completely closed. This may be done by a butterfly or plug valve in the arch pipe, or by closing the open end of the dip pipe by means of a movable plug.

(*b*) Types in which the liquor is raised at will, so as to seal the dip pipes.

(*c*) Types in which the liquor is lowered at will so as to unseal the dip pipes.

The earliest forms of anti-dips were mainly constructed on the principle of the

first of the above, one such being illustrated in Fig. 173. In most cases, however, these have proved more or less unsatisfactory, chiefly owing to sticking of the plugs or valves due to the accumulation of tar, or to the imperfect closing of the valves so that they are not gastight. Modern improvements of this type of anti-dips

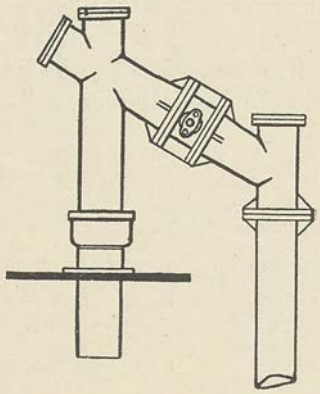


FIG. 173.—SIMPLE THROTTLE-TYPE ANTI-DIP.

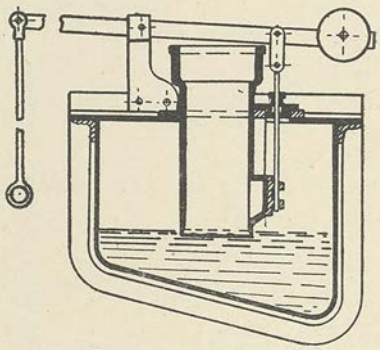


FIG. 174.—SIMMONDS' ANTI-DIP.

are the designs introduced by Simmonds and Davidson shown in Figs. 174 and 175. In Davidson's system the base of the dip pipe is machined on the inside so as to form a seating for the cast-iron cone suspended from the rod passing through a stuffing box in the specially designed bridge pipe. The cone is pulled up on to its seating and released by means of a weighted lever arrangement which is operated from the charging floor. The stuffing box is packed with greasy packing. The advantages claimed for this type are that it permits of continuous draining away of tar and liquor, so that the main is practically empty, and it does not—as is the case with so many dry mains—curtail the capacity of the main, or involve the use of complicated appliances which are out of reach during working.

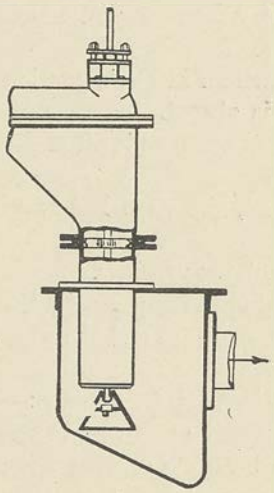


FIG. 175.—DAVIDSON'S ANTI-DIP.

In Simmonds' anti-dip the dip pipe is sealed in liquor in the usual way, and an aperture for the passage of the gas is provided in the side of the pipe above the liquor level. At this point a square valve face is cast on to the side of the pipe, the area of the gas outlet being equivalent to the cross-sectional area at the base of the pipe. The faced slide valve is operated by means of a rod passing through a stuffing-box and connected to a counter-weighted lever. The operating handle extends to the charging floor, being held down during the period of gasmaking so that the seal is by-passed, and released whilst the retort doors are open in order to prevent

the intake of air. A flange is provided at the valve-rod gland which gives sufficient room for the valve to be withdrawn when re-facing is necessary.

The same principle of interposing a liquor seal is made use of in Cort's anti-dip (Fig. 176), but in this case a double dip pipe is employed, the outer pipe being in the nature of a sliding sleeve. When the retort doors are closed the sleeve is drawn upwards to its fullest extent, so that the gas passes direct from the inner pipe to the foul main. When the doors are opened the sleeve, by means of suitable gear, is dropped, and forms a liquor seal which precludes the possibility of air going forward.

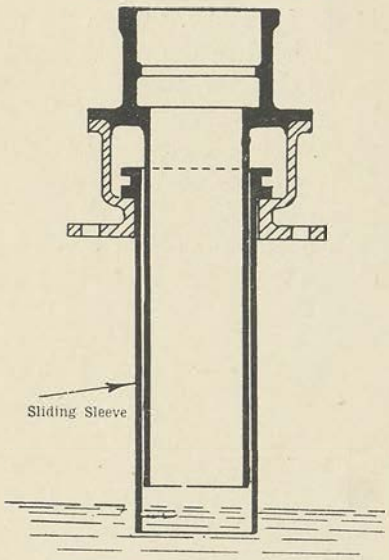


FIG. 176.—CORT'S ANTI-DIP.

Helps' anti-dip (Fig. 177) employs no mechanically operated appliance; hence one of the chief difficulties with dry mains is avoided. Attached to the back of the hydraulic main, and running the whole length of the main, is a displacement chamber. Communication is effected between the hydraulic and displacement chamber by means of the small pipes, as shown, whilst a three-way valve has two of its ports connected to the two connecting pipes respectively, and the third to a supply of gas under pressure, taken back (say) from the mains leaving the purifiers. The displacement chamber, by a turn of the three-way valve, is accordingly put in connection with the vacuum exerted on the hydraulic by the exhauster or with the pressure in the mains beyond the purifiers. The level of liquor in the hydraulic is set so as to give a clear passage through the dip pipe; and, when the retort doors are shut, the displacement chamber is under a similar vacuum to that prevailing

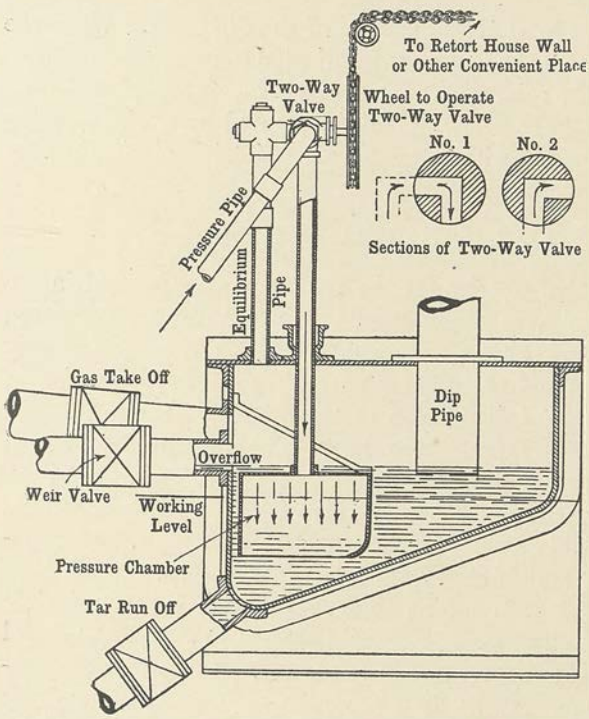


FIG. 177.—HELPS' ANTI-DIP.

in the hydraulic. When the retort doors are opened, however, the pressure gas is admitted to the displacement chamber. This causes a depression of the liquid in the chamber, with a corresponding rise in level in the hydraulic, the latter rise being sufficient to seal the dip pipes, thereby closing the free-way of the ascension pipes. The difference in level will, of course, be the same as the difference in pressure of the pressure gas used and the vacuum produced by the exhauster. In this system it will be noticed that all retorts in the bench are simultaneously sealed, whether their doors are open or not. A wheel is attached to the three-way valve, and the change is effected by a chain passing round the former and hanging down to the stage floor. It will be seen that the only working part, the three-way valve, never comes into contact with the newly made gas and tarry vapours.

Within recent years there has been a growing tendency to operate the hydraulic main with the dip pipe entirely unsealed. This practice has mainly been adopted with certain systems of vertical retorts, although it may be equally well applied to the horizontal bench. Two considerations enter into the reckoning, namely, that the yield of gas per retort and per ton of coal is undoubtedly enhanced by the elimination of the seal; but, on the other hand, unless extreme care is exercised the inert constituents in the gas may reach alarming proportions. As an example of an effective method of working horizontal retort benches with the dip pipes unsealed may be quoted the system in use at the Old Kent Road works of the South Metropolitan Gas Company. In this instance, the liquor in the hydraulics is maintained at a level just coinciding with the level of the bottom of the dip pipes. When the retort doors are closed the vacuum on the foul main is adjusted to from 3- to 6-tenths, whereas when the doors are open the conditions are reduced to level gauge. A retort-house governor is fitted to every four benches, and this is operated by a wire reaching down to the stage level and connecting with the necessary adjusting mechanism.

TAKE-OFFS FOR TAR AND LIQUOR

For many years the weir valve was by far the most common method in use for disposing of the liquor and tar from the hydraulic main. As before explained, the gas, liquor, and tar were removed through a common outlet, a tar shield usually being provided, so that liquor formed the greater part of the liquid remaining in the hydraulic. The three products of distillation then flowed together to the foul main, from the bottom of which the liquids were drawn off through seals and run to the storage wells, where separation, due to gravity, took place. In spite of the introduction of more effective appliances, the weir valve is still in fairly common use, and forms a ready and reliable means for the regulation of seals. The construction of the valve is simple, and is shown in detail in Fig. 178.

Another means for the disposal of tar and liquor is that introducing the principle of the tar box, in which the gas outlet is distinct from that of the liquids and seal regulation is effected by the height of overflow of the latter. The principle introduced is in reality that of the U-gauge, one limb being the hydraulic main and the other limb the tar-overflow pipe. The arrangement will be readily understood by

reference to Fig. 179. It will be seen that the tar-box casting is attached to the side of the hydraulic, seal regulation being effected by the running socket, as shown. Owing to the greater density of the tar, the height of the liquid level in the tar box will be slightly below that of the liquor in the hydraulic main. An important feature is the equilibrium pipe between the tar box and main, which ensures the same conditions prevailing above the two columns of liquid. Tar boxes of this type are, at the present day, very seldom erected, as they are not always reliable in their action and entail a good deal

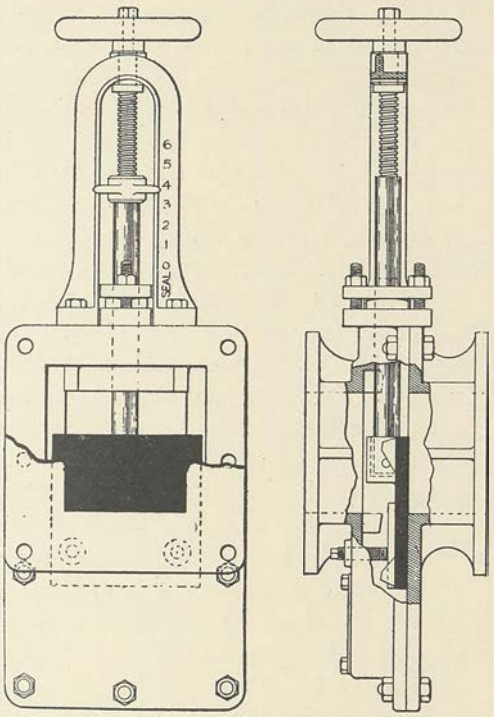


FIG. 178.—TYPICAL WEIR VALVE.

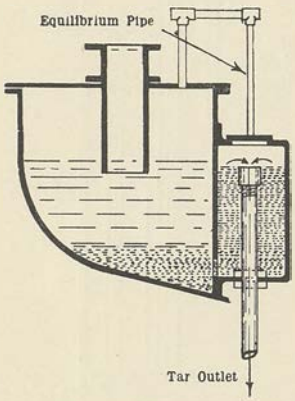


FIG. 179.—SHOWING PRINCIPLE OF ACTION OF TAR BOX.

of attention. They are, moreover, expensive in the first instance; and have largely given way to more modern principles.

TAR TOWERS

Probably one of the most striking features of present-day retort-bench equipment is the manner in which the Dillamore tar tower—an appliance originally introduced many years ago, but with mixed results—has forced its once-despised merits upon the attention of the gas engineer, so that it is now looked upon as furnishing a most effective means for seal regulation and tar and liquor disposal. It may be said that each engineer who favours tar towers has his own particular way of fitting them up; hence no hard and fast rules can be laid down. In general, however, it will be found profitable to aim at leaving the interior of the tower as unencumbered with pipework as possible, and with this end in view the author suggests the scheme shown in Fig. 180 as being the least costly and the most satisfactory from the stand-

point of reliability. The merits of tower systems are too well known to need repetition here. The more common defects which may go unnoticed for a time may be briefly summarized as follows :—

(*a*) In many cases an external or internal seal is employed, so that the liquor flow from the box may be readily seen. The warm liquor flowing out in this way is responsible for appreciable ammonia losses, and the liquor should preferably be led to a closely covered seal-pot.

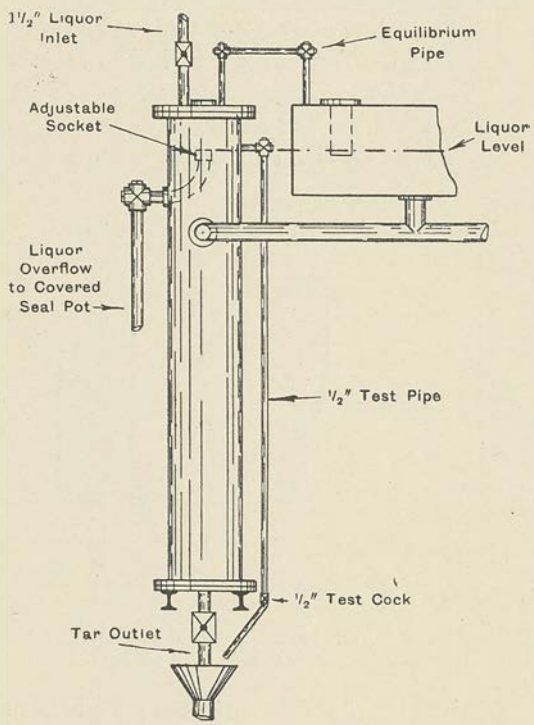


FIG. 180.—AN EFFECTIVE TAR TOWER SCHEME.

(*b*) Choked or partly choked equilibrium pipes may go unnoticed for some time, with the result that the seal on the dip pipes is not what it is thought to be.

(*c*) It must be remembered that a tar tower and the hydraulic main, connected together by the tar inflow pipe, in reality form a U-gauge, and the weights per unit of area of the two columns balance one another. Consequently, fluctuations in specific gravity in the liquid in the two columns will be responsible for a rise or fall in level, hence alteration of the seal. Differences in temperature are also followed by similar effects. It has been shown that if a variation of 30° C. occurs in the temperatures of the liquid in the tower and hydraulic main (for instance, if the temperature of the liquor in the tower rose from 20° C. to 30° C. and that of the liquor in the hydraulic main fell from 70° C. to 60° C.), this alone may be responsible for a variation of 4½-tenths in the seal. To minimize this effect as far as possible it is advisable to connect the main tar pipe to the tower as high up as can reasonably be done, and to ensure that the tower is flushed down before the accumulated tar reaches the level of this pipe.

(*d*) A special means should be provided for guarding against the possibility of unsealing the dip pipes when the tower is discharged. It is usual to run liquor into the tower whilst the tar is being run off ; but even under such conditions the outward flow may be greater than the inward flow, thus the level will fall. A simple means of seeing at a glance whether or not the seal is being maintained is to fit a ½-inch test pipe, as shown in Fig. 180. When the tower is flushed the ½-inch test cock is opened, and so long as liquor passes down the pipe a seal is ensured.

(*e*) The only questionable drawback to the liquor take-off from the tower as

shown in Fig. 180 is the possibility that the outlet pipe may become choked, and, owing to the liquor flowing into a covered seal-pot, the stoppage may not be immediately noticed. In this case the tower gradually fills, with the result that a heavy seal is thrown upon all the dip pipes. It is scarcely necessary to mention that on all installations of the kind, bends in the pipework should be rigidly avoided, and plugged crosses should be used wherever possible.

(*f*) It is always advisable to provide for a constant supply of liquor when towers are in use. Although this is frequently admitted at the hydraulic main, it is far preferable to arrange for a small supplementary supply to the top of the tower as well.

(*g*) In cases where outside or inside sealing arrangements are provided, care must be taken to ensure that all possibility of syphoning is avoided. To this end, some portion of the pipework must be open to the atmosphere, whilst it will be noticed that in the system shown in Fig. 180 this is not necessary, as syphoning could not take place.

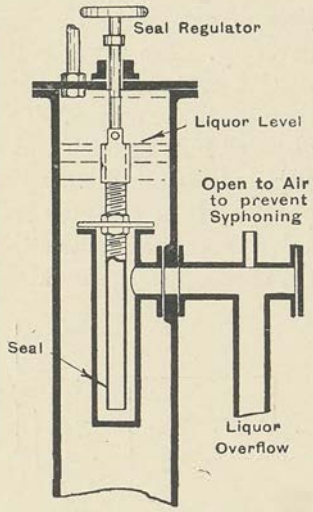


FIG. 181.—TOWER WITH INTERNAL SEAL.

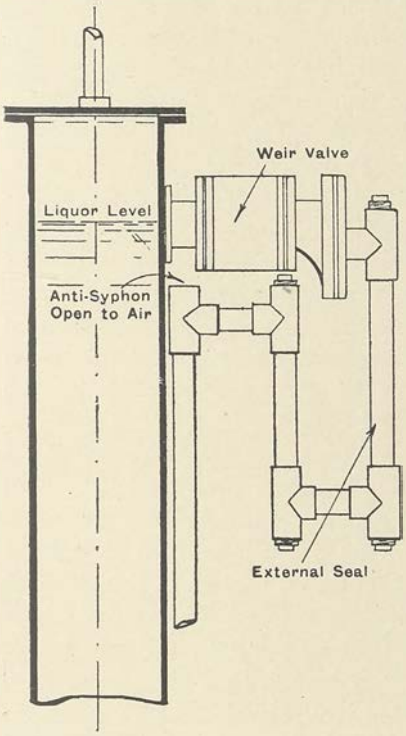


FIG. 182.—TOWER WITH EXTERNAL SEAL.

Sketches of the outside and inside seal types are given in Figs. 181 and 182, and the anti-syphon precautions will be noted. A decidedly uncommon and novel arrangement is that shown in Fig. 183. In this instance the depth of seal on the dip pipes is entirely governed by the constant overflow of tar, the outlet pipe for the latter being brought up from the base of the tower to a point sufficiently high to maintain the seal. Accordingly, it is tar, and not liquor, which is constantly trickling away; and since more liquor than tar is formed, a special draw-off cock for the former is provided about two-thirds of the way up the tower, and a certain amount of liquor is daily run off, so as to ensure there always being tar at the bottom of the tower. The chief advantage claimed is that the liquor may be worked up to greater strength than is the case with the more ordinary tower systems, whilst there is no constant stream of warm liquor running away to the wells.

An uncommon idea, infrequently met with, is that shown in Figs. 184 and 185. It con-

sists of combining the usually distinct apparatus of tar-tower and retort-house governor. The tower is made considerably higher than is general, and the upper portion contains a special receptacle which takes a floating bell of greater diameter than the tower proper. The bell chamber is closed by a cover plate having a centrally disposed hole through which a rod passes, by means of which the governor may be adjusted. Immediately below the bell chamber is the gas inlet. The subsequent passage of the gas may be seen from the section given in Fig. 185. The governor valve serves to throttle the passage of the gas should the vacuum increase above the normal, while, should the vacuum decrease, the valve is raised, with a consequent increase in the area of the gas passage, due to the increase in pressure of the gas on the bell.

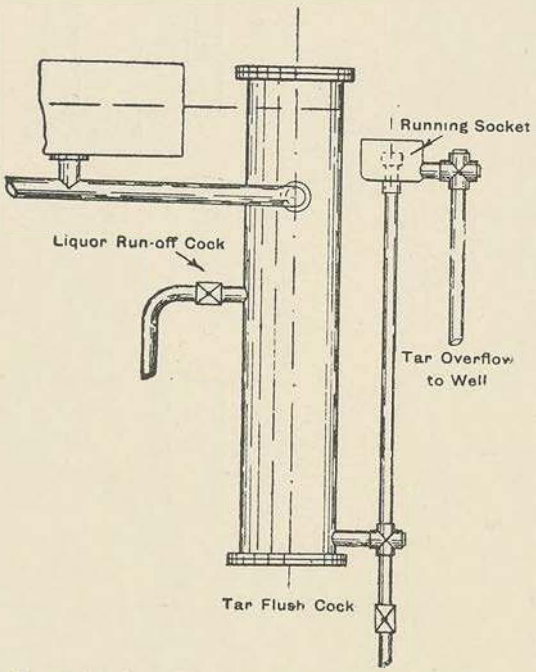


FIG. 183.—SEAL REGULATION BY TAR OVERFLOW.

During the last few years there has been a growing tendency to erect tar towers built up from mild steel plates and sections. It is somewhat difficult to understand why this should be done, for the ordinary cast-iron pipe cannot be excelled, and is extremely cheap. Possibly, the steel tower was originally introduced owing to the objection to sending cast-iron work long distances, when it is liable to rough handling and damage.

The experience of J. G. Newbigging in connection with ammonia losses may be mentioned, as bearing out the arguments that the internal or external seals with tar towers are unnecessary and actually wasteful, and that it is far preferable to take the liquor direct to an effectively sealed pot. It had been Mr. Newbigging's general custom to run liquor into his mains from an overhead tank, when striking differences in the amount of free and fixed ammonia led him to make investigations. Two deductions were made, the first being that ammoniacal liquor constantly overflowing the weir valves was in such a state that free ammonia was being driven off in large quantities, and, consequently, any exposure to either an air current in the pipe line or to the atmosphere meant a probable source of serious loss. To overcome such drawbacks, water, instead of liquor, was used for flushing the hydraulic mains, and in this manner ammonia loss was curtailed, owing, it is said, to a lower percentage of free ammonia in the liquor overflowing the weir valves. In view of these results, it might appear advisable to admit water instead of the usual trickle of liquor to the hydraulic mains, but the author considers the practice undesirable.

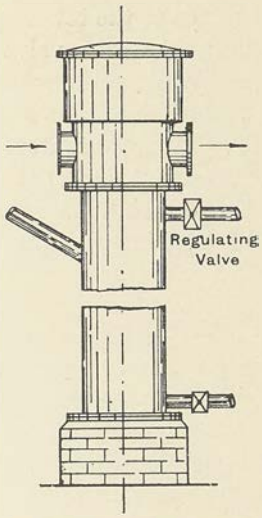


FIG. 184.—COMBINED TAR TOWER AND RETORT HOUSE GOVERNOR.

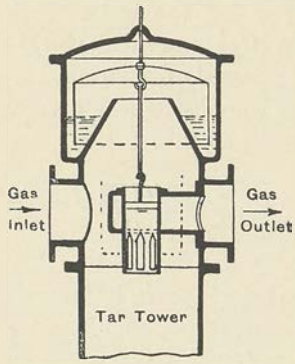


FIG. 185.—SECTION OF COMBINED TOWER, SHOWING THE GOVERNOR.

DRAKE'S HYDRAULIC MAIN REGULATOR

This system (Fig. 186), which is operated in conjunction with tar towers, has been introduced so as to provide a means for overcoming stoppages in the tar main without upsetting the normal conditions prevailing in the hydraulic main. In

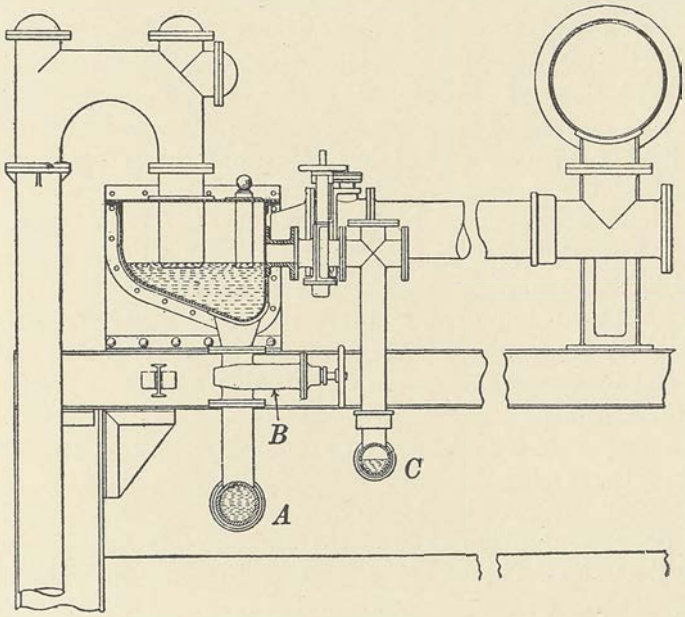


FIG. 186.—DRAKE'S HYDRAULIC MAIN REGULATOR.

the ordinary way the liquid products flow from the hydraulic to the tower by way of the tar main (*A*), the outlet from each hydraulic being fitted with a valve (*B*). If stoppages occur in the main the valves (*B*) are closed, and liquor under pressure from a pump is forced along the main into the tower, thus clearing away the obstruction, without upsetting the seal conditions in the hydraulic. A supplementary tar and liquor main (*C*) is provided, so that any excess liquor deposited during the flushing period is constantly drawn off, travelling to a seal-pot, and maintaining the normal seal. Once the obstruction is removed the valves (*B*) are again opened, and the tar tower is brought into action.

THE REFLUX PRESSURE SYSTEM

The operation of this system,[1] which was recently introduced by the author, will be readily understood by reference to Fig. 187, which shows the general arrangement of the retort bench, hydraulic mains, tar and liquor overflow, etc. The hydraulic mains are made throughout from mild steel. Tar and liquor flow from the hydraulics to a common 6-inch main which runs direct to a pressure box, the overflow in which is some 10 to 18 inches below the level of the bottom of the dip pipes. Thus both tar and liquor are always flowing down hill. The difference in level between the overflow in the pressure box and the height of liquor in the hydraulics is maintained by gas pressure communicated to the pressure box. The pressure required for this purpose varies between 10 and 18 inches of water, and is supplied by bringing back a ¾-inch service from the outlet of the scrubbers, where on many works the pressure is 25 inches and frequently more. The pressure gas from the scrubbers is taken, prior to its passage to the pressure box, through a specially designed controller, so constructed that, whatever the fluctuations of pressure at the outlet of the scrubbers, a constant pressure is maintained in the box. The governor is so constructed that it is entirely unaffected by sulphuretted hydrogen in the gas. It is also fitted with a special regulator, so that, by the turn of a milled head, the outlet pressure may be adjusted within extremely fine limits to give any desired depth of seal, or the dip pipes may be worked without a seal.

After leaving the pressure box, both tar and liquor pass to a separator where they are completely separated while in the hot state, the hot liquor being pumped up and returned to the hydraulics, thus ensuring continuous circulation. In this way the quality of the tar is improved, and it has a particularly low "water content." On the other hand, the re-circulation of hot liquor has a substantial purifying effect on the gas, and its ounces strength is considerably enhanced.

In Fig. 187 an arrangement is shown whereby the liquor is raised for re-circulation by means of a compressed gas lift. This is a decided improvement upon the ordinary steam pump, for the considerable loss of ammonia at the glands of the ordinary pump is thereby avoided. The gas lift, however, is a refinement which can be employed or not, and depends upon the taste of the engineer.

Fig. 188 illustrates the battery of gauges and the controller, which may be fitted in the engineer's office, so that regulation of the quality of the gas may be effected

[1] Pat. No. 165,581.

from head-quarters, or the apparatus may be set up adjacent to the retort house, in the valve-room, or in any other convenient spot. It will be seen that the series of gauges not only gives a dead-beat indication of all conditions prevailing at the moment, but it also gives a record of the work over twenty-four hours.

Probably no gas engineer will gainsay the fact that inconsistent quality of gas

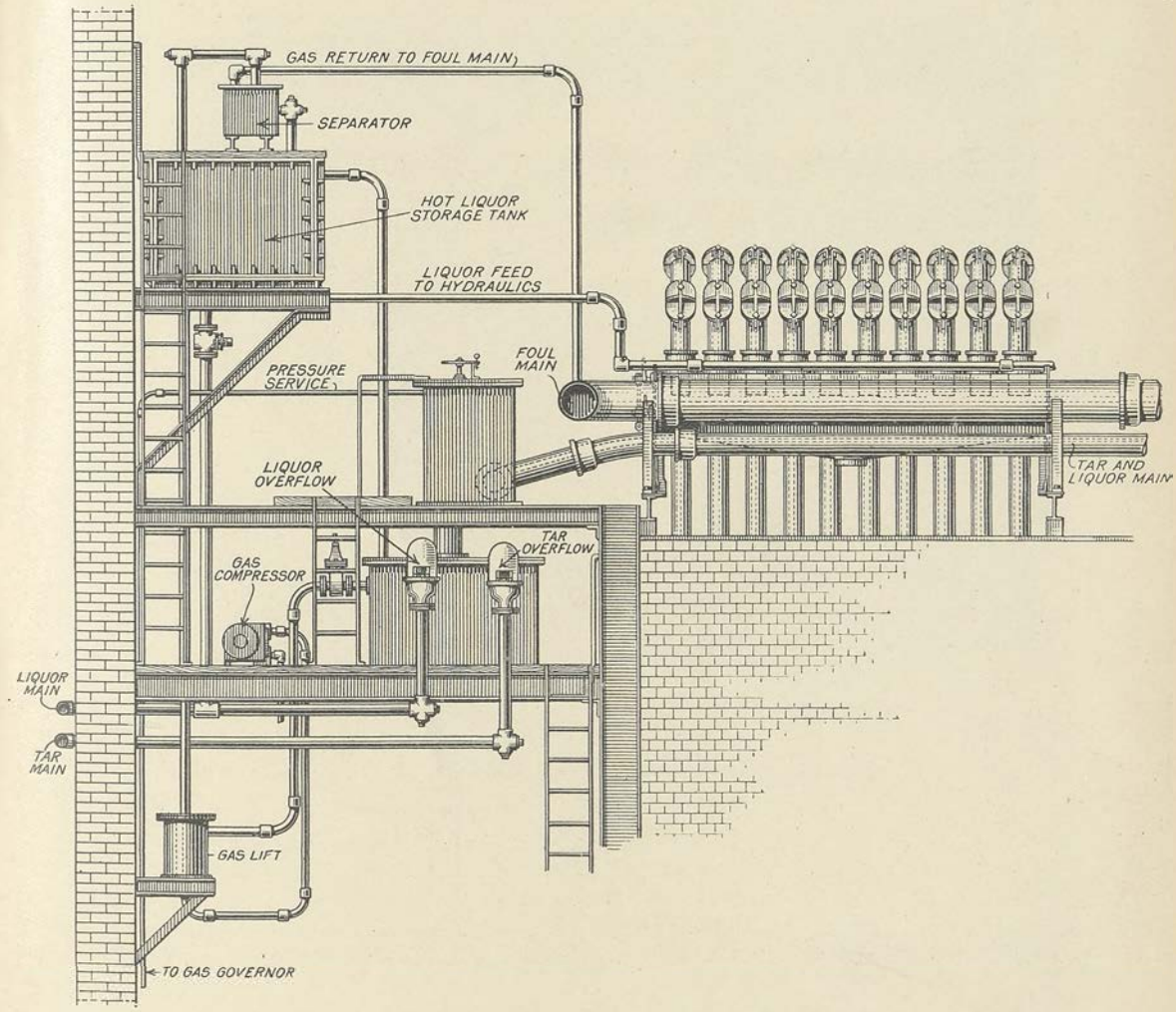


FIG. 187.—GENERAL ARRANGEMENT OF THE REFLUX PRESSURE SYSTEM.

and the temporary appearance of a high proportion of inerts is due to overpulling by opening out on the retort-house governor. Moreover, the frequent alterations of "draw" made during the day give rise to an inconsistency of quality, more particularly as those in charge of governor have usually a predisposition to carry as high a "draw" as possible. Again, adjustments of the retort-house governors usually

entail a climb to the top of the beds, and there is, consequently, a certain amount of trouble connected with the operation.

With the Reflux Pressure System a constant vacuum is maintained on the hydraulics day after day and week after week. The adjustment of gasmaking, in

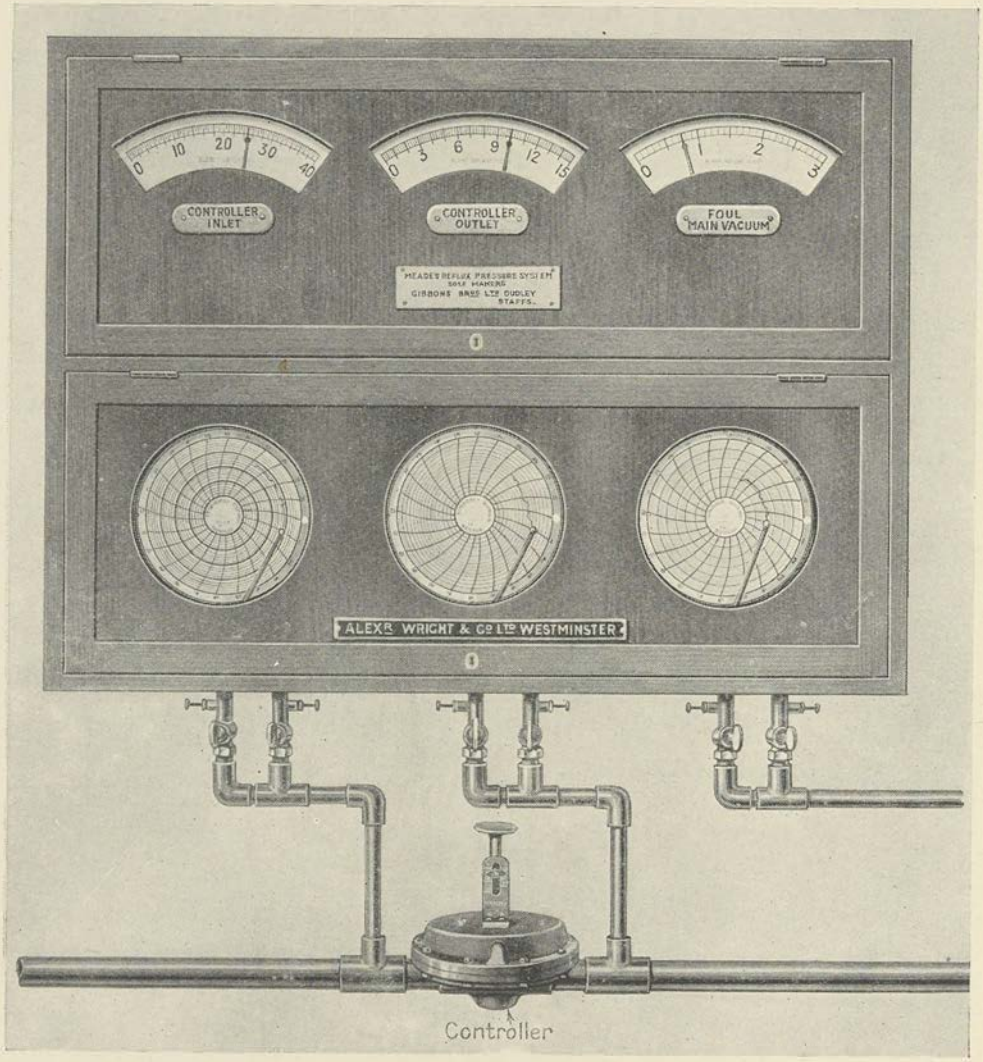


FIG. 188.—BATTERY OF GAUGES AND GAS CONTROLLER. REFLUX PRESSURE SYSTEM.

accordance with the quality of coal employed and quality of gas desired, is carried out by other means. In other words, the vacuum remains constant, and the depth of seal is altered, both immediately and simply. For instance, it may be assumed that with a certain quality of coal the usual practice is to work with five-tenths seal

and six-tenths " draw," and when the gas quality under such conditions is found to vary either above or below the usual standard, the " draw " is, respectively, increased or lowered.

Control of Quality

With the Reflux Pressure System, however, the process of adjustment is reversed, the " draw " on the foul main is kept constant and the seal is deepened or lightened at will. For instance, we may assume that normal conditions of quality are maintained by working with a ½-inch seal and a six-tenths " draw." Then, when gas quality is below normal, the same " draw " is maintained, but by a touch of the special controller the seal may be increased by one-tenth, or as much as is found desirable.

On the other hand, it has recently been shown by one of the Metropolitan gas companies that the yield of thermal units per ton of coal and per retort may be measurably increased if the dip pipes are unsealed and a draw of some five-tenths is worked when the retort doors are closed. When working in this way, the retort-house governor has to be adjusted so that the " draw " is reduced to about one-tenth when the doors are open. Working on this principle, however, is very much simplified by the Reflux Pressure System, for, by a turn of the controller, the dips may be slightly sealed during the operation of charging and discharging, and no alteration of the retort-house governor is necessary.

The methods at present employed for removing tar and liquor from the hydraulics may be broadly classified under two headings, namely :—

(*a*) Continuous systems, *i.e.*, overflow by weir valve, tar-pot systems, etc.

(*b*) Intermittent systems, *i.e.*, tar towers.

The former systems possess the disadvantage of causing the tar to travel up hill before it leaves the hydraulic. Thus, apart from the drawback of causing a viscous liquid to travel upwards over a weir or into a standpipe, there is always, with tar-pot systems, some unavoidable deepening or lightening of the seal owing to the difference in specific gravity of the tar obtained from different varieties of coal.

The tar-tower system possesses the great merit of constantly drawing-off the tar by way of a pipe having a decided fall, thus there is no question of causing the tar to ascend at any period in its travel. The inherent defect of the system is, however, its intermittent nature, necessitating running-off at fairly frequent periods. General experience has shown that it is after the procedure of running-off the tower that inerts in the gas make their appearance. This is due to the fact that it is extremely difficult to run liquor into the tower or mains as quickly as the tar is run out. The result is that unsealing of the dips takes place, and it may be so long as half an hour after running-off before the normal seal is made up. The Reflux Pressure System combines the advantages of the tar-pot and tower, but eliminates their defects. For instance, in this system the tar is continually running away in a down-hill direction ; but the system is continuous and demands no periodical running-off. The seal, therefore, is always maintained at the level at which it is adjusted.

In many gasworks it is customary to stop gasmaking on Sundays for a period of

twelve hours or longer. In such cases the pressure at the outlet of the scrubbers may fall considerably and may no longer be sufficient for maintaining the seal. This

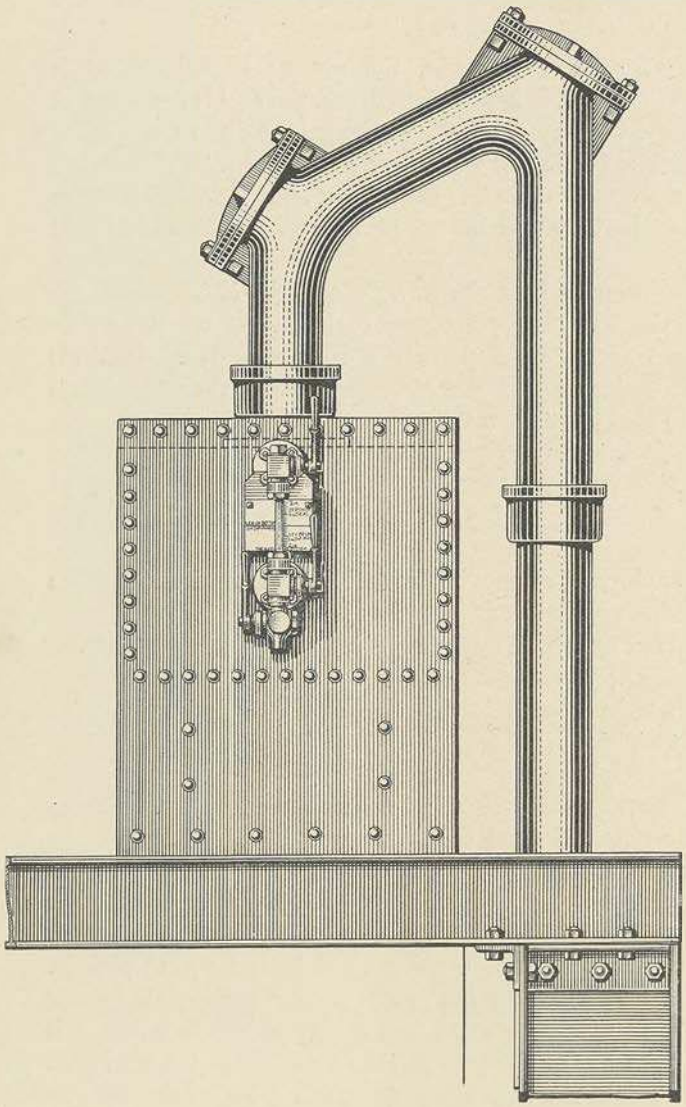


Fig. 189.—End View of Hydraulic Main, showing Liquor Sight Gauge. Reflux Pressure System.

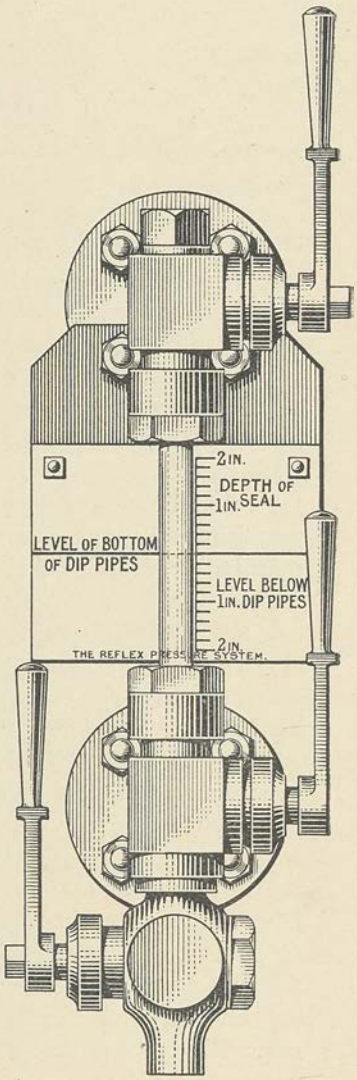


Fig. 190.—Enlarged View of Liquor Sight Gauge.

contingency is provided for in the Reflux Pressure System, and by merely turning a valve wheel, fitted to the top of the pressure box, the normal conditions of seal will be maintained, the tar and liquor flowing away temporarily over a special weir plate.

THE PITCHING-UP OF MAINS, ETC.

The pipes which are used for conveying the tar and liquor from the hydraulic mains to the storage well are often a source of trouble owing to the adherence of pitchy matter to the inside, thereby causing blockage. This is particularly the case where the pipes are subjected to radiated heat from the retort bench. The most effective means of collecting liquor, and at the same time furnishing a flushing system for the draw-off pipes and hydraulic, is to provide a tank into which all liquor running from the foul main, hydraulic mains, or tar towers, is taken. This liquor is then raised by means of a pump to an upper tank a few feet above the retort bench, and provides the constant feed to the tar towers as already explained. One function of the pump, however, is that of periodically flushing out the tar pipes. This is effected by fitting a connection from the delivery of the pump to the run-off pipes of each

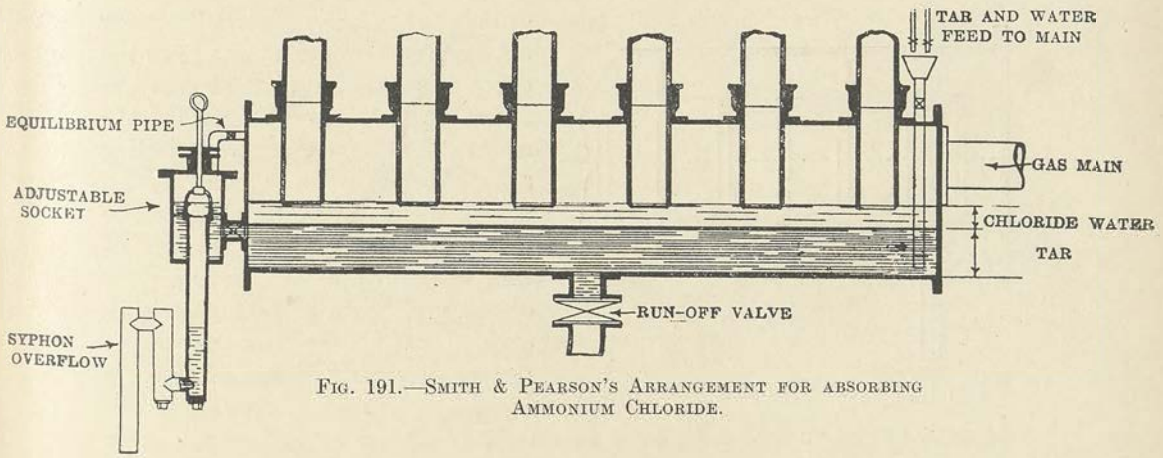


FIG. 191.—SMITH & PEARSON'S ARRANGEMENT FOR ABSORBING AMMONIUM CHLORIDE.

individual tar-tower system. Accordingly a flush of liquor at considerable pressure can be pumped backwards through the pipes and into the hydraulics. A short period of such flushing carried out once a day, or even once during each shift, assists in the prevention of stoppage. The system of liquor tanks, moreover, has other advantages, in that the warm liquor coming straight from the towers and foul main is permitted time to cool down before being discharged into the storage well, thus curtailing loss of ammonia. A further advantage is that the liquor run into the towers or mains can be kept in continuous circulation (only the surplus being allowed to drain off to the well through an overflow in the lower tank), which results in a greatly increased strength being obtained. When liquor is circulated in this manner it will usually be found that the proportion of "fixed" ammonia is appreciably greater than when ordinary methods are employed.

Smith and Pearson, in the course of their researches carried out with the Birmingham coal-testing plant, found that, so far as the pitchy deposits in the hydraulic main were concerned, the chief binding material in the pitch appeared to be ammonium chloride taken up from the gas in the hydraulic main. In order to eliminate this

effect, they absorbed the chloride before it could reach the tar by interposing a layer of water, 3 inches deep, on top of the tar. The water was run in hot, so that little free ammonia was taken up, and the chloride in the gas was reduced. Considerable benefit resulted from the arrangement, which is diagrammatically illustrated in Fig. 191.

HYDRAULIC MAIN AGITATORS

Where modern methods for the drawing-off of tar and the flushing of hydraulic mains are in use, little trouble is experienced from stoppage and erratic working due to "pitching-up." The disorganization resulting from the latter, however, has in some cases been sufficiently severe to warrant the use of special agitating devices.

A common type of apparatus for the purpose is illustrated in Fig. 192. It consists of an endless chain passing over two sprocket wheels, situated one towards each end of the hydraulic main. Projecting arms or scrapers are attached to the chain, which is so arranged that the underside drags along the floor of the main. By means of a projecting spindle the chain can be set in motion at periodical intervals. Needless to say, it is strongly inadvisable to encumber the hydraulic with apparatus of this type when it can possibly be avoided. If flushing or agitation is desired, it should be carried out by liquid and not mechanical means.

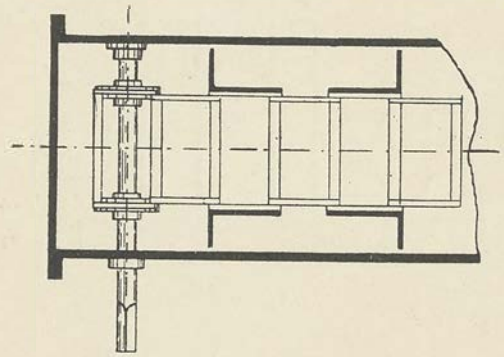


Fig. 192.—Hydraulic Main Agitator.

Modern hydraulic mains all tend to be somewhat smaller and more shallow than many of the old cast-iron types. The tendency is certainly to be encouraged, for the function of the hydraulic is not that of a storage tank, and the depth of liquor should be as shallow as possible, providing that it satisfactorily performs its primary duty of ensuring a seal. If a considerable volume of liquid is always allowed to remain in the hydraulic, there is a tendency for distillation to take place; and, as tar will inevitably settle out, the formation of pitch is only a matter of time, unless special precautions are taken to preclude it.

THE FOUL MAIN

The foul main may be called upon to perform more duties than one, and amongst other functions it provides:—

(*a*) A gas conduit between carbonization and primary purification plant.

(*b*) A drain pipe for liquor and tar.

(*c*) A primary condenser.

So far as the last duty is concerned, the total length of foul main should be given consideration when calculations for condensing capacity are made.

The size of the foul main must depend upon the combined areas of all pipes leading into it. Theoretically, the cross-sectional area should be equivalent to the sum of the areas of the latter pipes, but this is never carried out in practice, firstly because mains of such capacity are unnecessary owing to the condensation rapidly taking place, and because the foul main is delivering gas more or less continuously, whereas there is a sudden rush of gas into each hydraulic main as charging takes place.

Generally speaking, the following sizes for foul mains are those prevailing, and may be safely applied :—

Capacity of Bench per 24 Hours.	Size of Foul Main. If one.	If two.
(*a*) 30,000 to 100,000 cubic feet	6 inches to 9 inches.	—
(*b*) 200,000 to 500,000 cubic feet	12 inches to 15 inches.	—
(*c*) 1 million to 1¾ million cubic feet	18 inches.	14 inches.
(*d*) 2 million to 3 million cubic feet	24 inches.	18 inches.

Another rule is to make the foul main (if it delivers all the gas) of 125 per cent. the area of the main connections in the works.

Retort benches in the past were invariably supplied with a cast-iron foul main, but the modern practice is to construct the latter from lap-welded steel plates or solid drawn tubes. When the foul main is of greater diameter than 12 inches, steel should, as a general rule, be used, and in such cases it will usually be slightly cheaper than cast-iron. A further recommendation is that owing to the thinner metal walls employed in the steel pipe the outward radiation of heat is greater, hence the cooling effect on the gas is very much more pronounced.

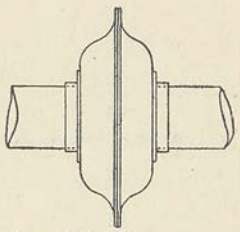


Fig. 193.—Expansion Joint for Foul Main.

As the foul main is situated above the retort bench, it is liable to undergo considerable expansion when the heats are raised ready for work ; accordingly some means must be introduced for the prevention of breakage. With the cast-iron main, the lead joints at the spigots will be sufficient to cope with any change of length, and flange joints should, therefore, be avoided, unless some form of expansion joint is inserted.

The steel foul main, having no flexible joints to yield to movement, should—if of any length—always be provided with an expansion joint similar to that shown in Fig. 193. In the usual way one of these joints will be necessary for each 100 feet of pipe. In modern work the foul main is usually supported on the cross-stays, or from them by chains or steel straps.

RETORT-HOUSE GOVERNORS

The retort-house governor is an auxiliary which is more or less essential in the larger works. It differs from the ordinary station type of governor (which forms the last piece of apparatus through which the gas passes before leaving the works) in that whilst the latter is employed with the object of reducing pressure, the retort-house governor is interposed for the purpose of reducing the intensity of vacuum created by the exhauster. This, however, is not its primary function.

In the same way that the station governor ensures a steadiness of pressure in the consumers' services, whatever may be the demand, so should the retort-house governor ensure a constant vacuum in the hydraulic main, whatever the volume of gas coming away from the retorts. The intensity of vacuum desired is obtained by means of " loading " on similar lines to the method prevailing with station governors.

Before the introduction of this apparatus the required vacuum on the foul main was obtained by regulation of the speed of the exhauster; whereas the uniformity of the " draw " was controlled as effectively as possible, but not without considerable difficulty, by means of the ordinary type of exhauster-governor working on the throttle of the engine or a by-pass. (For description, *see* Chap. XV.) This method of regulation is still in vogue in those works where no retort-house governor is installed.

The application of the retort-house governor requires some consideration in relation to the working of horizontal settings, owing to the operation of gasmaking being necessarily intermittent, and to the impracticability of charging the whole bench of retorts at the same moment. For instance, if a single retort bench, working into a common hydraulic main, is considered, it will be seen that, owing to the different periods at which the distinct rows of retorts have been charged, there will be a large volume of gas coming away from some dip pipes, whereas those retorts in which the charges are nearly spent will be yielding little or no gas. But the object of the retort-house governor being to maintain a constant " pull " whatever the quantity of gas coming away (and providing all dip pipes are equally sealed), there will be a similar vacuum on each retort; that is to say, there is every likelihood of drawing waste furnace gases up the pipes from those retorts where the charge is spent. Under the circumstances, the ideal would be to charge up an entire set, or series of settings, at one time (instead of carrying out the ordinary practice of travelling through the whole length of the bench on a definite row of retorts), and to interpose a retort-house governor for each unit so worked. The vacuum could then be gradually reduced as the period of carbonization on each distinct section advanced. Such procedure, however, is scarcely possible in practice.

Owing to the fact that the retort-house governor works in connection with a system of mains under a vacuum, the holder bell—or other reservoir—in communication with the main receives no support from the gas, consequently buoyancy has to be imparted to it by other means. In general, these governors may be divided into two groups, namely—

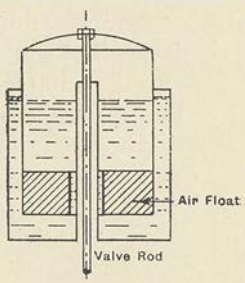


FIG. 194.

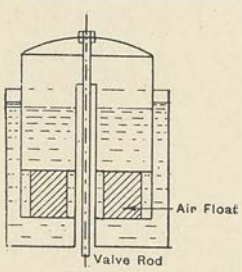


FIG. 195.

(*a*) those deriving their buoyancy from a system of air floats within the holder bell, and being regulated by direct loading of the latter;

(*b*) those in which no air floats are employed, but which are rendered buoyant by a counterbalance.

Both types are in common use, but (*b*) is, perhaps, preferable, owing to the tendency

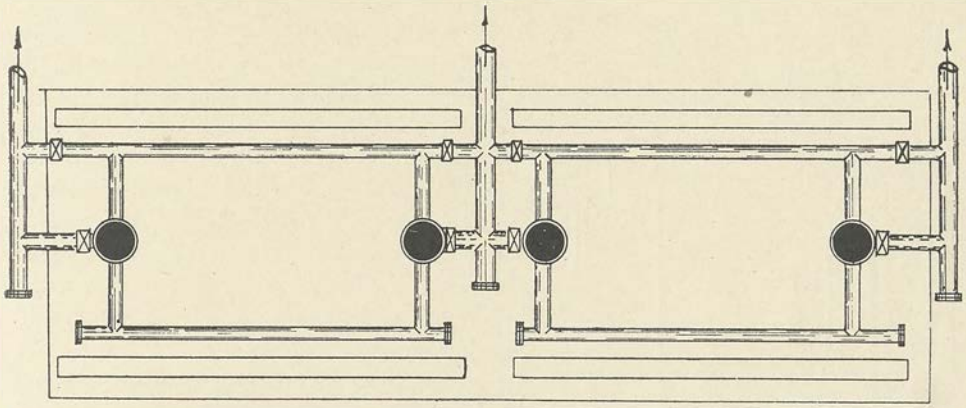


FIG. 196.—ARRANGEMENT OF FOUL MAINS AND RETORT-HOUSE GOVERNORS FOR LARGE BENCH.
NOTE.—VALVES (NOT SHOWN) ARE REQUIRED AT THE BASE OF EACH GOVERNOR.

of the float casings to corrode. The arrangement of the air chambers is shown in Fig. 194, and it may be pointed out that for retort-house governors this is preferable to fixing the floats with an exterior annular space as in Fig. 195. With the latter arrangement the governor frequently operates in too "lively" a manner for the best results. On the other hand, for exhauster governors, the annular chamber is preferable.

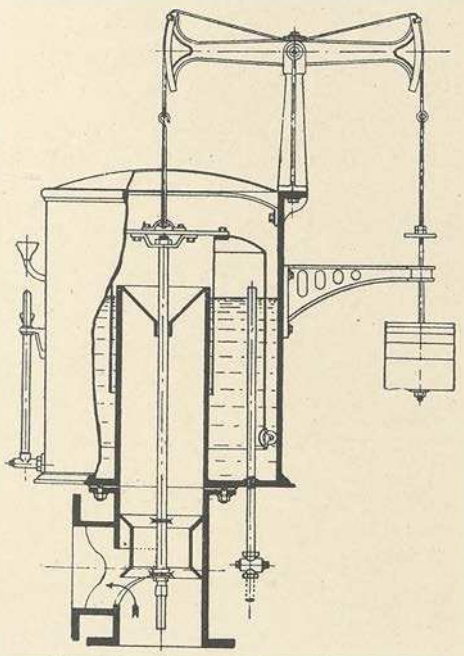


FIG. 197.—RETORT-HOUSE GOVERNOR.

The most suitable place for the governor is on top of the retort bench, and as close up to the end of each section of the foul main as possible. It is not so sensitive when fixed on the inlet or outlet of the condensers, as sometimes found. In a retort house of any size, more than one governor is necessary, and the different sections of foul main will best be controlled by some arrangement as that shown in Fig. 196. By-passes are advisable whenever they can be arranged for, as the governors will usually require attention about every four months, when both tank and valve should be cleaned.

A typical governor of the counterbalanced bell type, designed on Parkinson

and Cowan's system, is illustrated in Fig. 197. The passage of the gas along the foul main is governed by the sliding reel which depends from the centre of the governor bell. At the same time communication between the holder and the main on the retort-bench side is effected by the service pipe shown. By means of the weights the bell is so poised that the desired vacuum is obtained. Should the gas coming from the retort bench increase in volume, then the vacuum in the foul main will decrease, with the result that there is less "sucking-down" on the bell, which accordingly rises. This movement raises the reel and opens the gas-way until the previous conditions of vacuum are regained, and *vice versa*. This type of regulation, with the open reel, is to be preferred to those governors in which the gas in its tarry condition is forced to travel through narrow slots. These slots lend themselves to blockage, particularly when a system of dry mains is in use. It is as well to arrange for a thin layer of oil on the surface of the holder water.

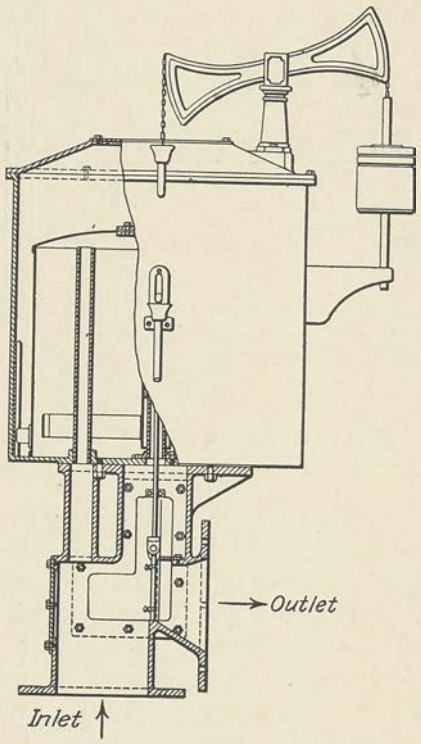


FIG. 198.—BRADDOCK'S RETORT-HOUSE GOVERNOR.

Another type of retort-house governor, in which the principle is essentially the same as the foregoing, is illustrated in Fig. 198. It will be noted, however, that the valve is constructed differently from that shown in Fig. 197. The following table shows the capacity of retort-house governors in relation to the size of their connections :—

Diameter of Inlet and Outlet.	Nominal Capacity per 24 Hours.
Inches.	Cubic Feet.
6	300,000
8	500,000
10	750,000
12	1,250,000
14	1,500,000
15	1,750,000
16	2,000,000
18	2,500,000

A new departure from the ordinary apparatus is the " Reeson " governor, shown in Fig. 199. In this apparatus the gasholder principle is done away with, and its place is taken by a small flexible reservoir formed by a leather diaphragm. This diaphragm, being in direct communication with the foul main, is caused to collapse or distend in accordance with the volume of gas passing along the main. The movement of the diaphragm then operates the butterfly valve and increases or diminishes the free gas-way. In this case a water-loading attachment for regulating the intensity of the vacuum is shown. The chief merits of the governor are its compactness and the small possibility offered for deterioration by corrosion.

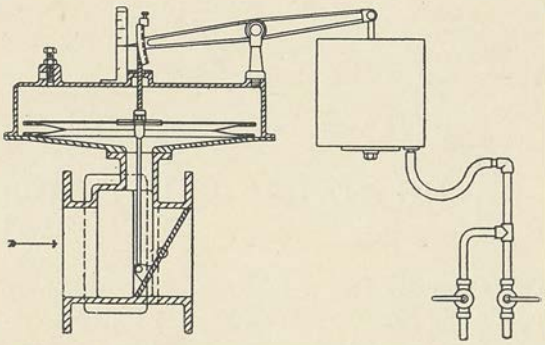


FIG. 199.—" REESON " GOVERNOR WITH WATER-LOADING ATTACHMENT.

For the purpose of regulation, many medium-sized works employ an ordinary butterfly valve operated from a bell.

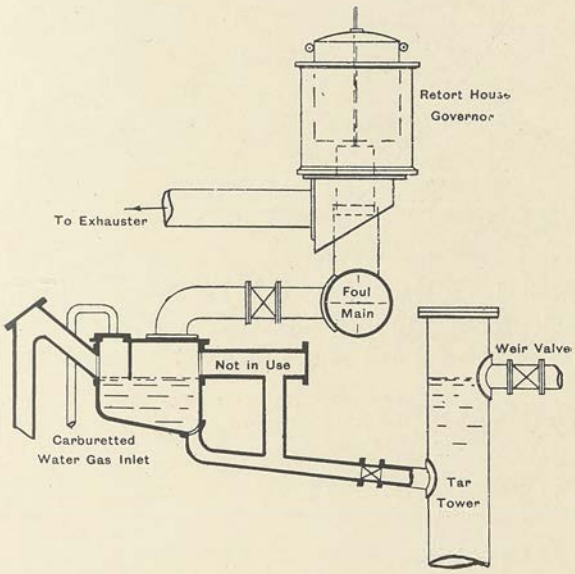


FIG. 200.—LANGFORD'S GOVERNOR AND TOWER ARRANGEMENT.

A novel hydraulic main and gas take-off arrangement has been introduced by Langford. This is shown in Fig. 200. It will be seen that the gas is taken off from the top of the hydraulic, whilst the liquor overflows by the weir valve attached to the tower and maintains the seal. Originally, both gas and liquor were removed in the ordinary way via the weir valve on the hydraulic, but excessive oscillation of the liquor occurred, which was particularly objectionable, owing to the peculiar type of ascension and dip pipes, unsealing frequently occurring. With the gas outlet moved to the top of the hydraulic, the vacuum from the exhauster was exerted at right angles to the surface of the liquid, thus oscillation was considerably curtailed. The disposition of the retort-house governor will also be noticed, whilst a further uncommon practice is that of leading the carburetted water gas direct to the hydraulic main, where it is intermixed with the coal gas.

CHAPTER IX

THE MECHANICAL HANDLING OF GASWORKS MATERIALS

The application of machinery to the handling of all types of gasworks material has during recent years undergone considerable extension, so that, nowadays, even establishments of a comparatively small order can instal certain types of labour-saving plant to advantage. Moreover, recent incidents in the labour world and the perfecting of the more or less crude apparatus of former years has added a certain stimulus to the introduction of mechanical means for performing a host of duties originally carried out by hand. The result is that whereas in 1893–7 about twenty men were required to produce a million cubic feet of gas per diem, to-day, in large installations of vertical retorts, the number is only four. Roughly speaking, it may be taken that the saving of a single man's wages warrants at the present time a capital outlay of between £1,400 and £1,300 on machinery. When deciding upon the question of the introduction of mechanical plant, however, considerable thought is necessary, so that the various charges and contra charges are correctly balanced the one against the other.

The principal considerations which each engineer must apply to the case in question may be briefly enumerated as follows :—

(1) Can the working costs be curtailed, and if so, what will be the annual saving ?

(2) Will better carbonizing results follow the introduction of machinery, and will more gas be obtained from the plant used and land occupied ? If so, what will be the effect on the wear and tear of plant ?

(3) Is the saving represented by (1) and (2) likely to be sufficient to meet the standing charges for interest on capital expenditure, depreciation and repairs ?

(4) Will efficiency be sacrificed in order to effect the apparent economy ? Loss of efficiency may mean losses in other directions.

(5) Will the reduction of labour relieve the management of any difficulties not actually measurable in terms of money ?

Retort-house machinery is not profitably employed in small works, although those manufacturing 20 million cubic feet or over per annum can to advantage instal such types as the " Rapid " or " Manual " machines, which require no mechanical power, and which may be classed as labour-saving devices though not necessarily causing much diminution in expenses.

A question of considerable importance is the amount of capital outlay which is permissible in order to save the wages of a single man. At the time of writing the ordinary labourer is receiving 1*s.* 8*d.* per hour, he works 47 hours per week ; and (in order to include all extras, such as insurance, holiday pay, etc.) a year may be assumed to contain 54 working weeks. The outgoings on one man (apart from overtime) amount, therefore, to about £210 per annum. On the other hand, the charges on capital have shown to be adequately met in cases of mechanical handling by setting down 5 per cent. for interest, 5 per cent. for wear and tear, and 7½ per cent. for depreciation, *i.e.* a total of 17½ per cent. Each year, however, the sum upon which interest has to be paid is written off by 6½ per cent. ; thus during the fourteen years over which the capital is paid back, the *average* rate of interest is only 2½ per cent., making the total average charges on capital 14½ per cent. Accordingly, the capital expenditure permissible in order to eliminate one man is rather more than £1,400—the charges on this sum at 14½ per cent. amounting approximately to the equivalent of a labourer's annual earnings.

As an example of the economy in labour to be effected on large works, the case of the 500 million works considered in Chapter I may be taken. The coal gas made per diem in this instance amounts to 1,600,000 cubic feet, and the total outlay involved in elevators, conveyors, coal breakers, charging machinery, power plant, and coke-handling plant is given as £20,350. Allowing the normal figures of 5 per cent. for interest on capital, 5 per cent. for maintenance, and 7½ per cent. for depreciation (*i.e.* a total of 17½ per cent.), the annual saving which must be effected is £3,560. This means a reduction in numbers of about 16 or 17 men, or (say) 5 or 6 men from each shift per day. About 30,000 tons of coal per annum would be handled, which means that a saving of 28*d.* per ton is necessary to meet the above expenditure. Accordingly, those in authority would have to be positively assured that such a saving would follow the introduction of machinery. On the works in question there is little doubt that this economy—amounting to about 2¼*d.* per 1,000 cubic feet of gas produced—could be effected.

Labour-saving machinery may be applied on gasworks for the following purposes :—

(*a*) The charging and discharging of retorts.

(*b*) The conveyance of coal from point of delivery to point of consumption.

(*c*) The breaking up of coal to the required size.

(*d*) The conveyance of coke from the retorts to a suitable storage place, or to other machinery for grading, screening, or washing.

(*e*) Labour-saving appliances in the retort house, such as mechanical pokers, also oxide and sulphate of ammonia handling plant.

The mechanical handling machinery introduced in gasworks is almost solely used in connection with the retort house, although on larger works other raw materials or by-products, such as oxide of iron or sulphate of ammonia, may be profitably dealt with in this manner. In fact, in any instance where a saving can be shown, after consideration on lines such as those already indicated, the instalment of machinery is justified.

CHARGING AND DISCHARGING MACHINERY FOR RETORTS

The past decade has witnessed a striking change in the design of machinery used for the filling and emptying of horizontal retorts. The introduction of the heavy charge and the mass system of carbonization has been responsible for much of this modification, so that discharging apparatus embodying the principle of the rake—at one time a very common type—has almost entirely disappeared. This is due to the necessity for leaving a considerable space above the charge in the retort in which the rake head may travel.

Stoking machinery employed in operating the retorts may be primarily classified under the following headings :—

1. Machines designed to minimize the labour of charging or discharging but which require no power other than manual labour for their operation.

2. Machines charging simultaneously from both sides of the bench, such as the Arrol-Foulis, or West's scoop charger.

3. Machines discharging from both sides of the bench simultaneously. These include those types worked on the rake principle, and which are not suitable for heavy charges.

4. Machines charging from one side of the bench only.

   (*a*) Projectors.

   (*b*) Those embodying the principle of the conveyor chain.

5. Machines discharging from one side only. These are exclusively worked on the principle of the pusher.

6. Discharging chargers, which simultaneously empty and refill the retort.

The last-named type, though not altogether satisfactory at the time of its introduction, is now reaching a stage of perfection which has resulted in its more general adoption. One of the chief disadvantages attending the use of the earlier types was the impossibility of working heavy charges, owing to the necessity for leaving the upper portion of the retort clear for the return of the conveyor chain. This difficulty has now, however, been surmounted.

It would not be possible to describe fully here the details of construction of all the machines now in operation in gasworks for filling and discharging retorts. It is merely proposed to consider some of the most familiar examples and to indicate briefly the principles upon which they operate.

The engineer who is contemplating the introduction of machinery should decide on the type of plant, in conjunction with the apparatus for conveying coal, before proceeding with the design of the buildings and retort plant. Many makers have different types of machinery, such as those with or without storage hoppers, measuring chambers, etc. It will, therefore, be found advantageous to settle upon the type and make at the outset. Once the machine is decided upon there are many points requiring attention, and at this juncture discussion between buyer and maker will prove of great assistance in the design of new buildings or alteration to existing ones. The maker should furnish a plan showing the over-all dimensions of his machine, the clearances required at the front, back, and sides, also the total weight when

loaded with coal, and the static load on each wheel. In addition, he should state the probable maximum load on any wheel due to abnormal circumstances—such as unevenness of the running track or excessive thrust caused by stoppage in the retorts, etc. (*see* page 59). If the rail gauge is known the floor can then be designed. The majority of makers have a regular form upon which the necessary requirements for their machines are set out, but they can, of course, depart from some of them (within reasonable limits) without affecting the efficiency of the machine. In obtaining tenders the engineer should give the salient requirements demanded of the machine, such as the number of retorts to be charged, their size and arrangement and the method of coal-feeding proposed.

So far as working capacity is concerned separate charging and discharging machines are, naturally, capable of dealing with a greater number of retorts than are the combined types. Machines operating from one side of the bench only are fast replacing those which operate simultaneously from both sides. In the latter type the number of operators is doubled, and the capital cost is increased by about 50 per cent. Where a chain or other working part enters the retort, the retort must be kept a better shape, and usually requires scurfing more frequently.

The working portions of the machine liable to breakage should be readily interchangeable, and the engineer should know what spare parts he is expected to stock, as such items have an important bearing upon the efficiency and cost of upkeep of the machine.

The Arrol-Foulis Hydraulic Charger

This charging machine is usually operated in conjunction with a hydraulic discharger. Chargers are provided on each side of the retort bench and deliver the coal from both ends up to the centre of the retort. Generally speaking, a system of overhead storage hoppers is provided in the retort house, and by means of suitable shoots the coal is led into the hopper carried on the front of the charger. The hopper on the machine is capable of holding sufficient coal to charge about fifteen retorts half-way through. The size of the hopper varies, however, with the capacity of the retort bench, and it may hold anything from 4 to 8 tons. Immediately beneath the hopper is fixed a revolving drum divided into compartments by radial partitions. By means of a ratchet and pawl arrangement a continuous rotary motion is imparted to this drum, and the extent to which it is turned regulates the amount of coal falling through from the base of the hopper. On being discharged from the drum the coal falls into a special trough which enters the retort for a few inches. A hydraulic pusher ram with a plate attached to the free end then comes into operation and carries the coal charge into the retort. On the backward stroke of the pusher bar the coal drum is again revolved so that another charge is ready to be pushed forward on the next outward stroke. By means of a special stopper bar the distance into the retort travelled by the ram is reduced by about 18 inches on each stroke, so that the coal is distributed comparatively evenly along the floor of the retort. For an ordinary medium charge seven strokes on each side of the bench are necessary to complete the work, but with the modern heavy charge the stopper bars should pre-

ferably be removed so that the retort may be packed. The hydraulic power is conveyed to the machine by flexible wired hose pipe, and the working pressure varies between 400 and 600 lb. per square inch. The machines travel in front of the benches on a double-line track, and a special three-cylinder hydraulic motor is provided for this purpose. The total weight of a machine with hoppers filled is about 12

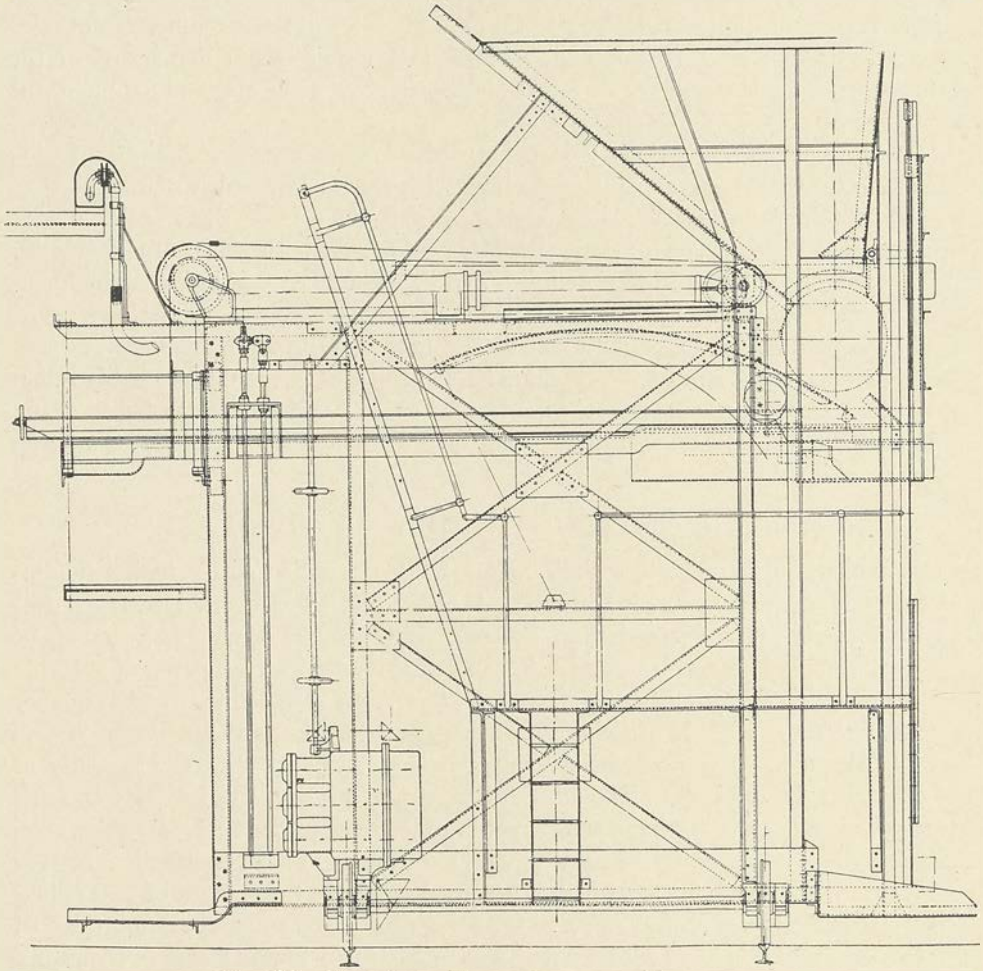


Fig. 201.—The Arrol-Foulis Hydraulic Charger.

tons. Two chargers and one hydraulic pusher are capable of dealing with about 40 retorts per hour with charges of about 18 cwt. The capacity of the machines is, therefore, about 36 tons of coal per hour.

The Hunter-Barnett Pusher

One of the first hydraulic pushers to be introduced was that invented about 1907 by Messrs. Hunter & Barnett. It is very generally employed in conjunction

with the Arrol-Foulis charging machinery, and is most suited to this owing to the motive power being water. The whole machine is self-contained. The frame is formed of substantial mild steel plates and angles rigidly connected together and mounted on cast-iron brackets (*A*) which carry the traversing carriage wheels (*B*). A three-cylinder hydraulic motor (*C*) is fitted at the front of the machine and is geared to the carriage axles (*D*) by cast-steel bevel wheels (*E*). The method adopted

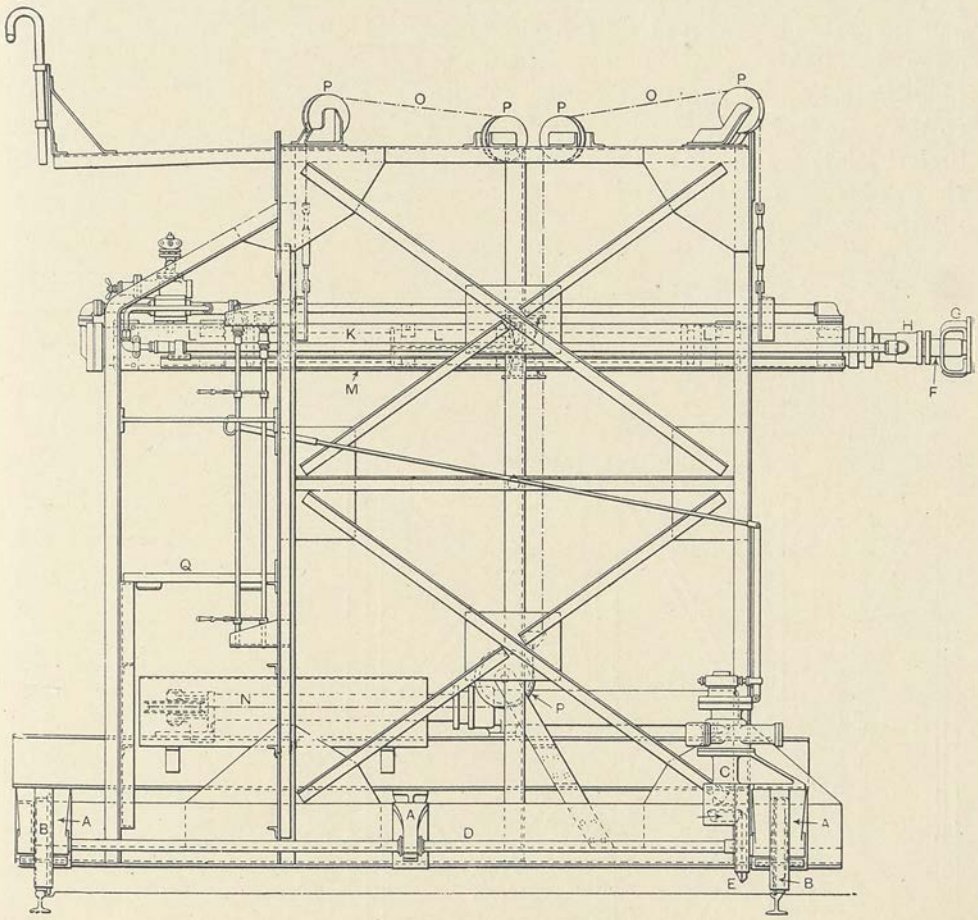


FIG. 202.—THE HUNTER-BARNETT HYDRAULIC PUSHER.

for pushing the coke through the retort is as follows:—A powerful telescopic ram (*F*) of hard, solid drawn, steel tube, provided with suitable pusher head (*G*) and fitted with internal drawback arrangement is used. The pushing head of the ram is water-cooled (*H*) to ensure that no undue heating may occur, and the ram works in a cylinder (*K*) of mild steel supported in cast-iron guides (*L*). These guides are mounted on a suspended beam (*M*) carried by chains (*O*) at front and backends. This suspended beam can be raised or lowered to suit the several tiers of retorts,

the motions being obtained by means of a hydraulic ram (*N*) situated at the foot of the machine. The suspending chains (*O*) are carried over guide pulleys (*P*) to the points of support at the front and back of the beam. The beam is guided in the machine frame so that no side movement can take place. All the operations are practically automatic; and a suitable platform (*Q*) is provided for the attendant, with all operating levers for valves and cocks placed in a convenient position within his reach. The hydraulic pressure may vary from 400 lb. to 600 lb. per square inch, and the water is conveyed by a flexible armoured hose pipe sufficiently long to carry the machine over a number of beds of retorts. When the outreach of the pipe is attained, the hose connection, as with the Arrol-Foulis chargers, is shifted to the next swivel joint on the main supply pipe and the machine carried on. Swivel joints are placed on the pressure main and are spaced to suit the length of the flexible hose pipe and adjusted to suit the particular arrangement used in the retort house.

The Williams-MacPhee Pusher

The Williams-MacPhee hydraulic pusher is one of the more recent of these

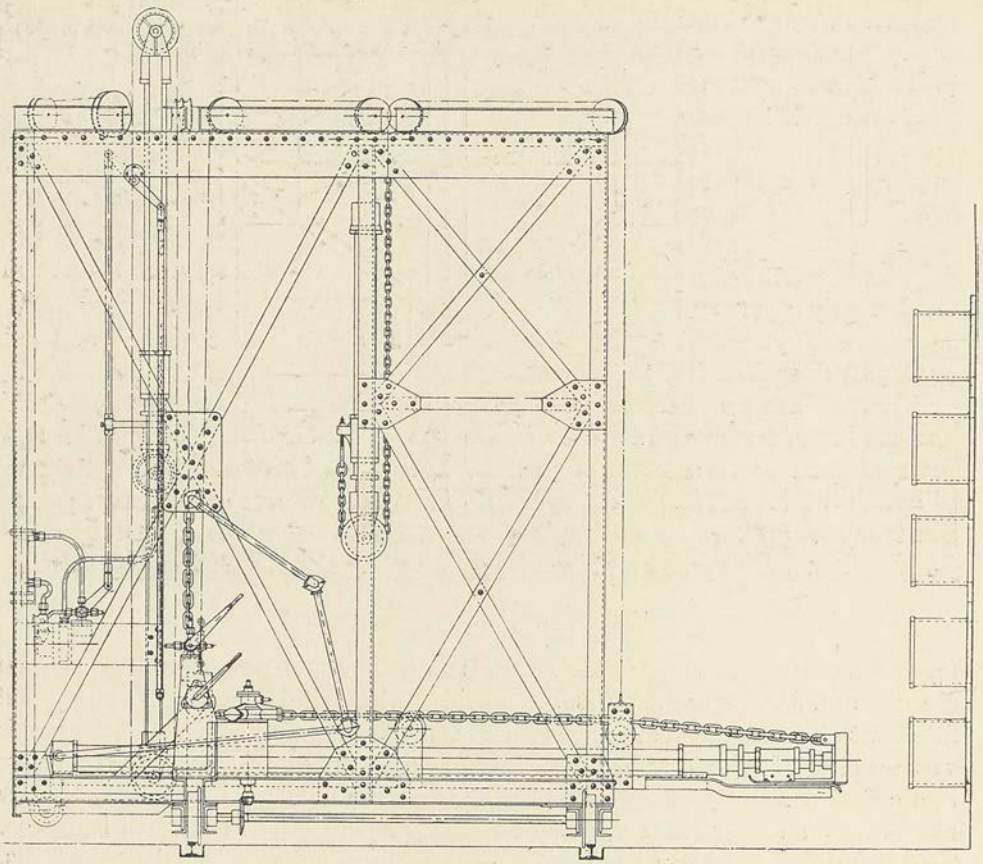


Fig. 203.—The Williams-MacPhee Pusher.

machines introduced and comprises many commendable features. The simplicity of the entire arrangement is its chief recommendation. The machine consists of a pusher constituted of an outer cylinder containing two telescopic rams of sufficient length to extend through a 20-foot retort. Each ram is provided with a stopper at its rear end, and on the smaller solid ram a pusher plate, similar in shape to the

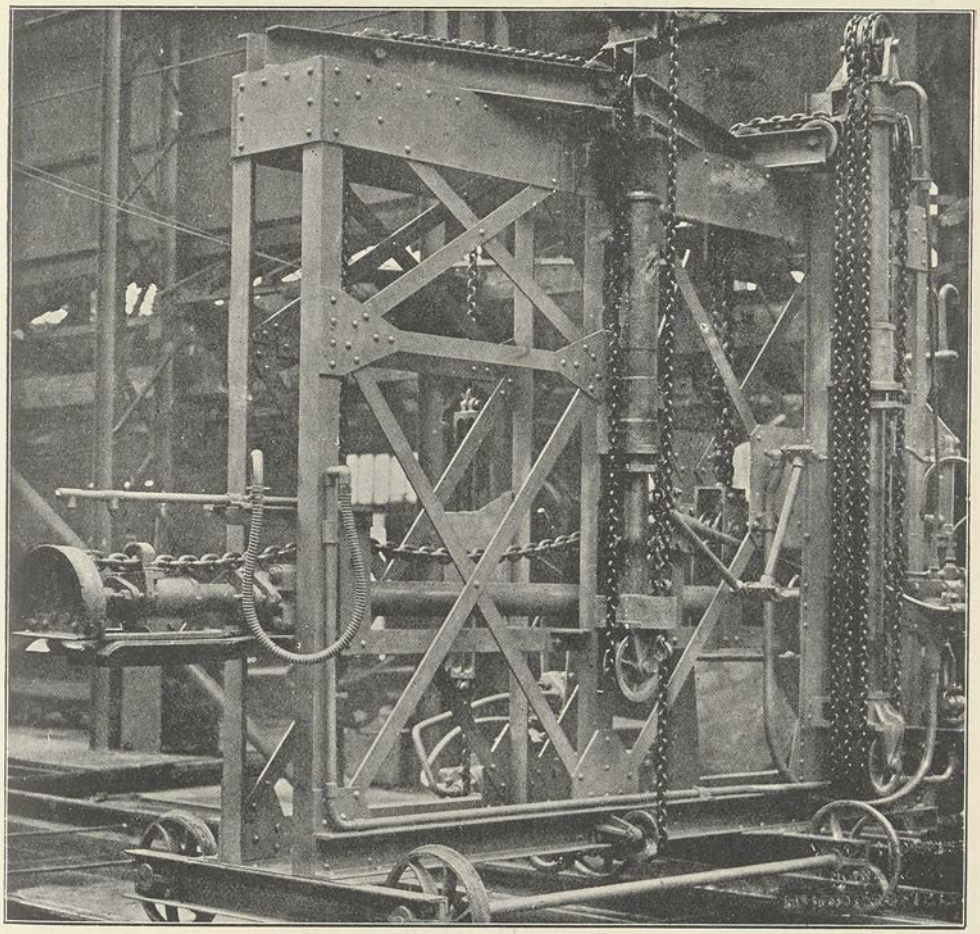


FIG. 204.—THE WILLIAMS-MACPHEE PUSHER.

retort but slightly smaller, is fitted. The ram is extended by admitting hydraulic pressure at the back of the cylinder, and by means of a special automatic return valve the pusher is withdrawn when the full extent of its stroke has been reached. Withdrawal is effected by a chain, attached to the pusher head, which passes around a pulley connected to a subsidiary hydraulic ram. This withdrawing ram is pulled into its cylinder by the tension of the chain during the outward stroke. The automatic return is arranged for by introducing a tappet rod connected by a lever to

the distributing valve of a small actuating ram, the stroke of which reverses the controlling valve and opens the exhaust port to the pusher cylinder, thus withdrawing the telescopic rams. This tappet is engaged by the ram-head at a predetermined point on the outer stroke. In practice it is found that the outward discharging stroke takes about 10 seconds to be completed, whilst the return stroke is accomplished in 8 seconds. The chief merit of this type of pusher lies in the fact that there are only four glands to pack, whilst only one of them has to withstand the severe effects of entering the retort. The wear and tear is, in fact, almost inconsiderable, a pusher chain lasting for about twelve months before it has finally to be discarded.

The De Brouwer Stoking Machine

The first charging machine involving the projector principle was introduced by the late M. De Brouwer, gas engineer at Bruges. The outstanding advantage of this machine compared with others in use at the time was its ability to charge a full-sized retort from one side only, thus avoiding the necessity of installing machines on both sides of the bench. The whole apparatus is extremely simple, and consists of a steel frame carrying a large grooved pulley, three band pulleys for guiding a broad band, a driving motor, and a telescopic feeding shoot for coal. The principle of operation will be readily understood by reference to the line diagram (Fig. 205). The three band pulleys are arranged on the inside of the broad endless coal belt, and are so placed that this belt is made to take about a quarter turn round the large grooved pulley. The coal band bears on the two flat flanges of the pulley and causes the pulley to revolve at the same speed as the belt. The band is driven by ordinary belt drive on to the front band pulley from an ordinary shunt wound variable speed electric motor of 4 to 6 b.h.p., having a speed variation of from 750 to 1,500 revolutions per minute. Equally good results, however, may be obtained with compressed air motors or rope drives. The ordinary type of machine as now in general use is illustrated in Fig. 206. From this it will be seen that at the upper portion of the travelling framework there is a small hopper or measuring chamber into which the coal is fed from continuous hoppers erected in the retort house. A telescopic shoot leads from the measuring chamber to the groove of the large pulley, thus the delivery tundish for coal automatically adjusts itself as the machine is raised or lowered to the various tiers of retorts.

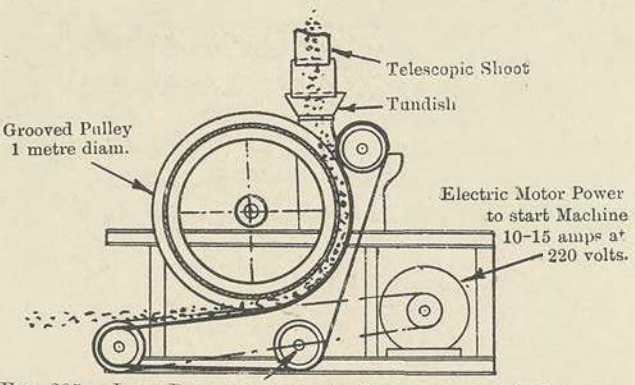


Fig. 205.—Line Diagram showing Principle of De Brouwer Projector.

The operation of charging is as follows :—Assuming that the overhead hopper

is already full, the operator first starts the motor and moves the handle of his speed-regulating rheostat into the position necessary for giving the projector belt the desired speed. This speed varies according to the length of the retort, the class of

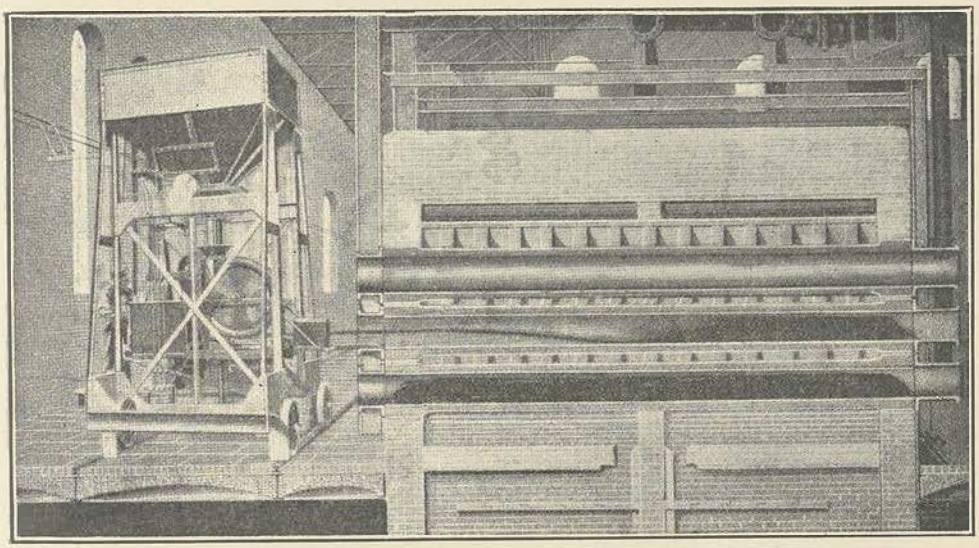


FIG. 206.—THE DE BROUWER PROJECTOR.

coal used, and the thickness of the charge required, and must first be found by trial. With ordinary broken coal and charges of about 9 cwt., the belt speed should be about 2,300 feet per minute, but for perfectly full charges a greater speed will be necessary. When the required speed has been attained, the hopper door is opened and the coal falls into the space between the belt and pulley. The centrifugal force exerted on the coal as the belt passes round the circumference of the grooved drum keeps the coal in contact with the belt, so that the velocity of the coal becomes the same as the velocity of the belt. As the coal reaches the front pulley the belt is suddenly deflected round the pulley, and the momentum keeps the coal travelling forward into the retort in a continuous stream. The distance through which the coal travels is gradually decreased as the operation of charging proceeds, this being effected by a gradual reduction in speed of the band. The whole operation of charging takes from 20 to 30 seconds, according to the amount of coal put into the retort.

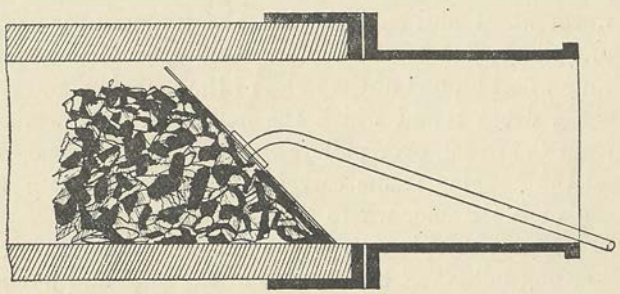


FIG. 207.—SLANTING STOP FOR USE WITH PROJECTORS.

The earlier machines were suspended from an overhead carriage and traversed along by hand, but as this was a somewhat slow process the later machines were arranged in a travelling carriage or frame, and were driven by power.

With projecting chargers of this type some form of obstruction or stop is required at the further end of the retort to prevent the coal piling up on the cool mouthpiece. An ordinary piece of plate with a supporting rod at the back is generally used for the purpose. It is as well to remember, however, that the vertical stop originally employed frequently accounted for a small portion of coal remaining uncarbonized at the end of the distillation period, and it is preferable to make use of the slanting stop as seen in Fig. 207. A more recent type of stop is shown in Fig. 208.

The following are the more interesting points connected with the De Brouwer machine :—

Large pulley : Diameter, 1 metre (39·3 inches).
Width on face, 15 inches.
Width of groove, 8 inches.
Depth of groove, $3\frac{3}{4}$ inches.
Average speed of pulley, 220 revolutions per minute.
Average speed of coal band, 2,300 feet per minute.
Power required, 10 to 15 amperes at 220 volts.

The Jenkins-De Brouwer Pusher

This machine has a strongly braced framework of steel channels and angles, forming a travelling carriage, and is fitted with wheels for running along rails in front of the retort bench, preceding the De Brouwer charger. An electric motor and gearing box is fixed on the main channels of the frame, on the left-hand side, for hoisting the pusher ram to suit the various tiers of retorts and also for propelling the machine along the rails. The motor is of $7\frac{1}{2}$ b.h.p., entirely enclosed, provided with end covers, dirt and dust proof, and connected by a suitable coupling to the first motion shaft in the gearing box. The gearing box is fitted with a worm and worm wheel and spur gearing, also a clutch for connecting either the hoisting or propelling gear to the motor. One spur pinion in the gearing box gears with a spur wheel on one of the axles of the machine, and the worm wheels shaft carries a chain drum round which the hoisting chains work. These chains pass upwards from the drum, over pulleys on the machine frame, down again and round pulleys on the hanging frame carrying the telescopic ram, and back to a point near the top of the frame, where they are anchored.

The telescopic ram is in three parts, the first or inner length being formed of a strong mild-steel bar cut out of the solid and having drilled holes for the driving sprocket teeth and a plate end. The plate end carries a hood or scoop at the top to hold the coke and keep it from crushing up. This inner bar slides within the second length. Inside the front end of the second length is fixed a suitable stop which fits into a groove on the top side of the first length, so as to fix the length of stroke of the first bar and to ensure it having a rigid bearing within the second length when

fully extended. The section of the second length is made up of two steel channels connected together by means of steel cover plates. This length has fitted at the back end four rollers running on cast-steel pivots. The rollers are of suitable size for running within the channels which form the third length. The stroke of the second length is governed by stops fixed in the front end of the third length with which the front rollers come in contact, thus ensuring a rigid bearing when fully extended. The third length is of similar but larger section to that of the second length. This length is also fitted with four rollers running on cast-steel pivots. These rollers are of suitable size for running within the fixed channels which form the lower portion of the hanging frame, which is fitted with stops at the front end

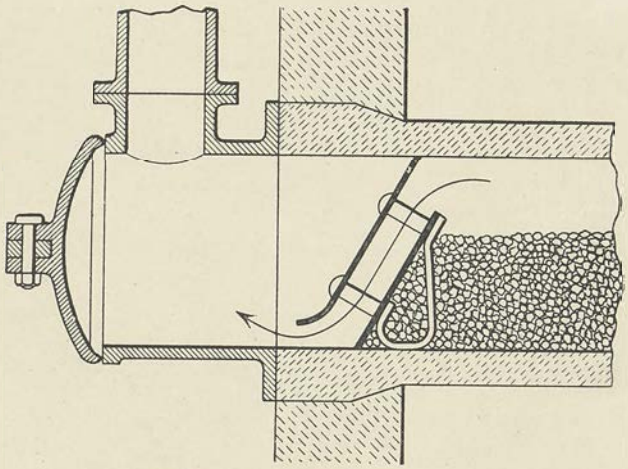


FIG. 208.—NEW TYPE COAL STOP.

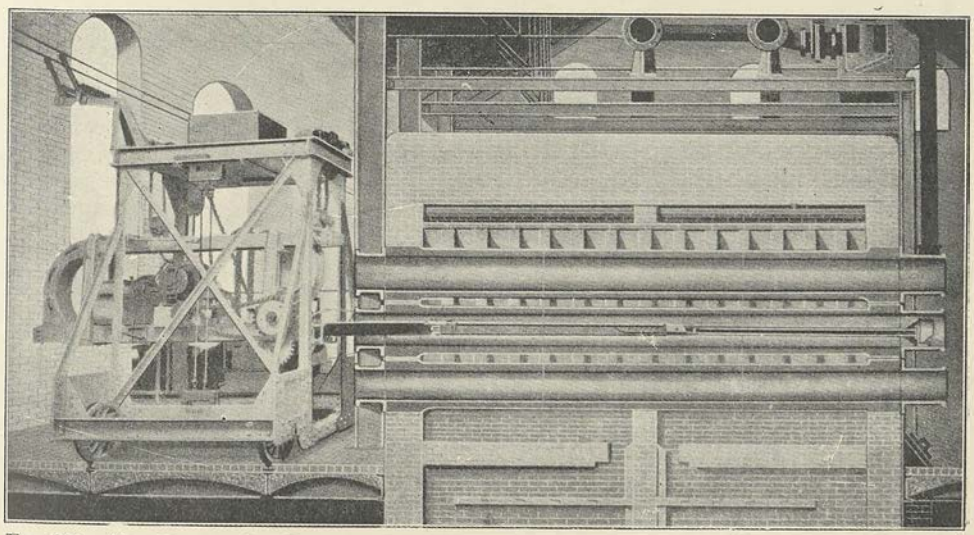


FIG. 209.—THE JENKINS-DE BROUWER DISCHARGING PUSHER, SHOWING THE TELESCOPIC RAM FULLY EXTENDED.

so that the third length also has a rigid bearing when at its extreme outward stroke.

On the underside, at the front end of the hanging frame, there is a steel rack pinion keyed to a shaft on the end of which is fitted a steel spur wheel to gear with

a similar wheel on a shaft fixed above. To this latter shaft is keyed a strong sprocket chain wheel. The pinion gears in the rack forming the first bar and also gears with the second and third portion, consisting of cast-steel jointed links, which pass

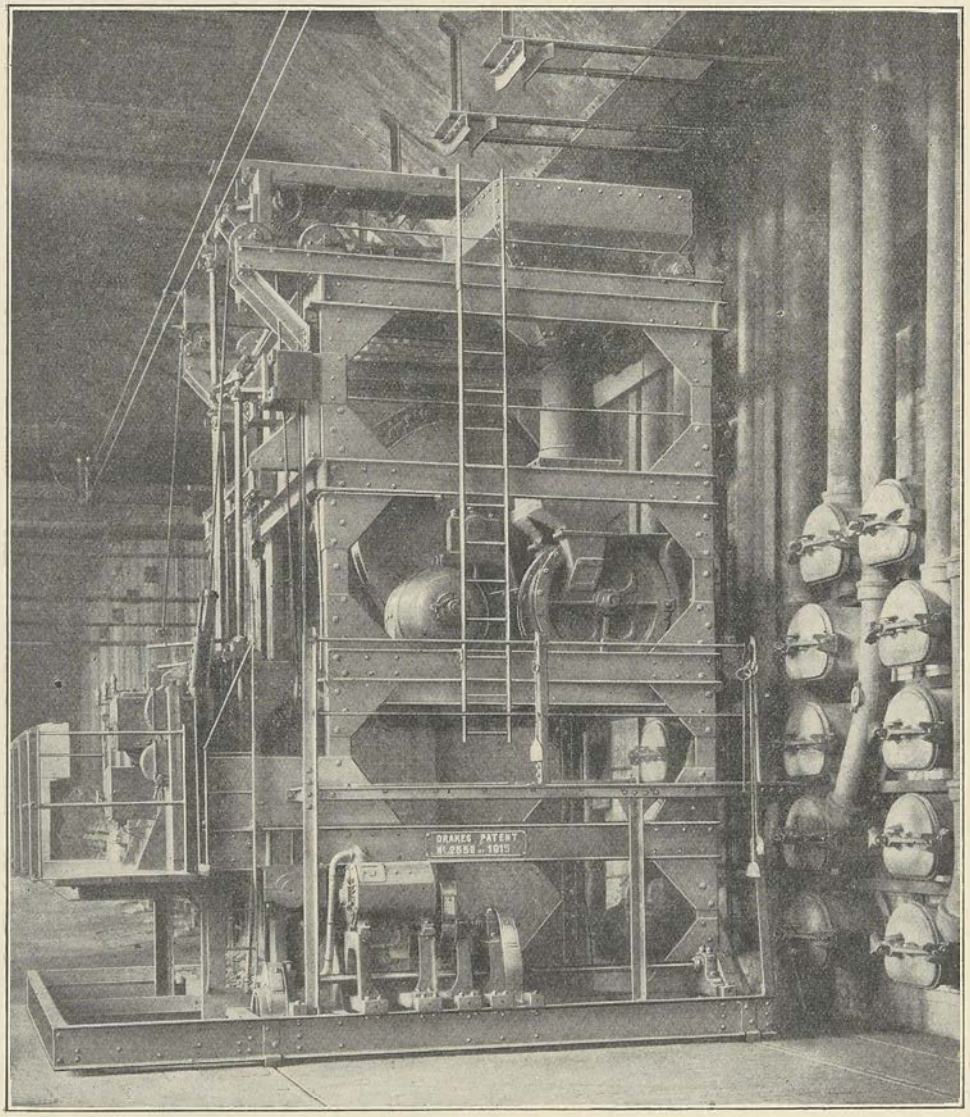


Fig. 210.—Drake's Combined Projector and Pusher, showing Projector.

upwards round the guide path at the back end of the frame when the pusher bar is out of the retorts. A water spray is fixed at the front end of the hanging frame for cooling the telescopic ram.

Motion is transmitted from the pusher motor by means of a pinion driving a spur wheel keyed at one end of an intermediate shaft having at the other end a

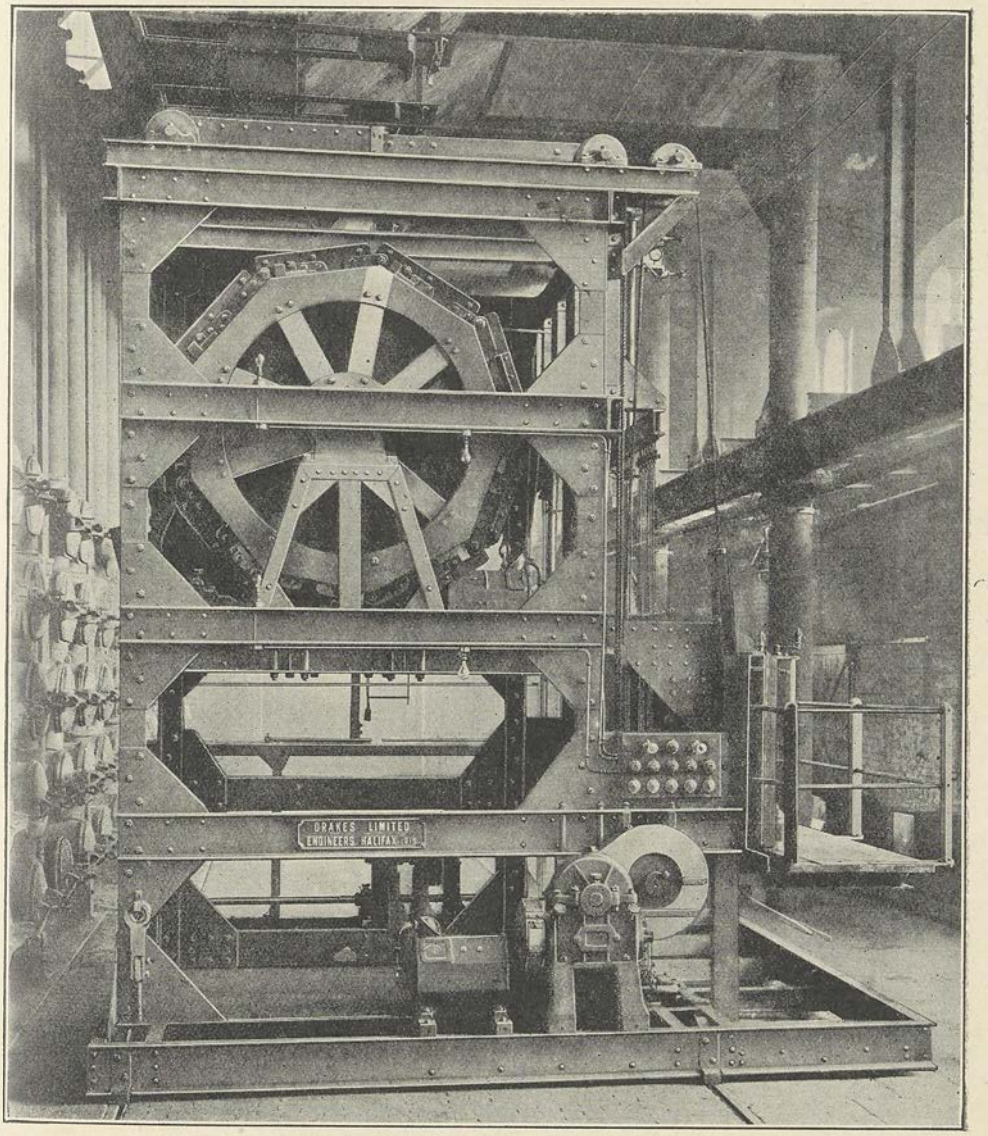


FIG. 211.—DRAKE'S COMBINED PROJECTOR AND PUSHER, SHOWING PUSHER CHAIN.

sprocket chain pinion for driving (by means of roller chains) the chain wheel near the end of the hanging frame.

The telescopic ram is driven by an electric motor which is an exact duplicate of the hoisting and propelling motor, and which is carried on a cast-iron bedplate

bolted to the channels of the hanging frame. The current for the two motors is collected from two overhead bare copper conductors by means of two trolley poles fixed near the top of the machine frame. From these poles the current is led by means of stranded copper insulated conductors carried in steel conduits to the switch and connection box on the platform. The connection box is fitted with the necessary double pole switch, automatic circuit breaker and distributing fittings. From this box the current is led to the reversing controller of the hoisting and propelling motor and to two bare conductors strained vertically on one side of the machine frame. The motor driving the telescopic ram collects its current from these conductors by means of two short trolley poles fixed to the hanging frame. An automatic cut-off is arranged so that the controller is returned to the "off" position at each end of the stroke of the ram, also when the hanging frame is moved to the top and bottom positions. A foot brake is attached to the machine for bringing it to rest exactly in front of the retort which is to be discharged.

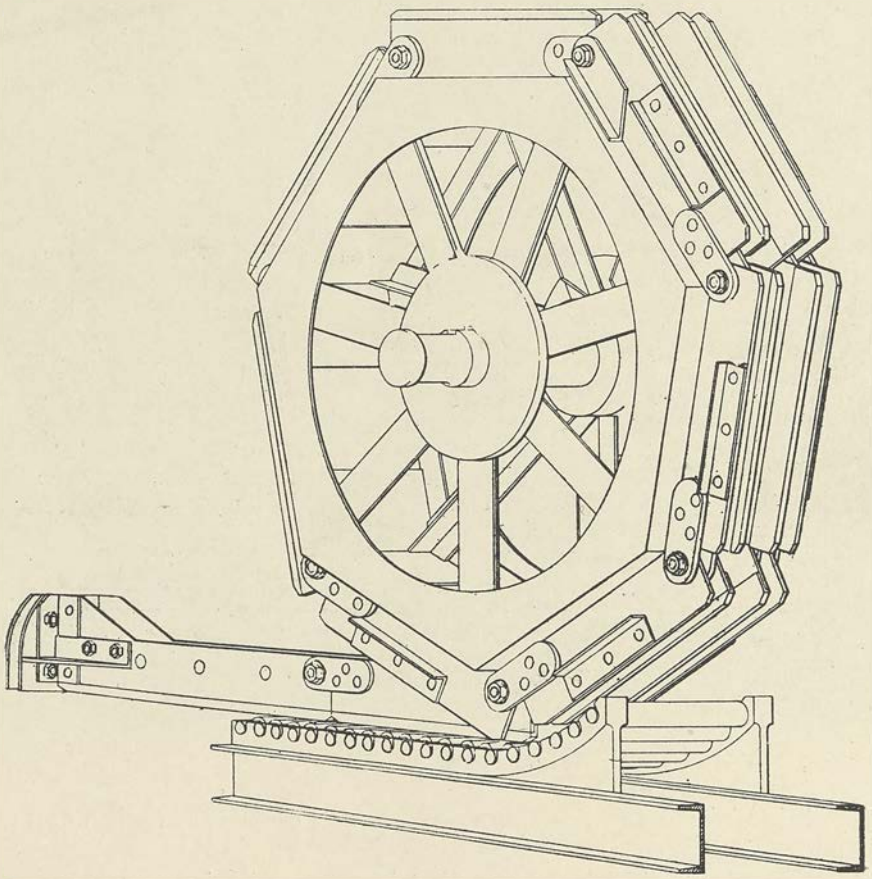


FIG. 212.—DRAKE'S PUSHER, SHOWING CONSTRUCTION OF THE CHAIN.

Drake's Projector and Pusher

Drake's stoking machine, in which the projector and pusher are mounted on a common wheel-base, is illustrated in Figs. 210 and 211. The principle of the projector differs entirely from that of De Brouwer. The outer casing contains a rotor very similar in construction to the paddle-wheel of a steamer, with the exception that it is divided down the centre so that with a feed at either side the coal is charged into the retort in two streams. These streams converge in the retort and form the charge. Owing to the manner in which the coal feed is arranged the lumps of coal are not knocked into the retort by the blades of the rotor, but they are picked up and thrown in by a centrifugal force. It will be seen that the coal drops from a storage hopper direct into a telescopic shoot, which in turn delivers to a breeches shoot feeding into both sides of the projector simultaneously. An apron is fitted to the front of the casing in order to prevent any spilling of coal.

The construction of the discharging pusher will be readily followed from Fig. 212. The ram is of taper construction, and the narrow end lets down into the wider end when folding round the drum. The chain is constructed from mild steel, and the links are fitted with renewable hard steel sliding pieces and hard steel horns. To one side of the shaft of the main drum is keyed a phosphor-bronze machine-cut worm wheel driven by a mild-steel worm running in an enclosed oil-bath.

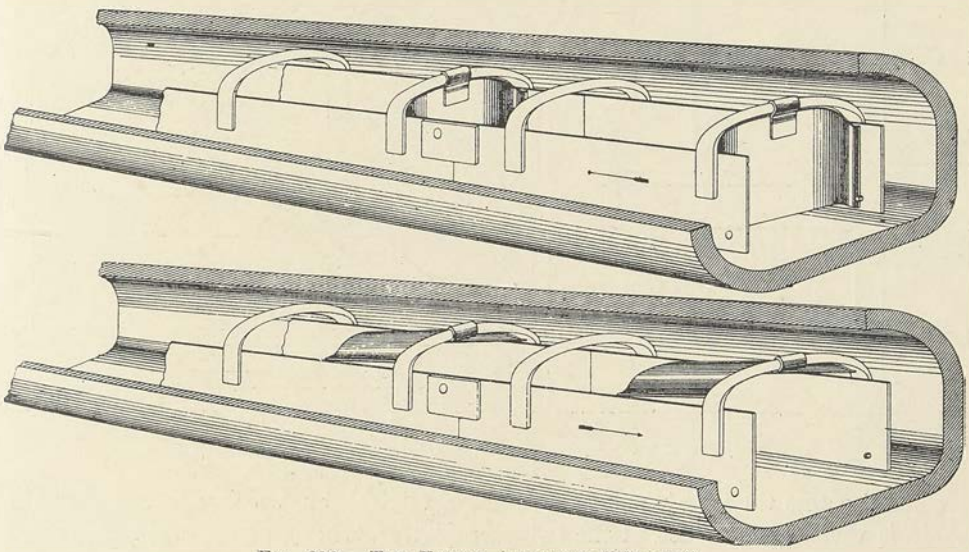


Fig. 213.—The Fiddes-Aldridge "Chain."

Discharging Chargers

One of the most interesting modern developments connected with the operation of gas retorts is the discharging charger, which effects the expulsion of the coke and

the refilling with coal in a single stroke. The first machine of this kind to be introduced was the Fiddes-Aldridge, which accomplishes the work by means of a specially designed push-plate conveyor consisting of two vertical parallel plates but with no bottom. These plates are hinged about every 3 or 4 feet, and are maintained in position by cross-bars arched to the same radius as the crown of the retort. Plates are suspended from the cross-bars, and are so arranged that when the conveyor or

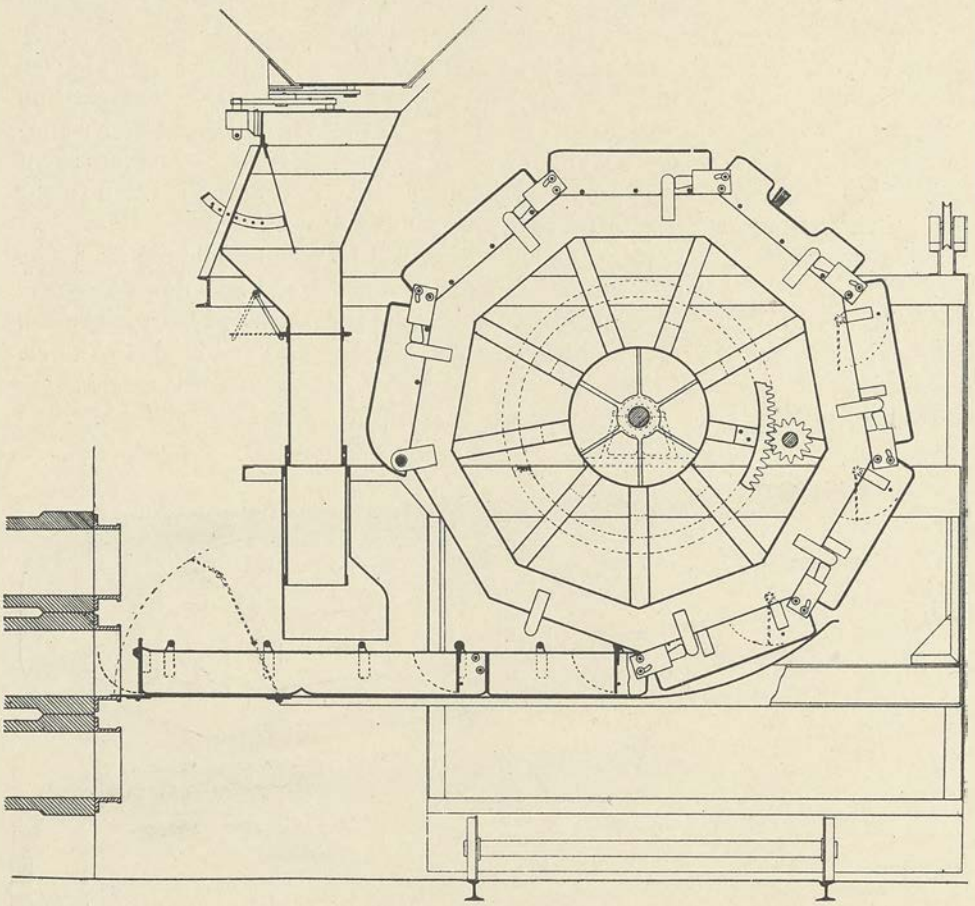


FIG. 214.—THE FIDDES-ALDRIDGE DISCHARGING-CHARGER.

" chain " enters the retorts the plates remain vertical, but are free to lift when the chain is withdrawn. Each of the swinging plates pushes a certain amount of coal into and along the floor of the retort; whilst on the backward stroke the plates lift automatically and assist in levelling the charge. The construction and working of the chain will be clearly followed from Fig. 213.

A measuring chamber over the chain receives the coal from continuous hoppers, the coal being dropped through a shoot into the chain as the latter passes forward into the retort. The chain passes round a vertical polygon wheel, which is

usually driven by electricity, mounted on a steel framework. Two frameworks are provided (an inner one and an outer), the inner frame rising or falling inside the larger one so that any tier of retorts may be charged. A hinged apron plate is lowered into the front of the retort mouthpiece, and acts as a connecting trough between the retort and the machine, the bottom of the apron plate forming the bottom of the chain. The front length of the chain (called the "fire-length") is

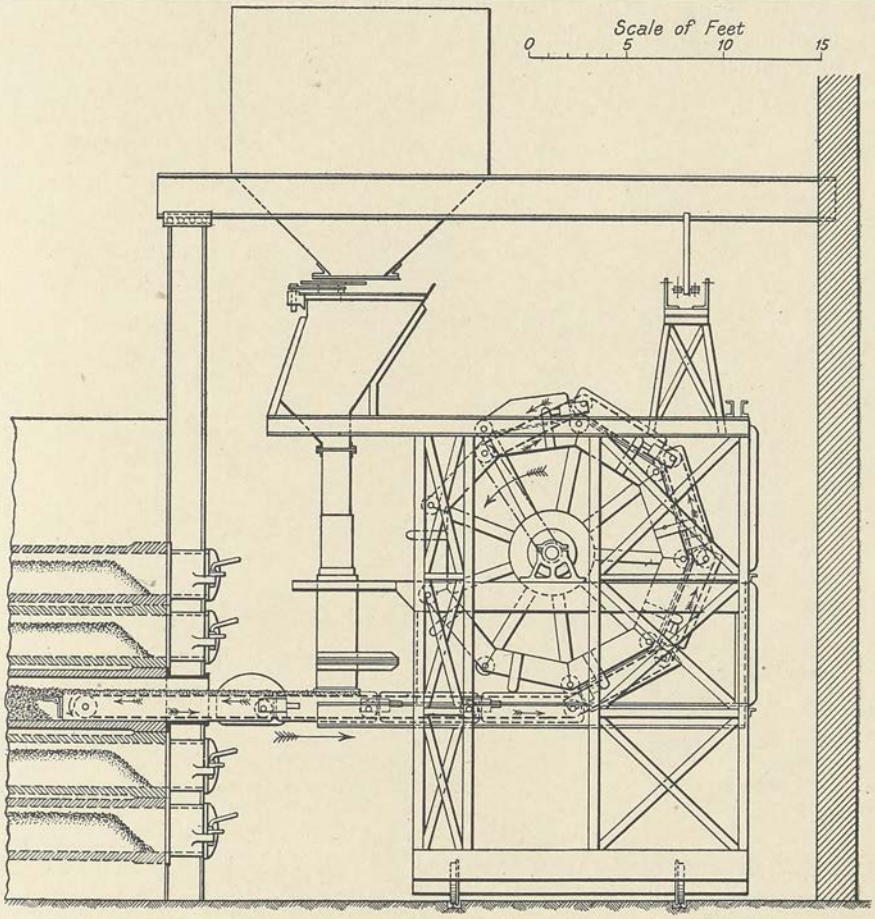


FIG. 215.—FIDDES-ALDRIDGE CHARGER-DISCHARGER. NEW TYPE.

very strongly constructed, and acts as a pusher head during the outward stroke. The operations of charging and discharging are performed simultaneously, about 30 seconds being necessary to empty and refill a 20-foot retort. The external dimensions of the machine are about 8 feet 6 inches long by 13 feet high. The standard pattern of the original type of Fiddes-Aldridge machine is fully illustrated in Fig. 214, from which part of the framework has been removed so as to give a clearer view of the driving wheel and chain.

The machine was originally introduced at a time when many engineers still favoured the light charge of coal, and one of the few disadvantages it embraced was its inability to completely fill the ordinary retort with coal. This was due to the fact that a certain amount of room must be left in the crown of the retort for the return of the chain plates. In the latest type of machine (Fig. 215), however, this drawback has been overcome, and retorts may now be completely filled if so desired. The main polygonal driving-wheel is still retained, and the modification has chiefly occurred in the construction of the chain. All push-plates are dispensed with, and instead there is a chain carrier inside which runs a flexible conveyor. The chain carrier and conveyor are set in motion and enter the retort together, the conveyor depositing

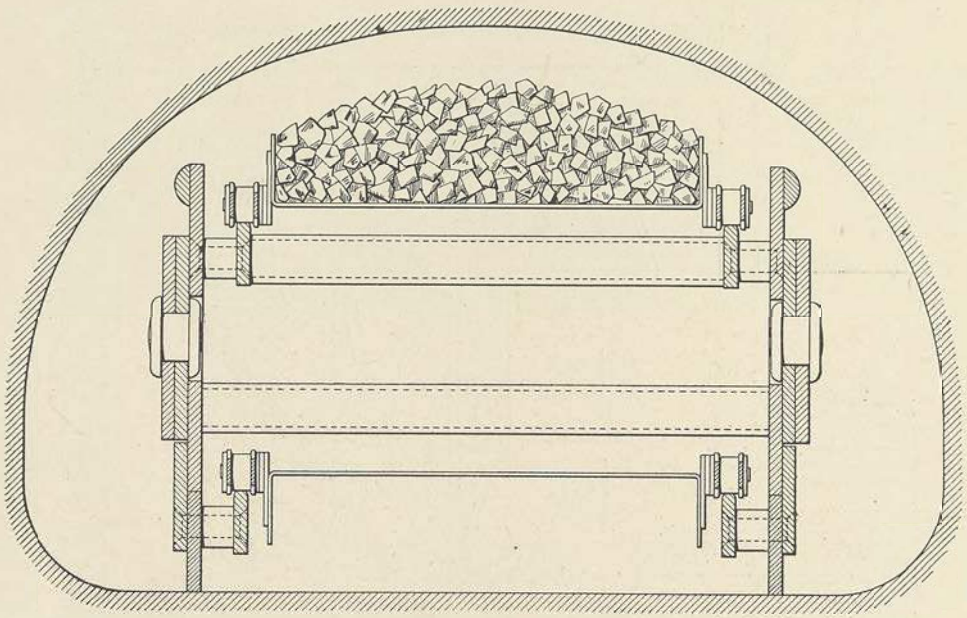


Fig. 215A.—The New Type of Fiddes-Aldridge Machine, for delivering Full Charges. Section of the Chain.

coal along the bottom of the retort until the far end is reached. The speed of the flexible conveyor is then increased as both are withdrawn, and coal is thrown over the end of the conveyor at such a rate as to fill the retort completely. By varying the relative speeds of the chain carrier and the running chain or conveyor any sized charge can be placed in the retort. The flexible conveyor runs the full length of the carrier chain, so that there is in reality one conveyor inside another. As explained above, a thin layer of coal is laid on the bottom of the retort during the outward discharging stroke, but this is not essential, and, if so desired, the whole of the charge may be delivered over the end of the conveyor during the return stroke. The construction of the machine will be followed by reference to Fig. 215A, in which the flexible and carrier conveyors are clearly seen.

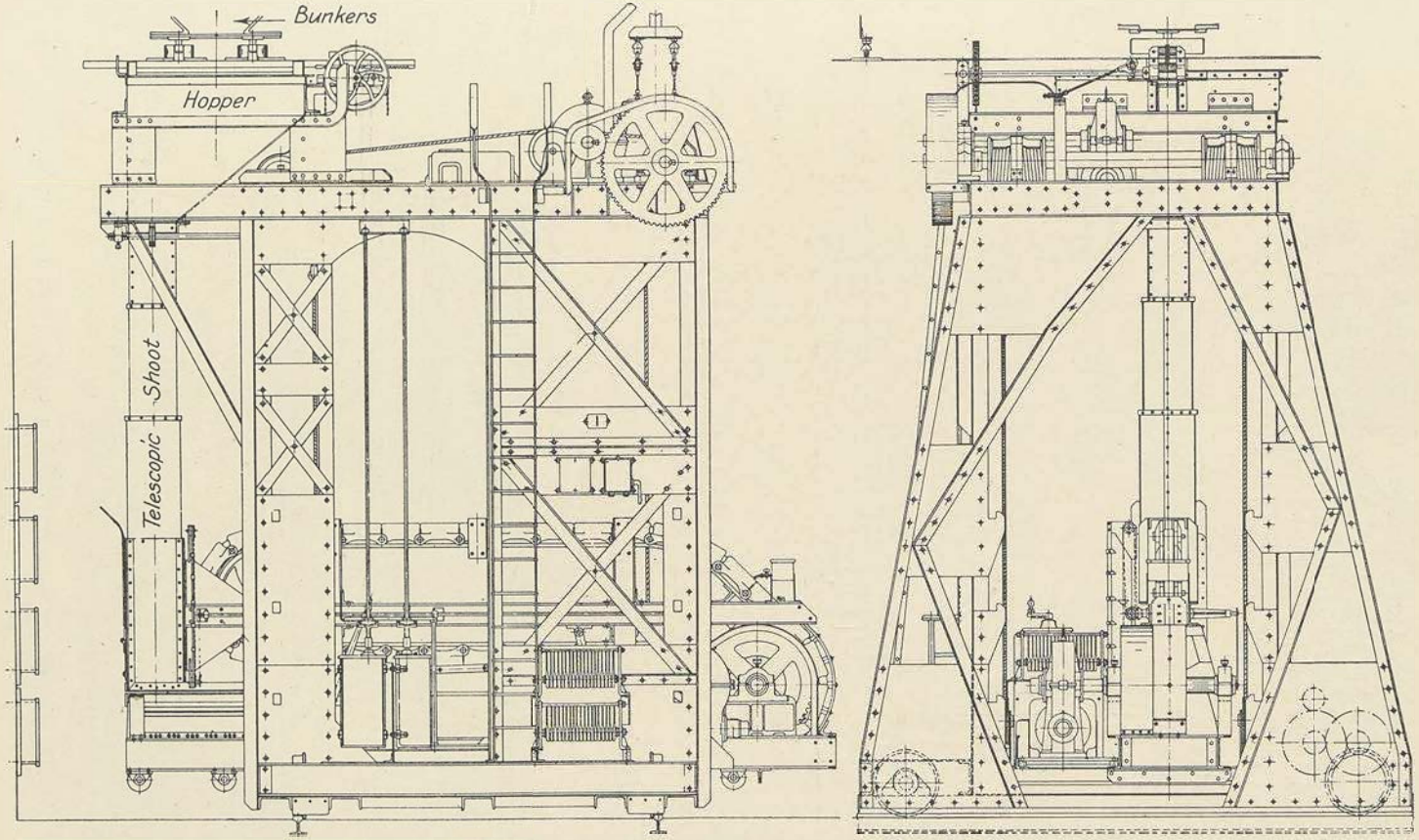


FIG. 216.—THE GUEST-GIBBONS DISCHARGING-CHARGER.

The Guest-Gibbons Discharging-Charger

This machine has been designed for the dual purpose of discharging the coke and completely refilling the retort with coal. The general construction of it is shown in Fig. 216. The portion of chief interest is the chain, which combines the coke pusher and means for introducing the coal charge.

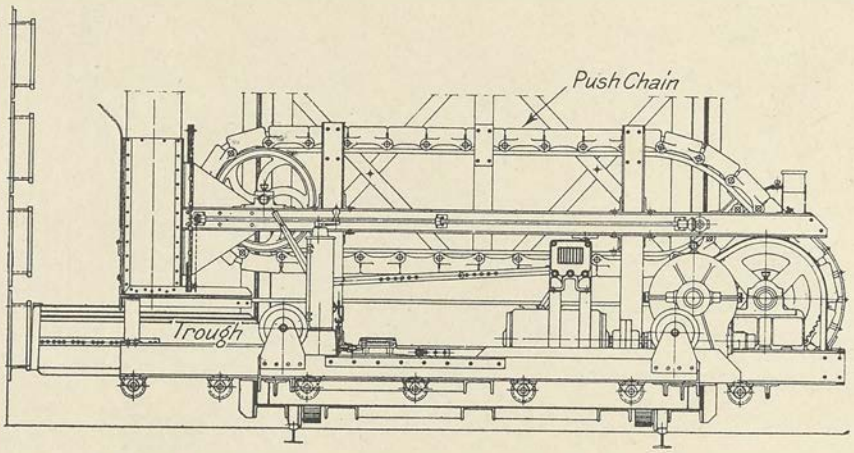


Fig. 217.—Guest-Gibbons Machine, showing detail of Push-Chain.

The machine hopper receives coal from the main storage bunkers, the coal falling (*via* a telescopic shoot fitted with an automatic cut-off door) into a retort-

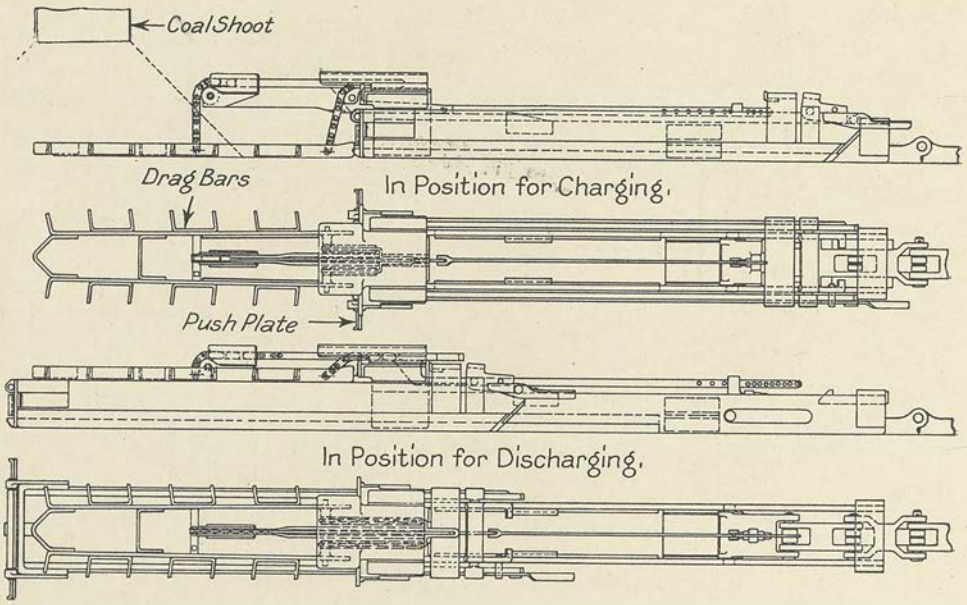


Fig. 218.—Guest-Gibbons Machine, showing two Main Positions.

shaped trough plate and on to the drag-bars in front of the push-plate. The structure carries a push-plate and drag-bars which is connected at rear end to a " push-chain," with links butting together, after the manner of the joints of a rule. Thus the chain can bend in one direction only. This push-chain is actuated by a sprocket driven

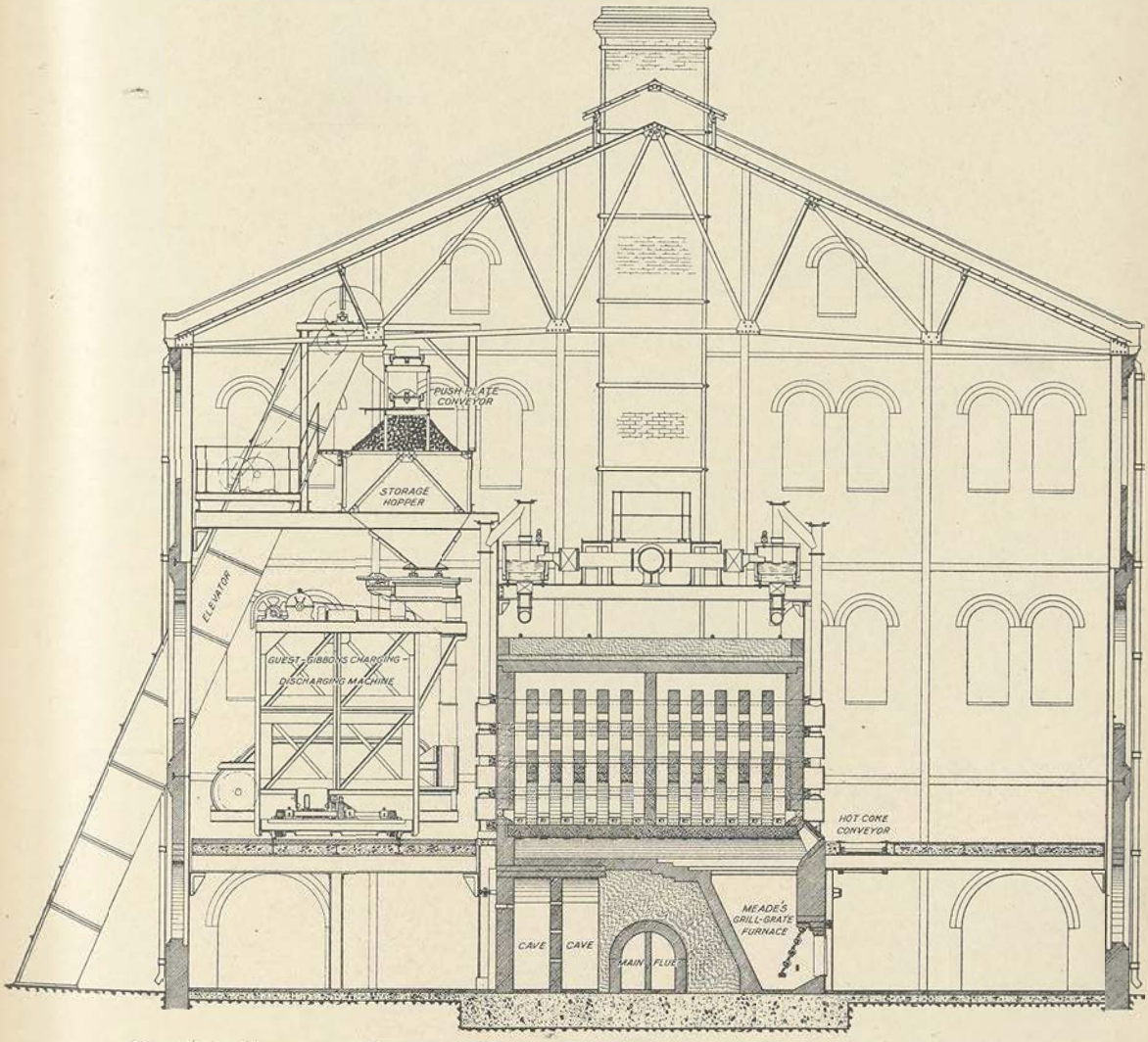


FIG. 219.—SECTION OF HORIZONTAL RETORT HOUSE, SHOWING COAL-FEEDING ARRANGEMENTS, CHARGING MACHINERY, HOT COKE CONVEYOR, ETC.

through reduction gear by a reversible crane type motor. The trough plate rests on rollers, and is run out (by frictional action of the charger-discharger) against the retort mouthpiece, where it is held by a toothed clutch while the machine is in action. It so forms a continuation of the retort, incidentally reducing to a minimum dust

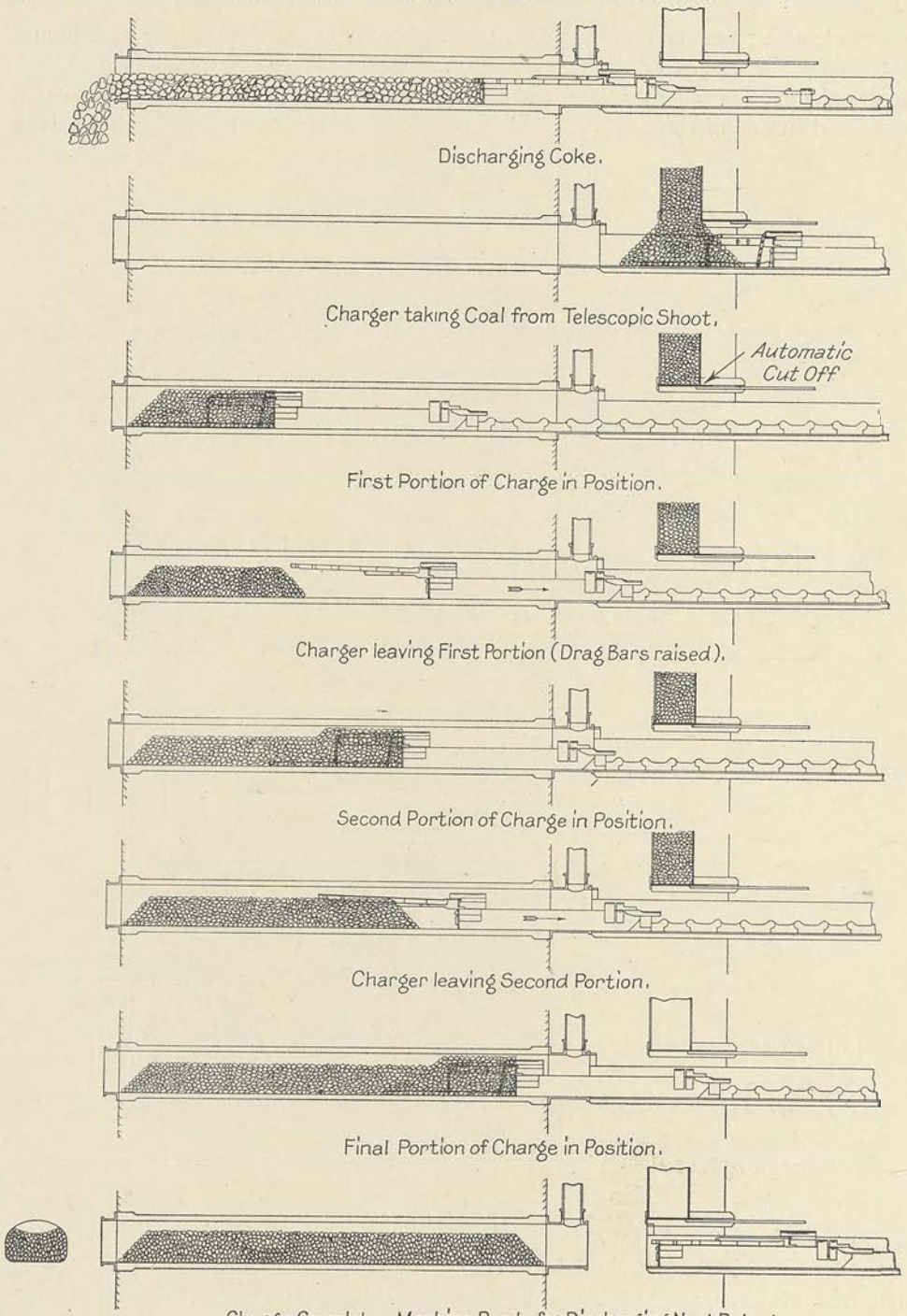


FIG. 220.—GUEST-GIBBONS MACHINE. DIAGRAM OF OPERATIONS.

and similar objections. Coal is received on the drag-bars, and the charger-discharger travels forward with the " shot " of coal (automatically closing on its way the cut-off at shoot bottom) until the required position is reached at further end of retort, when the mechanism being reversed causes the grid of drag-bars, before any backward movement is commenced, to lift vertically through the coal to the top of the retort, in which position it travels during the return stroke. This movement (1) frees the drag-bars from the coal; (2) loosens the coal as the bars pass vertically through it, while the drag-bars finally level the charge in the retort, the height to which they are raised being capable of adjustment. This provision, together with one for adjusting cut-off at the shoot bottom, enables the charge of coal to be regulated as desired. The charger-discharger is then brought back to the loading position, and a slight forward movement drops the drag-bars to level of retort bottom ready for the second instalment of coal, which, admitted through the cut-off door, is carried forward like the first one. Three such operations suffice for a 20-feet retort. For discharging coke, a foot-lever is depressed, and the drag-bars in their raised position are drawn back clear of the top of the push-plate by a short backward movement of the push-chain. In this way a fixed ram for discharging is formed. The operation of the machine will best be understood by reference to the diagrams given in Fig. 220.

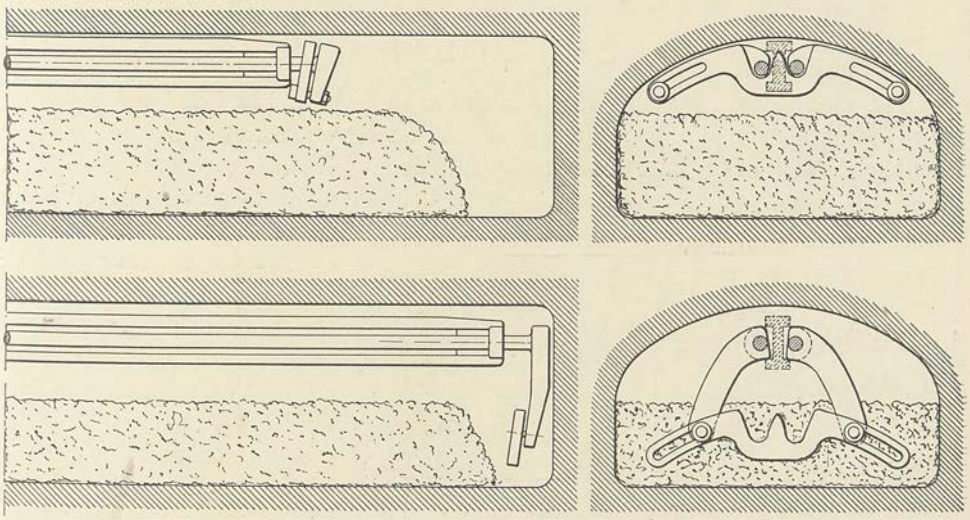


FIG. 221.—THE NERRIÈRE COKE DISCHARGER FOR STOP-ENDED RETORTS.

THE NERRIÈRE COKE DISCHARGER

An interesting example of a drawing machine designed for the extraction of coke from stop-ended retorts on small works is the Nerrière discharger. The apparatus has mainly been employed in France, and consists essentially of two jointed portions carried upon a horizontal piece, and terminated by two steel hooks which

lie against the roof of the retort, and which pivot upon two axes actuated from outside. The two hooks are connected by a steel traversing piece which is withdrawn behind them when the appliance is being introduced into the retort, but which descends behind the coke when it is to be extracted. The form and size of the different parts of the machine vary in accordance with the shape and size of the retort. The time taken to insert the extractor and withdraw a charge varies from 30 to 45 seconds.

SUBSIDIARY RETORT-HOUSE MACHINES.

During recent years machines have been introduced into the retort house for performing subsidiary duties such as the augering of ascension pipes, the clinkering of producers, and the poking down of fuel into the latter. Owing to the comparative immunity from stopped pipes in the modern retort house, however, the augering machine has disappeared, and the same may be said of the clinkering machine, which has been rendered unnecessary by the introduction of grates which preclude the formation of large masses of clinker. Indeed, the modern retort-house is conspicuous for the fact that, as compared with a decade ago, arduous working conditions entailing considerable effort in the face of severe heat, have almost disappeared.

Clinkering Machines

The mechanical clinkering machine shown in Figs. 222 and 223 was operated by hydraulic, pneumatic, or steam power, and effectively removed the heavy layer of clinker formed at the base of the fuel-bed in about one-fifth the time required with manual work. There is no particularly novel feature about its construction, which is on the principle of a ram, the head being designed to cut through hard masses of slag. As an instance of the saving effected it may be mentioned that at one of the larger London gasworks a single fireman was capable of dealing with three producers during his eight-hour shift; that is to say, he was deputed to clinker retort settings yielding about half a million cubic feet of gas per diem. With the aid of the machine the man increased his daily number of fires to eight, and his gas output to $1\frac{1}{4}$ million cubic feet. Other advantages were the saving of fuel, owing to the shortened period for which the doors were open, and decreased wear and tear on the false firebars.

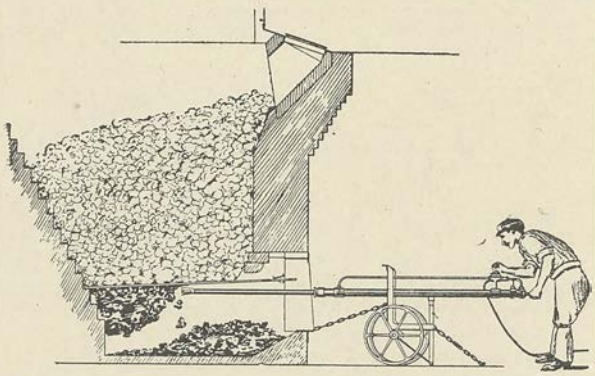


Fig. 222.—Mechanical Clinkering.

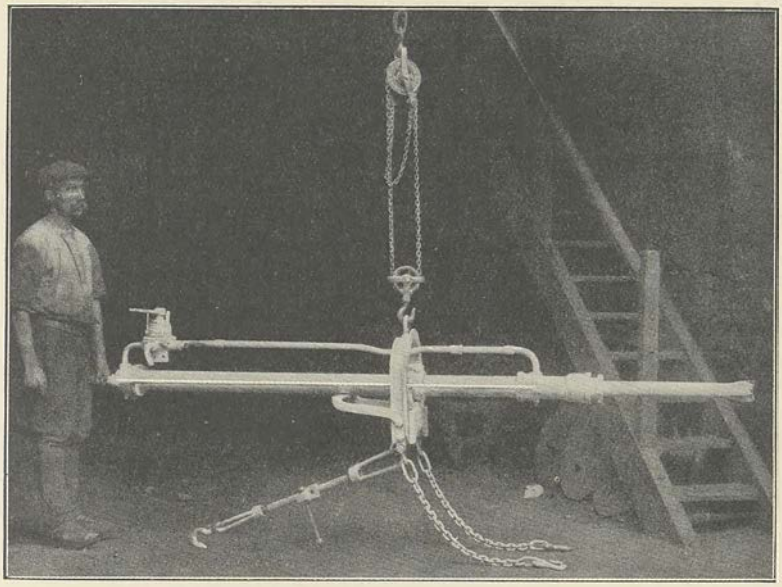


FIG. 223.—GILL'S MECHANICAL CLINKERING MACHINE.

THE FURNACE POKER

The object of this machine is to relieve the retort-house hands of one portion of their duties which demands much physical exertion. In the ordinary way the heated coke as it falls from the retort is poked down into the producer and levelled off by manual labour. For this reason it is customary to employ more men on the stage

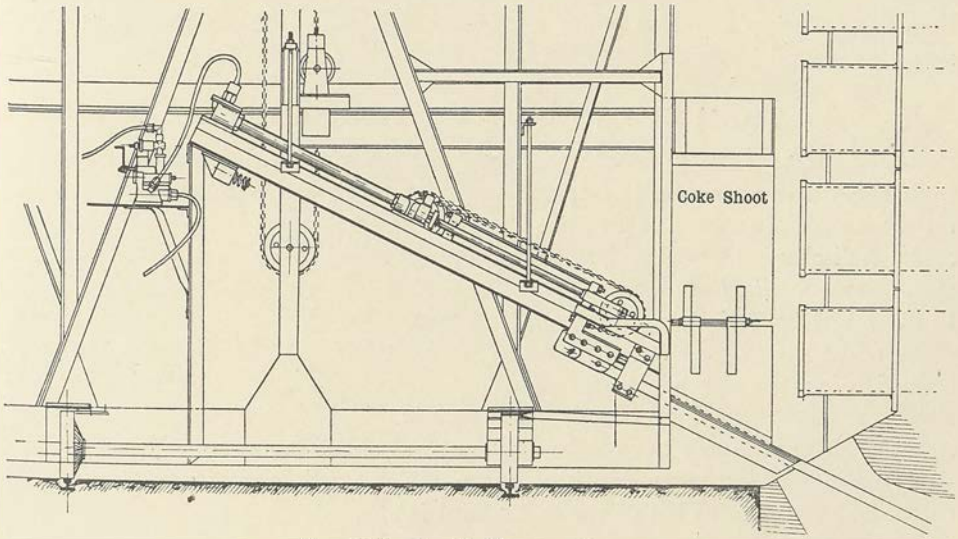


FIG. 224.—GILL'S FURNACE POKER.

during the "firing draw" than is the case when the coke is merely pushed out and taken to the stock heap. By installing the poker the necessity for extra labour is averted, and the work can be more quickly and effectively carried out. The hydraulic type of machine is shown in Fig. 224. As will be seen, it is customary to attach the poker to the side of the framework of one of the "pushers," so that no separate travelling carriage is necessary. The poker itself consists of a rod 9 feet long by 3 inches wide by $\frac{5}{8}$ inch in thickness, and is provided with a cast-iron fish-tailed head. It is actuated by two rams each about 4 feet in length and $1\frac{1}{2}$ inches in diameter, attached by means of chains to a slipper fixed at the back end of the rod. One ram is used for the forward stroke and one for the backward stroke, the length of the stroke being 6 feet. The time taken to charge a producer with about 9 cwts. of coke is approximately 25 seconds.

GENERAL POINTS

The cost of operating a retort house depends very naturally upon the magnitude of the installation, the proportion of the work which is carried out by mechanical means, and whether or not the men are worked up to their full capacity. A retort house may be fitted with the most economical type of charging and discharging machinery and yet be served in a more or less primitive manner as regards the intake of coal and the disposal of coke. The methods of conducting the retort-house work may be classified under three headings :—

(1) Manual labour entirely, for all works up to about 20 million cubic feet per annum.

(2) Manual machines, for works between 20 and 120 million cubic feet per annum.

(3) Power machines, for works making more than 120 million cubic feet per annum. It should be noted that there are a limited number of works making less than this quantity in which power machinery is installed, but in general this limit may be adhered to unless exceptional considerations come into account.

THE USE AND CONSTRUCTION OF GRABS

Little more than a decade ago the methods employed for discharging coal from ships and conveying it into the works or stockyard were largely dependent upon manual labour. At that time the grab had not come into general use ; the coal was discharged by being shovelled into tanks raised by hydraulic cranes and into stationary hoppers, from which the coal was taken, often some considerable distance to the retort house in trucks propelled by men. The skips, however, gave way to grabs, and the original type of the latter, which could only be discharged at a prescribed height, is now being supplanted by the self-acting grab, which effects discharge at any point immediately on dumping. This latter form is particularly suitable where coal may have to be discharged at about the same level as the filling —*i.e.* when working from ship into barge—for no man is required to release the catch, and economy of both time and labour is effected.

In general, modern grabs may be classified into two types, namely, those

operated by a single rope or chain, and those operated by two ropes. As yet, the first type is most common on gasworks; where, too, a preference is still found for chains rather than wire ropes. Modern practice, however, is gradually inclining towards the substitution of ropes for chains, the chief advantage gained being an appreciable reduction in weight for a given safe load, the ratio amounting to so much as 8 to 1 in favour of the wire rope, while, more important still, wire rope gives warning of impending failure, whereas chains do not. As it is frequently necessary to estimate on the spot the weight and safe load of various descriptions of crane chains, it may be useful to call attention to a quick and ready method which the author uses. For weight, take the size of the chain in eighths of an inch, square this, and the result is weight in pounds per fathom. For safe load, again take the square of the size in eighths and divide it by 10.

E.g. A one-inch chain $= \frac{8}{8}$ inch: $8^2 = 64$, therefore weight of chain $= 64$ lb. per fathom.

Again, $\frac{8^2}{10} = 6{\cdot}4$, therefore safe load $= 6{\cdot}4$ tons per square inch, with a factor of safety of about 5.

It would be impossible to deal here with the general construction of grabs, or to describe the numerous types which are now to be found. The subject is one which demands a volume to itself, as an instance of which it may be mentioned that during the past fifteen years well over a hundred patents for apparatus of the kind have been granted. The Barnard self-acting grab provides a typical example of the latest developments in these machines, but it is only one example of many of the same kind. The self-acting principle in brief consists of the employment of a single wire rope or chain passing round the grab sheeves. The grab in the open position is lowered by the crane on to the material, when the hoisting chain must be run out until the clutches engage with the pins carried by the crossbeam. Then, on hoisting, the jaws close in on the coal. For discharging, the grab is lowered so as to rest on the coal in the receiving hopper or store heap, and the hoisting chain or wire is slackened a few inches. This motion releases the clutches, and, on hauling up, the jaws are opened, thus discharging their contents.

A great advantage attached to the use of the self-acting grab is that its capacity for a given weight is much greater than the capacity of some of the more common forms. For instance, a Barnard grab having a capacity of 1 ton of coal weighs approximately 1 ton, while many of the older grabs of similar capacity weigh as much as 28 cwt. When this factor is considered in relation to the safe load of the crane it will be seen that with the new type of grab considerably more coal can be dealt with in a given time; or, in other words, a ship of given capacity can be discharged in less time. This fact is of supreme importance at the present day, when so much depends upon quick discharge. At what is probably the largest jetty attached to a gasworks in London the time of discharge has been reduced by one-third by the substitution of self-dumping grabs for those of an older pattern. With the self-acting grab, moreover, wear and tear is reduced owing to the elimination of shock due to a high discharge, while the dust difficulty is more or less surmounted.

A practical point to be borne in mind—particularly when dealing with coke—

is that the capacity of a grab to fill is in no way increased by dropping it down heavily on to the material. It is a fallacy to suppose that the jaws dig more effectively into the material if this is done; for, with properly designed grabs, the action of the jaws is a gathering one, and they have a natural tendency to dig themselves in.

ELEVATING AND CONVEYING MACHINERY

Only in exceptional cases is the gasworks engineer in a position to design in detail mechanical plant for the handling of his materials, and as there are to-day many contractors who are specialists in this type of work there should be no hesitation in placing the matter in their hands. If this is done, standardized details will not be departed from, and the system will gain in efficiency and economy. In obtaining tenders or settling upon new plant there are several points which the engineer with the erection of machinery in view should bear in mind. He should supply to the contractor figures showing the capacity of plant in tons per hour, stating the conditions of working. In return, the contractor should be asked for the following particulars :—

(*a*) Breadth of elevator buckets or conveyor band.

(*b*) Pitch of buckets, and speed of chain or band. The engineer should provisionally fix the speed, laying down a certain limit.

(*c*) Detailed specification of buckets and chain; or,

(*d*) Detailed specification of belt.

(*e*) Particulars of arrangement for taking up elongation of the chain or belt, and the facilities afforded for the renewal of working parts.

(*f*) Details of framing and supporting girders, with the thickness of all sheets and plates in hoppers, etc.

[1] (*g*) Power required for driving; also types and sizes of motors or engines supplied, and surplus power provided.

(*h*) Arrangements for lubrication; also what provision is made for the lessening of friction.

(*i*) If electrically driven, details of cabling, starters, and accessories (if any) supplied.

No general rule can be laid down as to the limiting size of a works on which coal or coke-handling plant can be profitably employed. It may be taken, however, that a minimum size plant (including buildings) would cost from £4,500 to £5,500; and 17½ per cent. on this outlay represents about £875. Accordingly a 60 million per annum works would have about 3*s*. per ton of coal used before the machinery could be shown to be profitable.

There is a certain similarity between elevators and conveyors in that, so far as types employed on gasworks are concerned, they consist almost solely of endless belts or chains passing around two terminal pulleys. To such chains are attached suitably shaped buckets or draw-bars. The length of the conveyor or elevator is

[1] The engineer will generally prefer to purchase his own motors, arranging for the surplus of power he thinks advisable. (*See* Chapter X.)

measured from centre to centre of the terminal sprockets. It is the common practice to construct chains for these purposes from malleable-iron or steel links; and, as after a certain period of working the metal takes up a permanent stretch, it is usually necessary to provide some form of automatic tightening gear. With the simple elevator it will generally be found sufficient if the bottom sprocket is fitted with adjustable bearings, so that any extension may be periodically taken up. For elevators of larger capacity a single chain is insufficient, and multiple strands have to be resorted to. An objection to these is that the different strands (usually two) will stretch unevenly, thus throwing the buckets out of alignment with one another. This particularly applies to the malleable-iron type; and in long lengths of conveying machinery it is usual to provide some form of adjustment for correcting the defect, distinct from that employed for automatically taking up any slack. The device for tightening each chain which is employed in many conveyors is shown in Fig. 225, whilst Fig. 226 illustrates the means introduced for taking up the total increase of length of the chain. In modern elevators for heavy purposes wrought-iron links connected together by turned bolts passing through machine-bored holes are almost exclusively employed.

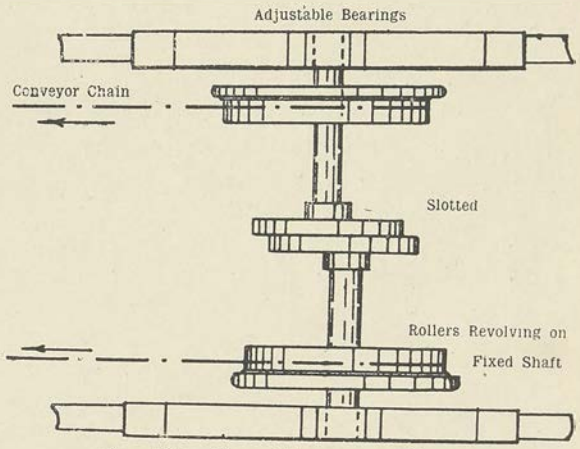


FIG. 225.—CHAIN-TIGHTENING DEVICE.

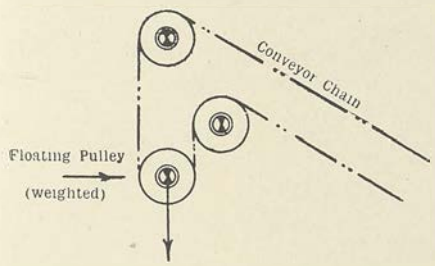


FIG. 226. — COMPENSATING DEVICE FOR TAKING UP SLACK IN DRAW-BAR CONVEYORS AND DRIVING CHAINS OR ROPES.

On gasworks, the principal materials requiring transport from one point to another are coal, coke (either hot or cold), clinkers, and in some cases oxide of iron, lime, and such-like materials. It is chiefly, however, materials of moderately high density which have to be considered. This fact is of importance in that it has an important effect upon the angle of slope of the elevators. Machinery dealing with vegetable matters of low specific gravity can be driven at very much higher speeds than that made use of for such substances as coal. Elevators for coal, moreover, should be inclined so that part of the load is borne by the rubbing strips attached to the guide supports. The whole weight is not then hanging from the driving sprocket, as is the case with the vertical elevator. For heavy materials the angle of slope (with the horizontal) should lie between 45 and 60 degrees, although many gasworks

elevators are erected at so great an angle as 70 degrees, or in some cases vertically. The speed should not exceed 130 feet per minute under any circumstance. In the De Brouwer combined hot coke elevator and conveyor the normal working speed is in the neighbourhood of 40 feet per minute, and the angle of slope is usually no more than 30 degrees with the horizontal. It is necessary to bear in mind that when a friable material such as coke is being dealt with the speed of an elevator of the bucket type should be low, because a high velocity of delivery entails considerable breakage of the material, in addition to curtailing the life of the receiving shoots. In general, it may be said that coke elevators should not be operated at a greater speed than 60 to 90 feet per minute. Capacity, usually based on tons delivered per hour, depends, of course, largely on speed, but also upon the size and pitch of buckets, or —in the draw-bar types—upon the depth, width, and pitch of the bars.

With bucket-conveyors much depends upon the extent to which each bucket is filled. Where average practical conditions are considered, the following formula may be taken as a useful guide to capacity :—

$$\text{Capacity} = \frac{S \times B \times W}{96{,}768 \times P} \text{ tons per hour.}$$

where B = Capacity of buckets in cubic inches.
S = Speed of conveyor in feet per minute.
W = Weight per cubic foot of substance carried (*see* page 363).
P = Pitch of buckets in feet.

Band Conveyors

Band or belt conveyors have attained a certain degree of popularity on gasworks, and for conveying the lighter materials, such as oxide of iron or sulphate of ammonia, they are probably to be preferred to other types. For such materials less power is required by a band conveyor than by any other, and the speed may run up to as much as 600 feet per minute. For heavier substances, such as coal and coke, the whole design must necessarily be of a much stiffer nature, whilst the band itself must be considerably stronger in order to take the greater weight imposed upon it. It is not generally realized that when used for coals the centre of the band, and not the outside edges, shows the greatest tendency to wear ; consequently the middle portions of the width require special care in their preparation. In a general way, leather material as used for ordinary driving belts is to be avoided, and the band is preferably composed of special insertion covered with india-rubber where it comes in contact with the rollers or guides. The upper portion which carries the load should be made from solid india-rubber, which may be reduced in thickness towards the edges. Canvas or balata is often used.

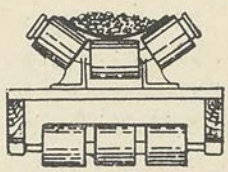


Fig. 227.—Band Conveyor with Troughed Leading Portion.

There are two main types of band conveyors, namely, those in which the leading and return portions of the belt pass over parallel guide rollers so that throughout its travel the belt is perfectly flat, and those in which the rollers are so arranged as to cause the leading portion of the belt to assume a trough-like shape (Fig. 227).

Other things being equal, a flat belt has the longer life, but considerably increased capacity is obtained by troughing. The angle between the troughing guide rollers must not be too sharp, for this causes the belt to fail at the bends.

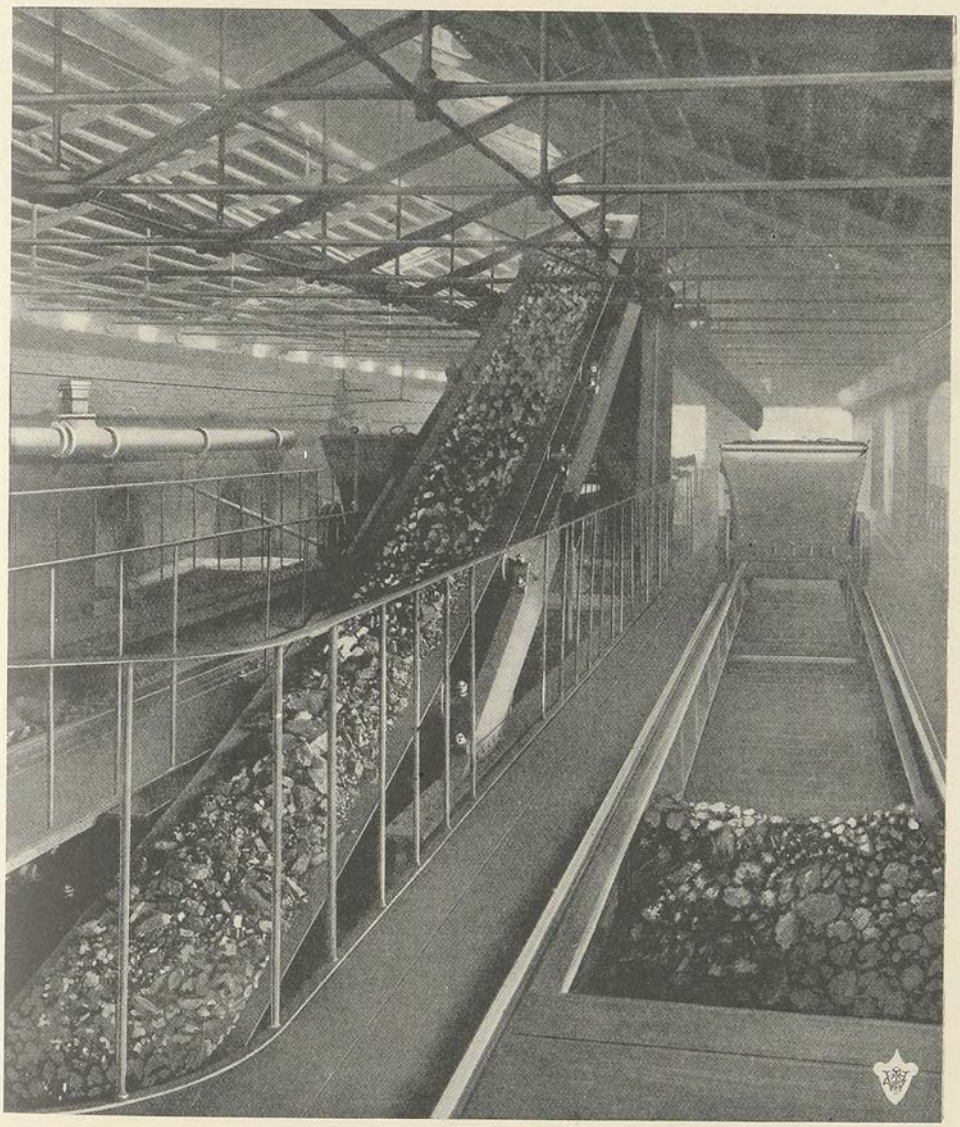


FIG. 228.—BELT CONVEYOR FOR COAL.

The speed of band conveyors depends largely on the weight of the material to be conveyed, but also to a considerable extent upon the size of the lumps. So far as the last-named factor is concerned the rate of travel should vary in inverse ratio

to the size of the pieces; hence large lumps must travel more slowly than smaller ones. Under normal conditions the speed for coal purposes will be from 150 to 300 feet per minute, although with fine coal this may be increased up to 400 feet per minute. The following table, compiled by Zimmer, gives an indication of the capacity of these elevators and the horse-power required to drive them. The author, however, is of the opinion that the speed given (600 feet per minute) is too great, the maximum figure for capacity too liberal, and the B.H.P. for wider buckets not adequate.

Speed and Capacity of Band Conveyors for Coal

Width of Band.	Speed.	Capacity.	Size of Coal.	B.H.P. for 100 feet length of Conveyor.
Inches.	Feet per min.	Tons per hour.		
12	150 to 600	10 to 35	From 2-inch to dust	3·2
18	„	50 to 175	„ 4-inch to ¾-inch	4·8
24	„	125 to 475	„ 6-inch to 1-inch	6·0
30	„	250 to 900	„ 7-inch to 2-inch	7·6
36	„	350 to 1,500	„ 9-inch to 2-inch	9·2

Band conveyors need not necessarily be operated on the level, but can also be used for elevating purposes. When conveying up-hill, however, the inclination should not be greater than 25 degrees, otherwise capacity will be reduced by slip. When the band is inclined the power necessarily increases in accordance with the height through which the load is raised. One of the chief advantages attached to this type of conveyor is that it does not injure in any way the material on which it is working.

The end rollers of a band conveyor should not be less in diameter than 5 inches for every ply of the belt; *e.g.* for a 6-ply belt the pulleys should be 30 inches diameter. The working stress in the belt when loaded should not exceed 30 lb. per inch of width per ply. The following table (compiled by J. E. Lister) gives the effective cross-section of the layer of material carried by belts of various sizes when running flat and when troughed, and it illustrates the great increase in carrying capacity to be obtained by troughing the belt.

Comparison between Flat and Troughed Belts

Width of Belt (inches).	Effective Cross Section of Material (square feet).	
	Flat Belts.	Troughed Belts.
18	0·08	0·19
24	0·16	0·34
30	0·27	0·55
36	0·40	0·80

There are many other types of conveying machinery in more or less general use on gas-works, the following being the more important systems :—

(*a*) The travelling-tray conveyor.
(*b*) The swinging-tray conveyor.
(*c*) The push-plate conveyor.
(*d*) The gravity-bucket combined elevator and conveyor.
(*e*) Telphers.

Tipping or Travelling-Tray Conveyors

Band conveyors are not wholly suitable for conveying substances of a heavy or abrasive nature, on account of the injury caused to the material forming the belt. Owing to the advantages they offer, however, conveyors embracing the principle of the band are frequently preferred by many engineers, and the travelling-tray conveyor, whilst disposing of the perishable belt, retains the desirable features of the system. Figs. 229 and 230 illustrate typical examples of travelling-tray conveyors. This type of conveyor consists essentially of an endless chain to which are attached a number of overlapping trough-like sections. The chief objection to the employment of these conveyors is their inability in many cases to deliver at intermediate points in their length. In the type illustrated, however, a special tip-up bar enables the conveyor to deliver at any desired point in its course, or at several points simultaneously, as well as over the extreme end. By a simple modification, moreover, the material can be carried up a gradient much in excess of the limiting angle of the material on the trays. In discharging a friable material such as coke over the end, the drop is minimized by the preceding tray intercepting the fall of material from the tray following it. The power required is low in comparison with types of conveyors such as the push-plate, and is usually under 5 per cent. of the weight of the moving parts. About 250 feet of conveyor carrying 20 tons of

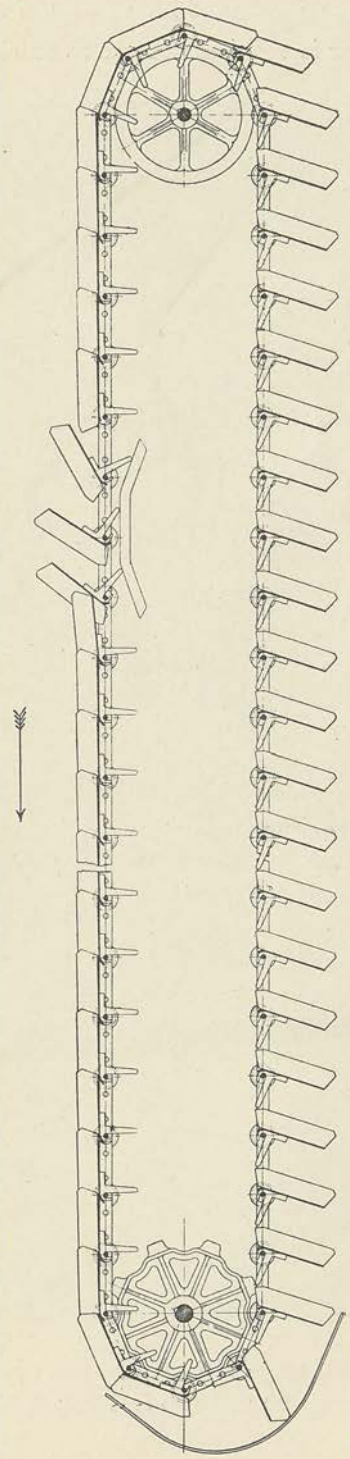


Fig. 229.—Babcock & Wilcox Travelling-Tray Conveyor

material per hour can be worked with one indicated horse-power. When the conveyor is required for use as an elevator back lips are applied to the trays. The

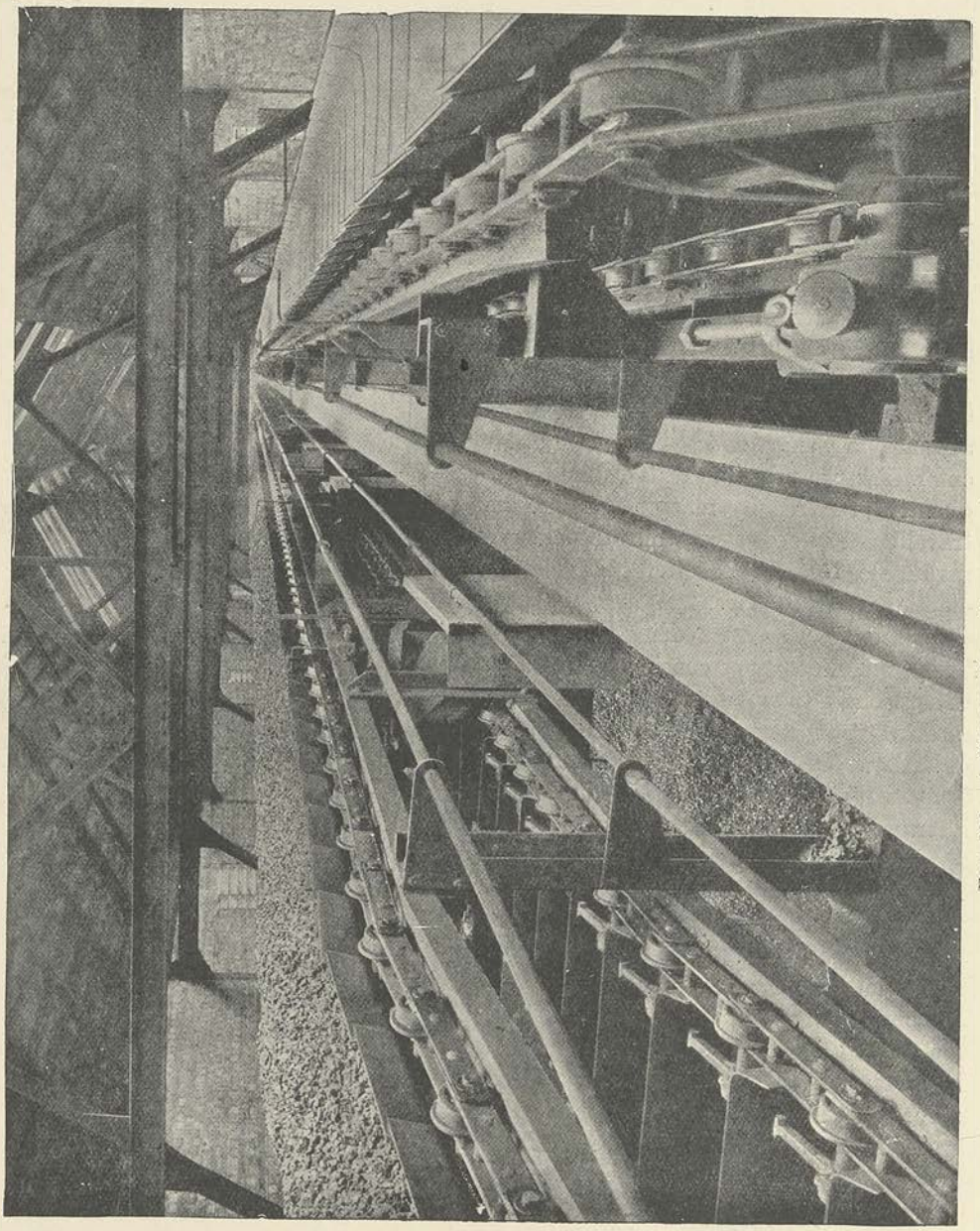


Fig. 230.—A Tipping-Tray Conveyor Installation.

normal speed of travel is somewhat less than with push-plate conveyors, and varies between 60 and 120 feet per minute.

Push-Plate Conveyors

A typical form of push-plate conveyor is illustrated in Fig. 231. Each push-

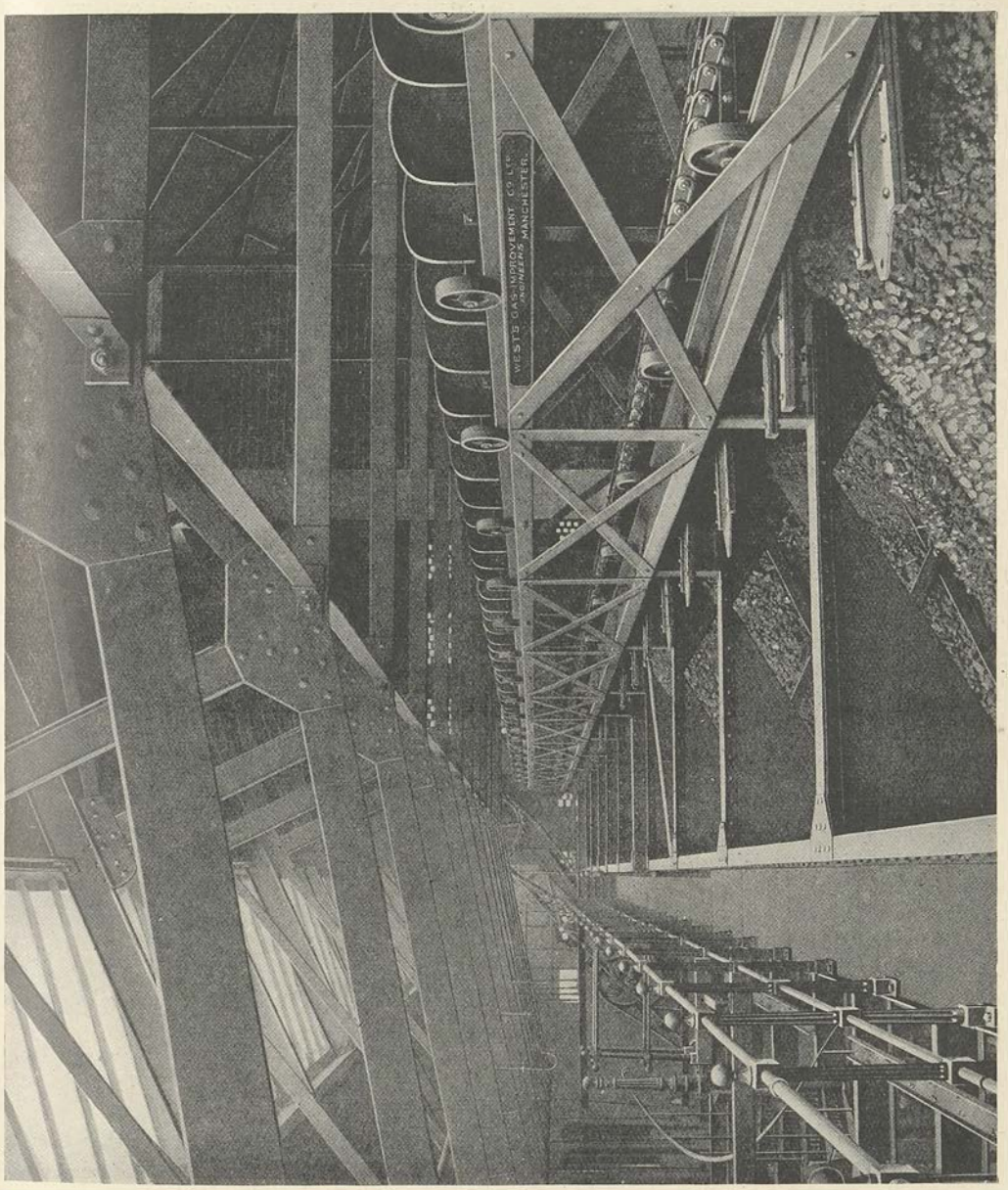


Fig. 231.—Push-Plate Conveyor. West's Type.

plate, it will be seen, has a projecting axle at either end to which special rollers are attached. The push-plates are secured by special chain attachments, and discharge

outlets with side doors are fixed at convenient intervals. Conveyors operated on this principle may be arranged with either a single or double chain, but in any case the push-plates should not be allowed to touch the bottom of the trough. For this reason, in those designs where guided rollers are not made use of, the plates are fitted with some form of skidder-bar which slides in its guides and takes the greater portion of the wear. So far as economy in motive power is concerned the roller types are to be preferred. The normal speed of these conveyors is somewhat greater than that of the tipping-tray type, and varies between 60 and 180 feet per minute. The capacity depends upon the speed, the size of the trough, and the pitch of the draw-bars. The pitch may be anything from 18 inches to 3 feet. With the usual trough of about 2 feet in width and having push-plates at a pitch of 2 feet the capacity is normally 30 tons per hour, with an average speed of 100 feet per minute. Conveyors of this type have been somewhat generally adopted for the removal of hot coke from retort houses. When used for this purpose it must be borne in mind that the friability of the coke will not permit of a high rate of travel, if disintegration of the material is to be avoided. In the De Brouwer hot coke conveyor the average rate of travel does not exceed 40 feet per minute.

Push-plate conveyors are very convenient for dealing with small coal owing to the ease with which the point of discharge can be altered, while by partly opening some of the discharge doors the coal can be discharged simultaneously at two or three points. The capacity of a 2 feet wide conveyor (placed horizontally) with scrapers or push-plates two feet apart would be approximately 150 tons per hour at a speed of 100 feet per minute. A reduction in capacity results from placing the conveyor on a slope, the falling off amounting to about 16 per cent. for each 10° inclination. Lister gives the following figures in connection with the capacity of push-plate conveyors when dealing with coal and running at a speed of 100 feet per minute.

CAPACITY OF PUSH-PLATE CONVEYORS

Size of Push-Plates.	Distance Apart of Push-Plates. 16 in.	18 in.	24 in.	
10 in. wide × 4 in. deep	30	27	20	tons per hour
12 in. „ × 5 in. „	45	40	30	„ „ „
18 in. „ × 6 in. „	—	70	50	„ „ „
20 in. „ × 8 in. „	—	—	90	„ „ „
24 in. „ × 10 in. „	—	—	150	„ „ „

(*Note.*—Above capacities refer to horizontal conveyors. For inclined conveyors deduct 16 per cent. from capacity for every 10 degrees rise from horizontal.)

GRAVITY-BUCKET CONVEYORS

The gravity-bucket or travelling-bucket conveyor has for some years been a foremost favourite in America, and is now assuming some considerable importance in this country. Briefly described, it consists of two endless chains held apart at a predetermined distance by suitable bars, to each end of which is fixed a small roller, these rollers running along special guide-tracks. The distance pieces between

the chains are fitted with buckets which are suspended from a point above their centre of gravity, and are free to swing. Thus, whatever the position of the endless chain, the buckets always hang in an upright position whether they are travelling vertically or horizontally. For this reason the gravity-bucket system may be employed to perform the combined duties of elevator and conveyor. Delivery at any desired point is arranged for by interposing a device which tilts the bucket and discharges its contents. The driving gear is unique, and usually consists of a spur-geared engine operating two sets of panels which successively thrust the chain in the direction of its travel, engaging with both sides simultaneously. In this way the chain is pushed forward link by link. An essential feature of the system is the provision of some type of filling device, so that the material may be delivered to the

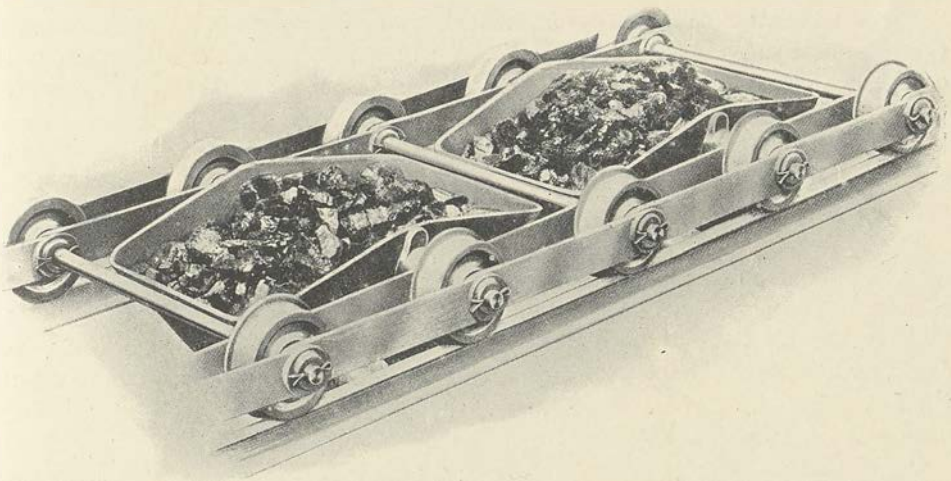


Fig. 232.—The Gravity-Bucket Conveyor.

buckets without undue spilling. The ordinary sprocket drive is, however, fitted in some of the more modern installations. The filler consists of a hollow casting securely keyed on a steel spindle. The casting is formed with five openings in its periphery, and these are arranged to centre with the buckets as the filler is rotating. The filler is driven direct by the conveyor chain engaging with an adjustable sprocket wheel bolted on the rotating hollow casting. The speed of the gravity bucket is necessarily low, the rate of travel normally varying between 25 and 50 feet per minute. The capacity depends upon the size and speed of the buckets used, and installations may be erected capable of handling from 20 to 100 tons and upwards per hour. The power required is low in comparison with many other types of conveyor, but depends largely upon the proportion of elevating work which is performed.

The following table gives the power required for various sizes of gravity-bucket conveyors :—

H.P. Required for Gravity-Bucket Conveyors

Size of Buckets (inches).	12 × 12		24 × 15		36 × 20	
Spacing of buckets (inches)	18	36	18	36	18	36
H.P. required for each 10 feet vertical lift .	0·46	0·23	1·35	0·67	3·8	1·9
H.P. required for each 100 feet per hour (unloaded)	1·20	0·90	1·70	1·30	2·4	1·6
H.P. required for each 100 feet per hour (loaded with coal)	3·20	1·90	7·40	4·20	18	9·4

THE MECHANICAL HANDLING OF COKE

The utilization of labour-saving machinery in connection with the handling of coke has always involved difficulties owing to the fact that in coke-manufacturing establishments the material has, in the first instance, a temperature approaching 1,000° C. In metallurgical works the question is simpler owing to the heat factor being eliminated, but the physical characteristics of the material, with its hard, gritty, and abrasive nature, present many difficulties which are not common to most other materials handled in bulk.

It is, in fact, probably owing to considerations of wear and tear that machinery for the purpose is of comparatively recent introduction, for engineers in the past hesitated to employ moving parts constructed of iron and steel which, in addition to withstanding abrasion, were faced with rapid contraction and expansion owing to the comparatively sudden changes of temperature resulting from the process of quenching the hot material. Experience, however, though perhaps unfortunate in the early days, has brought its consolations, so much so that when machinery of the kind is contemplated to-day the factor of wear and tear is accorded only secondary consideration, and the main decision turns upon the saving in operating costs which is likely to be effected. This must not be taken to mean that the factor of maintenance can be altogether neglected, for it must obviously have an important effect on economy. The question, however, is one which relates rather to the different methods employed than to the problem as a whole.

Before coming to a decision as to the installation of coke plant it is highly desirable to view those considerations which are not actually measurable in terms of money. For instance, efficiency of production might be sacrificed in order to effect an apparent economy, and machinery may possibly be followed by less effective working results. Moreover, the peace of mind of those in charge is a factor which deserves consideration, and when apparatus such as coke plant, which has to meet exceptional demands, is in question it is as well to take heed as to whether it will give rise to anxieties, such as breakdown, from which man-handling may normally be said to be free.

In considering coke-handling machinery as employed on gasworks it is necessary to bear in mind that the plant will have to effect one or all of the following operations :

(*a*) Conveyance of coke direct from the retorts to a suitable storage place.

(*b*) Conveyance of unquenched coke direct to water-gas generators.

(*c*) Treatment in grading, screening, washing and loading or bagging plant.

The methods employed at the present time for effecting this series of operations vary to some considerable extent, and in nearly all cases it is essential to introduce plant which has the functions of the elevator and conveyor combined. Put briefly, the plant may be classified under two main headings—

(*a*) Apparatus utilizing the ordinary principle of conveying, *e.g.* drag-bar, travelling-tray, or gravity-bucket conveyors.

(*b*) Transporter systems, *e.g.* electric telphers, or travelling skips.

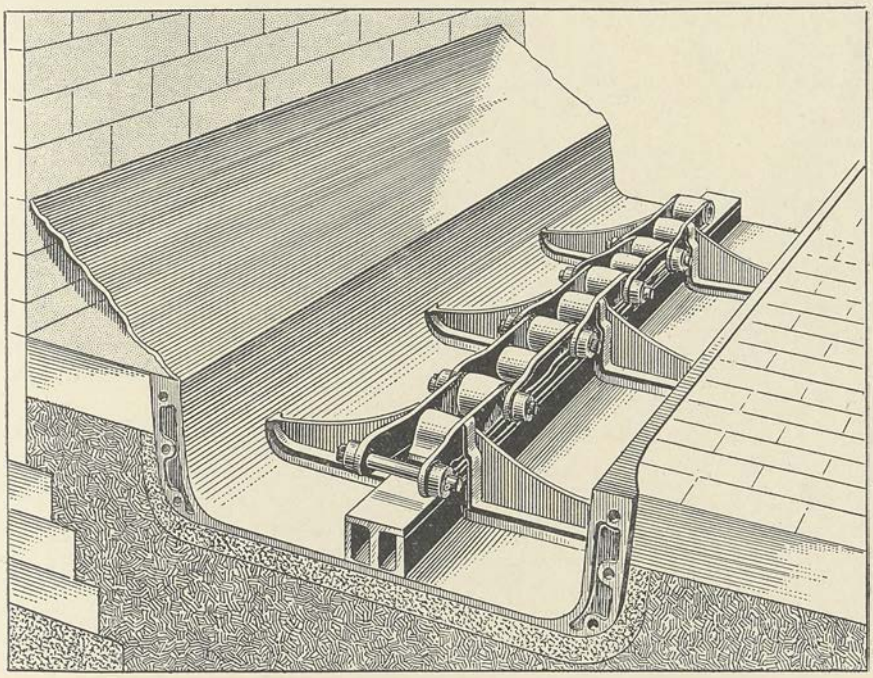


Fig. 233.—West's Hot-Coke Conveyor. Original Type.

Each method has its particular advantages, and the question as to which shall be adopted must be decided entirely by local conditions and requirements. In many cases a combination of the two types is the ideal arrangement, a conveyor being used inside the retort house and a telpher outside in the coke yard.

One of the earliest systems introduced for dealing with hot coke was that which was installed more than twenty years ago at the Gaythorn station of the Manchester Corporation Gas Department. The problem to be solved was the immediate removal from in front of each retort, as it was discharged, of 4½ cwt. of coke falling from the retort in 15 seconds. It was necessary to provide a conveyor of sufficient capacity, and travelling at such a speed as to convey the coke out of the way of the retort

house stokers without delaying them in their work. The design was carried out by Mr. John West, and consisted (Fig. 233) of a cast-iron trough 24 in. wide by 9 in. deep, in which an endless chain travelled on a central rail. The chain was composed of cast-steel links bolted together, and to each alternate pair of which were cast blades which conformed to the shape of the trough, but did not bear upon the sides or base of it. From such original and comparatively crude designs, however, effective appliances have now been evolved, and it is interesting to compare the present-day West model (Fig. 235) with its forerunner.

The De Brouwer Hot-Coke Conveyor

This type of hot-coke conveyor (illustrated in Fig. 234) has probably been adopted more extensively than any other system, both in this country and on the Continent. The conveyor consists of a trough of varying width and depth, to suit the quantity of coke to be dealt with, in which the chain slides. This trough usually

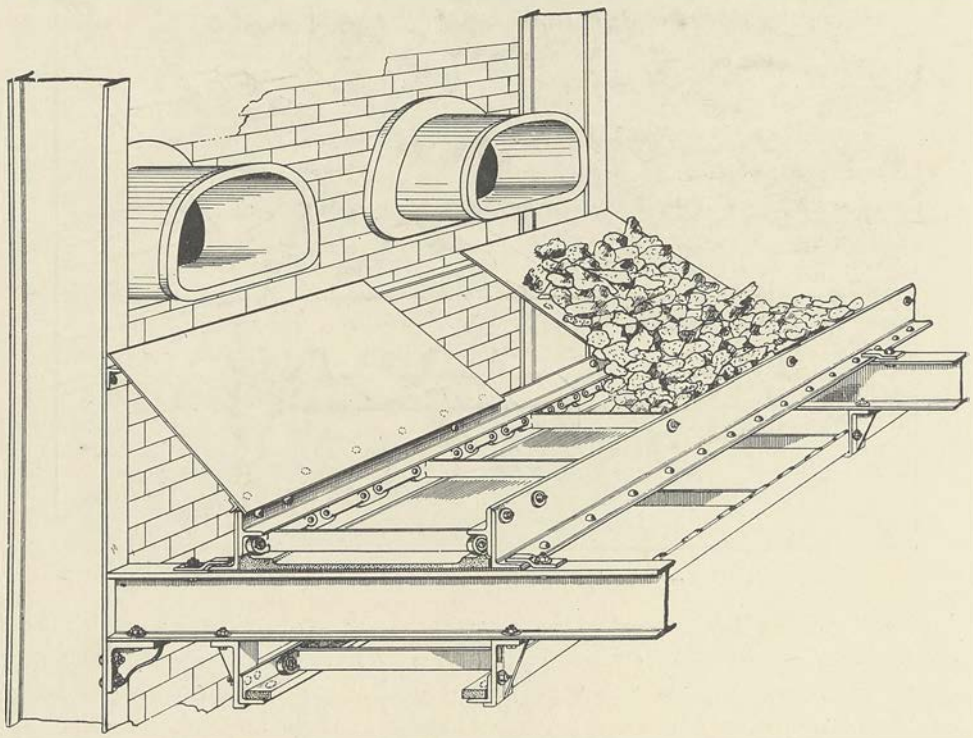


Fig. 234.—The De Brouwer Hot-Coke Conveyor.

consists of a $\frac{1}{4}$-inch or $\frac{3}{8}$-inch steel bottom plate with steel channels or angles riveted along each side, the joints being made so as to form a watertight pan in which are placed cast-iron renewable bottom plates. These bottom plates are about $\frac{5}{8}$ inch thick in the middle with raised paths $\frac{5}{8}$ inch deep on each side for the chains to slide

upon. The chains are protected by steel angles or tees bolted to the trough sides with special countersunk headed bolts. The sides of the trough are protected by $\frac{1}{2}$-inch steel renewable plates which are bolted on with countersunk headed bolts. These plates also hold the cast-iron bottom plates in position. In some cases the trough in the retort house is covered over with hinged doors of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch steel chequered plate, level with the floor, the doors on the retort bench side being used to deflect the coke from the retorts into the trough. After leaving the retort house

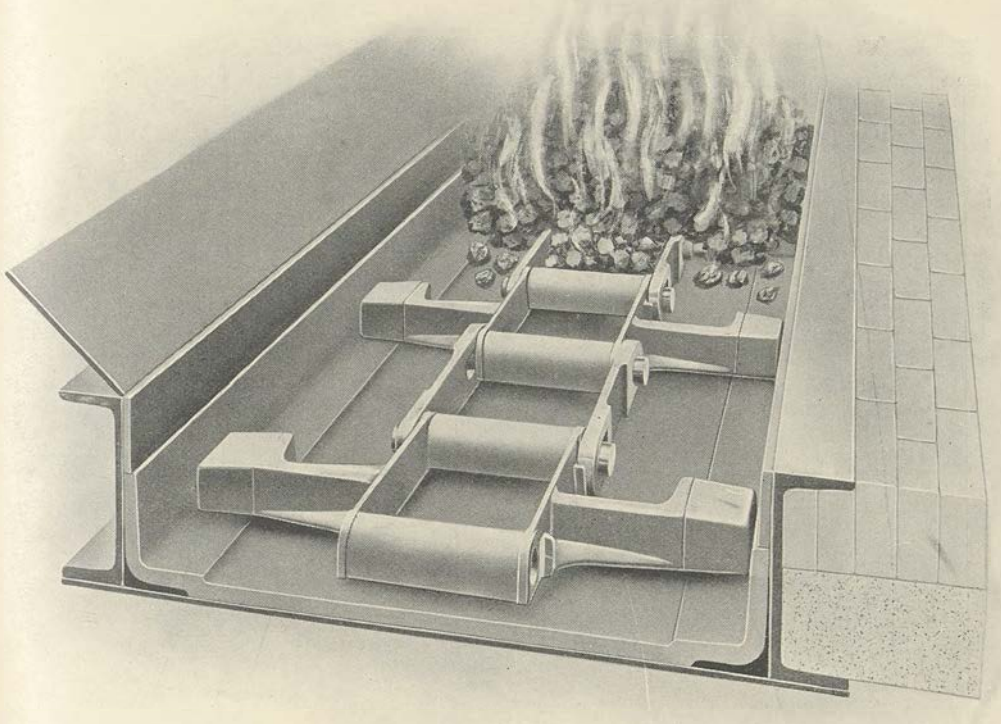


Fig. 235.—West's Hot-Coke Conveyor.

the conveyors usually rise at an angle, varying with the space available, to a suitable height for delivering the coke into hoppers, etc. In these cases the trough up the slope is made about 2 feet deep by means of $\frac{1}{4}$-inch steel side plates and is covered by $\frac{3}{16}$-inch steel plates bolted on the top, thus completely enclosing the trough and carrying the steam from quenching to a steel chimney near the top of the incline. By this means the steam is kept in contact with the coke for a considerable time and ensures the coke being properly quenched. The quenching sprays are fixed to the top plate over the trough near the bottom of the slope, the surplus water draining out through a grid fixed to the trough side on the level portion near the bend. Guide

rollers or wearing blocks are fitted at the bend to prevent the chains rising out of the trough, the angle of the incline deciding which shall be used. The return path for the chains usually consists of steel angles with cast-iron renewable wearing strips bolted on with countersunk headed bolts, supported either under or over the trough as is most convenient. The chain consists of best steel stamped block links (except where the cross-bars come, these being of cast steel, cast solid with the cross-bars), alternating with double links, the block links being made specially high to take all

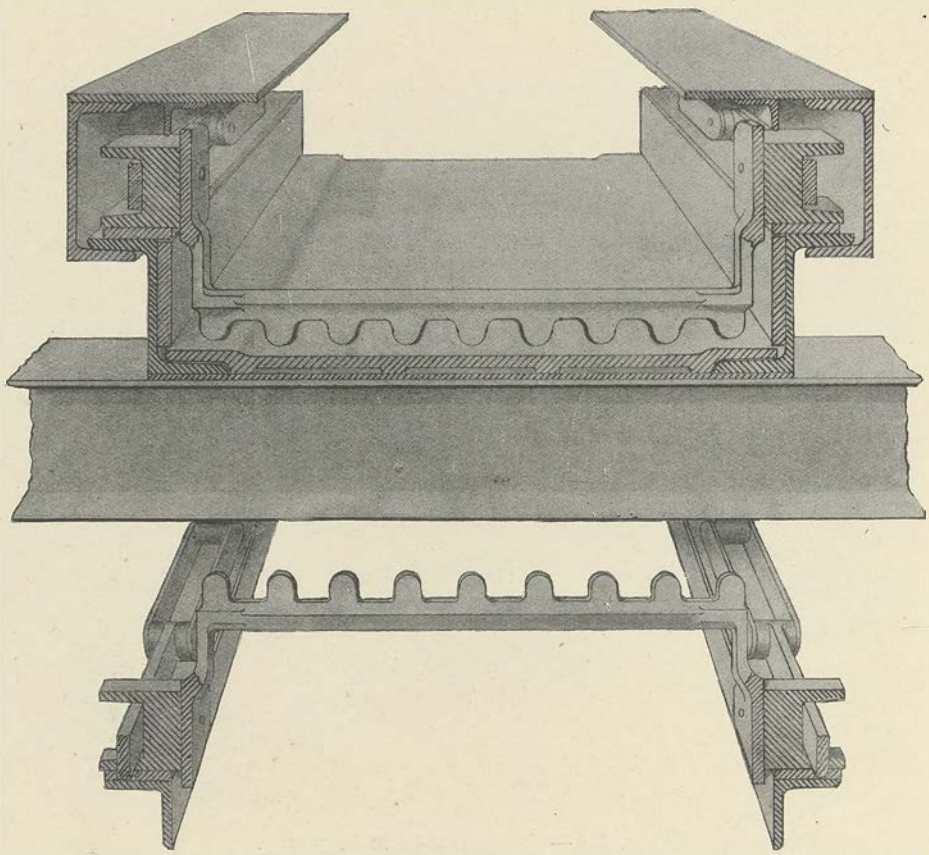


Fig. 236.—Dempster's Hot-Coke Conveyor.

the wear due to the rubbing on the wearing strips of the pan. The side links are connected in such a manner that the wear comes upon the full width of the portion passing through the hole in the block link and they are held together by rivets, which are made easy of removal while being perfectly secure and forming no part of the wearing surface. The two chains are held apart by 2½ inches by ½-inch flat cast-steel bars cast solid with the block links at intervals of 2 feet 1½ inches, for the transmission of the coke along the conveyor. The conveyor is driven by cast-iron wheels fitted with renewable manganese steel sprockets, and at each bend passes round cast-iron

flanged rollers. Suitable tension gear, as described on page 309, is provided for taking up any extension of the chain. A chain of the De Brouwer type will deal with from 50,000 to 60,000 tons of coke during its working life. The speed of travel of the conveyor is low, averaging about 40 feet per minute.

A somewhat similar type of hot-coke conveyor, but one in which a different type of chain is employed, is shown in Fig. 235. Dempster's hot-coke conveyor is another familiar pattern. As will be seen from Fig. 236, it is of the rake type, and is so arranged that only the rakes are in contact with the coke, all the moving parts being on an elevated pathway and screened from the coke by means of baffle plates. Thus the chains and sliding shoes are clear of both coke and quenching water. The trough is formed of channels and Z-steel sides with steel bottom plate. The inside of the trough is provided with cast-iron liners and steel flat-bars on the Z-sections for the chain shoes to run on. As in the other types of conveyors the return can be arranged overhead if so desired. The chains are entirely formed of low carbon steel to prevent corrosion by acid fumes, etc., evolved by the coke during quenching. The rakes are of malleable iron, and the sliding shoes of chilled cast-iron.

Drake's Tray Conveyor

This hot-coke conveyor is unique in that it embraces the principle of carrying the coke and not dragging it. The general construction is shown in Fig. 237, from which it will be seen that the conveyor consists of corrugated trays mounted on

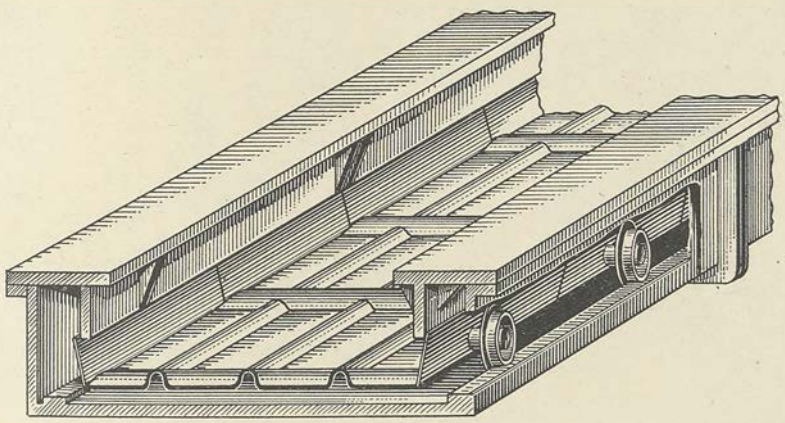


Fig. 237.—Drake's Tray Hot-Coke Conveyor.

wheels, and running in a cast-iron trough. There is in reality no wearing part with the exception of the wheels, which revolve upon a fixed pin. The connection between the trays is also by a pin, which acts as an axle when the trays are running round the drum, ready for the return. The trough is fitted with curtain plates which overlap the inside of the tray and which prevent the coke from getting over the side and into the path of the wheels.

The Travelling Skip Conveyor

A certain amount of wear and tear must always be anticipated when the apparatus employed gives rise to friction between coke and metal. One of the latest methods introduced in order to avoid this drawback is the travelling skip for dealing

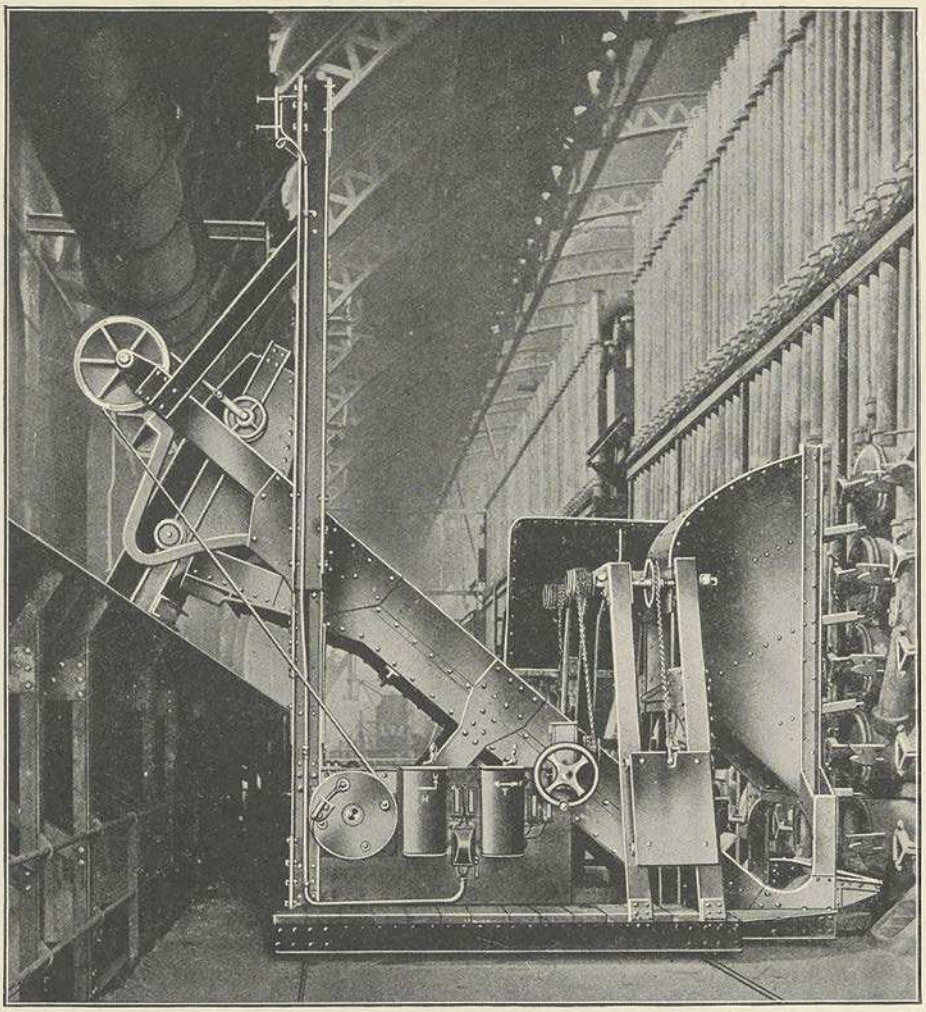


Fig. 238.—Drake's Travelling Skip System of Coke Handling.

with hot coke direct from the carbonizing chamber. The contrivance possesses the merit of extreme simplicity, and consists essentially of a travelling inclined elevator. in which the usual series of buckets is replaced by a single skip of large dimensions, The elevator is mounted on a bogie and travels on rails running parallel with the carbonizing system. By means of shoots the coke is delivered gently into the skip

from each tier of retorts, and the skip (travelling on two tracks, the divergence of which causes it slowly to tilt as it reaches the top of the incline) is elevated by means of two steel wire ropes which travel round large guide pulleys at the top end. The coke is thus discharged through convenient apertures in the side wall of the building, when it falls upon the quenching bench and is sprayed with water. When cooled, it

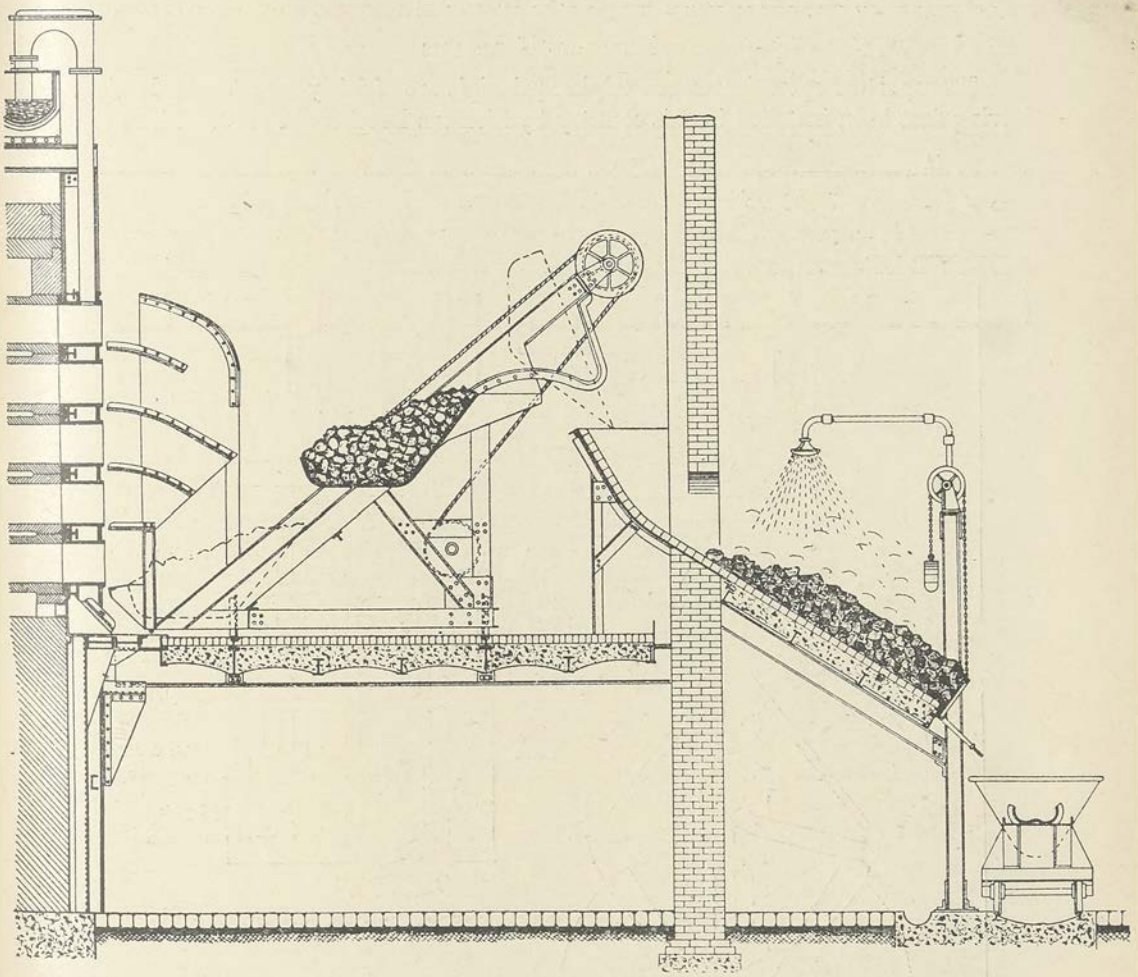


FIG. 239.—TRAVELLING SKIP CONVEYOR, SHOWING QUENCHING PLATFORM.

runs direct into wagons for transport. The machine carries two totally enclosed dust-proof motors, one for travelling and the other for hoisting; these operations can be effected simultaneously if so desired. An automatic cut-out switch is provided top and bottom in order to prevent overrunning of the skip, so that the attendant has merely to start the latter and it stops automatically at the right place. It is claimed that with this machine much time is saved, for a normal retort may be

discharged and the coke be deposited on the quenching bench in 35 seconds, while in another 10 seconds it is ready in position for a further charge. In addition, there is an absence of those influences liable to produce "manufactured" breeze, while many sources of corrosion and damage are avoided as no water or steam is continuously escaping inside the building. The travelling motor for a machine of normal size is of 7 h.p., and the hoisting motor is of 12 h.p.

Electric Telphers

Transporters operating on the telpher principle are of fairly recent introduction, having first been installed in this country by Siemens Brothers in 1903. There can

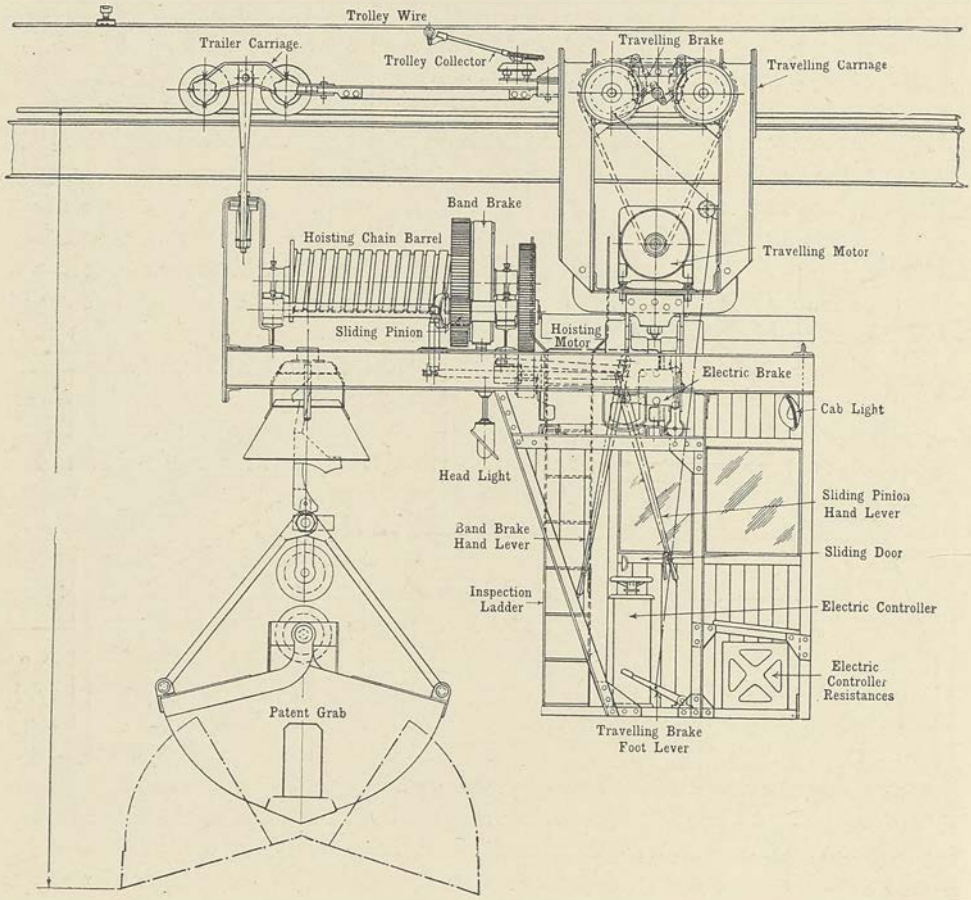


Fig. 240.—Standard Telpher Carriage (Strachan & Henshaw's Type).

be no question that they are destined to play a prominent part in gasworks methods of the future.

Telphers are mainly of two types, namely, those accompanied by an attendant, and those in which the whole of the movements are automatic and controlled elec-

trically from a fixed station. Continental practice favours the automatic principle, and abroad the man-handled telpher is looked upon as somewhat old-fashioned and wasteful; on the other hand, the automatic plant introduces electrical complications

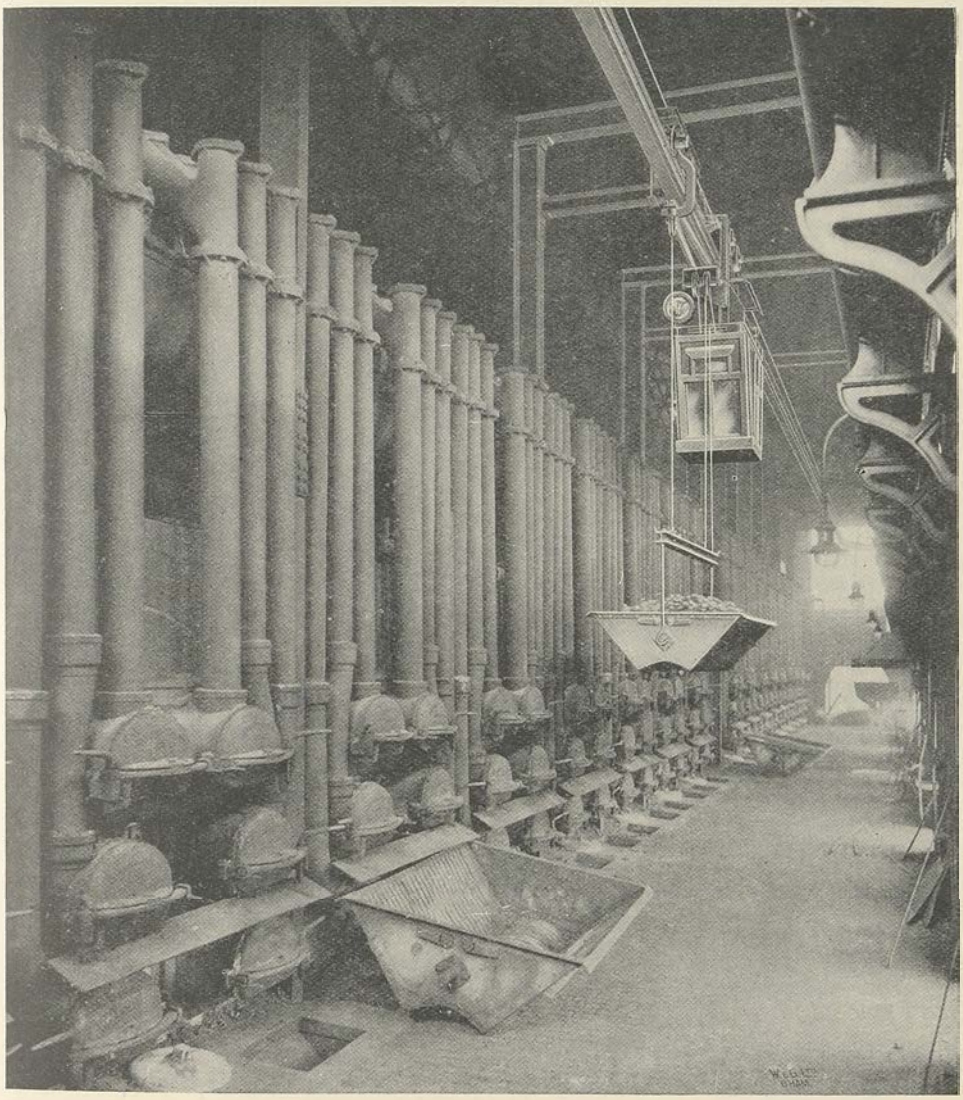


FIG. 241.—INTERIOR OF RETORT HOUSE FITTED WITH TELPHER PLANT FOR HOT-COKE HANDLING.

which are, perhaps, best avoided in conditions such as obtain on gasworks. Much more skilled attention is required, and when a breakdown occurs it is usually more difficult to locate and to deal with.

Telpherage possesses characteristics differing from those of any other type of conveyor. These may be enumerated as follows :—

1. The telpher is a combination of conveyor and elevator, and it will, therefore, perform the double duty of lifting and carrying.

2. The points of loading and discharge are variable within the range of its terminals to an infinite degree ; material can, therefore, be " picked up," conveyed or dropped anywhere.

3. The control may be (*a*) directly at the load by means of an operator travelling with the machine, (*b*) from one fixed point, or (*c*) from several independent points at any distance apart. Generally the direct control is adopted, as it is the simplest, cheapest, and most positive.

4. The ratio of cost of wearing parts to that of fixed structure is very low indeed, and, therefore, the maintenance and depreciation costs are considerably less than for any other conveyor.

5. Telphers of the high-speed type require an operator per machine, whereas in the case of conveyors of the " belt," " push-plate " or " bucket " type one operator can attend to the running of two or more conveyors if they are not far apart, and the discharge points do not require frequent alteration. Conveyors of this type cannot, however, be run, as is sometimes supposed, without attention.

6. A telpher can be automatically loaded from a heap and also similarly discharged by fitting any of the well-known types of grab, or, if the material to be dealt with is more conveniently and quickly handled by a skip, there are simple and effective means of loading the skip automatically from a storage hopper.

7. Any material conveyed by a telpher can be easily and accurately weighed and totalized in transit. It is rather costly to do this automatically ; but there are many cases where automatic weighing is essential.

8. The telpher conveyor is not confined either to straight lines or, indeed, to any particular direction. The route may be curved to almost any extent within reason, and branch tracks can be run off in any direction from a main line. A branch track can even be made to travel and maintain contact with a fixed main track when circumstances demand it.

The main constructional features of these machines will best be followed from the accompanying illustrations. For a standard telpher of about 35 cwt. gross capacity the travelling motor is of about 6 h.p., and the hoisting motor of 12 h.p. The power, of course, varies with the load to be dealt with and the speed required. The whole machine travels along a single track usually formed of a stiff joist with a rail section bolted to the upper flange. The two bogies on which the carriage is supported are pivoted to allow the machine to traverse curves of small radius, and in some cases they are made to run on the bottom flange of the track girders instead of along a rail. Machines for handling both coal and coke have been built to take loads up to 4 or 5 tons at a lifting speed of 80 feet per minute. In such cases the lifting motor is of 35 to 40 h.p. The system of dealing with hot coke direct from the retorts by means of lattice or bar skips attached to the lifting ropes is probably an ideal one. The coke is discharged from the retort direct into the skip, which is hauled up, con-

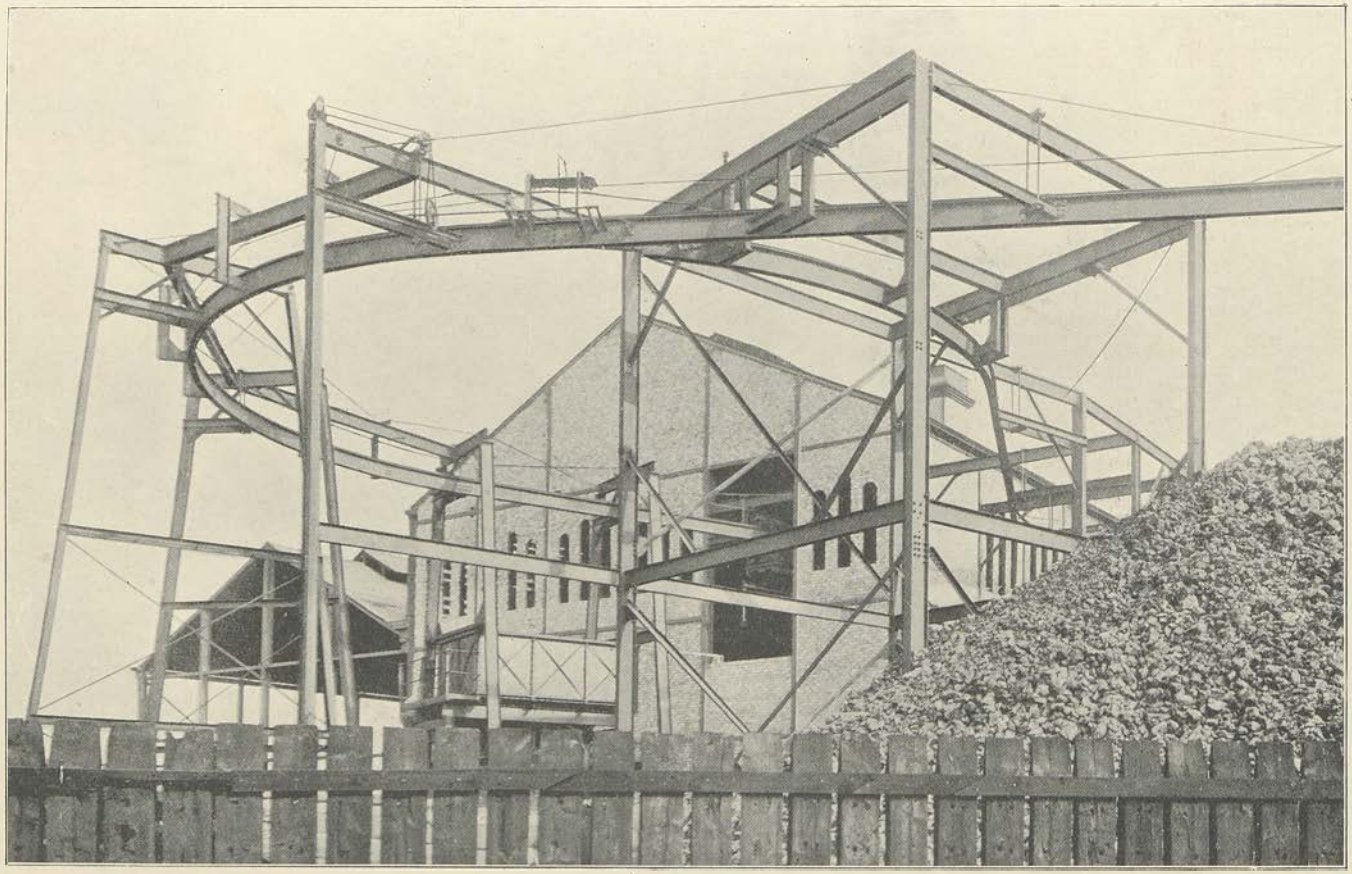


FIG. 242.—TELPHER TRACK, SHOWING BRANCH LINES AND SWITCHES. WIDNES GASWORKS.

veyed from the retort house, and lowered into a tank of water for quenching purposes. When quenching is complete the skip is raised from the tank, and the coke is deposited at the required spot in the store-yard ; or, if required for water-gas manufacture, it is tipped direct into the generator without quenching. When quenching coke by dipping the skip into a tank of water it is advantageous to permit as much of the cooling as possible to be performed by the escaping steam or by top spraying ; hence only the lower portions of the skip should be immersed.

The method of quenching by simply plunging the incandescent coke into water

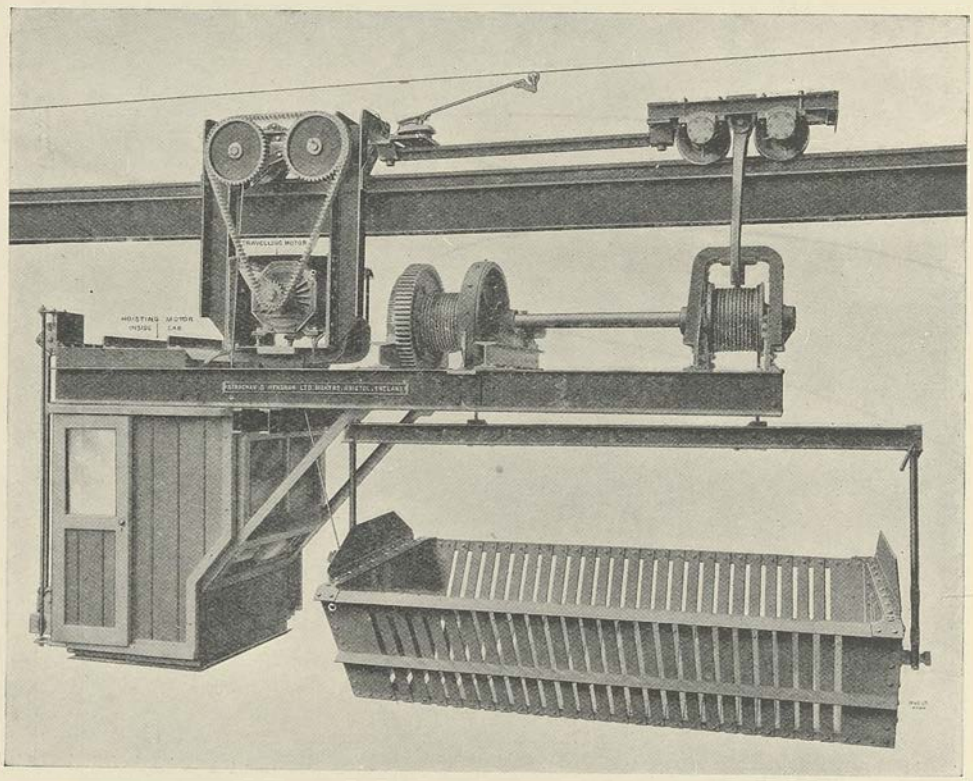


Fig. 243.—Standard Telpher with Coke Skip.

is usually found too severe, and considerable improvement has followed the practice of top-spraying in conjunction with the submersion of the base of the skip. An effective automatic spray has recently been introduced by means of which a large volume of water is spread uniformly over the top of the coke at the moment the skip is lowered into the tank, the water being turned on and the sprays brought into position by the descent of the skip. As the skip is hoisted the sprays are automatically lifted clear and the water is turned off.

The average telpher machine as designed for dealing with coke handles a gross load of two tons with a hoisting speed of 80 feet to 100 feet a minute, while a travelling

speed of 400 feet to 750 feet a minute may be attained. This is 10 to 20 times the speed of the ordinary coke conveyor. The most satisfactory arrangement of the track is to suspend it from overhead steel lattice girders, having spans of from 60 feet to 100 feet, supported at the end by steel trestles.

This arrangement gives fewest obstructions in the yard, and fewer trestles to

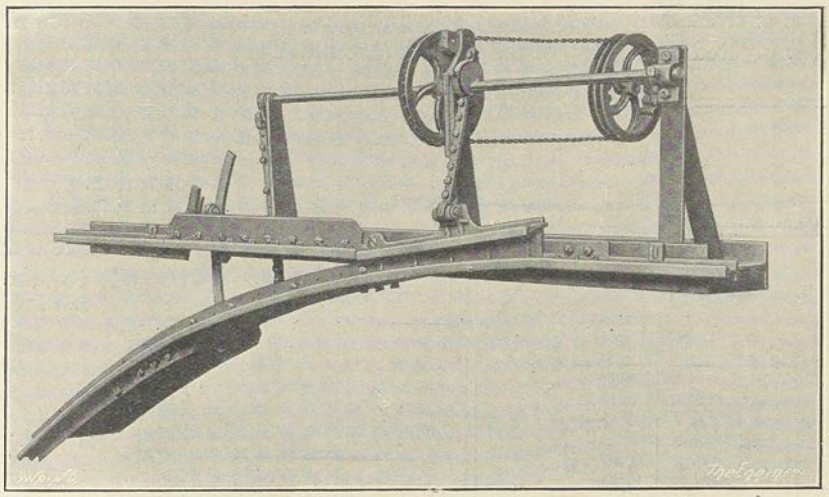


FIG. 244.—JUNCTION LINE OPEN.

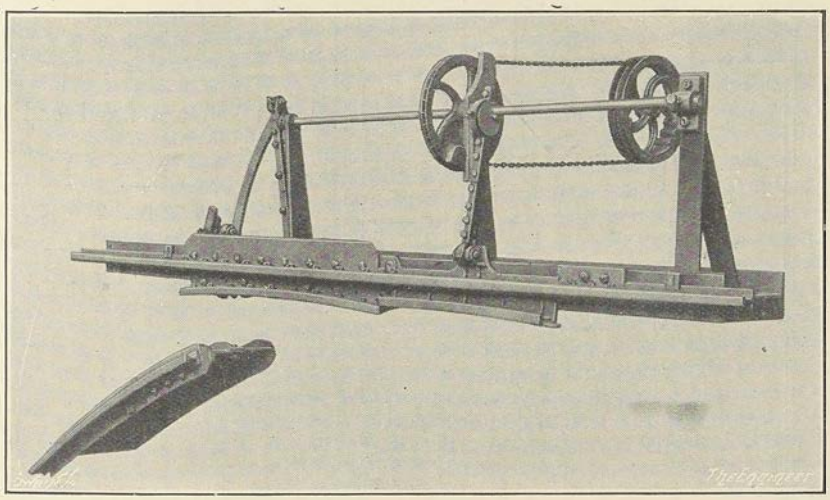


FIG. 245.—MAIN LINE OPEN.

suffer from the corrosive action of the coke mass surrounding them. Where, however, uprights are likely to be buried in coke they should be concreted up. The telpher collects its current from an overhead trolly-wire attached to insulators fixed above the track. A single wire is quite suitable where direct current generated at the works

is used, as a track return is then permissible ; but when current is derived from a town supply positive and negative leads should be fitted.

Track Switches

The method adopted for coupling up fixed branch lines to a main telpher track by means of track switches is clearly seen in Figs. 244 and 245. A double-rail steel casting is pivoted on the top of main track (the latter not being cut through by the switch), and it will also be observed that another small length of rail is carried by a swinging arm (generally of channel section) hinged to the side of the track joist. When the switch is operated for connection of the branch track the pivoted rail casting and the swinging rail at the side come into line simultaneously, and thus form a perfectly smooth curve between the fixed end of the branch and the main track. Similarly, when the switch is opened for through traffic on the main track, the other (straight) half of the rail casting falls back into exact alignment with the fixed main line rail, and the swinging arm folds back close to the main track girder, cutting the branch out, and leaving sufficient clearance for the telpher machine to pass. The gear is extremely simple and easy to operate, a force of about 20 lb. at the end of a 15-inch lever

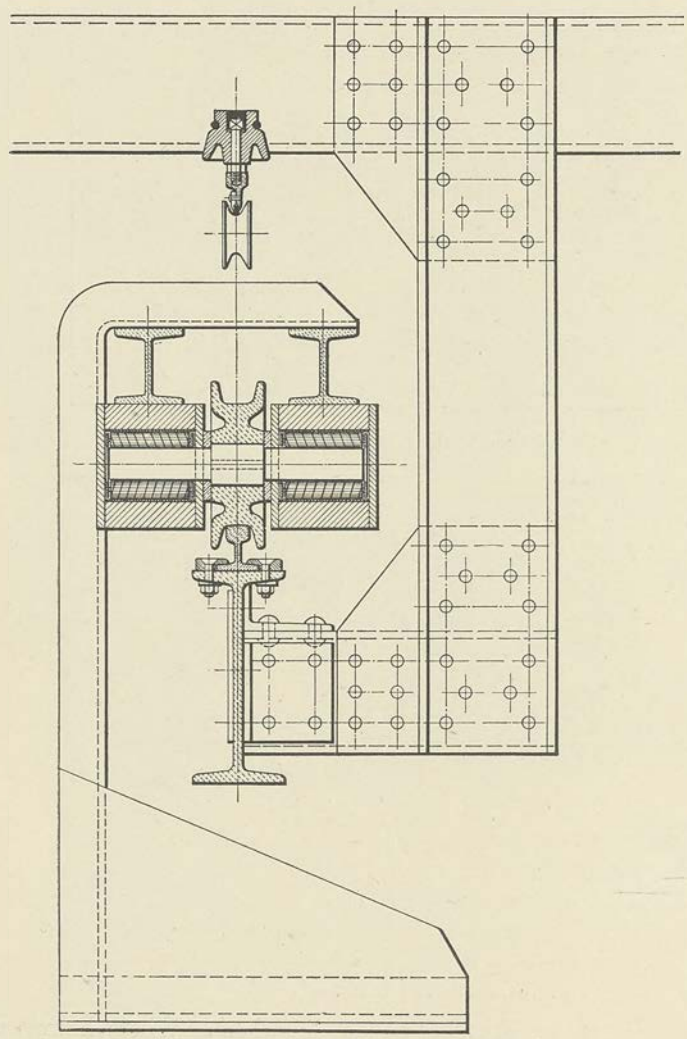


Fig. 246.—Detail of Wheel Carriages.

being sufficient to move the switch to either position. The operating lever, or hand wheel, makes exactly half a turn, and the switch becomes locked for either direction by its connecting cranks coming exactly to " dead centre " in each case. The overhead line switch, for changing the direction of the collecting trolley, is connected to this track-rail switch, and operates simultaneously with it. This form of track switch has proved highly successful, and a large number of them are in general use.

It will be gathered from Fig. 246 that the telpher is designed to travel upon a single bulb rail, which is clipped to the top flange of the track girder. The whole weight of the machine and the load carried by it is perfectly balanced about the centre of the rail, and the wheel carriages are connected to the main frame by means of ball-bearing swivels. The construction is such that a very high speed can be attained with negligible wear and tear, and with a very low power consumption. Curves of very small radii can be negotiated without any difficulty.

One of the points of conflict in connection with the telpher is that of top-rail *versus* bottom-flange support for the runners. There are very considerable differences in the two systems from an engineering point of view. Primarily, in the top-rail system the wheels are mounted above the track, with axles placed as beams supported at both ends and, therefore, in double shear ; whereas in the bottom-flange system the wheels must be mounted on cantilever pins in single shear, which is a serious disadvantage when the heavy loads of the present day are taken into account. From the aspect of wear and tear, moreover, the bearing surface is very much restricted in the bottom-flange system, whereas with a top-rail run there is no wear whatever on the track girder, which is essentially part of the structure. Again, very small radii may be negotiated with the top-rail system ; for instance, at the Southampton gasworks a 5½-ton machine, carrying a gross load of 2½ tons, traverses a curve of 9 feet 6 inches radius with perfect ease.

Machinery-Structure Ratio

When considering maintenance and depreciation it is essential to bear in mind the very important, but often neglected, machinery-structure ratio. In other words, the structure forms by far the greater proportion of telpher plant, whereas with the conveyor the machinery, or moving portions, accounts for a much larger proportion of the total initial cost. The general custom with mechanical handling plant is to allow 10 per cent. for depreciation on moving parts and 2½ to 3 per cent. on structures. In a telpher plant not more than one-third of the outlay is sunk in machinery, the structure accounting for two-thirds of the initial cost, whereas with conveyor systems the converse is very nearly true. Moreover, the power absorbed in driving a conveyor is at least double that required to drive a mono-rail telpher of the same capacity per hour and where the material is carried through the same space.

Telphers and Conveyors Compared

The principal advantages associated with telpher handling are the amount of ground which can be covered without excessive expenditure and the small amount

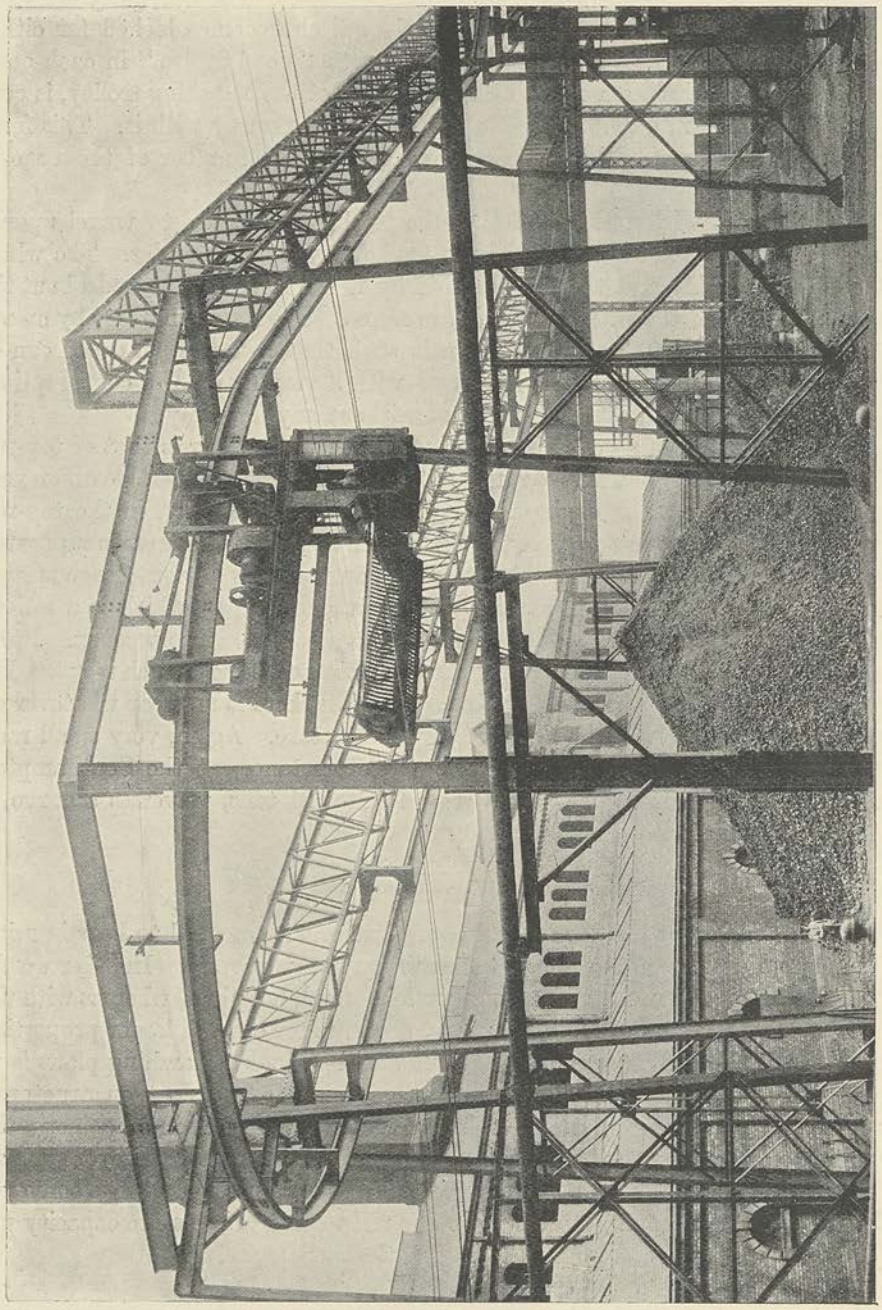


Fig. 247.—Telpher Installation showing Track (Dempster's Type).

of handling received by the coke, with a corresponding decrease in the production of breeze. Telphers, in general, are less costly than conveyors, which have necessarily

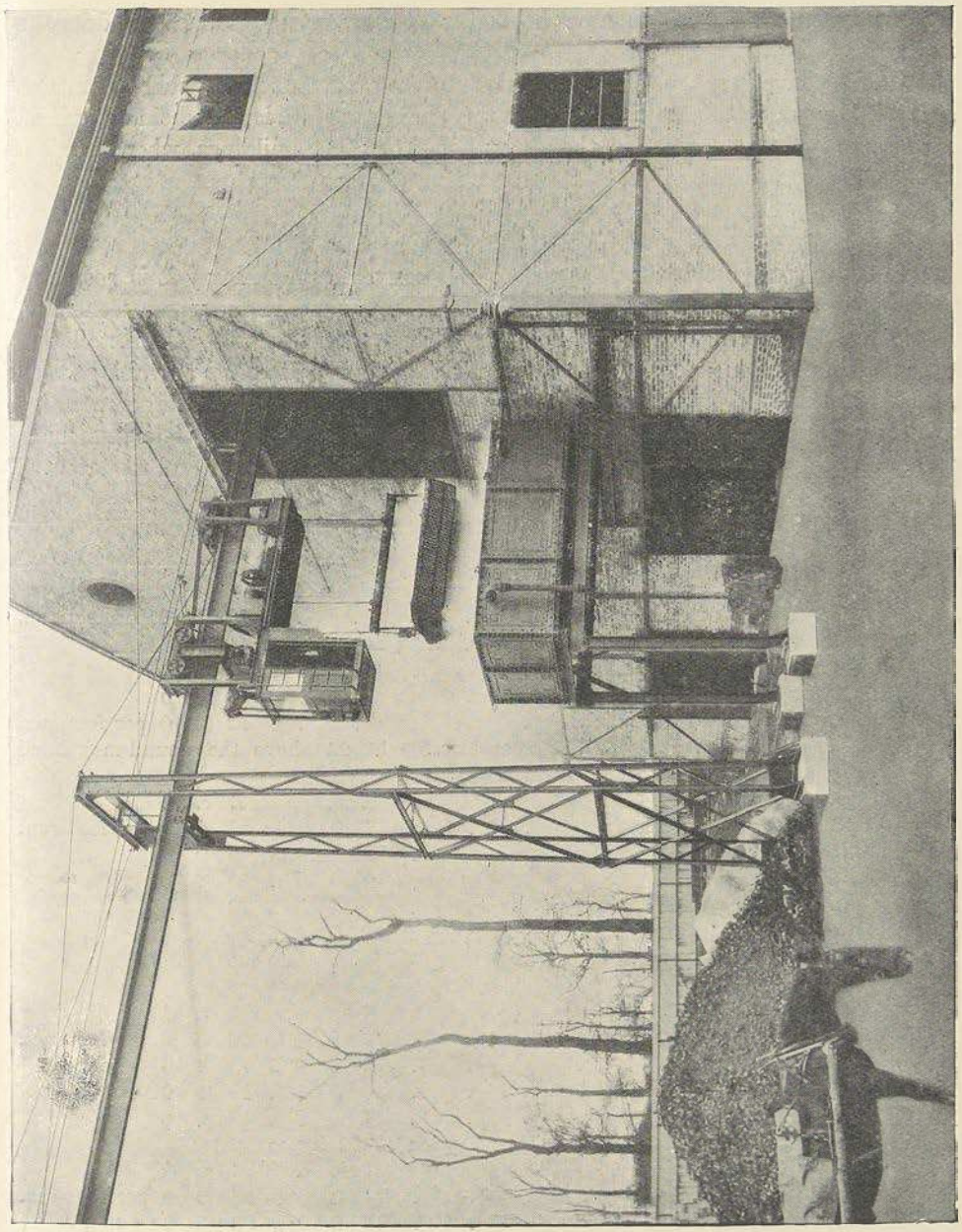


FIG. 248.—TELPHER SKIP BEING LOWERED INTO QUENCHING TANK (DEMPSTER'S TYPE).

to be of stout construction in order to withstand the conditions. On the other hand, the great advantage of the conveyor is the continuity of its action, and it does not, therefore, restrict the rate at which coke can be discharged from the carbonizing

vessels. Moreover, once set in motion the conveyor is more or less automatic in its action, and in some cases requires no driver in constant attendance, as does the telpher.

Unlike conveyors, the telpher does not require a straight road, while differences in level do not affect it. Its main advantage, besides speed, is that being overhead it occupies no ground space in the retort house or other buildings, where freedom from congestion is essential.

The Cost of Conveyors

In order to compare the relative costs of conveying machinery it is necessary to base figures on equivalent capacities for the different types in question. Generally, costs are based on the outlay per foot run. Thus the total length of the installation has some influence on this item. The following figures refer to costs prevailing at the time of publication. While, therefore, they give a useful indication of the comparative costs of various systems, it must be remembered that they are liable to be influenced at any time by the prevailing uncertainty in the markets for labour and materials.

Comparative Costs of Various Systems of Handling

	£	s.	d.		
(1) Electric Telphers—					
(*a*) Overhead track, structure, and trolley wire. Height of track, 45 to 50 feet	12	10	0		per foot run.
(*b*) Telpher machine, complete with motors, lifting capacity, 35 cwt. at 70 feet per minute	1,500	0	0		
(*c*) Skips for coke, 1 ton capacity (each)	85	0	0		
(2) De Brouwer Hot-Coke Conveyor	12	0	0		per foot run.
(N.B.—Yard conveyors supported at a considerable height above the ground may entail an outlay of £18 per foot run, which includes supports.)					
(3) Gravity-Bucket Conveyors—	£	s.	d.	£	s. d.
(*a*) Capacity 25 tons per hour	7	0	0	to 8	0 0 per foot run.
(*b*) „ 30 „ „	8	0	0	„ 9	0 0 „
(*c*) „ 50 „ „	9	0	0	„ 10	0 0 „
(*d*) „ 80 „ „	10	10	0	„ 12	5 0 „
(*e*) „ 100 „ „	12	5	0	„ 14	0 0 „
(N.B.—The above prices, for an average length of 250 feet, include the chain, buckets, wheel curves, track rail, fillers, vertical guides, etc., but not driving motor.)					
(4) Push-Plate Conveyors for coal—	£	s.	d.	£	s. d.
(*a*) Capacity 20 tons per hour	10	10	0	to 12	5 0 per foot run.
(*b*) „ 25–30 „ „	12	5	0	„ 13	0 0 „
(*c*) „ 35–40 „ „	13	0	0	„ 14	0 0 „
(*d*) „ 50 „ „	14	0	0	„ 15	0 0 „
(Conveyor complete, with exception of driving motor.)					
(5) Tipping-Tray Conveyors for coal—	£	s.	d.	£	s. d.
(*a*) Capacity 50 tons per hour	22	0	0	to 24	0 0 per foot run.
(*b*) „ 80 „ „	24	0	0	„ 25	0 0 „
(*c*) „ 100 „ „	25	0	0	„ 28	0 0 „
(6) Bucket Elevators—	£	s.	d.	£	s. d.
(*a*) Capacity 25–30 tons per hour	16	0	0	to 17	0 0 per foot run
(*b*) „ 45 „ „	18	0	0	„ 19	0 0 „
(*c*) „ 55 „ „	21	0	0	„ 22	10 0 „

THE CALCULATION OF HORSE-POWER

The power necessary to drive the various types of elevators and conveyors has in many cases been arrived at by practical experience and reference to the makers' records. It is, however, useful to be able to form an opinion as to the likely horse-power which will be required by any one installation, and the following simple but reliable methods will probably prove of some assistance to the designer.

First, in the case of conveyors such as the gravity-bucket and tipping-tray types, practical experience has shown that the tractive force is rather under 5 per cent. of the total weight of the moving parts and load. In addition to this 100 per cent. should be allowed for contingencies, such as neglect of lubrication and general inefficiencies. A gravity-bucket almost invariably performs two functions, first conveying horizontally, and secondly elevating the material.

Actually, four main factors have to be considered when calculating the power required to drive a conveyor, namely :—

(*a*) The work done against friction in moving the chain along the conveyor trough and return path.

(*b*) The work done in dragging or carrying the material along the effective length of the conveyor.

(*c*) The frictional losses at the terminal sprocket wheel bearings and other guide wheels, if any.

(*d*) The frictional losses in the driving gear.

For most purposes the horse-power required may be arrived at approximately by assuming a coefficient of friction in accordance with the conditions upon which the elevator or conveyor is operated. The various cases would be treated in the following manner :—

(*a*) *Vertical elevator.*

Let M = weight of material carried in pounds.
W = weight of moving parts in pounds.
K = coefficient of friction (see below).
S = speed in feet per minute.

$$\text{H.P.} = \frac{\text{MS}}{33{,}000} + \frac{\text{KS}\,(\text{M} + \text{W})}{33{,}000}$$

(*b*) *Inclined elevator.*

Let a = angle of inclination with horizontal.

$$\text{H.P.} = \frac{\text{MS} \sin a}{33{,}000} + \frac{\text{KS}\,(\text{M} + \text{W}) \cos a}{33{,}000}$$

(*c*) *Horizontal conveyor.*

$$\text{H.P.} = \frac{\text{KS}\,(\text{M} + \text{W})}{33{,}000}$$

So far as the value of K is concerned the result will be sufficiently accurate if this is taken as 0·45 to represent the average coefficient between coke sliding on metal, or metal on metal, *i.e.* it strikes an average for those conditions where both coke and the conveyor chain are sliding on a metal trough. It should be borne in

mind, however, that the above methods do not include the power absorbed by frictional losses at the terminal sprockets and in the driving gear.

In all cases where the expression "foot run" of conveyor or elevator has been used, it refers to the distance between the terminal sprockets and not to the length of chain employed. The latter will, of course, be approximately double the foot run length.

The following examples will show the method of working :—

(*a*) Horizontal coke conveyor, capacity 20 tons per hour, speed 40 feet per minute, length between terminal sprockets 100 feet, weight of moving parts of conveyor 50 lb. per foot.

$$M = \frac{100 \times 20 \times 2240}{40 \times 60} = 1867 \text{ lb.}$$

$$W = 100 \times 2 \times 50 = 10{,}000 \text{ lb.}$$

$$\text{H.P.} = \frac{KS\,(M + W)}{33{,}000} = \frac{0{\cdot}45 \times 40\,(11{,}867)}{33{,}000}$$

$$= 6{\cdot}44$$

(*b*) Inclined conveyor, of same type and capacity as above, rising at an angle of 30 degrees with the horizontal.

$$M = 1867 \text{ lb.} \quad W = 10{,}000 \text{ lb.} \quad \text{Sin } 30^\circ = 0{\cdot}5$$

$$\text{Cos } 30^\circ = 0{\cdot}866$$

$$\text{H.P.} = \frac{MS \sin 30^\circ}{33{,}000} + \frac{KS\,(M + W) \cos 30^\circ}{33{,}000}$$

$$= \frac{1867 \times 40 \times 0{\cdot}5}{33{,}000} + \frac{0{\cdot}45 \times 40 \times 11{,}867 \times 0{\cdot}866}{33{,}000}$$

$$= 1{\cdot}13 + 5{\cdot}58$$

$$= 6{\cdot}71$$

The horse-power required may be more accurately arrived at by taking into consideration those items which have been neglected (owing to their comparatively small influence) in the above treatment. An alternative method is, therefore, given below.

First assume the conveyor to be horizontal, and let—

L = effective length in feet.

W = weight per foot (in lb.) of the moving parts which convey the material.

F = coefficient of friction between the moving parts and the guides.

A = angle of repose of the material on the conveyor trough—35 deg. for coal, 45 deg. for coke.

C = capacity of conveyor in tons per hour.

w = weight of material per foot carried by conveyor.

S = speed of conveyor in feet per minute.

P = pull on conveyor chain.

Then, for a drag-bar coke conveyor the work done in foot-pounds per minute is as follows :—

(*a*) Work done in driving moving parts only

$$= 2 \text{ LWFS ft. lb. per minute.}$$

(*b*) Work done in conveying coke

$$= wL \tan A \ S \text{ ft. lb. per minute.}$$

Assume angle of repose of 45°, then $\tan A = 1$.

Capacity in lb. per minute $= wS$

$$= \frac{C \times 2240}{60} = 37\ C.$$

$$\therefore wL \tan A \ S = 37\ CL$$

(*c*) Frictional loss on terminal sprocket.

This depends upon ratio of diameter (D) of sprocket to the diameter (*d*) of the shaft bearing. For simplicity, this may be assumed to be 10 to 1. Take the coefficient of friction as 0·25, and assume that the friction is evenly distributed round the axle.

Then, taking the pull (P) to be equal on both sides of the bearing, the friction will be equal to 2PF.

The rate at which work is done against this friction

$$= S \times \frac{d}{D} = \frac{S}{10}$$

and the work done per minute $= \frac{2PFS}{10}$

$F = 0{\cdot}25$, therefore $\frac{2PFS}{10}$ becomes $\frac{PS}{20}$

i.e. 5 per cent. of PS.

Hence, about 5 per cent. of the driving power is lost at each sprocket shaft. That is, a loss of 10 per cent. for the two sprocket shafts.

(*d*) Frictional loss in driving gear.

The driving mechanism most usually consists of a double reduction spur gear, and it is usually assumed that 10 per cent. is lost at each reduction. This is equivalent to allowing 80 per cent. efficiency for the gear.

Combining the four above results, therefore, the horse-power may be obtained as follows :—

$$\text{H.P.} = (2LWFS + 37\ CL) \times \frac{100}{90} \times \frac{100}{80} \div 33{,}000$$

If the coefficient of friction is taken as 0·25, by no means too high a figure for a conveyor in which coke dust is likely to get between the rubbing surfaces ; and if the weight of the chain is taken at 50 lb. per foot run, *i.e.* a good practical average, then the above expression may be reduced to—

$$\text{H.P.} = \frac{1{\cdot}4\ L\ (25\ S + 37\ C)}{33{,}000}$$

Conveyor, partly inclined and partly horizontal.

If the conveyor is of the inclined type with an incline of *l* feet in length and rises to a vertical height of *h* feet. Then the additional power required can be arrived at as follows :—

Two new factors are introduced, namely—

(1) The h.p. required to overcome the additional friction on the guides, due to the change of direction of the chain at the upward bend.

(2) The h.p. required to lift the conveyed material through the height h.

(1) The load lifted $= w.l.$

Speed of lifting (vertically) $= S \times \frac{h}{l}$

$$\text{H.P.} = \frac{wl \times Sh}{33{,}000 \times l} = \frac{wSh}{33{,}000}$$

$$= \frac{Ch \times \frac{2240}{60}}{33{,}000} = \frac{37\,Ch}{33{,}000}$$

(2) Work per minute absorbed by friction.

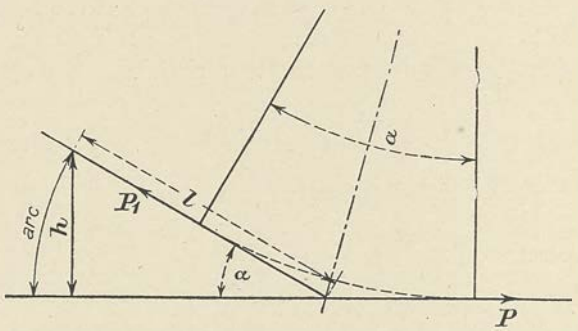


Fig. 249.—Diagram of Forces for H.P. Calculation.

Let $\alpha =$ angle of inclination (*see* Fig. 249)

$\theta =$ angle of contact in radians

$$= \frac{\text{arc}}{\text{radius}} = \frac{h}{l} \text{ (nearly) for small angles} = 0{\cdot}5 \text{ for } 30°$$

Let $P_1 =$ total friction under new conditions

$F =$ coefficient of friction as before (0·25)

Then, $P_1 - P =$ added friction (at bend).

Additional work due to friction per minute $= (P_1 - P)\,S$

but $\frac{P_1}{P} = e^{F\theta}$, where $e =$ the base of Naperian logs $= 2{\cdot}718$

$$\therefore \frac{P_1 - P}{P} = e^{F\theta} - 1$$

$$\therefore P_1 - P = P\,(e^{F\theta} - 1)$$

So that $S\,(P_1 - P) = SP\,(e^{F\theta} - 1)$

Thus, the additional power to be overcome due to this friction can be found by multiplying the predetermined h.p. (S.P.) by—

$$(e^{F\theta} - 1).$$

For an angle of 30 deg. this factor $(2{\cdot}718^{\frac{1}{8}} - 1) = {\cdot}13$, which indicates that the

h.p. in such a case is increased by 13 per cent. above that required for driving a similar conveyor which has no change of direction.

If this treatment is applied to the examples already considered in connection with the first series of formulæ given it will be noted that the horse-power required works out at a higher figure. The difference between the examples represents, therefore, the additional horse-power absorbed by the new factors which have been introduced. For example :—

Horizontal conveyor, capacity, etc., as in previous example (p. 339) :—

$$\text{H.P.} = \frac{1{\cdot}4\,\text{L}\,(25\,\text{S} + 37\,\text{C})}{33{,}000}$$

$$= \frac{1{\cdot}4 \times 100\,(25 \times 40 + 37 \times 20)}{33{,}000}$$

$$= \frac{140\,(1000 + 740)}{33{,}000}$$

$$= 7{\cdot}38$$

Partially inclined conveyor, rising at 30° with the horizontal :—

H.P. required to lift material up incline of 30° to height of, say, 10 feet

$$= \frac{37\,C\!h}{33{,}000} = \frac{37 \times 20 \times 10}{33{,}000} = 0{\cdot}22$$

Total H.P. $= 7{\cdot}38 + 0{\cdot}22 = 7{\cdot}6$

Increase of h.p. $= 13$ per cent.

13 per cent. of 7·6 $= 0{\cdot}988$

Total h.p. required $= (7{\cdot}6 + 0{\cdot}988)$

$= 8{\cdot}58$

In the examples for similar conveyors (worked out on p. 338) it will be noted that the other treatment gave results of 6·44 and 6·71 h.p. respectively.

The following table (Zimmer) gives a comparison between the relative power absorbed by various types of conveyors. In each case the conveyor is assumed to be of 50 tons per hour capacity, and to have an effective length of 100 feet :—

H.P. Required for Conveyors

Band conveyor for light materials	4·8 h.p.
Band conveyor for coal	5·0 „
Swinging conveyor	5·0 to 8·0 „
Push-plate conveyor	12·8 „
Worm conveyor	18·38 „
Tubular worm conveyor	25·0 „

CHAPTER X

ELECTRICAL PLANT IN GASWORKS

THE growing use of electricity as a source of power for operating gasworks plant has rendered a knowledge of this form of energy of increasing importance. A close acquaintance with the details of technical electricity is by no means necessary, for the practical construction of the apparatus is in the hands of specialists. Every gas engineer should, however, aspire to a working knowledge of the subject, and he should be in touch with the applications in practice of the more important theories. The importance of electricity has recently been emphasized by instances where gas concerns have, in addition, obtained powers for a public supply of current.

If electrically driven charging machinery is in use it is obviously economical in the majority of cases to operate other coal- and coke-handling plant by the same means. As a general rule it may be said that the ideal conditions for all power consumers is the continuous use of a set of plant working at something approaching its normal maximum capacity. To this end, it can usually be arranged to work the coal-handling plant together with charging machinery for ten or twelve hours out of the twenty-four, and the charging machinery during the night only. In small works it is possible to make use of the coal-handling and charging machinery alternately with the same power installation, and in this way the necessary electrical plant is considerably reduced. If coke conveyors are also installed it can be arranged to use two out of the three pieces of plant at one time.

Those who contemplate the introduction of electrical plant must bear in mind that if energy in this form is to be obtained at its cheapest it is essential that a good plant load should be maintained upon the generating sets.

Electricity when generated by means of town gas is an extremely cheap form of power, particularly when it is used on gasworks, for in such cases the gas consumed should be reckoned on " cost into holder " figures. In comparing costs with those of steam-driven generating plant the expense entailed in the provision of boilers should be included. If, however, existing excess boiler power is available, then generation by steam has its attractions. Steam, moreover, may be produced by means of materials which may frequently be almost unsaleable. In general, however, preference should always be given to generation by gas, unless other methods present indisputable advantages.

GENERATING PLANT

A point which has to be decided in each individual case is whether it is advisable to generate the current at the gasworks or to take advantage of the local supply.

Very much depends upon the cost at which the public supply can be obtained, and the probable cost of generation at the works. Some gas undertakings are now taking the available supply and are giving up generating, but in the majority of instances it is preferable to generate the current on the spot. Where the current is taken from a public supply it is very frequently alternating, and most classes of gasworks machinery can be quite satisfactorily driven by alternating current motors. If, however, the supply is generated on the works, it is advisable to instal direct-current plant, and for small plants a suitable voltage is 220–250 volts. For a larger plant, where the power has to be transmitted a considerable distance about the works, 440–500 volts is advisable. One of the advantages of the 220–volt supply is that electric lighting can be taken direct from the generating plant for use in such places as is desirable, whereas in the case of the 440–volt supply either a balancer or a small motor generator set must be installed for lighting purposes.

In gasworks, the current has usually to be transmitted only a very short distance ; consequently the most suitable system of supply—and that in common use—is the direct current. The advantages gained by the introduction of the multi-phase alternating system (*i.e.* the transmission of high power through small cables and with little loss over a long distance) are, therefore, of no material account. Furthermore, the nature of the requirements of the various units to be driven does not call for the peculiarities of the alternating system. In fact, the starting torque of direct current is preferable with the majority of motors employed. The alternating current demands more skilled attention, and there is greater liability to personal danger than with the direct system.

Once the system of supply and the motive power for the generators has been decided upon the type and size of plant should be considered. For small and medium-sized installations the standard horizontal single cylinder gas engine is to be recommended, the electric-lighting type being specially built for this class of work. For very large sets the vertical high-speed engine with two or more cylinders is more effective. There are two methods of driving the dynamo :—

(*a*) By belting.

(*b*) Direct drive by means of a flexible coupling.

Method (*a*) accounts for a small waste of power, but carries the advantage that the speed of the generator may be greater than that of the engine. Accordingly, for the same power a smaller generator may be used. The direct-coupled machine will, however, last longer (owing to its slower running speed), is safer (owing to the absence of moving belts), and occupies less ground space. Taking all points into consideration, it will usually be found that a direct drive—in spite of the slight extra expense incurred—is preferable, and of more lasting economy. The engine employed should be fitted with a magneto ignition and self-starter, except in the case of very small units. Generally speaking, for sets up to 50 or 60 kw. capacity a direct-coupled plant is the most satisfactory. Where direct-coupled plant is put down the best arrangement is to have the engines mounted direct on the concrete, and to use a two-bearing type of dynamo coupled to the engine by means of a suitable flexible coupling.

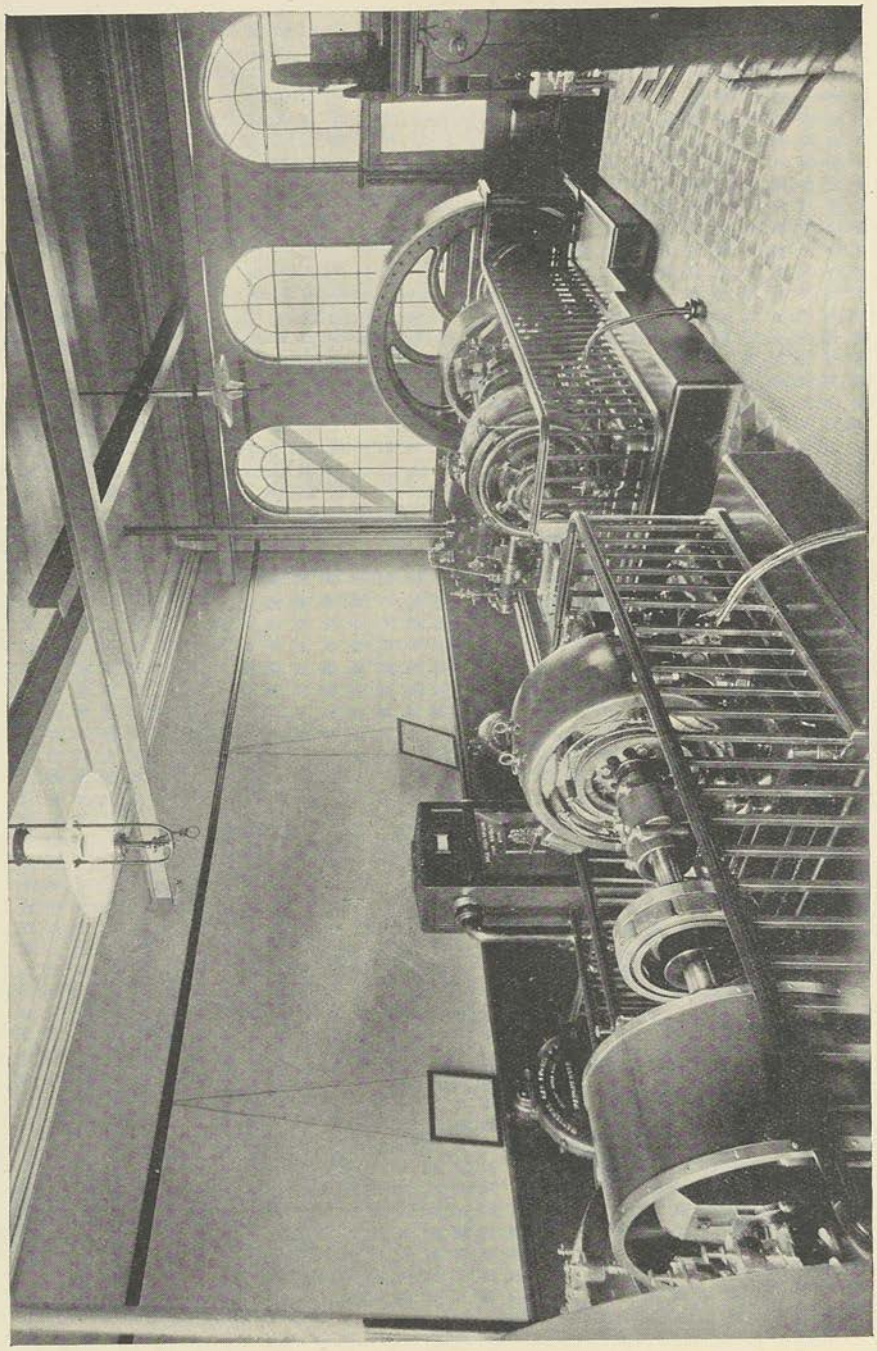


FIG. 250.—DIRECT-COUPLED GENERATING SETS. BRISTOL GAS COMPANY.

THE DYNAMO

A dynamo is a machine for converting mechanical into electrical energy. The mechanical energy supplied induces current in the armature windings, the current being collected by brushes and passing out for distribution to the switchboard. A small portion of the current is shunted through the field coils for magnetizing the field. The armature windings generate alternating current, and the commutator passes this out as a current of continuous flow (*i.e.* direct). Thus an alternating current dynamo, or "alternator," has no commutator. It is preferable when installing a gasworks dynamo to arrange for one having both series and shunt windings (compound), as this ensures a constant voltage for all variations of the load—this consideration being one of chief importance. The series and shunt windings of a compound-wound dynamo assist one another, the series coils ensuring that the voltage does not fall when the load increases.

Regulation and control of the dynamo voltage are obtained by the use of a shunt regulator which consists of a resistance (the amount of which can be varied) which is connected in series with the shunt field coils. Once the series coils have been designed and tested by the makers to give a constant voltage they should not be interfered with, and no regulator is provided in the series coils.

SIZE OF THE INSTALLATION

With regard to the size of the installation to be laid down it should be kept in mind, first, that it is necessary to arrange for more than a single plant, and, secondly, that it is not economical to work a set at much less than its normal capacity. In large works the night load is much smaller than the day load, as little work, except that entirely inside the retort house, is carried out at night. In medium-sized works the difference in load may not be very great and, as already pointed out, in small works the load curve may be very nearly straight. In the last-named case it is advantageous to instal duplicate plant, each set being capable of dealing with the maximum load. In some instances, where the difference between the day and night load is great, it may be preferable to have two plants of capacities equal to each period, with a stand-by equal to the lower capacity. Then, if the smaller unit breaks down, there is a duplicate to take its place, and if the larger one requires repairs there will be two small sets for providing the power. If this arrangement is adopted provision must be made on the switchboard for the parallel running of the set; for, if this is not done, there will probably be trouble when the two sets are both put on load together, more especially if the load happens to be of a variable nature.

For larger plants where the total load is likely to be 80–100 kw. or over, a fairly common practice is to instal three duplicate sets so designed that two of them running together will be able to carry the maximum continuous load and the first set acts as a stand-by. The plant should always be arranged so that one, two, three or more sets of which it consists can run in parallel. There is no difficulty in doing this, and modern well-designed level compound-wound generators

will run perfectly in parallel on a variable load. The makers' instructions regarding connections must, of course, be carefully carried out. The switchboard should be arranged so that all generators are connected on to a common set of bus-bars, the supply to the motors in the works being taken from this common set. By this means the whole of the generating plant can be made available for any part of the works, and by putting all the motors together on to the generating plant they balance out more evenly than if they were separated, consequently allowing smaller generating plants to be used.

In connection with running generators in parallel it is absolutely imperative that each generator should be protected on the switchboard by a circuit breaker, provided with an overload release and fitted with a reverse-current trip. This ensures that if for any reason a gas engine should fail and the dynamo should cease to generate, it will be disconnected from the main and will not be driven by the other dynamos which may be running.

In calculating the size of gas engine for a given dynamo it should be remembered that it is the usual practice to specify a dynamo output as the maximum load which it will carry continuously without a temperature rise exceeding a certain figure. On the other hand, it is usual with a gas engine to specify in the catalogue the maximum output which it will develop if firing on every stroke, but a margin of at least 10 per cent. must be allowed on the gas engine power for continuous normal duty. This margin need not be allowed on the dynamo.

A Typical Example

Consider a works carbonizing about 200 tons of coal per diem, and having from 130 to 150 retorts. The larger number would represent the normal maximum work of a combined charger-discharger, or two-thirds the work of separate machines. For the purpose of the example it can be assumed that the maximum power required by the machine is 18 h.p. The necessary motors would, therefore, be on lines such as the following :—

	B.H.P.
Charging machinery	18
Breaker, say 20 tons per hour	11
Elevator	9
Coal conveyor	7
Coke conveyor	10

Thus the maximum day load is 55 b.h.p. and the minimum night load 28 b.h.p. Motors of this type should run at an average efficiency of from 80 to 85 per cent. Assuming the lower figure, so as to allow for small losses between generators and motors, the following current would have to be supplied :—

$$55 \times \frac{100}{80} = 69 \text{ h.p.}$$

$$i.e.\ 69 \times 0{\cdot}746 = 51{\cdot}5 \text{ kilowatts.}$$

The latter, then, must be the power of the dynamo, *i.e.* it must generate as

a maximum 234 amperes at a pressure of 220 volts. In practice the next largest commercial size would be ordered, say 55 or 56 kw.

The efficiency of a dynamo rarely reaches more than 87 to 90 per cent., therefore the gas engine must supply sufficient power to allow for this loss. The power required at the coupling (assuming a dynamo efficiency of 88 per cent.) is—

$$\frac{56 \times 100}{88} = 63{\cdot}6 \text{ kw. or} = 63{,}600 \text{ watts.}$$

But 1 h.p. = 746 watts, therefore the required horse-power of the gas engine would be—

$$\frac{63{,}600}{746} = 85 \text{ b.h.p.}$$

The nearest convenient size would, therefore, be installed ; and it is important to note on what basis the b.h.p. of the engine is given by the makers. Frequently the figures given in catalogues refer to the maximum power obtainable calculated on a town's gas having a calorific power of so much as 600 B.Th.U. Nominal or indicated horse-power need not be considered. With regard to the duplication of the plant it must be remembered that although the day load amounts to 55 h.p., at times it will be very much less than this and the engine will not have a high load factor. In the event of the large plant being used for night work the load factor would be lower still (at times only about 20 per cent.), with a corresponding increase in gas consumption. During the night there may be an average required horse-power of 20 at the gas engine, and assuming a consumption of 22 to 24 cubic feet per horse-power hour with the small plant, or, alternatively, 34 to 38 cubic feet per horse-power hour with the large set, the difference between the consumption of the two sets is 13 cubic feet per horse-power hour. It will be understood that this excess consumption of the larger engine is due to its working at about one-quarter load only. By using the larger engine on the night load (*i.e.* for about 10 hours at a stretch) the waste of gas per night would be—

$$10 \times 13 \times 20 = 2{,}600 \text{ cubic feet;}$$

and if valued at 2*s.* 6*d.* per 1,000 cubic feet the monetary loss will amount to about 6*s.* 6*d.* per day, or £110 per annum. Thus in balancing up the merits of a single installation or two of half the capacity, it will be borne in mind that a saving of £110 per annum would be equivalent to the interest, wear and tear, and depreciation (in all about 10 per cent.) on a capital outlay of about £1,100. This sum would more than suffice to meet the extra cost of plant, switchboard, etc., for the duplicate plant. The amount of current necessary for electrically-driven machines (chargers and dischargers) may be taken at 0·2 to 0·4 units per ton of coal handled.

THE MOTOR

The motor is the reverse of the dynamo, that is to say it transforms electrical into mechanical energy. The greater portion of the current supplied is absorbed by the armature windings, whilst a small portion is drawn off by the field windings,

and the mechanical power obtained is derived from the energy of the current flowing through the armature in a magnetic field. There are three possible types of motors which may be used, the characteristics being as follows :—

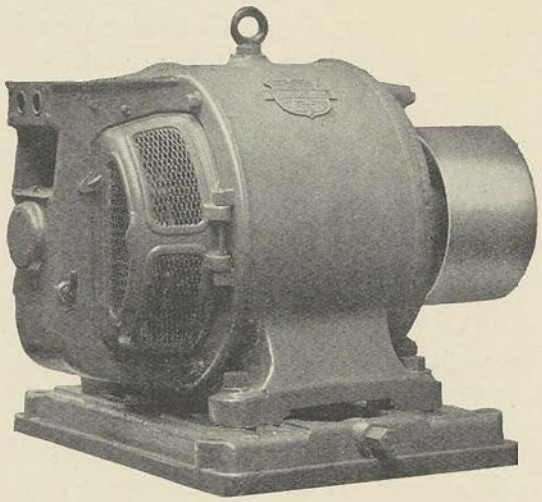


Fig. 251.—Standard Enclosed Ventilated Motor.

Shunt motors : These machines run at approximately constant speed with constant voltage, and may be employed where the load is approximately constant. They have not, however, the heavy overload capacity of series or compound-wound motors, and are most suitable for such duty as driving fans or pumps.

Series motors : These motors are only suitable when direct geared to the load they have to drive and should not be used for continuously running plant. They are mostly used for hoists, cranes, lifts, etc., and must never be used where there is a possibility of the motor running unloaded, as their characteristic is such that the speed will rapidly increase as the load decreases until a dangerous point is reached at which the machine may fly to pieces.

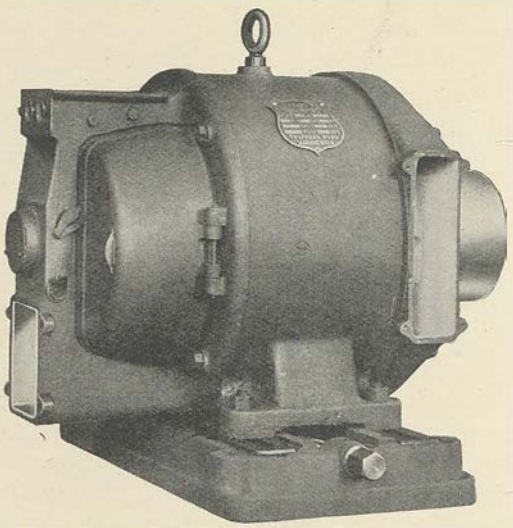


Fig. 252.—Standard Totally-Enclosed Gasworks Type Motor.

Compound-wound motors : These motors combine to some extent the characteristics of both the shunt and series motors and are generally suitable for driving gasworks plant. Their characteristic is that the speed decreases to a certain extent with increasing load, and rises with a decreasing load. Owing, however, to the shunt winding, this rise in speed is limited, and a machine reasonably compounded would decrease in speed by about 15 per cent. from no load to full load. They have the advantage that they will give a heavier overload than the shunt machine, and are capable of developing a particularly heavy starting torque which is of

great use for such machines as elevators and conveyors. They are also most suitable for machines in which there are large momentary overloads, such as coal breakers and pushers.

The compound-wound motor, whilst combining the commendable features of the shunt and series type, largely eliminates their defects, and is always to be recommended for general gasworks purposes. In order to effect economy in replacements it is preferable to keep to one type of motor and, if possible, to one make. It is not advisable to put down a larger motor than recommended by the makers, for loss in efficiency results and the average machine from a recognized maker will stand a temporary overload without ill effect.

ENCLOSED MOTORS

The size of motor is largely dependent upon the temperature rise to which it may attain, and in order to use a small motor for a given output good ventilation is essential. It is, therefore, obvious that a totally enclosed motor will have to be very much larger than a semi-enclosed motor of the same horse-power. Owing, however, to the dusty situation in which many gasworks motors are fixed it is frequently necessary to instal totally enclosed motors. Semi-enclosed motors can be used for driving pumps, fans, and plant generally where the situation is reasonably clean. Totally enclosed motors should in all cases be used for coal breakers, elevators, conveyors, and charging machinery. Special arrangements can sometimes be made to use pipe-ventilated motors, which combine the advantages of the totally enclosed and protected types of machines. Pipe-ventilated motors are machines which are totally enclosed but provided with openings to which short lengths of piping, 4 or 5 inches in diameter, can be connected. This piping is then taken to clean air and by means of a fan on the armature itself a certain amount of air is drawn into the motor for cooling purposes.

SWITCHES AND ACCESSORIES

The switchboard fulfils a function of extreme importance, consequently every care should be taken to ensure that each detail is capable of the work demanded of it. The switches should be up to full capacity, and the workmanship should be of the best, down to the smallest details of bars, studs, etc. The board may either be built into the wall so as to give outside access, or may be placed well away from it so as to provide ample space for repairs. The fittings on the board will vary with the requirements and with the different arrangement of the power units. Generally speaking, each generating set is provided with a separate panel fitted with a voltmeter and ammeter, a circuit breaker and a field-regulating switch, together with a main switch and fuse and an equalizing switch. In addition to the generating panels one or more feeder panels are usually installed according to the size of the plant. These feeder panels protect the different circuits running to the works, and are provided with main double-pole switches and fuses enabling any feeder to be isolated. In addition, earth lamps to enable faults on the system

to be detected should be fixed, and on large installations meters recording the consumption of power on each feeder, on the amount generated by each generating set, can usefully be fitted.

A distributing board is usually required in the retort house and the feeder cable from the generating plant is brought into this board and there divided up into a number of circuits, one of which goes to each motor. It is usual to provide fuses and in some cases switches and fuses at the point where the circuits are divided up. In addition each motor must be protected by its own starting panel, and it is advisable to have a combined type of panel fixed reasonably near the motor for the control of the individual motor. This panel should contain a starter with a "no-volt" and overload release (these releases automatically protecting the motor in case of overload), together with a double pole circuit breaker or a double pole switch and fuses. The overload release cuts off the current when it reaches a prearranged amperage should there be an unforeseen stoppage or "jamming-up" of the coal plant, and in this way the windings of the motor are prevented from being burned out. Again, the starter may be left on by accident or inattention, and when the current is off the "no-volt" release brings it back to "off," this preventing burning out should the main switch be closed in the absence of the operator. Totally enclosed switches should be made use of on the retort-house panel, the whole being boxed in and fitted with a glass panel for observation purposes.

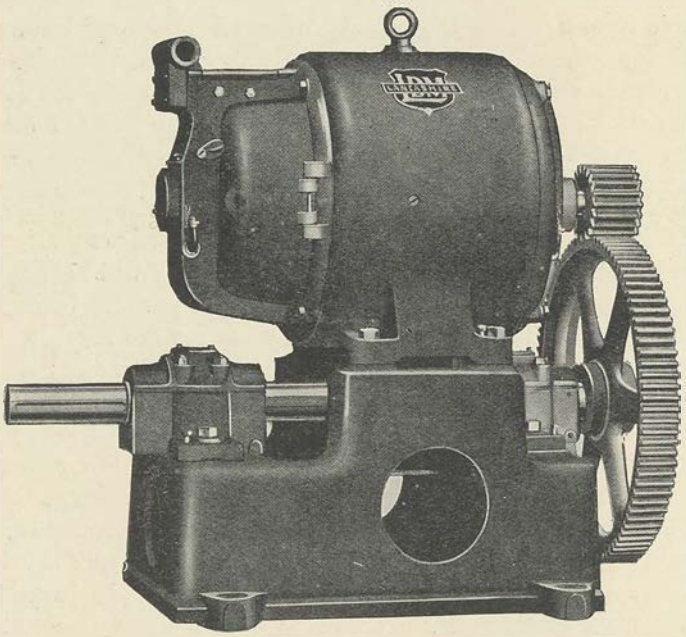


FIG. 253.—TOTALLY-ENCLOSED MOTOR WITH GEAR-BRACKET MOUNTED BELOW.

CABLES AND WIRING

It is a debatable point as to which is the best type of wiring to instal. In general, however, wiring laid in the ground should be avoided, owing to the difficulty of locating faults, and it is generally advisable to keep everything in a position where it can easily be got at and overhauled. The best policy is, perhaps, to

lay earthenware pipes in the concrete floor, and to draw all cables in. When the cables have to cross the gasworks yard, the safest method is to lay armoured cables in wooden troughing rather than to run V.I.R. cables in stoneware ducts.

The motor is fed by two cables, one carrying the current to it, and the other carrying the return current. The size of cable necessary for any given motor has to be calculated out by the full load current of the motor. The cables are usually referred to as of certain sectional area, and the size should be chosen so that the current does not exceed a density of 1,000 amps per square inch ; 2,500 megohm grade cable is the best that can be obtained and is very suitable for use in gasworks. There are various classes of protection available for cables, which may be either armoured or lead-covered, or supplied with an ordinary vulcanized india-rubber covering. For the majority of positions V.I.R. or vulcanized india-rubber can be used. This may in many instances be carried overhead by means of stranded steel suspension wires and leather suspenders, for example, from the generating station to the corner of the retort house, and may be run along the sides of the walls if a position where it is not likely to be damaged can be found. Where the cable is taken inside the retort house and put within reach of or near the motors it should be run in screwed steel tube. This tube should be run continuously right into the switchgear and from the switchgear direct into the motor terminal box.

CONSTRUCTIONAL POINTS

The retort house itself is a most unsuitable place in which to instal generating plant. It is very advisable that the generating plant should be installed in a separate building which can be kept reasonably clean and well ventilated. A thin brick or reinforced concrete building entails but small expense, and permits of the house being designed to suit the lay-out of the plant, and not the reverse, as is so often the case. Ventilation of the generating plant house is of importance, as discoloration of the commutators and the metal work on the switchgear is common if there is a leakage of gas. In no case should generating plant be installed near the purifiers or in the same house as the exhausters. Any trace of sulphur in the atmosphere will affect the insulation of generators and may eventually lead to trouble.

The inclusion of some or all of the following stipulations is advisable when specifying electrical plant for gasworks.

(1) Generators must be capable of developing their full load output on continuous rating with a temperature rise not exceeding 75° F. They must be capable of meeting an overload of 20 per cent. for two hours.

(2) Generators must be approximately level compound from no-load to full load.

(3) Temperature rise of semi-enclosed or protected type motors should not exceed 75° F. after six hours full-load run. Temperature rise on totally-enclosed motors should not exceed 90° F. or 95° F. after six hours full-load run. Temperature rise on pipe-ventilated motors should not exceed 85° F. after six hours full-load run.

All continuously-rated motors should be capable of developing an overload of at least 20 per cent. for one hour, and 50 per cent. for short periods. Totally-enclosed motors should be provided with terminal boxes so arranged that the conduit carrying the cable can be screwed right into the motors.

(4) Cable should be of 2,500 megohm grade V.I.R.

(5) Where cables are carried overhead stranded suspension wires should be used and the cable should be carried by leather or raw-hide suspenders. Where cable is run in tubing the tubing should be made continuous throughout.

(6) All motor frames, starter cases, and tubing should be efficiently earthed.

(7) All trenches for cables should be capable of easy inspection, and are preferably covered with some form of grid. If this is not done, a small inspection chamber should be built in at every point at which the direction of the cable or pipe is changed.

PRECAUTIONS AGAINST BREAKDOWN

If electrical plant is to operate with a minimum of trouble and derangement it is essential that it should not be left to look after its own welfare. Breakdowns and temporary stoppages largely arise from insufficient attention being given to elementary considerations; and, in order to be safeguarded, the gas engineer should ensure that the following points are fully appreciated and acted upon by those in charge of the plant:—

(*a*) All parts of electrical machinery must be kept perfectly clean.

(*b*) Any traces of oil on the windings should be immediately removed. Oil, if permitted to remain, will eventually destroy the insulation.

(*c*) The machines must be sufficiently large for their work. This point requires special emphasis so far as gasworks are concerned, for small extra loads are so frequently added without any thought being given to the original work for which the generating plant was installed.

(*d*) If in doubt as to the power required, most suitable type of plant, etc., leave the matter to the judgment of expert contractors, and see that your contract specifically binds them down so that you will get your work done as you require it to be done. On contracts for electrical machinery the balance of the purchase money should be kept in hand until the plant has been in operation for three months.

(*e*) Bear in mind that direct-coupled plant is the simplest, most compact, and probably the cheapest in the long run.

(*f*) If a belt-driven plant is employed, endeavour to keep the belt horizontal with the slack side on top. The chief merit of a belt drive is that it provides a flexible connection; and, in the event of an overload, it may give way and provide a "safety valve." The belts should be of the endless type, otherwise the joint may cause sparking. Sparking at the commutator gives rise to pitting, and if there is any sparking up to full load the machine requires attention. A high-class machine properly driven, should at all loads up to full load be absolutely sparkless.

(*g*) Extreme caution should always be exercised when a new dynamo or

motor is started up for the first time. Ensure that new plant is thoroughly dry before it is put to work.

CAUSES OF FAILURE

If difficulty is experienced in getting the plant to operate, the trouble may usually be traced to one of the following causes, which apply in general to both dynamos and motors :—

(*a*) *Earths.*—The generating plant switchboard should be provided with lamps for indicating earths on the system, and when an earth occurs, it should be located immediately and removed. It can most conveniently be located by means of a " megger," an instrument for measuring insulation resistences.

If the earth is found to be on the wiring, which is sometimes the case, the cable should be renewed or the defective pieces cut out and replaced. The usual places where earths occur are at sharp corners or in the junction boxes, or just where the cables enter the motor or switchgear. If the earths appear to be on the motor or generator, the brush gear and all connections should be carefully examined. By lifting the brushes from the commutator the armature can be tested, and, if the earth is on the armature, it is advisable to send the machine to the makers or some competent repairing works.

The causes of earths are frequently moisture, gas fumes, or dirt getting into the machines. Dirt is probably the most common cause of the trouble.

(*b*) *Shorts.*—Occasionally an armature will become very hot in one place and will spark badly on a definite commutator bar, at the same time smelling very strongly of burning varnish. This usually indicates that the coil of the armature is shorted, and it is necessary to take the armature out and have it returned to the makers.

(*c*) *Sparking Commutators.*—No machine should ever be allowed to run with a commutator sparking badly, and if the sparking cannot be cured by moving the brushes or cleaning the commutator, the makers should be requested to examine the machine. The trouble is sometimes caused by the brushes having been moved from the correct position. Manufacturers usually mark on the machine the correct settings for the brushes, and positions may be checked from these. When new brushes are fitted they should be carefully bedded so as to conform with the curvature of the commutator.

(*d*) *Fuses Blowing.*—The fuse is a protective device, and the fact that it keeps blowing is an indication that something is wrong on the circuit that it is protecting. This may be either a short or an earth, or, of course, there is the possibility that the motor may be overloaded. Careful tests should be made to find out which of these effects is causing the trouble.

(*e*) *Failure to Excite.*—Sometimes it will be found difficult to get the generating plant to excite, and no voltage can be obtained. If the plant is being started up for the first time, it is probable that the connections are not correct, and they should be carefully checked with the diagram of connections supplied. If the machine has, however, been run before, and nothing is wrong with the connections,

it is possible that the commutator is dirty and is preventing excitation, or some of the connections in the field coils may have become loose. The whole of the field coil connections should be carefully inspected and tightened up, and the commutator and brush gear should be thoroughly cleaned. If the machine does not then excite, it is advisable to communicate with the makers.

(*f*) *Reversal of Polarity of Dynamos.*—Dynamos driven by gas engines are sometimes liable to have their polarity reversed owing to the gas engine failing, when they are driven as a motor by the other dynamos that may be running. This will not occur if the switchboard is provided with properly acting reverse current circuit breakers. An indication of this trouble is given by the voltmeter trying to read in the wrong direction when the machine is run up again for starting. The polarity must be put right before any further attempt is made to run the machine, for, if the dynamos are put in parallel under these circumstances, a serious accident may occur.

(*g*) The fault may be with the prime mover, which may not be working up to speed. If the drive is by belt there may be excessive slip.

(*h*) *Breakdowns on Motor Field Coils.*—The trouble may be in the field coils. A faulty coil can nearly always be located owing to its heat.

(*i*) If the motor has a field coil on the bottom special care should be exercised to avoid oil collecting round it. The insulation may soon be affected in this way.

In general, it may be said that normal attention to the machinery, keeping the commutators and brush gear clean and renewing the brushes when necessary will prevent most of the troubles that may arise, and where serious breakdowns have occurred it is advisable to communicate with the makers rather than to attempt to effect repair without specially skilled assistance. A testing ammeter to enable the load taken by any motor to be measured is a very useful piece of apparatus to keep on the works, and a "megger" for measuring insulation resistances is certainly desirable on a large installation.

USEFUL MEMORANDA

A Volt is the unit of electrical pressure or electro-motive force. An Ampere is the unit of current strength, *i.e.* the unit in which the rate of flow is measured. The current strength varies directly as the pressure producing it, and inversely as the resistance opposed to its flow.

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

An Ohm is the electrical unit in which resistance is measured.

Watts = volts × amperes.

A Board of Trade unit = 1 kilowatt-hour.

A Horse-power = 746 watts, or 1 kilowatt = 1·34 h.p.

1 Kilowatt-hour = 1·34 h.p. hours = 3,440 British thermal units.

CHAPTER XI

GAS-MAKING AND OTHER COALS

Coal, the natural gift to which our country may be said to owe its commercial pre-eminence, provides as fascinating a problem as can be met with in any of the highways of modern science. The phenomena surrounding its formation are as yet open to controversy, while the more material question of its economic utilization presents a subject which provides one of the most pressing themes for the investigation of the present and future generations. Coal has been described as a store of primæval solar energy, slowly accumulated during untold millenniums, which mankind nowadays draws upon as a source of practically the whole of his available light, heat, and power in artificial form.

That coal is mineralized vegetation is a point upon which all doubt has been removed. It may be simply defined as the product of the decay of vegetable matter under the prolonged influence of pressure, heat and moisture. Stopes and Wheeler [1] suggest that coal may be defined as "a compact, stratified mass of mummified plants (which have in part suffered arrested decay to varying degrees of completeness) free from all save a very low percentage of other matter." Veins, partings, etc., which are found in nearly all coals, are local impurities, and are not part of the coal itself.

The classification of coals is based upon the geological period of their formation, the two main groups being known as "carboniferous" and "tertiary." It is the former which are generally distinguished by the name of "true" coals, and in this category are included steam coals and anthracites, cannel coals, and the misnamed bituminous types which, almost solely, are suitable for gas-making purposes. The tertiary coals, on the other hand, embrace those types of the nature of lignite or brown coal.

Scientific records appertaining to the gradual formation of coal from vegetable matter prove of little interest to the practical gas-maker, and the same almost may be said of the composition of coals as determined by ordinary laboratory methods. Nowadays, the gasworks value of a coal is gauged, not by its specific gravity or its "unoxidized hydrogen" content, but by its capability to conform with certain practical expectations. The constitution, as distinct from the composition, of coal is still more or less shrouded in mystery, although recent investigators have classified the main components in a manner which is of distinct service to those directly interested in carbonization. Composition as determined by ultimate

[1] *The Constitution of Coal*, 1918.

analysis may almost be said to be of academic interest alone, and—according to one authority—is " as likely to afford an idea of the constitution of coal as the total weights of stone, metal, glass, and other materials forming a cathedral would convey an idea of its architecture and design."

The methods now in vogue for the examination of coal may be classified into two groups, namely, (*a*) Destructive methods, and (*b*) Non-destructive methods. Destructive methods have proved of certain usefulness in the past, but it is now generally realized that the constitution must be determined by such means as will not involve any radical change in the chemical constitution of any one of the component parts of the substance. The non-destructive methods which comply with this condition are, notably, microscopic examination of sections by transmitted light, the use of special solvent, and contact photography. The solvent processes, perhaps, can scarcely claim to come within the sphere of non-destructive methods, but their application has proceeded along with the scientific, as opposed to the directly chemical, means, and has resulted in the unearthing of much of the valuable information now at our disposal.

THE ORIGIN OF COAL

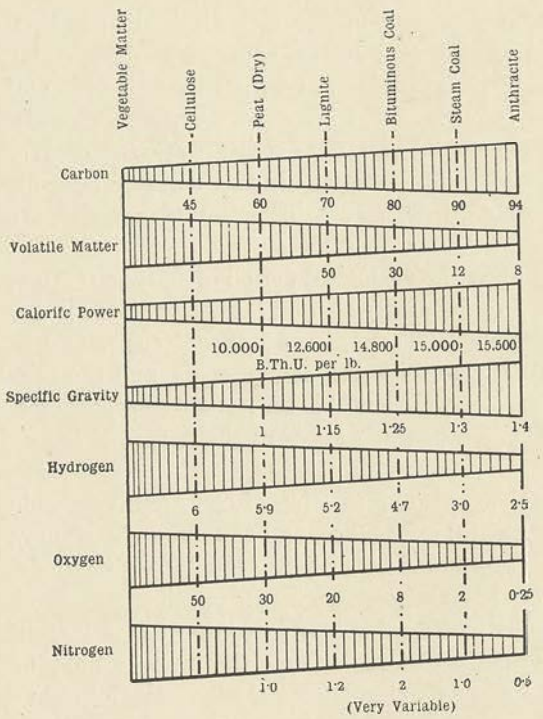


FIG. 255.—THE FORMATION OF COAL.

(The figures for the various properties and constituents vary considerably for the same types of coal. Those given above represent the average.)

It is not proposed to follow out in detail the gradual formation of coal from the original vegetable matter. Sufficient it is to say that the respective changes are partly physical and structural, and partly chemical. The accompanying diagram (Fig. 255) enables the changes, so far as the salient properties and constituents of the coal are concerned, to be followed up. From this it will be noticed that the looseness of structure of the original matter gradually gives way to a more compact and homogeneous mass, whilst the volatile bodies are progressively displaced by constituents of a " fixed " nature. The moisture (*i.e.* the hygroscopic water), hydrogen, oxygen, and nitrogen of the cellulose all tend to be expelled, whereas the carbon remains, and increases in propor-

tion as the process advances. The carbon, it must be understood, increases, not synthetically, but merely owing to the evolution of the remaining constituents; which fact is best illustrated by recalling that the volume of the final substance amounts to only one-tenth to one-sixteenth of the original vegetation from which it was formed.

Cellulose, one of the main constituents of vegetable tissues, may be considered as the basis from which the gradual evolution of coal can be conveniently followed. It has been shown that the carbonic acid exhaled by animal life and resulting from all forms of combustion is regenerated into oxygen by plant life coupled with the agency of the sun. Expressed chemically in its most simple form, the nature of this extremely involved action is somewhat as follows:—

$$6\ CO_2 + 5\ H_2O = C_6H_{10}O_5\ \text{(cellulose)} + 6\ O_2.$$

Experimental results in connection with the artificial conversion of cellulose indicate that it undergoes changes on the following lines:—

$$4\ C_6H_{10}O_5 = C_{21}H_{16}O_2\ \text{(coal-like residue)} + 3\ CO_2 + 12\ H_2O.$$

Although, however, this may be true for artificial conversion, we know that in all natural conversion methane is produced; thus, considering pure cellulose, humus matter would be given by the decomposition, and the reaction would approach the following:—

$$6\ (C_6H_{10}O_5) = C_{21}H_{20}O_8\ \text{(humus)} + 8\ CO_2 + 7\ CH_4 + 6\ H_2O.$$

Bergius says that the differentiation of the various types of coal is not due to the time occupied in their formation, or to the prevailing temperature, but to marked increase in the pressure; and he supports his theory, and shows it to be in conformity with geological facts, by pointing out that anthracite has been formed where the earth's crust has become folded, thus squeezing the layers of carbonaceous matter to a terrific extent. Peat, lignite, bituminous coals, and anthracite form a series further and further removed from vegetation and wood in composition and character. The brown colouring of the lignite is a transition stage to the black of the coal, and whilst the vegetable structure disappears the specific gravity increases uniformly, until (as is now not generally disputed) the final stage of conversion is arrived at by the formation of graphite containing 100 per cent. of carbon. A point of importance to note is that a portion of the total carbon is in such a state of combination that it is capable of being volatilized, but this proportion decreases as the formation proceeds. It is for this reason that steam coals and anthracites are of no use to the gas engineer, owing to their indifferent capabilities as regards gas yields and coke. Steam coals are intermediate in composition between bituminous coals and anthracite, and should not be confused with the latter. In average bituminous coals, as used for gas-making, the volatile carbon amounts to from 15 to 20 per cent. of the total carbon, and is of extreme importance, in that it accounts on distillation for the most valuable constituents of the gas and tar.

THE CONSTITUTION OF COAL

Coal, so far as its constitution is concerned, is still largely a mystery, and new light is constantly being shed on the final mode of existence of the degradation products of the original vegetation. Recent investigation has mainly consisted of attempts to find out by extraction with suitable solvents what coal consists of. In this way it has been established that the majority of coals contain constituents, one of which is soluble in pyridene, and which is of a resinous character, while the other is insoluble. The insoluble portion is of a humus nature, and appears to be a degradation product of the cellulose contained in the original vegetation. The resinous portion, on the other hand, accounts for the coking and swelling properties of coal, and is, therefore, of main interest to the gas engineer.

Of the earlier investigators, Lewes[1] suggested that the coal substance consisted of four fundamental bases which he denoted as (*a*) carbon residuum, (*b*) humus bodies, (*c*) resin bodies, and (*d*) hydrocarbons. He stated that in general the various types of coal owe their varying characteristics to the proportions in which these substances are present, and each of the constituents has its own distinguishable products of decomposition when subjected to distillation. For instance, the ability to form coke and to yield a high proportion of gaseous products depends upon whether the hydrocarbons and resin bodies are in excess (in which case the coal is of the gas-making type), or whether the carbon residuum or humus bodies are present in the greater proportion, when a non-caking coal of an anthracite nature results. In fact, as the anthracite stage is approached the constituents are composed largely of the carbon residuum basis, the remainder consisting chiefly of resin compounds. Lewes[2] says that for a coal to have the property of caking or "coking," the resin bodies and hydrocarbons have together to be present in the proportion of at least 50 per cent. In the ordinary type of gas coal he says that the four constituents are present in approximately the following proportions :—

Carbon residuum	30 per cent.
Humus bodies	20 „
Resin bodies	25 „
Hydrocarbons	25 „

With an anthracite coal, on the other hand, the distribution is given as follows:—

Carbon residuum	72 per cent.
Resin bodies	28 „

In this case it will be seen that the high calorific power of the anthracite coals is chiefly dependent upon the entire elimination of the low heating-power constituents. For instance, the humus bodies (which, on heating, account largely for water vapour, carbonic acid, and carbonic oxide, having a comparatively low calorific power) give way to resins and carbon. It is the humus which accounts largely for the low heating value of the lignites. The approximate calorific powers of the four fundamental substances may be taken as follows :—

[1] *The Carbonization of Coal*, by V. B. Lewes. [2] *Loc. cit.*

Resin bodies	16,400	B.Th.U. per lb.
Hydrocarbons	15,900	„ „
Carbon residuum	14,600	„ „
Humus bodies	13,300	„ „

From the above it will be seen that the maximum calorific power is yielded when the presence of the humus bodies can no longer be traced, as is the case with the anthracites and many of the steam coals.

Lewes points out that the composition of the humus and resin bodies is as follows :—

	Carbon.	Oxygen.	Hydrogen.
Humus	63	32	5
Resins	79	11	10

He shows that the whole of the oxygen present in the coal is due to these two bases. Hydrogen, in addition, is present in the hydrocarbon substance, but the unsaturated hydrocarbons in the gas are chiefly derived from the resinic compounds, whilst the hydrocarbon base is responsible for the paraffin group. In the past, authorities on carbonization have emphasized the importance of the " unoxidized hydrogen " content of the coal, and by deducting the quantity of combined hydrogen from the total have arrived at a figure for hydrogen which they consider of importance owing to the supposition that this is the only available hydrogen for the yield of free hydrogen and hydrocarbons in the gas. Thus a coal which on ultimate analysis shows 5 per cent. of hydrogen and 8·8 per cent. of oxygen would be rated on an " unoxidized hydrogen " content of $\left(5 - \frac{8{\cdot}8}{8}\right), = 3{\cdot}9$ per cent. It must be pointed out, however, that only a portion of the original oxygen in the coal combines to form water in this manner, a further material amount being found in combination in the condensible vapours forming the tar, and as oxides of carbon. Primarily, the proportion of oxygen gives a useful indication of the extent to which humus bodies are present in the coal, whilst the *direct* subtraction of the hydrogen percentage from the oxygen percentage enables an opinion to be formed as to calorific power. For instance, Constam and Kolbe have given the following figures :—

Coal.	Oxygen.	Hydrogen.	Difference.	Net Calorific Power.
	Per cent.	Per cent.		B.Th.U. per lb.
Nottingham, bright	10·20	5·30	4·90	13,912
Ditto hard	9·24	4·97	4·27	14,072
Durham I	5·66	5·48	0·18	15,392
Durham II	3·70	5·46	1·76	15,766

These figures indicate that with coals of the bituminous type the calorific power is inversely proportional to the excess of oxygen over the hydrogen, and therefore bears a ratio to the quantity of humus bodies present. At the same

time a knowledge of the percentage of oxygen is of decided value to the gas engineer, in that it conveys a useful idea as to the proportion of volatile matter. The latter is accounted for by both humus and resin constituents (in addition to the hydrocarbon bases), in both of which oxygen is present. Lewes has emphasized the importance of oxygen and has laid down the following axioms :—

(1) The higher the oxygen in the coal, the higher the volatile matter.

(2) The higher the oxygen, the lower the coke yield.

(3) The higher the oxygen, the greater the amount of CO and CO_2.

(4) Oxygen above 10 per cent. or below 4 per cent. means inferior coke or indicates a non-coking coal.

As an illustration of the last statement the figures for the types of non-caking coals (about 13 per cent. of oxygen) and for anthracites (0·25 per cent.) may be recalled.

Stopes and Wheeler,[1] while agreeing that the classification suggested by Lewes deserves careful consideration, point to the fact that it is purely hypothetical, and there is considerable doubt whether " carbon residuum " and " hydrocarbons " exist at all in a normal coal. They state that his assumptions, therefore, are possibly quite incorrect, and that anthracite coals, for example, are not compounded of resin compounds and carbon, and that coking coals do not contain 30 per cent. of free hydrocarbons.

It would seem that, as our knowledge of the subject stands at present, the suggestion made by Wheeler is the most helpful. This authority assumes that most coals contain—

(*a*) A degradation product of cellulose (insoluble in pyridene).

(*b*) A " cellulosic " constituent (soluble in pyridene, but insoluble in chloroform).

(*c*) A resinous constituent, probably derived from the resinous portions of the original vegetable matter which produced the coal (soluble both in pyridene and in chloroform).

Bone [2] states that among the parent substances in the organic *débris* from which coals have originated, the following are chiefly of concern :—

(*a*) Celluloses, *i.e.* ligno-celluloses, essentially carbohydrates $n(C_{12}H_{18}O_9)$ of a cyclic type.

(*b*) Resinic, *i.e.* gums, resins, and waxes, compounded of carbon, hydrogen, and oxygen.

(*c*) Nitrogenous, *i.e.* proteid bodies, or compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur.

This worker states further that there is some evidence that small quantities of hydrocarbons are present in coals, whether associated with the resinic constituents or independently of them is not quite certain, but they are neither so prominent nor invariable as the three principal constituents mentioned above.

[1] *Monograph on the Constitution of Coal*, 1918, p. 46.

[2] *Coal and its Scientific Uses*, p. 73.

GAS-MAKING COALS

The quantity of coal now used for gas-making purposes in the United Kingdom amounts to about 18,000,000 tons per annum, while some 20,000,000 tons are utilized in coke-ovens. Generally speaking, it may be said that the favourite coals of the gas engineer are those occurring in the Northumberland and Durham districts. Other fields from which large supplies are drawn are those of West Yorkshire, South Lancashire, Nottingham, and Derbyshire, also Staffordshire and Warwickshire. Owing to the decided variation in quality which occurs in coals mined in adjacent or even in the same seams it is difficult to distinguish with accuracy between the products of the different districts ; in fact, it is by no means uncommon to find both steam coal and gas-making types occurring in the seams of any one mine. The problem with which the gas engineer is chiefly confronted is that of balancing gas-making capabilities against expense of delivery. In the majority of cases it will be found most economical to take the coal nearest to the point of consumption, even though the quality is not all that might be desired.

In general, the typical analysis of a gasworks coal of good quality will approximate to the following, although as regards ash content it is by no means an uncommon occurrence to find the inert matter even in coals of good reputation mounting up to as much as 15 per cent.

TYPICAL GAS-MAKING COAL

Carbon	80 per cent.
Hydrogen	5·5 „
Oxygen	8·8 „
Nitrogen	1·5 „
Sulphur	0·8 „
Ash	3·4 „
Volatile matter	30 to 35 „
Calorific power	14,400 B.Th.U. per lb.

The above analysis is representative of the good quality gas coal such as was obtainable prior to the late war. Many gas engineers will, however, have good cause to remember the abnormal proportion of inert matter which was delivered in the coal during the years 1917, 1918, and 1919, at some periods the amount of ash being as much as 30 per cent. The cause for this exceptional deterioration in quality was mainly to be traced to the discontinuance of the process of picking over the coal at the pit-heads, a situation which arose partly from the shortage of labour.

In the following table there are set forth the differences in ultimate analysis of typical coals from the various seams of the country ; but, as already pointed out, it must be recognized that this standard of judgment is not to be relied upon. If used intelligently, however, the chemical composition of a coal will give some insight into its value for gas-making purposes. Particular attention should be given to the proportions of ash, oxygen, and sulphur. With regard to the last-named, although a certain amount is chemically combined with the chief elements, and forms,

accordingly, some portion of the conglomerate, the quantity so combined is extremely small, and is but a fraction of that existing as iron pyrites (" brasses ") or sulphates.

TYPICAL BRITISH COALS

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Durham	81·1	5·37	7·01	1·56	1·12	3·84
Lancashire	77·91	5·40	9·32	1·31	1·45	4·61
Nottingham . . .	77·36	5·66	10·22	1·34	1·65	3·77
Derbyshire	79·68	4·94	10·28	1·41	1·01	2·68
Scotland	78·53	5·63	9·22	1·00	1·11	4·51

So far as the Durham types are concerned, New Pelton and Holmside qualities are classified as " gas bests," whilst " gas specials " include Thornley, Wearmouth, and Londonderry. " Gas seconds " comprise types such as Pelton Main. Of the Derbyshire varieties the " deep softs " are those chiefly employed for gas production, the best-known qualities being Birley Silkstone and Mickley Thin. The West Yorkshire fields provide the chief sources of supply for the many large gasworks of that county, and of the typical gas coals the most notable seams are the celebrated Silkstone, also the Stanley Main, Beeston, and Middleton varieties. In addition, cannel seams are still being worked, but only to a comparatively small extent.

CANNEL COAL

Cannel or " candle " coal is unsuited to the present-day requirements of gasworks. It was somewhat extensively used in the days when statutory requirements as to illuminating power were more severe, and before the general introduction of carburetted water-gas as a source of enrichment. Although varying in constitution to some considerable extent, it is an extremely rich coal containing a high proportion of resinic bases. As regards its occurrence, the seams in some cases turn gradually, almost imperceptibly, into a bastard cannel, and finally merge into shale. Its characteristics resemble in many ways those of the Scottish gas-making coals. Cannel may be said to range in position between lignites and bituminous coals, and contains on an average as much as 45 per cent. of volatile matter. The chief objection to the use of cannel is the poor quality coke which it yields. The coke, owing to its powdery nature and high percentage of inert matter, is practically useless for fuel purposes. In some cases cannel coke will contain upwards of 60 per cent. of ash. The specific gravity of cannel is rather higher than that of bituminous coal, and lies in the neighbourhood of 1·27. The ultimate analysis varies between the following limits :—

Carbon	64	to	85 per cent.
Hydrogen	5	„	10 „
Oxygen	4·5	„	15 „
Nitrogen	1	„	2·5 „
Sulphur	0·3	„	2·5 „
Ash	5	„	20 „

As regards gas-making yields a high quality cannel is capable of giving, in exceptional cases, 14,000 cubic feet of gas, with an illuminating power of from 35 to 45 candles. Cannel tar is of a distinctly paraffinoid nature.

In recent years cannel coals and shales have mainly attracted attention from the point of view of oil production, and during the war extensive experiments were carried out with this purpose in view.

SPACE OCCUPIED BY COALS, ETC.

For the purpose of estimating stocks of coal or coke it is necessary to have some idea of the space occupied per unit of weight by various solid substances. For the use of the gas engineer the following figures will be found suitable, but the physical condition of the material may account for some variation in either direction :—

1 Ton of—

Ordinary gas coal (unbroken) occupies	42 to 43	cubic feet.
„ „ (broken) „	40	„ „
Cannel coal (varies considerably) „	35 to 45	„ „
Anthracite „	35 „ 39	„ „
Coke (unbroken) „	85 „ 92	„ „
Breeze „	60 „ 65	„ „
Lime (1 yard = 12½ cwts.) „	42	„ „
Oxide of iron (Dutch) „	45	„ „
„ „ (Prepared) „	41	„ „
„ „ (Belgian) „	40	„ „
Sulphate of ammonia „	47 to 48	„ „

CONSIDERATIONS AFFECTING THE PURCHASE OF COAL

It is extremely difficult to lay down any hard and fast stipulations on which to base the purchase of coal intended for gas-making purposes. A final choice should not necessarily be influenced by a comparison of thermal units per ton and total residuals, but by a consideration of net financial standing after all charges have been balanced against receipts. It is for this reason that many concerns still adhere to the poorer classes of coal where the collieries producing these are near the gasworks, thus saving in freightage charges. High yields of gas per ton are undoubtedly alluring, but useful contrasts between the working results of different gasworks cannot be drawn on this basis. The only true gauge is the annual or half-yearly balance-sheet.

Coal for all the larger gasworks is purchased by contract, usually for a period of twelve months. In the ordinary way these contracts are entered into as dating from 1st July in each year, for a specified monthly quantity. In the majority of cases a fixed yearly price is settled, but occasionally a somewhat higher price for the six winter months has to be conceded. The various coal groups have by this time established a reputation, either good or indifferent, for the class of material they turn out ; and as each district or series of seams has its own particular name, the name alone is often sufficient to convince the purchaser of what he is buying. For all that, coals occurring in the same locality vary considerably, and too much

reliance must not be placed in a name. There are many methods of arriving at an approximate comparison between the suitability of different coals for gas-making purposes, the chief being the following :—

(*a*) Proximate analysis. That is to determine, chiefly, the volatile content. This gives some gauge of the gas-yielding and coking properties of the coal. The test is best carried out by Lessing's method, in which electrical heating is employed.

(*b*) The calculation of pounds of sperm per ton, or the pounds of sperm which can be purchased for a shilling. This is a time-honoured method which has proved of some value in the past, but which has entirely lost its significance at the present day. To obtain the value of a coal in pounds of sperm per ton the make of gas per ton is divided by 5 (which is the cubic feet of gas consumed by the standard test burner per hour) ; the result is then multiplied by the illuminating power and by 120 (120 being the number of grains consumed per hour by the standard sperm candle). Finally, it is necessary to divide by 7,000, which is the number of grains in 1 lb. Put briefly :—

$$\text{Pounds of sperm per ton} = \text{make} \times \text{illuminating power} \times \cdot 003428.$$

(*c*) Calculation at current prices of total yields of gas, coke, etc., obtained from a ton of the coal. The figure obtained is then balanced against the cost of the coal, and comparison between various coals is made on these lines. This method cannot be applied with accuracy, and is not to be recommended.

(*d*) The use of a coal-testing plant. On the larger works it is still customary to submit small samples taken from fresh consignments of coal to a laboratory experimental plant. The total gas evolved, in addition to the main by-products, is then carefully collected and measured. The usual procedure is to take $\frac{1}{1000}$th part of a ton of coal (2·24 lb.), which is carbonized in a small cast-iron retort.

The coal-testing plant of the Birmingham Corporation gasworks is probably the most elaborately equipped of those now in use. It is on an exceedingly large scale, and in reality forms a complete gasworks in itself. Various types of retort settings are in use, including regenerative horizontal beds, and both intermittent and continuous vertical systems. The horizontal test bench is capable of dealing with 31 tons of coal per diem, and consists of four beds of full-sized through retorts. The intermittent vertical installation has a capacity of 14 tons a day, and the continuous bench is capable of dealing with 20 tons per diem. Elaborate apparatus is installed for the purpose of arriving at an accurate knowledge of the capabilities of the various coals tested, and their behaviour under different systems of carbonization.

(*e*) Comparison by " gas multiple." This is one of the most recent methods, and can be looked upon as affording the most satisfactory means of comparing the gas-yielding proclivities of various coals. The yield per ton is obtained by careful experiments in the test plant, and the illuminating power and calorific value of the gas evolved is noted. The " make " of gas is then multiplied by the candle power, and the result gives the " gas multiple."

For example, two coals (*a*) and (*b*) might be tested with the following results : —

(*a*) 12,000 cubic feet of gas per ton. Candle power, 15.
(*b*) 13,000 „ „ „ „ „ 14.

Then for (*a*) the gas multiple is 180,000, and for (*b*) it is 162,000. Coal (*a*) would then be adjudged the most desirable from the point of view of gas yield.

As candle power has now lost its significance the modern method of computing the "gas multiple" is to multiply the gas made per ton of coal by the average calorific power. In other words, this gives the yield of gaseous thermal units per ton of coal. The figure should normally vary, for good quality coals, between 6,500,000 and 7,000,000 B.Th.U., straight coal gas only being considered.

CALORIFIC POWER RECOVERED

Suggestions have frequently been made that calorific power should be made a basis on which to adjust the value of coal. Thus a certain price per ton would be charged for a definite calorific power, and a *pro rata* reduction made when the heating value was below the standard. For those who employ coal as a fuel the system has many advantages. The gas engineer, however, is concerned not so much with the number of heat units in his original coal, but with the number which will be recoverable on distillation, and—more particularly—the form in which they will be recovered. The latter consideration is rarely accorded the share of attention it merits, but a simple illustration is sufficient to indicate its importance. Of the original heat units in a ton of coal about 95 per cent. are recovered in useful form in (*a*) the gas, (*b*) the coke, (*c*) the tar. Heat units sold in the gaseous form are by far the most remunerative; therefore, the original calorific power of the coal should be recovered in the gas as far as possible. According to general experience, coke accounts for from 60 to 65 per cent. of the original calorific power of the coal, tar from 6 to 8 per cent., and the gas for 25 to 35 per cent., while a loss approaching 5 per cent. is generally found, this being partly accounted for by retort carbon and sulphur impurities.

Bedson[1] has given figures representative of the heat distribution of the products of distillation in ordinary gas retorts. The heat in 100 lb. of dry gas coal was distributed as follows:—

	Per cent. of Original Calorific Power of Coal.
In coke sold	47·8
In coke used for heating retorts	11·4
In gas (sold)	21·3
In tar	6·1
In liquor, sulphur, and loss	13·4

Another example of the manner in which the original calorific power of the coal is distributed after carbonization is given by the following table,[2] which relates to statistics obtained from 8,500,000 (metric) tons of coal distilled in Germany. The figures are instructive in that they relate to results on a large scale.

[1] *Gas World* (Coking Suppt.), Feb. 2, 1917, p. 16.
[2] *Die Wirtschaft der Deutschen Gaswerke*, 1914, p. 14.

	Percentage by Weight of Coal Carbonized.	Percentage by Heat Units recovered from Original Coal.
Gas (made)	17·5	24·0
Gas (sold)	16·6	22·8
Coke (sold)	56·0	67·0
Tar	5·0	6·0
Ammonia	12·42	—
Cyanogen	0·02	—
Retort Carbon	0·06	—

COAL WASHING

All coals as won from the pit contain varying proportions of inert matter and undesirable impurities. Chief amongst these are siliceous and calcareous matter, shale, and pyrites. The question of washing coal for the removal of these impurities is not one which directly concerns the gas engineer, who normally employs coal which has merely been picked over and in some cases screened. During the war the quality of coal deteriorated to such an extent that some of the larger gas undertakings seriously considered the possibility of washing the coal before carbonizing it. Up to the present, however, no development of this suggestion has occurred.

The effect of washing on the quality of coal is well illustrated by the following figures which have been given by G. Knox [1]:—

Inert Matter removed by Washing

Material Washed.	Ash per cent. before treatment.	Ash per cent. after treatment.
Fine coal	31·00	5·7
„	22·72	4·1
Slurry $\frac{1}{8}$ in. to 0	23·70	2·2
„ $\frac{1}{25}$ in. to 0	13·28	4·25
Belt pickings crushed	35·80	8·60
Slurry	30·25	4·83
„	18·42	5·21
„	16·00	5·03
Anthracite, shales, rubbish	49·07	5·46
Waste slack	24·95	1·12
Fine coal	18·42	3·75

So far as the efficiency of washing apparatus is concerned it is usually specified that the treated coal shall contain not more than 2 per cent. of free inert matter, while the residue shall contain not more than 2 per cent. of free coal.

Theoretically, the principle of coal-washing depends upon the fact that particles of differing specific gravity fall through water (or some other prescribed solution) at

[1] *Proc. S. Wales Inst. of Engineers*, 1919.

different velocities. A particle of given dimensions and specific gravity when falling through a liquid attains a maximum limiting velocity, which is dependent upon the specific gravity and diameter of the particle. If, therefore, we have two particles of equivalent size, it follows that their specific gravities must differ in order that separation may be effected. At the same time, velocity depends upon diameter, and it is important to note that if, for example, we had a particle of coal (1·3 sp. gr.) and a particle of shale (2·3 sp. gr.), the diameter of the coal being 4·3 times that of the shale, then both would fall at the same rate. To overcome this difficulty, therefore, it is customary in most cases to pass the coal firstly through a 2-inch screen, the screened material being washed, while the larger coal is dealt with on a hand-picking belt.

For an average mixture of coal and shale the velocity may be calculated from the following formula (Rittinger) :—

$$V = 1{\cdot}28\sqrt{D}\ (d-1)$$

where V = velocity in feet per second.
D = average diameter of particles in feet.
d = specific gravity of the material.

Knox has prepared a most interesting graph (Fig. 256) which illustrates the limits within which separation of different sizes of particles of various specific gravities can be effected. If any horizontal line of the graph is taken it gives the relative sizes of the particles which fall with equivalent velocities. For example, a particle of pyrites $\frac{1}{8}$ inch diameter, one of shale with pyrites $\frac{1}{4}$ inch diameter, one of shale $\frac{1}{2}$ inch diameter, and one of coal $1\frac{3}{4}$ inches diameter, would all fall, or be floated, at the same velocity. It will be appreciated, therefore, that to ensure efficient separation it is essential that the sizing should be such that heavy and light particles do not assume an equivalent velocity. In other, words the sizing must be such that the rate of fall of the largest light particle is rather less than the velocity of the smallest heavy particle.

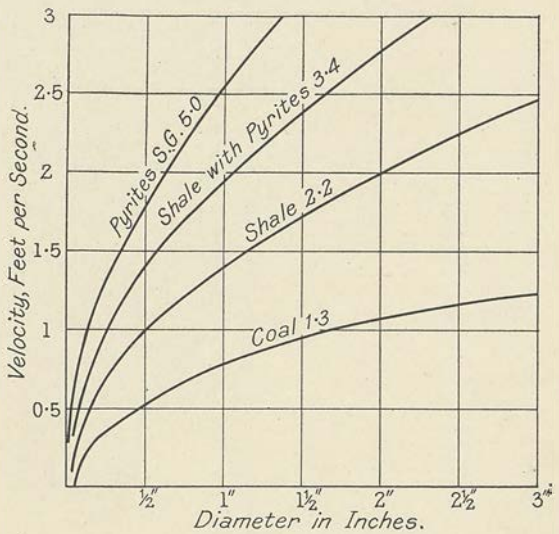


Fig. 256.

Coal-Washing Machinery

The principles involved in the plant employed for separating impurities from coal may briefly be summarized as follows :—

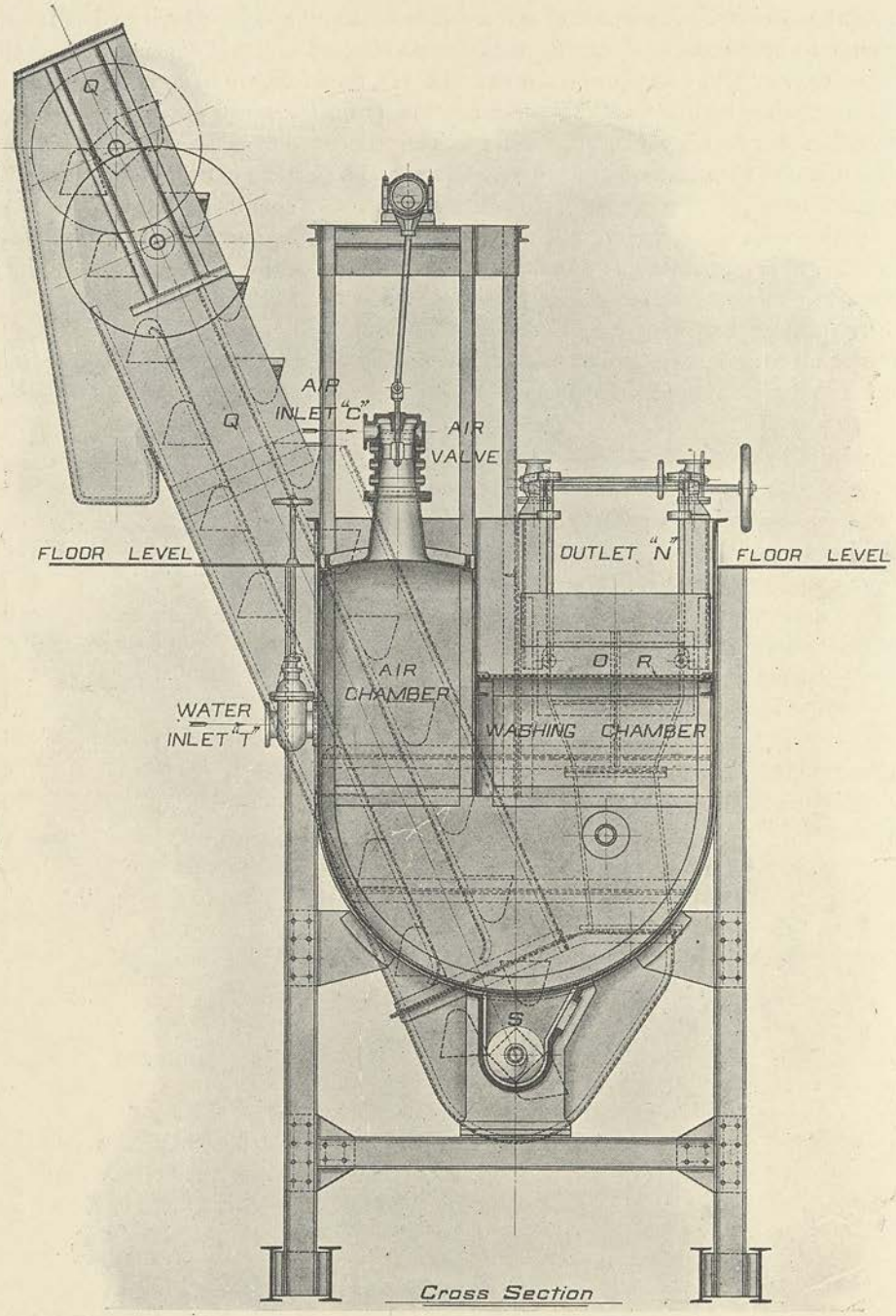


FIG. 257.—THE BAUM COAL WASHER.

(*a*) Treatment of coal in an ascending current of water, whereby the lighter particles are lifted and the heavier particles sink.

(*b*) Exposure of coal alternately to upward and downward currents of water.

(*c*) Sluicing down an inclined surface, whereby the larger and lighter particles are washed down more quickly than the smaller and heavier particles, or the lighter particles are caused to ride over weirs, whereas the heavier particles are held up by the weirs.

(*d*) Treatment in jigger trays whereby the small heavy particles are jerked forward more quickly than the lighter ones. In conjunction with the jigger effect a stream of water is frequently employed for assisting separation.

The Baum washer is operated on the principle of "first wash, then classify," and is shown in Fig. 257. Any coal below 3½-inch mesh is washed without previous screening in one washer box, the specifically heavier products going to the bottom and the lighter products (*i.e.* the coal) going away with the water. The Baum washer is capable of dealing with any quantity of coal up to 150 tons per hour, and the application of the water is effected by air at a pressure of about 2 lb. per square inch. The air valve is provided with a sleeve piston which is raised and lowered by an eccentric. When the valve is in the lower position air passes direct from the blower and exerts its full pressure on the surface of the water. When the valve is in the upper position the air supply is cut off from the washer box, which is simultaneously opened to the atmosphere. In this way, alternate depression and rebound of the water take place. The coal to be washed, lying on the grid *R*, is thus subjected to the pulsations of the water, and the dirt falls to the bottom, whence it is removed by the elevator, *Q*. The worm conveyor, *S*, collects towards the elevator any dirt deposited further along the washer box. The coal, along with the middles and light dirt, overflows into a second section of the washer box, where it undergoes further treatment, the good products overflowing at *N* to be dealt with according to requirements. The washing water enters at *T*, and passes with the washed coal over the outlet *N*. It is afterwards clarified before being returned to the box.

The Coppée washer (Fig. 258) deals with each size of coal in a separate box, the classification usually being as follows :—

(1) Nuts	¾ in. to ⅞ in.
(2) Beans	½ in. to ¾ in.
(3) Peas	¼ in. to ½ in.
(4) Small	0 in. to ¼ in.

Pulsation of the water is produced by plungers driven by adjustable eccentric rods, the stroke of the rods being regulated to suit the class of coal undergoing treatment. The pulsation gives rise to thorough agitation of the coal in the water, the dirt falling to the bottom of the box, while the coal is carried away by the overflowing water. For the smallest coal a machine of slightly different design is employed, but the principle made use of is the same.

The Draper washer (Fig. 259) employs the principle of upward-current classification.

The coal to be washed is elevated from the slurry tank into a revolving screen which separates the wet coal into sizes from $\frac{3}{16}$ inch to 0. The oversize passes into a separate washing compartment, and the undersize is only what passes through a $\frac{1}{100}$ mesh, which averages about 2 per cent. This revolving screen is partially immersed in water which enables the finest sizes to be treated without clogging. The various

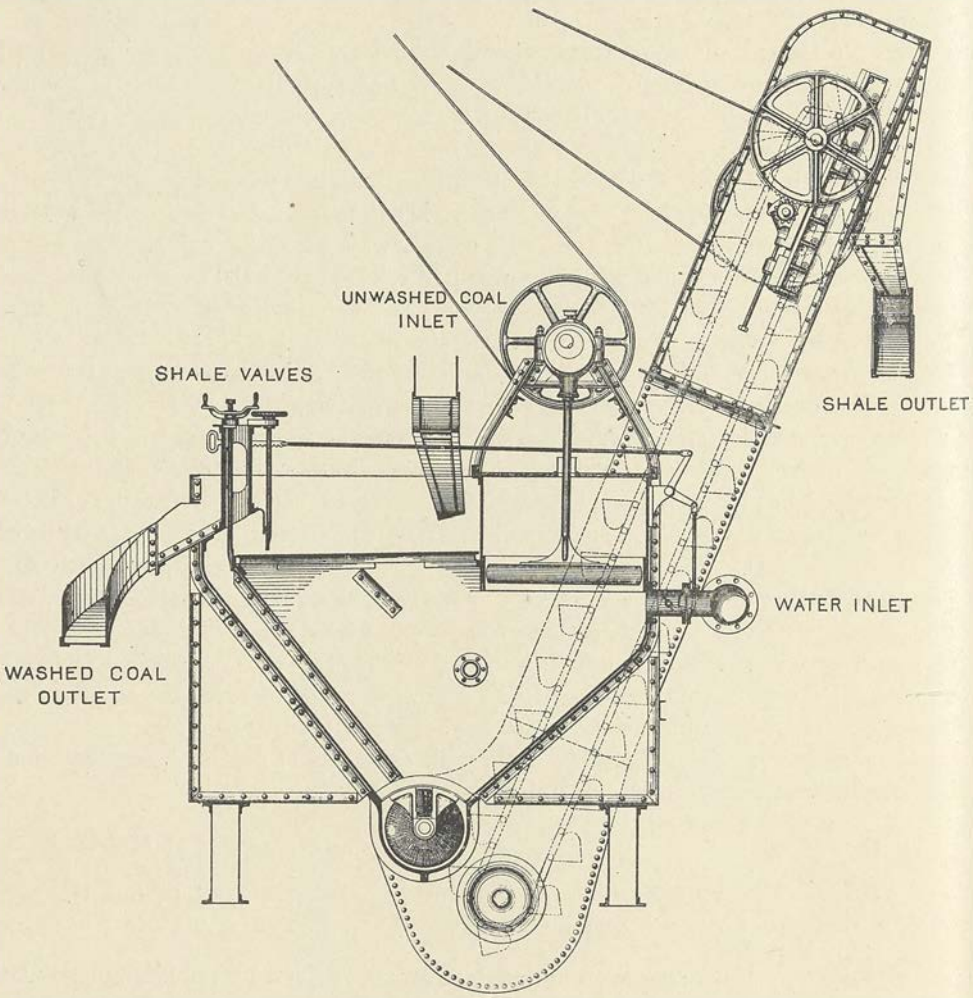


Fig. 258.—The Coppée Coal Washer.

sizes pass through water-sealed revolving star delivery valves, and through the feeder launders into the washer, where they meet an upward current of water regulated in velocity so as to float the lighter coal particles, and at the same time allow the heavier particles of shale to fall. This is accomplished by a very simple device, consisting of an inverted plain or perforated cone attached to a straight length of

pipe, in which the greater water velocity creates a zone of maximum lifting effect, below which only the heavier particles can descend, and in the cone itself the decreasing velocity produces a minimum lifting effect, being just sufficient to float the lighter particles over the sill into the shoot.

Coal after washing is usually allowed to drain in bunkers and to dry in air, and although many attempts have been made to effect artificial drying, by means of heat and the centrifuge, the method has not developed to any extent in this country. As regards the proportion of water in washed coal, this depends largely

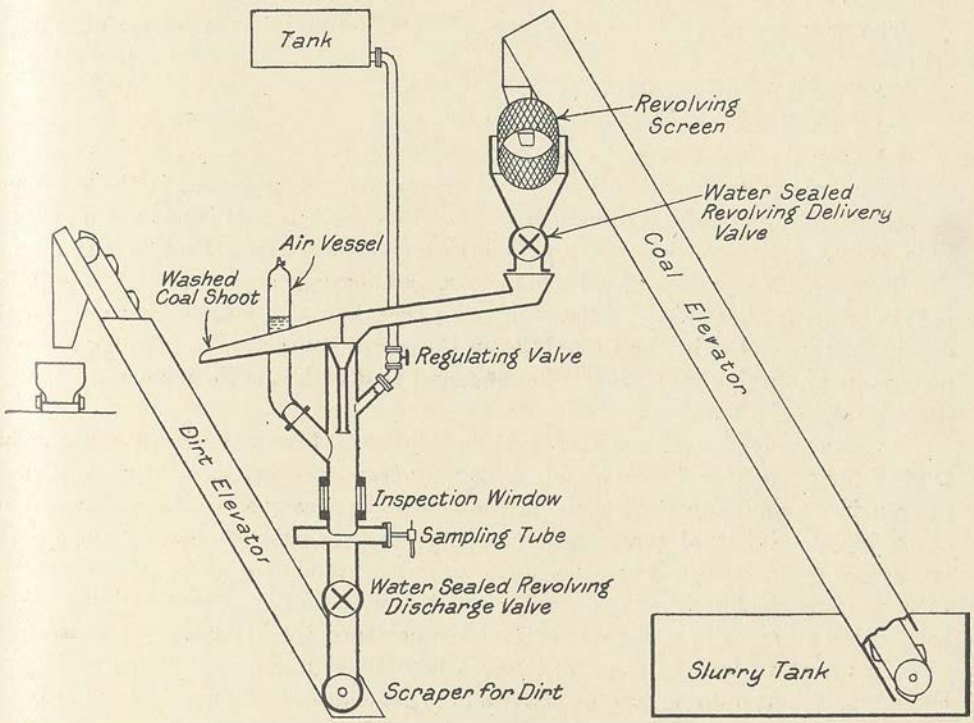


FIG. 259.—THE DRAPER COAL WASHER.

upon the size of the coal, but it may be as much as 10 per cent. above that in the normal sample.

THE STORAGE, SPONTANEOUS COMBUSTION, AND DETERIORATION OF COAL

The problem of the spontaneous combustion of coal is one which the gas engineer is continually called upon to face, owing to the fact that the bituminous coals used on gasworks suffer most in this respect. Cannel coals are less affected, and steam coals and anthracite are least liable of any. Originally, there was a general opinion among gas engineers that spontaneous ignition was due to the oxidation of the "brasses" or pyrites in the coal, and that the action was greatly accelerated by

damp and moisture, the pyrites being oxidized by the oxygen contained in the water. This idea probably originated in the fact that if a quantity of pyrites is picked from the coal, made into a heap, and then exposed to air and moisture, the heat of the pile rapidly rises, owing to the oxidization of the sulphur due to the action of the air and moisture. In many cases a temperature will be reached at which combustion in air begins, and the mass will then burst into flame. In contradiction of this theory, however, it must be pointed out that while some coals containing a very high percentage of pyrites are quite safe, those containing a small proportion often give great trouble when stacked.

The storage of coal presents several disadvantages, the chief of which are :—

(*a*) Possibility of spontaneous ignition.

(*b*) Loss due to weathering.

(*c*) Loss due to cost and effect of handling.

There seems to be little doubt that spontaneous combustion is the outcome of a combination of several causes, and that while pyrites itself is not alone responsible, it may play some subsidiary part in assisting the action. Factors such as the size, dampness, proportion of volatile matter, and general composition, all play their part in bringing about a rise in temperature. It is, however, interesting to note that conclusions arrived at by the United States Bureau of Mines were that moisture plays no part in promoting spontaneous heating, and that high volatile matter does not of itself increase the liability to fire.

It is common knowledge that coal as soon as it leaves the seam has a great avidity for oxygen, and, remarkable as it may seem, the greater the proportion of oxygen in combination with the coal the greater appears to be its proclivities for absorbing an additional quantity from the air. Lewes pointed out that the " resin bodies are the compounds present in the coal most likely to possess this property. It is the chemical reactions so caused which lead to slow combustion, and, when accelerated by any rise in the surrounding temperature, this is capable of generating sufficient heat to lead to the spontaneous ignition of masses of broken coal large enough to prevent the escape of heat as it is developed." Many bituminous coals will absorb more than three times their volume of oxygen ; but after a time they get coated with an oxidized surface, and their absorptive properties become less vigorous until new surfaces are exposed by the breakage of lumps, etc. It is probable, then, that the spontaneous heating in coal heaps is due to the rise of temperature occasioned by the oxidation of part of the carbon together with the sulphur in the coal ; and in cases where actual firing takes place, it may be assumed that the heat generated in the stack is greater than that dispersed by radiation. Thus the temperature rises till the ignition point is reached. The greater liability of some coals to fire is due, therefore, not to the sulphur they contain, but to their proclivities for absorbing oxygen ; and the greater the quantity of oxygen absorbed, the greater will be the tendency to fire. The heating effect, too, is probably cumulative ; for a rise in temperature increases the capacity of the coal for taking up oxygen.

S. W. Parr,[1] as a result of numerous experiments conducted with Illinois coals, arrived at the following principal conclusions :—

(*a*) The oxidation of coal is continuous over a wide range of temperatures, beginning, with freshly-mined coal, at ordinary temperatures.

(*b*) At low temperatures initial oxidation is due to the presence in the coal substance of certain unsaturated compounds having a marked avidity at ordinary temperatures for oxygen.

(*c*) Although the slow oxidation is exothermic, it does not, when air is freely circulated, cause any material self-heating of the coal round about, until a temperature of from 60° to 80° C. is reached.

(*d*) The self-heating at any temperature is more rapid the finer the state of division of the coal.

(*e*) The presence of moisture increases the chemical reactivity of the coal-air system at any temperature.

(*f*) At a temperature of about 135° C. in air the constituents of coal begin to oxidize more freely with the evolution of carbon dioxide and water, a state of affairs which must be regarded as highly dangerous.

(*g*) The point at which oxidation becomes autogenous or self-propellant lies somewhere below 200° to 270° in air. As soon as this temperature is reached there will be a rapid rise to the ignition point of the coal, which in general is above 350° C.

Bacon and Hamor [2] are of the opinion that the subject of spontaneous firing of coal requires more inquiry from a fundamental standpoint. They state that the entire process is essentially one of " surface combustion " ; but between the initial absorption of oxygen by the coal substance and its final expulsion in the products (water and oxides of carbon) an entire series of complex phenomena may be involved.

Means of Prevention

Many divergent views have been expressed as to the most effective means of preventing spontaneous ignition in coal stacks. One authority may be found strongly to advocate ventilation, while others suggest that free access to the air actually causes fire. Again, the free use of the hosepipe is recommended by some, whereas it is pointed out, on the other hand, that the use of water is likely to be followed by serious results, especially in confined stores.

Primarily, then, it is necessary to find out the conditions actually favourable to combustion. In the first place, there seems little doubt that there is far greater liability in hot weather than in cold. With regard to the question of ventilation, many opinions have been expressed ; and some few years ago it was quite a regular practice to resort to such expedients as perforated iron pipes, wickerwork baskets without bottoms, also elaborate ventilating shafts of brick and wood, so as to ensure the passage of a good strong current of air through the heap. Great caution, however, is necessary, for it must be borne in mind that when once a fire has been started it will not continue to burn unless the supply of oxygen is maintained ; and very often

[1] University of Illinois, Bulletins Nos. 17 and 46.

[2] *J. Soc. Chem. Ind.*, Vol. xxxviii, 12, p. 161 T.

the ventilating shafts, by the formation of a draught, supply the necessary oxygen for sustaining and augmenting the fire. Ventilation, therefore, is liable to cause great mischief. Perhaps, taking everything into consideration, it is wiser to adopt surface ventilation only.

Owing to the greater tendency of some coals to fire, it is as well to keep the various classes in distinct heaps as far as possible. Experience has shown that it is inadvisable to stack all the large coal in one heap; for probably, owing to disintegration, a "dust-pocket" will be formed somewhere towards the bottom. The spaces between the lumps afford excellent opportunities for the creation of a draught, and, consequently, a steady supply of air to the pocket. In such a case we get conditions similar to those occurring with insufficient artificial ventilation. The heap should be piled so that lump and fine are distributed as evenly as possible. A point which usually escapes observation is the tendency of the large lumps (when tipped on the apex of a heap) to run to the outside, leaving the centre of the heap composed of slack. This is undesirable, and the coal should be spread out as the heap is built up. English coal spread out in this way was stacked at Berlin to a height of 46 feet for more than twelve months, and no trouble was experienced with it. The depth of the heap is another point which has received a good deal of attention. According to information available, it appears that there is some relation between the liability to spontaneous combustion and the height and volume of the heap in which it occurs. There also appears to be a "critical height" above which it is inadvisable to go, and for ordinary gas coals this ranges between 15 and 20 feet. Excessively high heaps should, of course, be avoided as far as possible, for pulverization is sure to take place towards the bottom.

The British Fire Prevention Committee recently issued a special warning in regard to the storage of coal in bulk with special reference to spontaneous combustion. The following precautions were included:—

(*a*) Stacks should not be higher than 10 feet.

(*b*) Iron perforated pipes 3 or 4 inches in diameter, or, failing these, either suitable earthenware pipes or ducts formed of incombustible material should be inserted vertically in the stacks as they are built up. The lower ends of these pipes, or ducts, should be at different heights from the ground throughout the stacks. There should be one pipe or duct to about every 300 square feet of surface.

(*c*) A thermometer should be lowered occasionally through these pipes or ducts to ascertain the temperature at the centre of the stack.

(*d*) If wet, very small, very soft, or impure coal is received, it should be dumped around the edges of the stack, or in some location where the air can get to it freely and where other coal will not be packed on top of it.

The United States Bureau of Mines states that in making a coal pile of mixed sizes, the coal should be so handled as to make a homogeneous pile and prevent the segregation of coarse and fine coal. This frequently determines the most desirable machinery for unloading coal.

It is common practice to limit the height of a coal pile for two reasons:—A pile too high crushes the lower layers of coal, producing more fines; the larger the

pile the less heat-dissipating surface there is exposed in proportion to the heat generating capacity of the pile. Twelve feet in height is a common limit.

Dealing with a Burning Heap

The undue heating of a coal heap is usually accompanied by "steaming" and an offensive smell, due to the escaping hydrocarbon vapours. When these are noticed, the usual procedure is to turn the hose on to the apparent seat of the trouble and drown out the fire. When a fire does occur, however, it is necessary to avoid the use of water until the area actually affected has been located. The coal round about this area should then be dug out, and the smallest possible quantity of water made use of. By far the best practice is to get the affected coal away to the retort house and carbonize it as soon as possible.

A coal heap should be kept continually under observation. The most usual means of recording the temperature is that of inserting $1\frac{1}{2}$ to 2-inch pipes, one end being knocked down to a point. A thermometer—attached to a cord—can then be lowered into the pipes and the temperature noted. As the drop in temperature while the thermometer is being withdrawn is likely to be somewhat considerable, a more accurate reading will be obtained if a maximum thermometer is used. When greater accuracy still is required, it is necessary to use a low-temperature pyrometer with electrical connections. A great deal of trouble will be saved if the temperature pipes are suspended in position before the heap is made, for the task of forcing them down into an existing heap is certainly tedious. An idea from America is that of a coal auger, the head of which contains a small maximum thermometer. It is claimed that the point of the auger can be driven 20 feet in from three to five minutes, and about ten minutes is required for the thermometer to attain the temperature of the surrounding coal. Temperatures taken in this manner have been found to be several degrees higher than by the pipe method—the difference being ascribed to the circulation of air in the pipe. When the temperature rises above 35° C., the upper layers of coal at least should be removed. Disturbance of the heap by driving in rods, etc., to the seat of the fire should be avoided, for this merely has the effect of inducing air currents, and hence provides an additional supply of oxygen. When a fire actually breaks out, some prefer to use sand instead of water. While water cools the material and reduces the temperature below ignition point, sand smothers the fire and cuts off the supply of oxygen. Sand certainly recommends itself for use in cases in which the action of water is known to have a deleterious effect upon the surrounding coal. If the fire were large, however, it would afford but little check.

In an investigation by the Experimental Station of the Illinois University into the storage and handling of coal many instances were supplied in reply to inquiries, that showed how seldom water alone proves effective in subduing fires in coal-stores, chiefly owing to the difficulty of supplying it in sufficient quantities to cool the entire mass. The following example of the successful use of water is therefore all the more interesting :—

The Fuel Agent of the Canadian Pacific Railway states that he always recommends the use of water if the fire is a small one, and particularly if it is detected in an incipient stage. His practice is to locate the hot spot by driving test rods into the pile and then to dig a pit one or two feet deep right over the centre of the trouble; to drive and pull pointed rods or open pipes from it down into the heating mass and then to fill the pit with water, thus quenching the fire at its very centre. At the same time, if the fire is a large one he surrounds the whole heated part with a water curtain made by digging a ring ditch one or two feet deep and perforating its bottom with a row of holes as in ventilation. This ditch, like the central hole, is kept full of water from the hose, and if there is any tendency for the fire to be driven outward from the centre, it is quenched by the water curtain. This method of putting out a fire is of course costly, but it is enormously quicker and less costly than that of digging out and results in far less loss of material.

Dealing with Wet Coal

That damp coal has an undesirable effect when carbonized in ordinary horizontal retorts is indisputable. In works in which there are chamber-ovens or vertical retorts, the moisture matters but little. Accordingly, the dry coal could be reserved for the horizontal house, while the wet coal could be disposed of in the verticals. For some unexplained reason, certain coals prove themselves particularly liable to spontaneous combustion when under a covering of snow. Occasionally fires have been caused by hot pipes which run through the heap or under the ground upon which the coal is stacked. Thus it appears that a very small source of external heat is sufficient to start the action, especially if the heat is local and applied towards the centre of the mass. Another point is that of the local application of water. While a shower of rain seems to have little effect, a stream of water confined to one small area will probably cause a rise in temperature. This is best illustrated by the case of the covered coal store with a leaky roof, and the fact that fires frequently occur directly under the leak. Leaky water-pipes in the vicinity of the heap very often lead to trouble.

Finally, for the prevention of heating, and for the treatment of fires, the author suggests the following points:—

1. Stock different types of coal in separate heaps.
2. Surface ventilation only.
3. Mix lumps and fine together. Small heaps are less dangerous than large ones.
4. Do not pile to a greater height than 20 feet.
5. Avoid external sources of heat, such as hot pipes.
6. Attend to leaky water-pipes or gutters in the vicinity of the heap.
7. When temperature rises to 35° C., remove top layers and carefully watch.
8. Do not disturb the fire by pushing in bars, etc., from the side of the heap.
9. Apply water to the seat of the trouble only, particularly if fire occurs in confined stores.
10. Remove and carbonize the affected coal as soon as possible.

Deterioration

The deterioration of coal due to storage is another vexed question. Though all are agreed that some loss does take place, the estimates as to the amount vary considerably. The question has probably received far more attention in Germany than in this country. Prenger, engineer of Cologne gasworks, has found that the decrease in gas-making value of English coal is from 3 to 15 per cent., or an average of 7 per cent., when stored in the open, and from 0 to 10 per cent., or an average of 4 per cent., when stored under cover. Some authorities state that practically no deterioration occurs. No doubt a great deal depends on the class of coal in question. The loss in calorific value appears to be quite slight, although the heating value of the coke is reduced in some cases. This usually makes itself felt in the percentage of coke used as fuel. The results of some experiments carried out on the coal-testing plant at the Saltley gasworks of the Birmingham Corporation by W. B. Davidson showed that the gas multiples for coals which had been stocked for periods of six months to two years were in every case lower. No definite loss per annum is fixed by the tests, but it would appear to be no more than 2 per cent. The experiments showed that while the gas value decreased the liquor increased very appreciably; but the coke was markedly inferior. The following figures are those given by a well-known English gas coal which was tested after the intervals stated :—

	Moisture.	Make per ton. Cubic feet.
On arrival	2·71 ..	11,818
After 3 months	5·22 ..	10,708
„ 5 „	5·64 ..	9,780
„ 6 „	7·58 ..	9,630

The ideal state of affairs on a gasworks would, of course, be to take in just as much coal as is required for present requirements, so as to avoid any necessity for keeping a stock in hand. Owing, however, to the fluctuating output of gasworks, and to the fact that collieries turn out an amount which is fairly constant all the year round, these conditions are impossible. Moreover, in some cases a reduction in price may be obtained for coal delivered during the summer months; and many gas companies are eager to seize upon this opportunity. In respect to coal deliveries, the United Kingdom is more fortunate than many other countries. In Germany, for instance, some works are obliged to take the whole of their coal during the summer season, owing to waterways being closed by frost throughout the greater part of the winter. In the same country, too, stored coal is liable to deteriorate to a far greater extent, owing to the wider variations of temperature and fluctuations of weather conditions.

At the present day far more coal is stacked out in the open than in elaborate stores, such as were erected as part of the retort house on nearly all works in years gone by. There are still, however, many believers in the indoor method; and there is no doubt that coals deteriorate to a much less extent when sheltered from the weather. The opinion is expressed by some engineers that coals are just as likely to heat up under cover, and when they do so they are far more difficult to get at.

Under any circumstances, care should be taken to see that the store is not situated too near to the heat of the retort bench. It is with stores of the closed type that particular care is necessary with regard to the use of water. When coal is stacked in a bin and takes fire, the application of water to the red-hot carbon will in all probability be followed by the formation of water gas. This gas, in addition to being a source of danger to the men, owing to its poisonous nature, may mix with a sufficient quantity of air to form an explosive mixture, which might conceivably result in the destruction of the bin. When coal is stored in covered bins some arrangement should be provided by means of which the affected layers, which are frequently at the base of the heap, may be summarily removed. For this reason the more recent practice of constructing a small tunnel from end to end of the store and below floor level is to be strongly advised. The tunnel is made sufficiently large to take a conveyor, and by means of pouches fitted with sliding doors placed at frequent intervals the coal in the affected area can be quickly removed and carbonized. An arrangement of this nature is seen in Fig. 260.

The Storage of Coal under Water

Owing to the tendency of stored coal to fire the practice of submerging the heaps in water has been adopted. In such cases special reservoirs, usually constructed of reinforced concrete, are required. The method has, so far, been confined almost solely to America and the Continent. When submerged, the coal is protected more adequately than if it were housed; and no matter what the weather conditions, the variation in temperature of the mass will be comparatively small. It is now generally recognized that the gases occluded in the pores of the coal—more particularly oxygen—are indirectly the cause of heating and deterioration. The escape of the oxygen should therefore be arrested as far as possible. By immersing coal and keeping it continually sealed this condition is fulfilled, the gases being more or less confined, whilst little or no oxidation takes place. Breaking up of lumps and pulverization are also considerably reduced, because the water forms a cushion between the various pieces, thus lessening the effect of the movement of the lumps one on another. The better physical condition of the coal is, however, probably due, in part, to the absence of heat, which in itself is to a great extent the cause of the opening out and disintegration of the larger pieces. There is no limiting depth for the heaps of coal when immersed, and accordingly a considerable saving of space can be effected; in fact, by adopting the wet method the capacity per unit of ground area could be easily doubled. The most undesirable factor in connection with the system is that of expense. One of the largest reservoirs for storing coal in this way is that on the banks of the Oder, at Stettin, where 20,000 tons may be submerged. Another series of tanks for storing coal, at Omaha, U.S.A., are 22 feet in depth, with the side walls carried on piles. Piles are also driven under the whole of the floor area at a pitch of 5 feet, and are capped with square slabs of concrete on which the floor rests. The side walls of concrete are about 2 feet thick at the top and 4 feet 6 inches at the bottom, whilst the concrete floor is protected from the bite of the coal "grab" by means of embedded rails.

The Duquesne Lighting Company of Pittsburgh have recently constructed a huge concrete basin, capable of containing 100,000 tons of coal below the water-line. It is 791 feet long, 153 feet wide, and 25 feet 6 inches deep, built of concrete slabs 40 feet × 50 feet, arranged to permit expansion and contraction. The expansion joints are made watertight by means of pitch and tar paper, and are supported on 12-inch concrete blocks. The internal walls have a 1 : 1 slope, and the outer embankment a batter of 2 : 1. A stone wall is erected on the top of the embankment, as

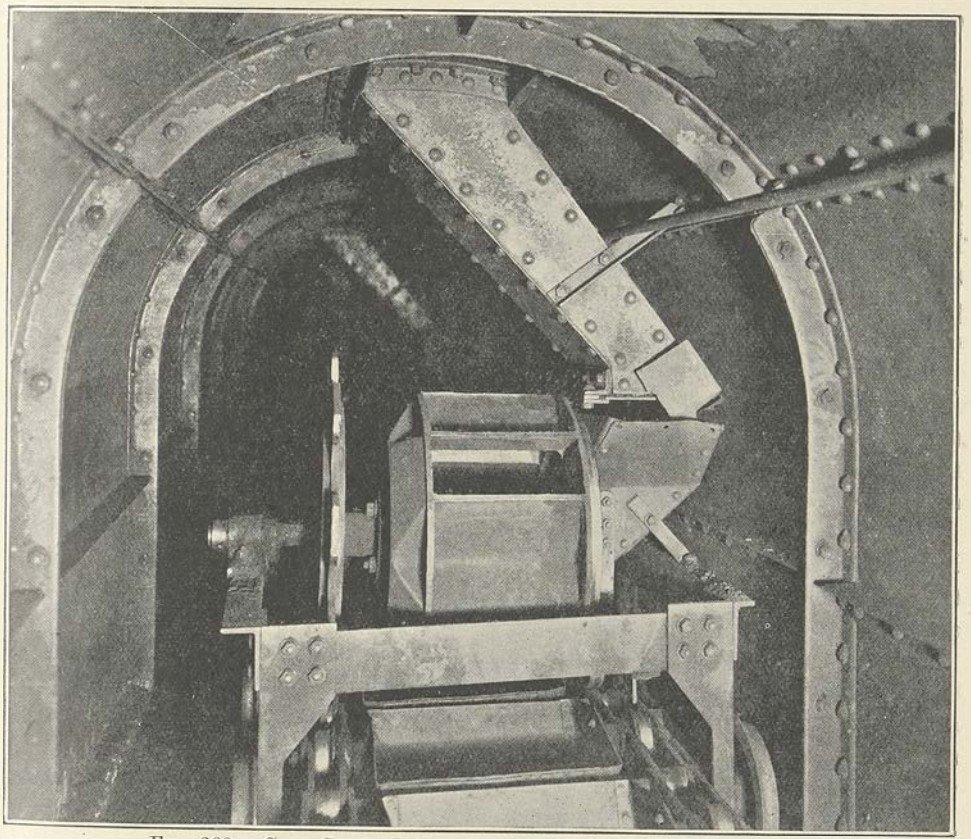


FIG. 260.—COAL STORE TUNNEL SHOWING CONVEYOR AND POUCHES.

a protection against erosion at high water, and cranes are provided for handling the coal. The water discharge system comprises four 18-inch pipes fitted with check valves, which permit the water to rise inside the basin when the river rises during flood season, thus guarding against risk of lifting the bottom when the external water level is considerably higher than the internal. Water is pumped in as required, through a 14-inch pipe leading from the power-house to four 12-inch outlets, 160 feet apart and 6 feet below the top level of the reservoir.

As an instance of the immense stocks of coal held in reserve on gasworks it may be mentioned that the bunkers at the Tegel works at Berlin are over half a mile in length and are capable of containing nearly a million tons of coal.

CHAPTER XII

THE HIGH TEMPERATURE CARBONIZATION OF COAL

THE nature of the primary and secondary reactions associated with the carbonization of coal in closed retorts has occupied the attention of the scientist and investigator for nearly a century ; yet, although, to-day, we are in a position to understand several of the more perceptible developments accompanying this phenomenon, there still remain many anomalies on which light has yet to be shed. The results of carbonization, and the final mode of existence of the innumerable products yielded, are materially influenced by considerations other than that of the temperature at which distillation occurs, so that it is impossible to form an opinion as to ultimate effects until the exact conditions under which the process is carried out are known.

The distillation of coal is usually characterized as " destructive," but the term is in reality a misnomer, owing to the fact that it implies finality ; this only being the case so far as the original structure and substance of the raw material are concerned. The distillation of coal differs from that of a complex liquid in that the treatment of the latter is carried out in a number of stages, depending upon the original nature of the substance and the character of the products required. With the liquid, " fractionation " essentially occurs, whereas coal is dealt with in a single stage, innumerable products being simultaneously evolved and no attempt being made, in the first instance, to separate out the various substances. A further fact of interest is that with coal, once distillation has occurred, there is no possibility of reproducing the original substance by collecting the products and causing them to recombine. In the case of a complex liquid, however, the various fractions may be remixed, when a substance more or less in accordance with the original substance will result.

The four fundamental bases of which the coal conglomerate is considered by some investigators to exist are fully discussed in the previous chapter, and it is there pointed out that when subjected to distillation each of these bases gives rise to its own particular degradation products. Lewes found evidence that the primary decomposition of the coal substance accounts for the various constituents in the following manner :—

	Gaseous Products.	Liquids.	Solids.
Humus bodies, yield . .	Carbon monoxide Carbon dioxide Methane	Water Thin tar	Free carbon
Resin bodies, yield . .	Carbon monoxide Carbon dioxide Ethylene, and unsaturated hydrocarbons	Water Rich tar	Free carbon Pitch
Hydrocarbons, yield . . .	Methane, ethane and other paraffins	Heavier tars	Free carbon Pitch

Carbon Residuum. *Unaffected by distillation.*

In the study of carbonization it is essential, in the first place, to distinguish between the primary and secondary products of distillation, and to bear in mind that, in spite of the ultimate gas containing about 50 per cent. of hydrogen, this element, *per se*, is not necessarily evolved from the coal in the early stages, but results from the degradation of carbon and hydrogen compounds, and to some extent from the production of water gas. The lowest temperature at which carbonization actively occurs varies between 300° and 400° C., when chiefly hydrocarbons of a considerable nature are evolved, the permanent gas yield being comparatively small. At such temperatures primary products alone would be expected, but even at this stage some secondary decomposition will have occurred, so that a series of products of a purely primary nature will never be found. Low temperature distillation in the absence of degradation would account for the following, which (according to Lewes) constitute the true primary gas :—

1. Water vapour.
2. Carbon dioxide and carbon monoxide.
3. Hydrocarbons of the paraffin series.

The bulk would be made up of these, whilst, in addition, there would be smaller quantities of :—

4. Unsaturated hydrocarbons.
5. Ammonia.
6. Sulphuretted hydrogen.

A large proportion of the paraffin hydrocarbons would be of a condensible nature, accounting for tar rich in the methane hydrocarbons. From the above it will be seen that the water vapour and oxides of carbon are the first products to be evolved, and that of the primary constituents methane is by far the most important.

THE DECOMPOSITION POINT OF COAL

In considering the question as to the temperature at which coal, when subjected to heating, commences to decompose, it is necessary to distinguish between the evolution of the occluded gases (which may be evolved at a temperature so low as 100° C.) and the volatile products arising from actual decomposition. An enormous amount of research has been carried out in connection with the initial decomposition of coal, but it is only proposed to consider here the later theories which have been propounded. Burgess and Wheeler[1] heated bituminous coals in a vacuum, and showed the following to be the sequence of events :—Occluded or condensed gases (unextractable at ordinary temperatures) continued to be removed in small quantity up to 150° or 200°. These gases were mainly the paraffin hydrocarbons, the higher members of the series predominating. A decomposition-point was reached at about 200° C., for there was then a copious evolution of water (small quantities of gas being also evolved), and water continued to make its appearance at successive stages in the distillation up to 450° C. (the highest temperature reached in the experiments). The gases evolved during the period of most rapid formation of water contained a high percentage of the oxides of carbon. The decomposition of some sulphur-containing organic compound occurred between 200° C. and 300° C. This decomposition began at about 270° C., and was approximately completed at 300° C. ; simultaneously with the hydrogen sulphide resulting from the decomposition the gases evolved contained a considerable proportion of the higher olefines ; the evolution of these did not, however, cease or diminish until a temperature of 350° C. was reached. Liquids other than water began to distil at about 310°, at which temperature a thin reddish-brown oil appeared. A decomposition point occurred at about 350°, when a rapid evolution of gas and much viscid oil was formed. Decomposition continued with increasing rapidity as the temperature was raised.

Many other investigations may be quoted in support of the fact that the first products of decomposition are invariably water and the two oxides of carbon. As these substances are the first decomposition products of celluloses and ligno-celluloses Stopes and Wheeler[2] point out that the natural conclusion is to consider the cellulosic constituents of the different fuels to be responsible for their first decomposition products. It is also found that as we pass from fuels containing a high proportion of oxygen to those with a high carbon content decomposition becomes more difficult. As regards the decomposition of coal the principal facts brought to light[3] are as follows :—

(1) With all coals, whether bituminous, semi-bituminous, or anthracite, there is a well-defined decomposition-point, at a temperature lying between 700° and 800° C., which corresponds with a marked increase in the quantity of hydrogen evolved. With bituminous coals the increase in the quantity of hydrogen evolved falls off at temperatures above 900°, but with anthracite coals it is maintained up to 1,100° C.

[1] *Trans. Chem. Soc.*, vol. 105 (1914), p. 131.
[2] *The Constitution of Coal*, 1918, p. 9.
[3] Stopes and Wheeler, *loc. cit.*

(2) Evolution of hydrocarbons of the paraffin series ceases approximately at temperatures above 700° C. (3) Ethane, propane, butane, and higher members of the paraffin series form a large percentage of the gases evolved at temperatures below 450° C.

From these facts Burgess and Wheeler drew the conclusion that coal contains a compound which undergoes decomposition at temperature above 700° C., and yields hydrogen as its principal gaseous product; and they held the same compound to be responsible for those hydrocarbons of the paraffin series making their appearance at low temperatures.

Taylor and Porter,[1] as a result of a number of experiments with American coal, have shown that a high-grade bituminous coal of the gas-making type decomposes by heat primarily into paraffin hydrocarbons, and a completely altered non-volatile residue, with small quantities of water, carbon dioxide, and carbon monoxide. The three latter products are the first produced, although in small quantity. From some other types of bituminous coal, they are produced in greater relative quantities than from the gas-coal type. Complex and varied secondary reactions induced by superheating the hydrocarbons, water vapour, and carbon dioxide are of great importance in industrial high-temperature carbonization.

The products of low-temperature carbonization from coal of the Pittsburgh type on an industrial scale at about 427° to 482° C. will consist of a rich gas amounting to 0·6 to 0·7 cubic feet per pound of coal, and a large yield of oil or tar, comprising 10 to 12 per cent. of the coal. This tar consists chiefly of paraffin hydrocarbons, is very low in (or possibly entirely devoid of) benzene and naphthalene derivatives, and practically devoid of free carbon. The gas will contain 6 to 7 per cent. of unsaturated hydrocarbons and 20 to 25 per cent. of ethane and its higher homologues, and consequently will have a high calorific and illuminating value. The tar may be either redistilled or subjected to cracking processes, so as to produce light oils whose yield will be greater than, and probably at least double, that obtained by high-temperature carbonization.

These investigators also suggest the following hypothesis in connection with the constitution of coal. All kinds of coal consist of cellulosic degradation products more or less altered by the processes of aging, together with derivatives of resinous substances in different proportions, also more or less altered. These substances are many in number, and closely graded into one another in their nature and composition. They all undergo decomposition on moderate heating. Some, however, decompose more rapidly than others at the lower temperatures. The less altered cellulosic derivatives decompose more easily than the more altered derivatives, and also more easily than the resinous derivatives. The cellulosic derivatives on moderate heating decompose so as to yield water, carbon dioxide, carbon monoxide, and hydrocarbons, giving less of the first three products the more mature and altered they are. The resinous derivatives, on the other hand, decompose on moderate heating, so as to yield principally the paraffin hydrocarbons, with probably hydrogen also as a direct decomposition product.

[1] U.S. Bureau of Mines, Paper No. 140.

The more mature bituminous coals with good coking properties contain a large percentage of resinous derivatives, and their cellulosic constituents have been highly altered. The younger bituminous and sub-bituminous coals consist chiefly of cellulosic derivatives much less altered than those in the older coals. They undergo a large amount of decomposition below their fusion points, and (partly for this reason) many of them do not coke.

THE ELEMENTS IN COAL AND THEIR RELATION TO CARBONIZATION

Of the elements in coal, carbon is present in the greatest proportion, partly fixed and partly capable of volatilization. In the ordinary way from 15 to 20 per cent. of the total is present in the "free" state, and the actual distribution is somewhat as follows:—

Distribution of Carbon in Coal

(*a*) As hydrocarbons	. . . . .	8	per cent.	of total carbon.
(*b*) As carbon monoxide and dioxide	. . . .	2–3	„	„ „
(*c*) As tar	. . . . .	8	„	„ „
(*d*) Remaining in coke	. . . . .	80–85	„	„ „
(*e*) Other sources, such as "scurf"	. . . .	1	„	„ „

From the gasmaking point of view the carbon and hydrogen are the two most important constituents. The hydrogen passes off partly in combination with oxygen as steam, and partly combined with carbon to form hydrocarbons of both the saturated and unsaturated series. By far the largest quantity, however, is found as free hydrogen in the gas. A certain proportion of the hydrogen remains behind in the coke, but with the modern tendency to conduct carbonization at extremely high temperatures, little can withstand the final stages of the period, and the amount so remaining seldom exceeds 0·5 per cent.

Although the solid residue left behind in the retort contains a greater proportion of carbon and less hydrogen than the original coal, the reverse is the case with the volatile portion which shows a preponderance of hydrogen. The constitution of this volatile portion largely depends upon the temperature prevailing. As a general rule the volume of permanent gas obtained is in direct ratio to the temperature employed, whilst the quality varies inversely with the temperature. Of the carbon and hydrogen compounds, those evolved at the lower temperatures of carbonization are mostly condensible at ordinary temperatures, and the permanent gas obtained consists mainly of methane, ethane and ethylene; that is to say, hydrocarbons of the paraffin and olefiant series. In addition, a small proportion of hydrogen due to secondary reaction will be present. The liquid products will be largely of a paraffinoid nature. It is during the early stages of carbonization that the richer constituents are evolved, and as the temperature throughout the entire mass gradually rises to the present limit of about 1,100° C. the volatile products are composed mainly of methane and hydrogen, the proportion of the former diminishing and of the latter increasing as the period proceeds, until finally little more than the residual hydrogen and nitrogen of the coke remain to be expelled. Owing to

the thickness of the modern heavy charge the heat penetrates to the interior of the mass comparatively slowly; accordingly hydrocarbons and gases of a primary nature are continuously being evolved until the central cool core is carbonized through. Portions of these primary gases, however, only exist momentarily. They undergo degradation into simpler compounds on coming into contact with the heated coke, and are further decomposed whilst travelling along the free space to the outlet of the retort. For this reason it is advantageous to distinguish between not only primary and secondary products, but also between primary, secondary and tertiary effects. That is to say, to consider the ultimate substances obtained to consist of:—

(*a*) True primary products escaping further degradation.

(*b*) Secondary products resulting from decomposition due to passage through the hot coke mass.

(*c*) Tertiary products resulting from the further degradation of secondary products owing to the exposure of the latter to radiant heat and to hot surfaces during their passage from the retort.

It is the hydrocarbons of both the saturated and unsaturated series which are chiefly affected by these further influences, but oxygen-bearing substances and nitrogen compounds also undergo some change.

In addition to being present in the coal substance, oxygen is derived in some quantities from the moisture in coal, the latter varying from 4 to 10 per cent. This moisture is in the main detrimental to the process of carbonization, in that it tends to reduce the temperature of the retort owing to the large quantity of latent heat absorbed in converting the water into steam. In the earlier stages the oxygen of the coal, as distinct from that emanating from the moisture, is evolved largely as oxides of carbon, whilst on combination with the hydrogen some portion will give rise to water. Colman is of the opinion that the oxygen is originally evolved as volatile compounds of carbon, hydrogen and oxygen, and that these on further heating are decomposed into carbon monoxide, carbon dioxide and steam. Whatever the manner of formation of the oxides of carbon, however, it is quite evident that the carbon dioxide, during its passage through the outer coke layers, tends to combine with the red-hot carbon, undergoing reduction to carbon monoxide. In this way secondary reaction is responsible for an increase in the combustible gases at the expense of an inert and useless diluent. The greater the temperature of distillation the more pronounced will this interchange be.

Of the oxygen present in coal the greater portion combines with hydrogen to yield steam, about 25 per cent. exists as oxides of carbon, and a small proportion is found as compounds of hydrogen and carbon, such as the phenols, etc., in the tar. So far as the steam derived both from the original moisture in the coal and from the direct combination of hydrogen and oxygen is concerned, a large proportion of this will eventually condense out as water, whilst some portion will account for the formation of water gas during its passage through the heated coke. It will be seen, accordingly, that the importance attached in the past to the "unoxidized hydrogen" content of a coal was much over-estimated, for an appreciable portion

of the oxygen of the coal substance is disposed of in other ways than by direct combination with hydrogen.

The Nitrogen of Coal

The element nitrogen, although of more or less subsidiary importance, enters materially into the reckoning when the economics of carbonization come to be considered. The aim of the gas engineer must be to recover in the most valuable form the largest possible proportion of the total nitrogen present, which on further treatment forms the basis of one of his most valuable by-products, sulphate of ammonia. The amount of nitrogen in bituminous coals is, on the whole, the least variable of any of the constituents, the figure fluctuating but little on either side of 1·4 per cent. This percentage corresponds with a yield of about 34 lb. of nitrogen per ton of coal employed, whilst the average yield of sulphate of ammonia, amounting to 27 lb. per ton, represents a quantity of ammonia equal to 7 lb., or about one-sixth of the total nitrogen. In addition, a small portion may be usefully recovered in the form of cyanide compounds; but comparatively few gasworks are provided with the necessary plant for this purpose. For some years attention has been directed towards the possibility of recovering a greater proportion of the original nitrogen, but although plants for the production of low-grade gas are operating successfully in this direction, the conditions under which the increased yield is obtained are scarcely consistent with ordinary gasworks methods. As an instance, mention may be made of the Mond gas apparatus, by means of which an average yield of 96 lb. of sulphate of ammonia is obtained, this quantity representing nearly 25 lb. of recovered ammonia, or about 65 per cent. of the total nitrogen.

One of the earliest attempts to determine the relative quantities in which nitrogen is distributed among the various products was made by Foster, in 1883. This investigator employed a Durham coal containing 1·73 per cent. of nitrogen, and the conclusions arrived at are as follows:—

Nitrogen	remaining in coke	48·68	per cent. of total.
„	free in gas and combined in tar	35·26	„ „
„	as ammonia	14·50	„ „
„	as cyanogen	1·56	„ „

Investigation of this kind is attended by considerable difficulties, and several other workers have derived figures on the same lines, but in no case are they in close agreement. The researches of McLeod, conducted in 1907, are, however, considered most trustworthy, having been carried out under everyday conditions. McLeod's figures are as follows:—

Nitrogen	in coke	58·3	per cent.
„	free in gas	19·5	„
„	as ammonia	17·1	„
„	as tar	3·9	„
„	as cyanogen	1·2	„

The figures which Short obtained for conditions existing in coke ovens are

instructive, in that, with the present tendency towards mass carbonization in gas-works, they probably approach more nearly the actual state of affairs. Short's researches show the following distribution :—

Nitrogen in coke	43·3 per cent.
„ „ tar	3·0 „
„ „ ammonia	15·2 „
„ „ cyanogen	1·4 „
Free nitrogen in gas	37·1 „

F. Sommer [1] states that the maximum yield of ammonia is obtained between 800° and 900° C., and shows the distribution of nitrogen at this temperature to be as follows :—

	Westphalian coal.	Silesian coal.
Best distillation temperature, ° C.	800 to 850	900
Nitrogen in dry ash from coal	1·896 per cent.	1·5485 per cent.
„ „ ammonia	17·85 „	19·19 „
„ „ hydrocyanic acid	0·47 „	1·05 „
„ „ tar	1·63 „	2·66 „
„ „ coke	72·23 „	60·32 „
„ „ gas (by difference)	6·82 „	16·78 „

In recent tests with a moderate quality coal in continuous vertical retorts the Gas Investigation Committee [2] has given the following figures for the distribution of nitrogen :—

	Coal charge unsteamed.	Steaming at 32·7 per cent.
Nitrogen in coke	60·1 per cent.	49·7 per cent.
„ „ tar	6·8 „	8·9 „
„ „ liquor (as NH_3)	17·9 „	19·5 „
„ „ „ (as cyanide)	1·5 „	1·1 „
„ „ gas and lost	13·2 „	20·0 „
„ „ „ as cyanogen	0·5 „	0·8 „

In all cases the results conclusively show that by far the greater proportion of nitrogen remains behind in the coke ; but with the prolonged periods and high temperatures of modern distillation methods the proportion remaining in the solid residue is undoubtedly far less than was the case some few years ago. The effect of a long-sustained heat such as exists with the present-day 12-hour charge was shown by Watson Smith to be conducive to the most complete expulsion of the nitrogen from

[1] Stahl und Eisen, 1919, pp. 261, 294, 349. [2] *Proc. Inst. Gas Eng.*, June, 1920.

the coke, and he found in the case of coke-oven coke (which is essentially subjected to this type of heating) that the nitrogen percentage was only 0·384.

It would appear that in all cases the figures given for the nitrogen distributed as cyanogen are considerably below those prevailing in modern practice. At the present time there are many cyanogen plants at work recovering on an average from 4 to 5 lb. of ammonium sulphocyanide per ton of coal, these quantities of sulphocyanide representing from 0·75 to 1 lb. of nitrogen, or nearly 3 per cent. of the total nitrogen. As nitrogen, however, is drawn in from the atmosphere and furnace it is possible that a portion of the nitrogen combined in the cyanogen is obtained from such external sources. The nitrogen combined in tar is chiefly present in the form of nitrogenous bases such as pyridine.

It will be realized that if it were possible to recover the whole of the original nitrogen in coal as sulphate of ammonia the yield of sulphate would approximate to 180 lb. per ton of coal carbonized.

A good deal of uncertainty exists as to the type of coal which is likely to prove the most efficient producer of ammonia. Schilling, for instance, says that the amount of ammonia yielded rises and falls according to the quantity of nitrogen in the coal. Knublauch is of the opinion that the coals which give very high yields of gas and tar have a tendency not to form ammonia, the hydrogen uniting with the carbon, whilst the coals which account for high ammonia yields show an inclination to leave the nitrogen in the coke and not to form free nitrogen in the gas. More important considerations, however, do not permit of a coal being purchased on its nitrogen-yielding proclivities alone.

With regard to the formation of ammonia, there is now little doubt that it is the direct result of two distinct reactions, and that whereas the chief of these takes place at lower temperatures, the second is probably most in evidence at higher heats. Accordingly, ammonia resulting from distillation may be formed :—

(*a*) By direct evolution from an ammonia-yielding body contained in the coal.

(*b*) Synthetically, by the combination of hydrogen and nitrogen.

Little is known as to the actual mode of existence of the nitrogen compounds in coal, but there is evidence to show that the element is combined in two or more ways. Lewes is of the opinion that the humus bodies are most likely to be those carrying the nitrogen. So far as the coke is concerned, Harger says the only conclusion he could arrive at, after careful consideration of all the facts, was that some of the nitrogen in the coke is present as one or more stable organic nitrogen ring compounds.

Under the influence of distillation ammonia is one of the first compounds to be expelled, the evolution commencing at temperatures between 300° and 400° C., and continuing up to about 540° C., when the whole of the primary portion appears to be evolved. Little or none is given off as the temperature rises from 540° C. to 870° C., but beyond the higher temperature further appreciable quantities are discernible. Accordingly, the maximum yield of ammonia is obtained only when the distillation temperature has reached 870° C. or slightly over. The possibility of an easily decomposible compound being able to exist at this temperature is

explained by the fact that if an unstable gas be diluted with some considerable quantity of inert gas the temperature necessary to bring about decomposition increases rapidly in proportion with the amount of dilution. Thus the ammonia is quickly exhausted away from the retort before feeling the effects of degradation. It is in this manner that the high yield of ammonia in the Mond plant may be explained, for an excess of steam and air is admitted to the base of the fuel-bed and forms an enveloping gaseous mass (containing a high percentage of inert constituents) which shields the ammonia on its passage through the producer.

The production of the secondary ammonia, as distinct from that evolved as a primary compound, has been explained by Tervet, who states that a portion of the nitrogen remaining in the coke can be liberated in the form of ammonia, so long as the ammonia is brought into a state of strain which shall prevent it from subsequent degradation. This state is effected by subjecting the ammonia to the superior affinity which exists between the combined nitrogen in the coke and free hydrogen at a particular temperature and in a diluting atmosphere. Thus synthesis between the free hydrogen in the retort and the nitrogen evolved from the coke at higher temperatures is taking place.

Important work on the question of the effect of temperature and other conditions on the yield of ammonia has recently been carried out by Cobb and Hollings, who are still engaged in the research. In their experiments these investigators have studied the decomposition of the ammonia from coal when the products are subjected to differing conditions. In each case a small quantity of coal was distilled in a boat contained in a specially sealed and heated tube, and the ammonia present in the products was estimated. The gases evolved from the coal were first drawn away from a tube which was so designed and arranged that secondary reaction had no time to exert its influence ; in the second series of experiments they were drawn through a heated tube and subjected to radiant heat ; whilst, thirdly, the tube was packed with coke, and the gases drawn through this. The results of their experiments may be briefly tabulated as follows :—

(*a*) Minimum heat action .	.	.	22·5 per cent. of nitrogen in coal recovered as ammonia.			
(*b*) Gases subjected to radiant heat	.	17·2	,,	,,	,,	,, ,,
(*c*) Gases passed through hot coke	.	9·4	,,	,,	,,	,, ,,

From these figures conclusions can be drawn as to the effect of high temperatures and travel over heated surfaces on the yield of ammonia. The temperature of 800° C. (1,470° F.) was used throughout.

The effect of the heavy charge of long duration in ensuring the gases being swept from the retort before decomposition has occurred to any extent is shown by the following figures given by Ferguson Bell[1] :—

6-hour charges of	6	cwts. of coal,	yield of ammonia	7·26 lb. per ton.				
8-hour	,,	7¾	,,	,,	,,	,,	8·26	,, ,,
10-hour	,,	9½	,,	,,	,,	,,	8·45	,, ,,
12-hour	,,	11½	,,	,,	,,	,,	8·50	,, ,,

[1] *Proc. Inst. Gas Eng.*, 1909.

Sommer [1] states that in practice the yields of ammonia from a given coal vary according to the rate of increase in temperature, the maximum temperature reached by the products of distillation, and the time the products are in contact with the hot walls. The following table illustrates how the above-named factors vary according to the type of carbonizing apparatus employed:—

INFLUENCE OF TIME AND TEMPERATURE ON AMMONIA YIELD

Type of Carbonizing Chamber.	Weight of Charge.	Carbonizing Period.	Temperature.	Glowing Wall Area. Per ton coal.	Time of Action.
	Tons.	Hours.	° C.	Sq. ft.	Sec.
Horizontal retort	0·118	5	1165	290	112·3
Vertical retort	0·50	7	1150	176	2·4
Horizontal chamber . . .	10·3	24	1100	68·3	3·4
Sloping chamber	6·6	24	1050	83	2·3
Coke oven	6·4 coal 0·88 water	30	1000	84	8·4

Sommer says that no definite conditions can be given as most favourable for all classes of coal, as these depend upon the properties of the individual coals. Thus for a Silesian or English coal rather higher temperatures give the best yields of ammonia, so that vertical retorts or coke ovens will give good results. In these ovens the time and temperature factors balance one another. A Westphalian coal requires a lower temperature or much faster cooling, and will, therefore, give better results in a horizontal or sloping chamber, more especially if wet coal be used. Gas retorts are poor in every respect for all classes of coal from the point of view of ammonia recovery—*e.g.*, high temperatures and slow cooling.

The small portion of the original nitrogen of the coal which is found as cyanides is almost wholly in the form of hydrocyanic acid, although small quantities of free cyanogen are also present. Hydrocyanic acid is essentially a high temperature product, and probably makes no appearance in the retort below temperatures of 870° to 925° C. When higher temperatures were first introduced in conjunction with the light 6-cwt. coal charge a distinct increase in the yield of cyanogen was noticeable, whilst the yield of ammonia showed some falling off. There seems little doubt that the greater portion of the cyanogen is produced at the later stages of the charge, when the temperature is at a maximum, and the traces of synthetically produced ammonia which may be coming away have few diluent gases to shield them from decomposition. It is at these higher temperatures that a portion of the ammonia is split up into its elements hydrogen and nitrogen which react with carbon and yield hydrocyanic acid. It does not necessarily follow, however, that a high yield of cyanogen means a decreased production of ammonia, and in many cases a high yield of both products is obtained.

Some investigators, such as Kulmann, have shown that if carbon monoxide and

[1] Stahl und Eisen, 1919, pp. 294, 349.

ammonia are passed over spongy platinum a small quantity of hydrocyanic acid is formed, and this has led to the supposition (probably erroneous) that cyanogen may be formed in some degree by the double decomposition of carbon monoxide and ammonia. Others support the theory that ammonia and carbon disulphide react to form the product. It must be remembered that, like ammonia, hydrocyanic acid itself is liable to decomposition at the higher temperatures, and that the quantities in which it is ultimately found probably depend to some extent upon the amount of diluent gases which are present to conduct it from the retort.

As regards the decomposition of ammonia, Bueb carried out a series of experiments which showed that at temperatures of about 750° C. approximately 4 per cent. of the nitrogen of the ammonia was converted into cyanogen, whereas at 980° C. nearly one-quarter of the amount had undergone this change. A somewhat remarkable result was obtained by Cobb and Hollings in connection with hydrocyanic acid. In the experiments previously quoted, after decomposition of ammonia had taken place the products were tested for cyanogen, but in no case could the presence of this compound be detected. This is probably explained, however, by the fact that the conditions favourable to the production of cyanide were absent.

Several attempts have been made to increase the recoverable proportion of the total nitrogen in coal, but their measure of success has been such that the suggested methods have only been adopted on gasworks in isolated instances. Among them may be mentioned the liming of coal, originated by Cooper, and operated at the Cheltenham gasworks. In this process lime is charged with the coal into the retorts. In order that thorough admixture may take place the coal is slightly damped on the surface by a steam jet, thus causing the lime to cling to the lumps. The quantity of lime intermixed with the coal is usually about 2 per cent. As a result of its employment the sulphate of ammonia recovered per ton of coal carbonized showed an average increase of nearly 2 lb. The improvement in the yield of ammonia in this case may be due to the fact that admixture of a caustic alkali has some tendency to convert the residual nitrogen of the coke into ammonia.

Some thirty years ago a method[1] was introduced for extracting nitrogen in the form of ammonia from the coke of shale retorts, by passing steam through the fuel-bed whilst in a highly heated condition. In this way the recovered ammonia increased by about 200 per cent. Several suggestions were made for the application of the same principle to the recovery in the form of ammonia of the nitrogen left behind in the coke produced on gasworks. One promising suggestion provided for dropping the red-hot coke as it came from the retorts into special chambers maintained at a high temperature into which—for a short period—steam could be blown. A certain quantity of blue water gas was thus obtained, and at the same time a large additional yield of ammonia. Another means was based on the fact that when hydrogen, or a gas rich in hydrogen, is passed through highly heated coke the hydrogen combines with the latent nitrogen to form ammonia. Such conditions are obtained

[1] Compare West and Wild's system, p. 109.

by blowing water gas into the retort towards the end of the charge. This scheme has been tried on several works but has now been discontinued, preference now being shown for admitting the water gas to the hydraulic or foul mains.

J. G. Aarts [1] proposes that the hot mass of coke, after its discharge from the carbonizing chamber, should be exposed over its whole length and at both sides to jets of superheated steam directed towards the middle of the mass under constant conditions of quantity, velocity, and temperature. In this way advantage is taken of the usual fissures in the longitudinal direction of the mass to allow of the rapid escape of the gases containing ammonia, so that dissociation of the latter is avoided as far as possible. Aarts' invention provides for the glowing mass of coke, as it leaves the carbonizing chamber, to be moved past tubes arranged transversely to the direction of movement, and provided with steam nozzles. The velocity and quantity of the steam should, the patentee says, be regulated in accordance with the velocity, mass, and temperature of the coke, so that "a sufficient quantity of nascent hydrogen is formed to give the maximum yield of ammonia, and that the temperature of the coke is reduced sufficiently to prevent as far as possible decomposition of the ammonia formed."

So far as gasworks are concerned the many suggestions for recovering a greater proportion of the nitrogen of coal have as yet led to no very satisfactory result; but the problem is of deep concern to the gas engineer, and should not be allowed to rest. It has been solved in part by the introduction of the vertical retort and the process of steaming the coal charge (*see* page 424).

Details of the working of vertical retorts collected over a considerable period show that, with steaming carried out continuously, the normal yield of 35 gallons of 8 oz. ammoniacal liquor per ton of coal may be enhanced to something between 50 and 60 gallons. The reason why this appreciable increase occurs has not as yet been definitely explained, but as ammonia begins to decompose at a temperature of 500° C., and is almost completely broken down if it comes into contact with hot surfaces at 800°, it would seem that the steam, involving as it does an absorption of heat, exercises a cooling action in the retort, and also acts as a shield to the ammonia vapours. In this respect it may be noted that the continuous vertical retort, unlike the horizontal pattern, is not subject to a stage in the distillation period when the temperature of the charge approaches that of the retort, and thus the chief disintegrating influence is eliminated. Again, the work of Tervet and Beilby throws a good deal of light on the question. Tervet, in fact, succeeded in obtaining a yield of ammonia equivalent to 57 lb. of sulphate of ammonia per ton of coal, and he showed that, if a stream of hydrogen is passed through the incandescent coke remaining after carbonization, ammonia is formed by combination of the hydrogen with the residual nitrogen of the coke. This work was corroborated by Beilby, who employed a mixture of air and steam in lieu of hydrogen, so that the vertical retort process of to-day may be looked upon as a partial application to the gas retort of the principles made use of in the manufacture of Mond gas. A later development which should also

[1] Eng. Pat. 11,202, 1916.

assist very considerably in augmenting the yield of ammonia is the process of Perkin and West, whereby a stream of moderately low quality gas is passed in at the base of the vertical retort at such a rate as to carry the volatile matter away before degradation has time to occur. Although the method has primarily for its object the preservation of the hydrocarbons there can be little question that it must also reflect on the ammonia, for conditions of a thoroughly shielding nature are introduced, while synthesis is encouraged.

Some extremely interesting results have recently been published by Salmang,[1] who endeavoured to increase nitrogen recovery during the gasification of coke by adding chalk or oxide of iron to the bed of fuel in the generator. Varying mixtures of steam and air were passed through the fuel-bed, and under the most favourable conditions 59 per cent. of the free nitrogen was recovered as ammonia, a figure which agrees very closely with the yield obtained with the Mond gas plant. When, however, 5 per cent. of chalk was intermixed with the coke the proportion of nitrogen recovered increased to so high a figure as 96·3 per cent., and with 5 per cent. of oxide of iron added the figure was 70 per cent. Salmang says that under given conditions of ammonia concentration and duration of heating the rate of decomposition of ammonia in the presence of steam is only about an eighth to a twentieth of what it is in a nitrogen atmosphere and without steam. In fact, the yield of ammonia is increased by the presence of steam in conjunction with a considerable excess of air. The effect of lime, too, was to increase the nitrogen obtained as ammonia up to 12 per cent. in the case of coke derived from coal, and up to as much as 100 per cent. when coke derived from peat was experimented with.

Unfortunately, so long as towns' gas of the present description is made, it is not possible to arrange for the atmosphere which is most amenable to maximum ammonia output—namely, a mixture of steam and air, and with the air excluded the maximum recovery obtained by Salmang was 20 per cent. less than with a steam-air mixture.

Sommer [2] corroborates the fact that the presence of steam has a tendency to conserve ammonia, and he accounts for this by suggesting that the ammonia under such conditions is present as the hydroxide (NH_4OH), which is comparatively stable. Moreover, he is of the opinion that the inclined chamber oven is productive of better results than can be obtained with the vertical retort, for the necessary conditions—*i.e.*, shortened time of contact with the hot charge through rapid removal of the gas—are more readily obtained therein. A similar advantage is obtained by increasing the size of coke ovens and by lowering the level of the upper collecting flue so as to avoid undue heating of the gas as it passes out. Benzol, in addition to the ammonia, is thereby conserved, particularly towards the closing period of carbonization when all the moisture has been driven from the coal. Speaking of moisture in the original coal, it may be mentioned that although dry coal is looked upon as essential in the ordinary gasworks process there can be no doubt that, whatever the effect of moisture in other directions, it is certainly helpful in the way of ammonia recovery,

[1] *Z. Angew. Chem.*, 1919, 32, p. 148.
[2] Stahl und Eisen, 1919, 39, pp. 261, 294, 349.

as is shown by the large increase in this by-product which is obtained when improperly dried washed coal is used.

When coal is carbonized a small proportion of free oxygen is always evolved from the coal substance as distinct from that which may be drawn into the retort through ill-fitting doors. This oxygen has a decidedly lowering influence on both ammonia and benzene, which have comparatively low ignition temperatures. Sommer [1] points out that the oxidation of ammonia by air begins at 150° C., and increases in effect with rise in temperature. At 250° 5·86 per cent. of the ammonia is oxidized, although moisture acts as a decided preserving agent. At 450° 12·89 per cent. of ammonia was shown to be lost under dry conditions and 2 per cent. in the presence of moisture. It is interesting to note, however, that sulphuretted hydrogen, which is a primary product of carbonization and which is, therefore, invariably present in the gas mixture simultaneously with ammonia, is oxidized very much more readily. It has accordingly a distinct protective action, particularly as—unlike ammonia—its tendency to oxidize is accentuated by the presence of moisture. Sommer found, in fact, that at 100° C. 25 per cent. of sulphuretted hydrogen was oxidized, and at 425° 95·3 per cent. disappeared; whereas at the same temperatures under dry conditions only 0·26 and 1·48 per cent. was affected. Thus the sulphuretted hydrogen by its more ready action with oxygen tends to conserve the ammonia and prevent its destruction.

Thomas Gray has stated that the ammonia formed during the earlier stages of carbonization is evidently a primary product; but as the heat penetrates the charge water still present in the interior is vaporized, and, along with the water vapour which results from the decomposition of the coal, passes through the highly heated and almost completely carbonized outer skin. It is then partly decomposed by the incandescent carbon, with the formation of carbon monoxide and carbon dioxide, while the hydrogen liberated unites with the nitrogen of the coke to form ammonia synthetically. This is brought about by subjecting the ammonia to the superior affinity which exists between the combined nitrogen in the coke and free hydrogen at a particular temperature and in a diluting atmosphere. Thus, during the later stages of carbonization, when hydrogen is being freely evolved, the Tervet reaction comes into play, and continues throughout the remainder of the period, though the ammonia which is formed towards the end of the process is, no doubt, decomposed to some extent.

J. W. Porteous [2] has given the opinion that ash in coal is injurious to the yield of ammonia for the reason that when it contains a certain amount of iron in an oxidized state, or even as pyrites, the iron influences the ammonia already formed, and by catalytic action at certain temperatures (600° C. and upwards) accounts for the destruction of ammonia.

THE SULPHUR OF COAL

A portion of the sulphur present in the coal substance is of a more or less "fixed" nature and remains behind in the coke. This portion is usually present in the original

[1] *Loc. cit.* [2] Coke Oven Managers' Assocn., November, 1919.

coal as calcium sulphate, whilst the volatile sulphur is chiefly derived from pyrites and certain organic sulphur compounds. Coals as commonly used for gasmaking contain a percentage of sulphur varying from 0·6 to 1·2, and that remaining behind in the coke, under modern conditions of carbonization, seldom exceeds 0·8 to 1 per cent.

Powell and Parr [1] suggest that sulphur occurs in coal in four characteristic forms, two of which are organic and two inorganic. The classification is made as follows :—

(*a*) If the resinic organic type is shown to be organic sulphur by its lack of an ash, its presence in the portion of the organic material soluble in phenol indicates its association with that substance.

(*b*) The humus organic sulphur is shown to be organic by the very small amount of ash in the compounds in which it occurs. These compounds are shown to be closely related to humus substances by their chemical action.

(*c*) The pyritic or marcasitic sulphur is present as FeS_2 as indicated by the iron-sulphur ratio when the pyrites is oxidized and taken into solution.

(*d*) The sulphate sulphur is shown to be such by the fact that it dissolves in dilute hydrochloric acid as sulphate without preliminary oxidation.

All four forms were definitely proved to be present, and free sulphur was not found in any of the coal samples tested. The experimental data suggest that when coal is coked the sulphate sulphur is retained by the coke, but in some form other than inorganic sulphate, that the pyritic sulphur is partially volatilized and a portion is also left in the coke, probably as sulphide. All the pyrites are decomposed. The resinic sulphur is left in the coke, but in a form different from that existing in the coal, and the humus sulphur volatilizes partly, but some remains in the coke in a changed form.

The forms of sulphur in the coke were also studied, but could not be identified. A small part of the sulphur exists as sulphide, and the remainder is probably in combination with carbon. This last form is extremely stable to strong acids, oxidizing agents, and heat, but readily gives up its sulphur as hydrogen sulphide when subjected to the action of nascent hydrogen. During the coking process, secondary reactions between constituents of the coal and the decomposed sulphur compounds affect the quantity of sulphur retained by the coke.

As previously pointed out, sulphuretted hydrogen is a primary product of distillation, and is one of the first products to be evolved. Colman says that the sulphur probably comes off in the first place as volatile compounds of carbon and hydrogen, and that these, when more strongly heated, yield sulphuretted hydrogen. A small quantity of sulphur, hydrogen and carbon compounds are, however, ultimately obtained, as an instance of which may be mentioned thiophen (C_4H_4S). This is frequently found in the tar, although traces of it are usually present in the small percentage of sulphur compounds in the finished gas.

The sulphur compounds, as distinct from sulphuretted hydrogen, are chiefly

[1] Univ. Illinois Experimental Station, 1919.

formed at the higher temperatures, due to the combination of part of the sulphur with carbon. The higher the temperature of distillation the greater will be the quantity of sulphur driven off from the coke, and extended travel of the gas through heated coke or in contact with hot surfaces accounts for the decomposition of sulphuretted hydrogen and the subsequent formation of carbon disulphide. Accordingly, when secondary reaction at high temperatures is permitted to take place, the easily removable sulphuretted hydrogen gives place, in part, to undesirable compounds, such as carbon disulphide, which are only eliminated from the gas with great trouble. Sulphuretted hydrogen is usually present in the crude gas in the proportion of about 1·5 per cent., whilst the other sulphur compounds together total no more than 0·05 per cent.

The influence of yield of gas per ton (therefore, temperature) on the production of sulphur compounds other than sulphuretted hydrogen has been shown by figures given by Lewis T. Wright :—

Gas made per ton. Cubic feet.		Sulphur other than H_2S. Grains per 100 cubic feet.
6,896	..	13·91
8,370	..	19·16
9,431	..	26·75
10,772	..	36·93
11,620	..	44·17

Again, the influence of the duration of the carbonizing period is illustrated by the following results given by Ferguson Bell [1] :—

Duration of charges.	CO_2 per cent. by volume.	H_2S per 100 cubic feet.	CS_2 per 100 cubic feet.
Hours.		*Grains.*	*Grains.*
6	3·20	736	43·40
8	3·19	996	60·20
10	3·10	814	56·10
12	3·25	620	47·40

Some investigators have given the opinion that the distribution of the sulphur of the coal amongst the products of carbonization depends largely on the character of the constituents forming the ash. J. R. Campbell,[2] for instance, found that when the coke ash is rich in oxides of iron, calcium, and magnesium, a coke free from sulphur cannot be obtained. In this respect the figures below, given by Percy, are of interest :—

[1] *Trans. Inst. Gas Engineers*, 1909.

[2] *Chemiker Zeitung*, Feb. 10, 1917.

Coal.	Ash in coal, per cent.	Sulphur in coal, per cent.	Sulphur found after carbonization.	
			In coke, per cent.	In volatile products, per cent.
No. 1 . . .	7·36	0·789	0·696	0·093
No. 2 . . .	5·76	0·973	0·844	0·129
No. 3 . . .	16·53	3·264	2·424	0·840
No. 4 . . .	48·31	1·746	1·352	0·394

The manner in which the sulphur of coal is distributed after carbonization has been given by Short,[1] who experimented with a Durham coking coal containing 0·824 per cent. of sulphur when dry.

DISTRIBUTION OF SULPHUR

	Per cent. of total sulphur in coal.
Free sulphur. In coke	72·53
„ „ In tar	1·45
Sulphur as H_2S. In gas, „ „ „ In liquor	24·0
Sulphur in other forms. In gas, In liquor	1·72
Difference (unaccounted for)	0·30

The Gas Investigation Committee [2] have calculated the distribution of sulphur from the results of a series of tests carried out with continuous vertical retorts at Uddingston gasworks. The effect produced by steaming the coal charge is shown in the following table:—

EFFECT OF STEAMING ON DISTRIBUTION OF SULPHUR

	Coal charge. Unsteamed.	Steaming at 32·7 per cent.
Sulphur in coke	59·7 per cent.	43·9 per cent.
„ „ tar	3·8 „ „	8·6 „ „
„ „ liquor	7·7 „ „	6·9 „ „
„ „ gas	21·3 „ „	39·3 „ „
„ lost	7·5 „ „	1·3 „ „

DISTRIBUTION OF ELEMENTS IN COAL AND GAS

Below is set out a table showing the *approximate* distribution of the elements in a ton of coal and the manner in which each element exists after the process of carbonization. The table is, of course, merely illustrative, and does not do more

[1] *J. Soc. Chem. Ind.*, 1907, vol. 26, p. 581. [2] *Proc. Inst. Gas Eng.*, June, 1920.

than give a general indication of the lines on which the rearrangement of the elements takes place. It is assumed that no less has taken place and that no other products (*e.g.*, furnace gases and air) have been introduced.

1 Ton of coal.			
Consisting of :—			
1,792 lb. *carbon*.			
	Distributed as coke	1,385	lb.
	„ as breeze	107	„
	„ in gas, as CO and CO_2	30	„
	„ in gas, as hydrocarbons	130	„
	„ in tar	122	„
	„ as scurf, cyanide, etc.	18	„
123 lb. *hydrogen*.			
	Distributed in gas and tar	98·5	„
	„ as ammonia	1·0	„
	„ as water	18·5	„
	„ in coke	5	„
197 lb. *oxygen*.			
	Distributed as CO, CO_2 and combined in tar	49	„
	„ as water	148	„
34 lb. *nitrogen*.			
	Distributed in gas (free)	11·8	„
	„ in coke	14·1	„
	„ in tar (combined)	1·0	„
	„ as ammonia	5·8	„
	„ as cyanogen (total HCN 4 lb.)	1·3	„
18 lb. *sulphur*.			
	Distributed as gaseous impurities and in liquor	6	„
	„ in coke	12	„
76 lb. *ash* remaining in coke and breeze		76	„
2,240 lb.		2,240	lb.

The yield given for water amounts to 166½ lb. (148 lb. from oxygen and 18·5 from hydrogen), this being equivalent to about 16 gallons of virgin liquor. No allowance, however, has been made for the water which as steam is converted into water gas. In the ordinary way, from 10 to 12 gallons of condensed water, or virgin liquor, are obtained, the remainder of the steam being decomposed in contact with the hot coke.

A comparison between the chemical composition of the solid substance before and after distillation, *i.e.*, the contrast between coal and coke, is shown as follows :—

Before Distillation. Coal.		After Distillation. Coke.		
80 per cent.	carbon	88·0 per cent.		
5·5 „	hydrogen	0·2	„	
8·8 „	oxygen	traces to 3·0	„	(very variable)
1·5 „	nitrogen	2·0	„	
0·8 „	sulphur	1·0	„	
3·4 „	ash	5·8	„	

THE HYDROCARBONS

Before the chemical phenomena associated with the process of carbonization can be followed it is essential that some knowledge of the chemistry of the hydrocarbons should be obtained. The author feels that in a technical volume he will not be expected to retread the ground covered in elementary textbooks on chemistry. He proposes, therefore, to confine himself to a brief *résumé* of the composition and behaviour of the chief hydrogen and carbon compounds met with.

Carbon differs from other elements in forming an abnormally large number of compounds with hydrogen—called hydrocarbons. The simplest is methane (CH_4). The various compounds are classified as " saturated " and " unsaturated," according as to whether the carbon atoms are (owing to their tetravalent nature) fully saturated or not. When hydrocarbons are arranged in order of molecular weights, they comprise a series, each member of which contains so many atoms of carbon and hydrogen more than the preceding member. The more important series of hydrocarbons may be summarized as follows :—

I. The Paraffins

General formula	C_nH_{2n+2}	
Methane	CH_4	Saturated hydrocarbons.
Ethane	C_2H_6	
Propane	C_3H_8	
Butane	C_4H_{10}	
Pentane	C_5H_{12}	
Etc.		

II. The Olefines

General formula	C_nH_{2n}	
Ethylene	C_2H_4	Unsaturated hydrocarbons.
Propylene	C_3H_6	
Butylene	C_4H_8	
Amylene	C_5H_{10}	
Etc.		

III. The Acetylenes

General formula	C_nH_{2n-2}	
Acetylene	C_2H_2	Unsaturated hydrocarbons.
Allylene (methyl-acetylene)	C_3H_4	
Crotonylene	C_4H_6	
Etc.		

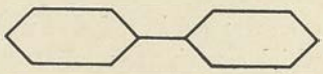
IV. The Aromatic Series

General formula	C_nH_{2n-6}
Benzene	C_6H_6
Toluene (methyl-benzene)	C_7H_8
Xylene (three isomers)	C_8H_{10}

The general formula of the aromatics gives the appearance of a high degree of unsaturation. In practice, however, it has been found that benzene possesses no

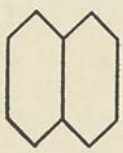
marked unsaturated character. The aromatics, in fact, resemble the paraffins rather than the olefines, in that they give rise to substitution products more readily than to addition compounds. It should be noted that an aromatic hydrocarbon never contains fewer than six carbon atoms, and whereas this series is readily attacked by nitric and sulphuric acids the paraffins are unattacked, while the olefines yield addition compounds. Other aromatic hydrocarbons of importance in the study of carbonization are those which contain more than one benzene nucleus in the molecule. They are of two classes, namely :—

(*a*) Multinuclear hydrocarbons, *e.g.* diphenyl ($C_{12}H_{10}$), in which the benzene nuclei are linked together directly, or they are united by one or more carbon bonds. Thus :—

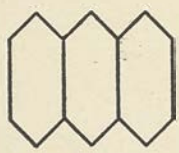


Diphenyl, $C_{12}H_{10}$.

(*b*) Condensed benzenoid hydrocarbons, *e.g.* naphthalene ($C_{10}H_8$) and anthracene ($C_{14}H_{12}$), in which case two or more benzene nuclei are united through one or more carbon atoms. In other words, the benzene nuclei are, so to speak, fused together so that certain of the carbon atoms are common to both rings. Hence the term " condensed-ring " compounds. Thus :—

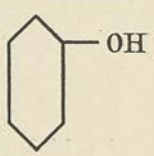


Naphthalene.

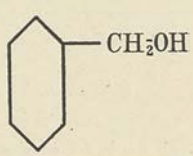


Anthracene.

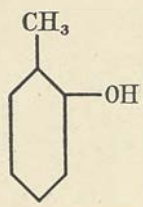
Of the remaining hydrocarbons commonly met with in the products of carbonization phenol is of importance. This is an aromatic body containing a hydroxyl group directly attached to the benzene ring. While substances having the hydroxyl directly attached in this way are known as phenols, those which have the hydroxyl in the side chain are known as aromatic alcohols. The phenols of toluene are known as cresols. Thus :—



Phenol, $C_6H_5.OH$.



Benzyl alcohol, $C_6H_5.CH_2.OH$.



Ortho-cresol, $C_6H_4.CH_3.OH$.

THE DEGRADATION OF THE HYDROCARBONS

The secondary reactions which take place during the carbonization of coal have been the subject of an unusual amount of research. The variable and complicated conditions under which these changes occur, however, render the path of the investigator extremely difficult. When a comparison of results is made, therefore, it is not surprising to find the expression of a number of contradictory opinions, although with regard to many of the more important facts a certain amount of uniformity is displayed. Primarily, it is recognized that when subjected to certain severe influences many of the less stable products evolved from coal are unable to withstand their tendency to decompose, with the result that they are split up into more stable compounds of a similar nature. This degradation or reconstruction chiefly applies to the carbon and hydrogen compounds, although—as previously shown—substances (such as ammonia and carbon dioxide) composed of other elements are by no means immune. It must be recognized that in order to obtain the maximum yield of gas from a definite bulk of coal it is not sufficient to submit the solid mass alone to a very high temperature, but the primary volatile products must afterwards come under the influence of further heat, so that some portion of the condensible vapours will be converted into permanent gas. Moreover, whereas there is no limit of temperature beyond which it might be inadvisable to heat the solid residue, the same does not apply to the primary products, as too great exposure to intense heat has detrimental results in their case. In the gas retort this secondary reaction is occasioned by the passage of the products through the heated coke mass and during their travel to the exit of the retort in contact with the heated walls of the vessel and by the action of radiant heat in the free space. Accordingly, the extent to which the primary products undergo decomposition depends partly upon the limits to which the retort is heated, but in greater degree upon the manner in which the volatile products leave the retort and upon the time spent in contact with the hot surfaces. Degradation, then, is mainly influenced by the following conditions :—

(*a*) The temperature to which the products are submitted.
(*b*) The nature of the solid surfaces to which they are exposed.
(*c*) The length of contact time with these surfaces.
(*d*) The atmosphere prevailing within the retort.

When the decomposition is such as to be beyond the economical limit, " overcracking " of the gases and vapours is said to occur. It will be seen that heat may be encountered by the products in two distinct ways—namely, by contact with the heated coke and retort walls and by direct radiation from the heated surfaces. Some years ago Young pointed out that the action of these two forms of heat is distinct ; that whereas contact with the hot surfaces appears to act with more or less equal effect on all substances, the radiant heat tends to have a selective action, and most readily attacks those molecules which absorb heat the more easily. In the light of recent research, however, it would appear that this conclusion is by no means established ; the most severe effects seem to occur during the passage of the pro-

ducts through the layers of red-hot coke. Chiefly, it is found that the heavy hydrocarbons, particularly the olefines, the acetylenes and the lower members of the paraffin series, are most prone to these influences, whilst the more stable methane is only affected by drastic conditions. The small proportion of rich gas present in the primary products consists largely of ethane and its homologues, ethylene and acetylene, and Colman states that the condensible compounds are relatively rich in hydrogen, and belong to those series in which the carbon atoms are united in open chains. If, however, they are present in closed chains, they are combined with much more hydrogen than is the case with the aromatic hydrocarbons, and are probably akin to the naphthenes and similar compounds. In their passage through the coke the primary gases ethane, ethylene, acetylene, and methane all tend to undergo decomposition, whilst the condensible products become partly gasified and altered in character to some extent. Accordingly, whilst a greater yield of permanent gas is obtained at higher temperatures, considerable deterioration in quality follows the breaking down of the richer constituents into less valuable products.

The comparative value of the various constituents so far as the illuminating and calorific powers of the ultimate gas are concerned is emphasized in the following table :—

	Calorific power, B.Th.U. per cubic feet at 15° C. and 30 inch bar.		Candle-power. Candles per foot.
	Gross.	Net.	
Benzene	3,738	3,587	165
Ethane	1,730	1,579	7
Ethylene	1,559	1,456	10
Propylene	2,301	2,151	—
Methane	992	890	0·9
Carbon monoxide	318	—	nil
Hydrogen	320	269	nil

For the purpose of calculating the calorific power of coal gas the average calorific power of the unsaturated hydrocarbons may be taken as equivalent to the calorific power of propylene (*i.e.*, 2,301 B.Th.U. gross per cubic foot) when the gas has not been stripped for benzol recovery. When dealing with stripped gas, however, it should be remembered that as, from the thermal standpoint, the most valuable hydrocarbon has been removed, the average calorific power of those remaining will be lowered. In such cases, the average figure for the unsaturated hydrocarbons may be taken as equivalent to the calorific power of ethylene, namely, 1,559 B.Th.U. gross per cubic foot.

With regard to candle-power the effect of methane is questionable. When

burned by itself it appears to show but poor light-giving properties, but when present in an admixture such as coal gas it undoubtedly accounts for an increase in illuminating power out of proportion to that shown in the above table. Whatever its effect as an illuminant, however, methane—owing to its high calorific value—is one of the most desirable constituents of modern gas. Fortunately, this hydrocarbon is the most stable of those present, and consequently suffers to a comparatively slight extent from the degrading influences in the retort.

One of the first investigators to turn his attention to the decomposition of gases was Berthelot,[1] who, in 1863, carried out a number of experiments with the hydrocarbons. Previous to Berthelot's work it had been shown by other research that the ultimate resolution of a hydrocarbon into its elements, hydrogen and carbon, can in no way be regarded as the immediate result of a single change, but that gradual breaking down into molecules containing a smaller number of atoms takes place. Thus ethylene (C_2H_4) was considered to be resolved into free carbon and methane, and so on.

(*a*) Ethylene, $C_2H_4 = C + CH_4$.
(*b*) Ethane, $C_2H_6 = C_2H_4$ (ethylene) $+ H_2$.

The four hydrocarbons of chief interest to the gas engineer are the primary product ethane (which largely disappears at present-day temperatures), ethylene, acetylene and methane. Berthelot, as a result of his studies, was of the opinion that these hydrocarbons underwent decomposition in the following manner :—

(*a*) Ethane, either (1) $C_2H_6 = C_2H_4$ (ethylene) $+ H_2$,
or (2) $2\ C_2H_6 = 2\ CH_4$ (methane) $+ C_2H_2$ (acetylene) $+ H_2$.
(*b*) Ethylene, either (1) $C_2H_4 = C_2H_2$ (acetylene) $+ H_2$,
or (2) $2\ C_2H_4 = C_2H_6$ (ethane) $+ C_2H_2$ (acetylene).

(*c*) Acetylene. This he concluded was never resolved into its elements, but was capable of undergoing polymerization or condensation into benzene at high temperatures. Thus $3\ C_2H_2 = C_6H_6$.

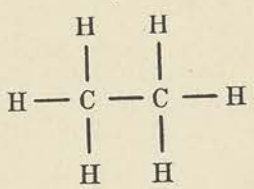
(*d*) Methane, either (1) $2\ CH_4 = C_2H_2$ (acetylene) $+ 3\ H_2$,
or (2) $2\ CH_4 = C_2H_6$ (ethane) $+ H_2$.

In 1894, Lewes, in a number of experiments on the hydrocarbons, of which he chiefly studied ethylene, concluded that this compound is primarily decomposed into equal volumes of methane and acetylene on the following lines :—$3\ C_2H_4 = 2\ CH_4 + 2\ C_2H_2$. With regard to methane he agrees with Berthelot that this is transformed into hydrogen and acetylene, but that the acetylene subsequently polymerizes or is resolved into its elements hydrogen and carbon. There is general agreement as to the marked stability of methane. But that degradation of this constituent does take place at higher temperatures and under certain conditions is shown by the manner in which the quantity has decreased in modern coal gas.

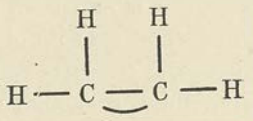
[1] *Ann. Chem. Phys.*, 1863, 1866, 1867, 1869.

Lewes states that for the methane to fall below 30 per cent. in a coal gas made from a good coal indicates degradation of the products by overheating, and, although decomposition to a certain extent is essential, it may be said that with straight coal gas the economical limit is probably reached when the methane has been reduced to about 28 per cent.

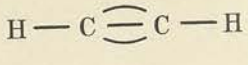
The tendency of hydrocarbons to dissociate is well illustrated by consideration of their structural formulæ and the arrangement of the carbon affinities. Thus we get—



Ethane (C_2H_6).



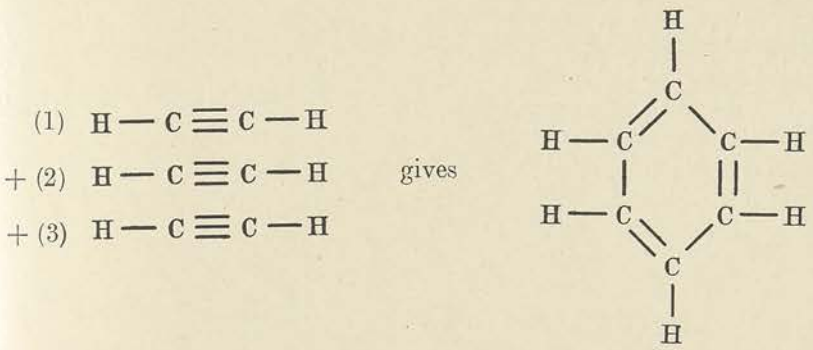
Ethylene (C_2H_4).



Acetylene (C_2H_2).

In each case it will be seen that the carbon atoms are not wholly saturated with hydrogen, and in order that each affinity may be satisfied the carbon atoms unite with one another. A bond between the carbon atoms as indicated invariably gives rise to a state of instability, so that the molecule at this point tends to sever, and to recombine into two molecules with the addition of hydrogen. In the case of ethylene and acetylene this tendency becomes still more marked, as double and treble bonds exist between the carbon atoms. The force of attraction between the atoms virtually acts along a straight line, but in the case of these two compounds it may be looked upon as being bent from its proper path and curved round so as to unite with the other carbon atom. Hence a condition of strain is set up in the bond, which on but slight provocation straightens out and takes up another hydrogen atom. Where double or treble bonds exist they may be taken as an indication of instability; and the greater the number of bonds uniting the carbon atoms the greater will be the tendency to decompose. Bone supports this theory by showing that acetylene tends to break down across the triple bond, yielding free carbon and hydrogen, whilst if other hydrogen is taken up methane will be formed.

Of the hydrocarbons in coal gas, benzene and its homologues (which are present to the extent of about 0·75 per cent.) are the most important. Their presence has been accounted for in various ways, but there is little doubt that they are high temperature degradation products. This is simply shown by the fact that whereas modern gas and tar emanating from heavy coal charges are of a distinctly paraffinoid nature, the hydrocarbons from the lighter charges, which afford ample opportunity for "over cracking," contain a greater proportion of benzene derivatives. Many investigators have sought to prove that benzene is the direct result of the polymerization of acetylene. Thus three molecules of acetylene (united in open chains) undergo rearrangement to yield the closed benzene formation:—



There is little doubt that such a reaction takes place to some extent, although, in the main, it seems probable that the benzene results at moderate temperatures from the paraffin derivatives. Bone has found that at low temperatures acetylene exhibits a strong tendency to polymerize, forming benzene, etc., so that when acetylene is the principal primary product in the decomposition of another hydrocarbon (for example, ethylene) there is always a marked secondary formation of benzene and other aromatic hydrocarbons. This tendency towards polymerization reaches its maximum between 500° and 700° C. and practically ceases to exist above 1,000° C.

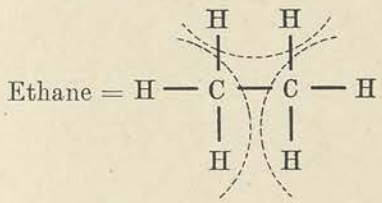
With regard to the actual method of decomposition of the hydrocarbons the work of Bone [1] may be looked upon as classical. This investigator propounded entirely new theories, based on the fact that carbonaceous residues, such as CH and CH_2, are capable of an extremely fugitive existence. With the exception of methane, however, he is of the opinion that the mode of decomposition of any particular hydrocarbon cannot be expressed by means of a single chemical equation. The degradation of methane is, in the main, a direct disunion into carbon and hydrogen—$CH_4 = C + 2H_2$. The free carbon deposited from this reaction is of a hard and lustrous type, being wholly different from that resulting from the decomposition of the other hydrocarbons. So far as ethane and ethylene are concerned, the effect of high temperatures is to cause a dissolution of the bonds uniting the carbon atoms, thus giving rise to the residues ≡ CH and = CH_2. Bone states that these residues may subsequently—

(1) Meet with other similar residues and form $H_2C = CH_2$ and HC ≡ CH.

(2) Break down directly into carbon and hydrogen.

(3) Be directly hydrogenized into methane.

These three reactions may occur simultaneously, depending upon the temperature, pressure, and amount of hydrogen prevailing. In the case of ethane, Bone represents the changes in the following way :—



[1] *J. Chem. Soc.*, 1908, p. 1197.

The bond between the carbon atoms tends to break away, whilst two hydrogen atoms also escape, thus decomposing the molecule into three distinct portions, namely :—CH_2, CH_2, and H_2. Ethane then has yielded [2 (CH_2) + H_2], which on recombination may become either—

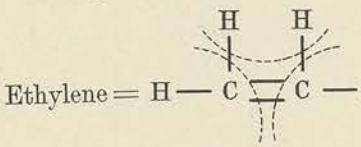
(1) C_2H_4 (ethylene) + H_2,

or (2) 2 C + 2 H_2 + H_2,

and by hydrogenation, *i.e.* + H_2, we get—

(3) 2 CH_4 (methane).

In the same way ethylene has a tendency to split up across the double carbon bond into the following residues :—



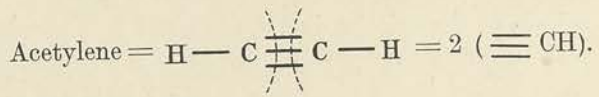
These then reunite to yield—

(1) C_2H_2 (acetylene) + H_2 (hydrogen),

or (2) 2 C + H_2 + H_2,

or (3) by hydrogenation (*i.e.* + 2 H_2) = 2 CH_4 (methane).

With regard to acetylene, the change may take place either by polymerization, as already mentioned, or by dissolution into residues. In the latter case a weakness develops across the triple bond between the carbon atoms :—



The CH residues then give—

(*a*) 2 C + H_2,

or (*b*) by hydrogenation (*i.e.* + 3 H_2) = 2 CH_4 (methane).

There is little doubt that in addition to degradation a certain amount of synthesis takes place at definite temperatures in the retort. The increase in the quantity of methane at higher temperatures is in all probability due to this cause. Burgess and Wheeler, in their well-known work, state that evolution of hydrocarbons of the paraffin series ceases almost entirely at temperatures above 700° C. ; but at the same time there are certain indications of an increase in the methane above this point. Pring and Fairlie, in a contribution to the proceedings of the Chemical Society, state that results of their experiments show that at temperatures between 700° and 730° C. acetylene reacts with hydrogen to give methane and ethylene. At a temperature of 1,200° C. carbon was found to combine with hydrogen to give both methane and ethylene, the rate of formation of the methane being 100 times that of the ethylene. A certain amount of acetylene was also formed at this temperature, but the quantity was too small to be measured.

Some of the most enlightening work on the behaviour of the hydrocarbons has been carried out by Cobb and Hollings, at Leeds University. In this instance

a small portion of coal was distilled in a boat and the volatile products were subjected to various conditions. In the first case they were removed from the heated tube with the utmost rapidity ; secondly, they were subjected to the radiant heat of the tube ; and, thirdly, they were collected after passage through a heated coke surface. The results obtained go clearly to show that the last-named condition is attended by the most severe forms of degradation. A summary of these results is given here, and Table I indicates the percentage composition of the gas obtained under the different conditions.

TABLE I

PERCENTAGE COMPOSITION OF NITROGEN-FREE GAS

	Minimum heat action.	Radiant heat.	Hot coke surface.
	Per cent.	Per cent.	Per cent.
Unsaturated hydrocarbons	6·3	5·0	3·3
Methane	33·1	30·9	27·3
Hydrogen	42·5	46·6	51·2
Carbon monoxide	13·1	14·3	14·7
Carbon dioxide	4·3	3·4	3·2
Oxygen	0·7	0·1	0·5

At the same time the actual volume of each constituent obtained in cubic centimetres per gramme of coal was recorded. In Table II these figures have been reduced to cubic feet per ton—a measurement with which the gas engineer is more familiar.

TABLE II

YIELD OF NITROGEN-FREE GAS

	Minimum heat.	Radiant heat.		Hot coke surface.	
		Expt. I.	Expt. II.	Expt. I.	Expt. II.
Unsaturated hydrocarbons	538	525	563	287	472
Methane	3,157	3,552	3,444	3,516	3,588
Hydrogen	4,197	5,346	5,238	6,315	6,708
Carbon monoxide	1,614	1,614	1,471	2,045	1,937
Cubic feet per ton	9,506	11,037	10,716	12,163	12,705

It is seen that the result of subjecting the volatile products to the action of radiant heat is an increase of about 14 per cent. in " make " per ton, whilst by passage through the column of heated coke the increase amounts to 30 per cent. That the quality of the gas is lowered by the decomposition which has resulted from the further action of heat is shown by the reduction which has occurred in the propor-

tion of heavy hydrocarbons present. Hydrogen has increased in volume by 50 per cent., whilst methane remains moderately steady, showing that the extra hydrogen has not been obtained at its expense. The hydrogen appears to be chiefly the product of the decomposition of the heavy hydrocarbons and of the gasification of products which would otherwise yield tar.

Cobb and Hollings also conducted experiments on the decomposition of the various hydrocarbons in the presence of hydrogen and methane, and, therefore, under conditions approximating to those prevailing in a retort. A mixture was taken consisting of equal parts of hydrogen and methane to which were added small percentages of the hydrocarbons to be tested. Temperatures of 800° C. and 1,100° C. were selected for the study of decomposition, and only experiments in which the gases were passed through a tube packed with coke have so far been recorded. With regard to methane it was found that at 800° C. only about 2 per cent. was decomposed in one minute, whereas at 1,100° C. degradation was very rapid. In the latter case, however, there was an increase in volume of about 44 per cent.; but a considerable loss of calorific value was noticed owing to the carbon of the decomposed methane being deposited in the solid state. The results of the two experiments are shown below.

METHANE

		At 800° C.	At 1,100° C.
Gas before	Methane	50·9 per cent.	50·9 per cent.
	Hydrogen	49·1 „	49·1 „
Gas afterwards	Methane	49·5 „	6·6 „
	Hydrogen	50·5 „	93·4 „
Percentage of methane decomposed		2·8 „	87 „

So far as ethane is concerned it was found that the chief products of its decomposition are ethylene and methane. At 800° C. the following results were noted after heating for forty-six seconds:—

ETHANE, at 800° C.

Composition of gas.	Before.	After.
Ethane	4·2 per cent.	0·9 per cent.
Methane	47·5 „	48·9 „
Hydrogen	48·3 „	48·9 „
Ethylene	nil	1·3 „
Acetylene	nil	Trace

In this case the percentage of ethane decomposed amounts to 79, but at a temperature of 1,100° C. the figure rose to 88 per cent.

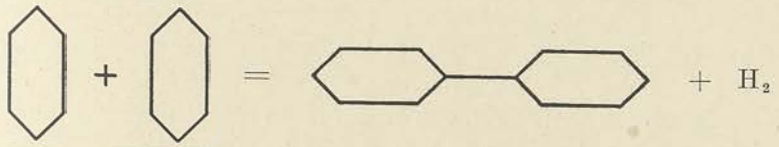
Ethylene was found to show rather more stable properties than ethane, the quantity decomposed at 800° C. being 62 per cent. after heating for forty-five seconds, and at 1,100° C. no trace of the product remained. The decomposition products consisted largely of hydrogen and methane, with a very small proportion of acetylene at the lower temperature.

The experiments with benzene are of particular interest in that they indicate the stable nature of this product at low and moderate temperatures and its complete instability at higher temperatures. At 800° C. the decomposition was negligible, but at 1,100° C. a very different result was obtained.

BENZENE, at 1,100° C., heated for forty-two seconds.

Composition of gas.	Before.	After.
Benzene	5·0 per cent.	nil
Methane	47·8 „	11·1 per cent.
Hydrogen	47·2 „	88·4 „
Ethylene	nil	nil
Acetylene	nil	Trace

In connection with benzene it is interesting to note the views of F. Haber,[1] who considers that the aromatic hydrocarbons are disposed to form more complex molecules with the elimination of hydrogen. Thus two molecules of benzene give diphenyl :—



$$2\,C_6H_6 = C_{12}H_{10} + H_2$$

T. F. E. Rhead [2] states that benzene hydrocarbons produced during the distillation of coal appear to be formed by three main groups of reactions, namely :—

(*a*) Condensation of olefines.

(*b*) Dehydrogenation of corresponding naphthenes.

(*c*) The polymerization of acetylene.

The same authority states that, if the necessary naphthenes predominated in the primary products of coal distillation, a temperature of 500° C. and upwards would give the maximum yield of benzene hydrocarbons ; but apparently the olefines predominate because the maximum benzene yield is obtained at 700° C. and upwards.

J. W. Cobb,[3] in a recent endeavour to determine how benzene and its homo-

[1] *Ber.*, vol. 29, p. 2191.

[2] *Proc. Soc. Chem. Ind.*, July, 1917.

[3] *Proc. N. Brit. Assocn. Gas Managers*, Sept., 1918.

logues decompose under the action of heat, found that, in a stream of nitrogen rich in benzene, decomposition just started at a temperature of 550° C. and at this stage a solid resembling naphthalene was deposited. This was identified as diphenyl [1] and was produced in increasing quantities, together with hydrogen, as the temperature was carried higher. At still higher temperatures, however, decomposition went a stage further, diphenyl-benzene being found. These results are a little perplexing in that, although benzene is found in some quantity in coal gas and tar, diphenyl is present in quantities scarcely sufficient to be separated. Here is an instance of so-called differences between theory and practice, or, between laboratory and large-scale results, indicating that some important factors had not been taken into account. The discrepancy was, however, ascribed to the prevailing atmosphere, or the state of dilution of the benzene by other gases, notably hydrogen and methane. When experiments were repeated, in which the benzene was highly diluted with nitrogen, decomposition was lessened, and the yield of solid condensates, such as diphenyl, decreased. Hydrogen was then employed in lieu of nitrogen as a diluent. By gradually diluting further and further with hydrogen, the quantity of molecular condensates gradually diminished until, when the benzene was reduced to a proportion of about 8 per cent. by volume of the mixture, only traces of diphenyl were produced, the benzene being practically undecomposed by the treatment. A reason was, therefore, clearly established for the stability of benzene during carbonization at such temperatures as 800° C. At higher temperatures (900° C.) benzene was found to be readily decomposed, even when highly diluted with hydrogen, and deposition of the characteristic grey methane carbon was noticed. When the temperature was raised to 1,100° C. with an atmosphere imitative of carbonizing conditions, benzene disappeared entirely, as was found in the earlier research.

Further experiments were made with toluene. In this case, when decomposition occurred at 600° C., the solid condensate produced was found to be stilbene. At the same time an oily substance was formed. At higher temperatures increasing decomposition was noted, and at 750° C. it was quite extensive. The most noteworthy distinction from the behaviour of benzene, however, occurred when a hydrogen atmosphere was employed, for it was found that the decomposition of the toluene was very much accelerated, with the production of large quantities of benzene, and smaller amounts of solid condensates. What happens then, is that the hydrogen atmosphere can act directly on the toluene producing benzene and methane.

The decomposition of the xylenes was found to be very similar to that of toluene, yielding, in an atmosphere of hydrogen at 750° C., toluene and benzene by reduction, and a limited quantity of solid condensates. Cresol is also reduced extensively (at 750° C. in hydrogen) to toluene and, necessarily, to benzene also.

The conclusions set out above clearly indicate that there is a tendency for hydrogen (which is the predominant product of carbonization) to reduce the single

[1] Compare Haber, p. 409.

ring benzene compounds to benzene, but at the same time to preserve the benzene nuclei intact. A similar action of hydrogen on the attached groups of more complicated ring compounds most probably accounts for the production of naphthalene and anthracene. Hence the formation during high temperature conditions of the horizontal retort of a considerable quantity of the aromatic hydrocarbons and naphthalene, with a corresponding decrease in the yield of paraffins and phenols.

THE MODERN REQUIREMENTS OF CARBONIZATION

There can be no question that in comparing the relative merits of various systems of carbonization too much importance has been attached to considerations of " yield of gas per ton of coal." During the past fifteen years a notable advance has certainly been made in the process of carbonization, the volume of gas obtained from coal having been increased by some 40 per cent. as a result of the introduction of improved carbonizing apparatus and methods. It has now to be borne in mind, however, that with the introduction of the Gas Regulation Act, the question of volume has lost much of its former significance, and the true criterion at the present day must necessarily be the yield of gaseous thermal units per ton of coal.

In discussing the advances made during the past fifteen years it is not possible to neglect the factor of gas volume obtained per ton of coal, and it is of interest to follow out the means whereby the yield has been enhanced from some 10,000 cubic feet to upwards of 14,000 cubic feet. Primarily, the introduction of the modern form of regenerative setting composed of material having greatly improved refractory qualities has rendered the first essential—the employment of high distillation temperatures—possible. The prolonged heating of the solid residue at temperatures of about 1,100° C. is followed by the evolution of practically the last traces of volatile matter, with the result that the constituents of present-day coke are almost wholly of a " fixed " nature. It must be realized, however, that the procurement of high makes of combustible gas does not in any way depend solely upon the efficient burning-off of the charge, but is due to a combination of small influences, each of which requires expert and detailed supervision. On the average gasworks there are many insignificant items, probably unnoticed in the general way, which may account for some slight disorganization of working, and it is the suppression of these and the maintenance of the whole machine up to concert pitch which tells its tale in the end. In addition to the higher heats of distillation now in use, the increased volume of gas may be ascribed largely to the following :—

(*a*) More complete gasification of tarry vapours, so that otherwise condensible products yield permanent gas.

(*b*) Increase of volume obtained by over-cracking the primary gas within the economical limit.

(*c*) The use of light seals, or no seals, in the " hydraulic " mains, and the strict avoidance of tar seals.

(*d*) The employment in the hydraulic main of a vacuum slightly greater than the intensity of seal on the dip-pipe.

(*e*) The use of heavy charges of coal in the retort.

(*f*) Steaming the coal charge, thus producing water gas *in situ*.

(*g*) The employment of prolonged charges in preference to those of short duration as used some few years ago.

(*h*) Over-exhausting.

Nothing has been said with regard to the quality of coal made use of, this having some considerable influence on the final results. It is, however, a factor over which the average gas engineer has little control, it usually being necessary (on the grounds of economy) to take the coal from the nearest colliery.

It will be seen that the increased volume is composed chiefly of—

(*a*) Hydrogen, from the coke residue, from degradation, and from the gasified tarry vapours.

(*b*) Methane, from the gasified tarry vapours and from degradation of heavy hydrocarbons, also to some extent from synthetic sources at the higher temperatures. A portion of this methane is eventually decomposed, so that in the final gas it shows some deficiency compared with lower yields of gas.

(*c*) Nitrogen, from in-travel of the furnace gases, from the residual coke, which chiefly evolves this gas in the final stages, and from the atmosphere.

(*d*) Carbon monoxide, from the formation of water gas (particularly if "steaming" is practised), and from the reduction at high temperatures of carbon dioxide.

(*e*) Carbon dioxide, from the in-travel of furnace gases.

Any proportion of carbon dioxide above the normal may be accounted for by excessive vacuum on the retorts, followed by the introduction of air through defective lids and mouthpiece joints. It seems probable, therefore, that a portion of the carbon monoxide and hydrogen must in this way be burnt to carbon dioxide and water direct in the retort. Consequently, if inert constituents are to be kept within reasonable limits, all joints should receive particular attention. It is an excellent plan to put a whole bench periodically under slight pressure (by closing back temporarily the retort house governor) when defective joints immediately show themselves.

(*f*) Oxygen, free from the atmosphere. *E.g.* from imperfectly fitting doors or bad joints on that portion of the apparatus which is under a vacuum. Also introduced at the purifiers for purposes of revivification.

As regards item (*b*) it is interesting to note the increase in gas volume which would result from the complete thermal degradation of the hydrocarbons and other gases containing hydrogen. The following table [1] shows that, by completely decomposing 100 cubic feet of normal coal gas, the final volume obtained would be swelled to 133 cubic feet :—

[1] R. Lessing, *Gas J.*, cxlv, p. 493.

	In Gas.	Vols. Hydrogen per Vol. Constituent.	Total Hydrogen.
	Per Cent.		Per Cent.
Saturated Hydrocarbon Gases:			
Methane	22·68	2	45·36
Ethane	1·53	3	4·59
Propane	·31	4	1·24
			—— 51·19
Unsaturated Hydrocarbon Gases:			
Ethylene	2·89	2	5·78
Propylene	·29	3	·87
Butylene	·05	4	·20
Acetylene	·10	1	·10
			—— 6·95
Vapours:			
Benzene	·72	3	2·16
Toluene	·13	4	·52
Xylene	·22	5	1·10
Naphthalene	·01	4	·04
			—— 3·82
Hydrogen	37·73		37·73
Other gases	33·34		33·34
	100·00		133·03

The effect of the temperature of carbonization on hydrogen and the unsaturated and saturated hydrocarbons has been well illustrated by the figures given below which were obtained by A. H. Middleton [1] in connection with coke ovens.

Effect of Temperature on Hydrogen and Hydrocarbons

Temperature of distillation	400° C.	500° C.	600° C.	700° C.	800° C.	900° C.
Hydrogen in gas (per cent.)	21·2	28·3	33·8	41·6	48·2	54·5
Saturated hydrocarbons (per cent.)	60·1	56·2	50·7	45·0	39·1	34·2
Unsaturated hydrocarbons (per cent.)	6·3	5·8	5·0	4·4	3·8	3·5

The effect of one important influence—that of over-exhausting—is admirably illustrated in the following table, in which the make in neither case is particularly high, but which gives an excellent indication of the manner in which the additional 800 cubic feet of gas per ton is accounted for :—

[1] *Gas World* (Coking Section), lxxii, p. 15.

	Level-gauge in retort.	Over-exhausting.	Difference.
	Cubic feet per ton of coal.	Cubic feet per ton of coal.	
Hydrogen	5,676	5,709	+ 33
Methane	3,780	3,494	− 286
Carbon monoxide	1,164	1,254	+ 90
Carbon dioxide	264	346	+ 82
Heavy hydrocarbons	408	422	+ 14
Oxygen	60	90	+ 30
Nitrogen	648	1,485	+ 837
Total	12,000 cubic feet	12,800 cubic feet	+ 800
Candle-power	18	15	
Calorific power	575 B.Th.U.	559 B.Th.U.	

The table is compiled from percentage composition figures obtained by W. B. Davidson in distilling a standard second-class Midland coal. The most noticeable results of the over-exhausting are a marked deficiency in the valuable heavy hydrocarbons and methane, whilst nitrogen has increased by 130 per cent.

It cannot be too strongly emphasized, however, that the principle of over-exhausting, with the consequent introduction of excessive quantities of waste furnace gases and air, is entirely wrong in principle. So long as gas continued to be sold on the volume basis the introduction of large volumes of incombustible matter may certainly have appealed to the commercially minded; but the position has been completely altered by the introduction of the heat-unit basis of selling. The result is that whereas carbon dioxide, nitrogen, and oxygen could at one time be sold for so many shillings per 1,000 cubic feet, to-day they yield nothing in the way of revenue, and merely detract from profits by reason of the fact that they consume power for their distribution and appropriate valuable space in holders and district mains which would otherwise be available for revenue-producing constituents. On the other hand, it must be borne in mind that if the conditions prevailing in the retort are such that no foreign constituents are drawn in, then valuable products from the coal will assuredly be finding their way from the retort. They will be consumed in the furnace and be wasted. Accordingly, it is not economically possible to produce straight coal gas entirely free from foreign constituents, but the operations should be so controlled that incombustible matter is under normal circumstances never permitted to exceed from 12½ to 15 per cent. It should be understood that this limit applies to the gas as produced, and not necessarily as supplied, for the author feels that, until further research is completed and the results of prolonged practical experience can be turned to, it is not politic to discuss the relative merits of distributing gas of high or low thermal concentration. The crux of the whole problem is that the producer is paid solely for British Thermal Units; accordingly the most effective system of carbonization must inevitably be that which produces the cheapest

heat unit. The standard of comparison to-day is, therefore, the total number of gaseous heat units obtained per ton of coal. The figure must necessarily be elastic owing to the variation in the quality of gas coals now utilized. For a good class Durham coal, however, it should be possible to obtain 6,750,000 B.Th.U. per ton, although it may be mentioned that in some instances a yield of 7,000,000 units is now being reached under the best conditions. These figures refer, of course, to straight coal gas production, and are not applicable to those cases in which the coke in the retort is being partially gasified by the admission of steam. In all cases of comparison, however, it is important to remember that, in calculating the cost of production of a gaseous heat unit or a " therm," the net cost of coal (after deducting the revenue from residuals) should be taken, for the most economic process is not necessarily that which yields a maximum of gaseous units with, probably, a minimum of coke and ammonia.

The question as to the increase of volume of permanent gas obtained by over-cracking in the free space is a vexed one, and some authorities point out that the yield is swelled to only a meagre extent in this way. If we consider any of the degradation reactions, however, it is possible to show by means of Avogadro's law that some increase of volume does take place. For instance, if the reaction $CH_4 = C + 2\ H_2$ is taken as an example, it is seen that one molecule of methane gives rise to two molecules of hydrogen. In other words, a cubic foot of methane yields on degradation double its volume of hydrogen; that is, an increase of 100 per cent. in permanent gas. Similarly, ethylene (C_2H_4) may decompose into acetylene (C_2H_2) and hydrogen (H_2). Thus one molecule has yielded two molecules of gas; again an increase in volume of 100 per cent. The extent of such decomposition, however, is relatively small in comparison with the total volume of gas present, and Lewes has shown that in the long run intentional over-cracking in the retort will probably account for only an additional 400 or 500 cubic feet. Lewes' experiment on the effect of degradation of the primary products is of extreme interest. First, he obtained a semi-primary gas having an analysis approximately as follows :—

Hydrogen	27·5 per cent.
Saturated hydrocarbons—1, Methane	48·0 ,,
,, ,, 2, Higher members	10·1 ,,
Unsaturated hydrocarbons	3·0 ,,
Carbon monoxide	7·3 ,,
Carbon dioxide	2·5 ,,
Nitrogen	1·6 ,,

This gas was then passed through a tube containing broken porcelain, and heated to 1,100° C., when an increase of volume of 11 per cent. resulted, the composition then being as follows :—

Hydrogen	52·3 per cent.
Methane	34·0 ,,
Unsaturated hydrocarbons	2·5 ,,
Carbon monoxide	8·8 ,,
Carbon dioxide	1·0 ,,
Nitrogen	1·4 ,,

The original volume of semi-primary gas obtained amounted to 4,500 cubic feet, and this was swelled by 495 cubic feet by the second treatment, or to 11,200 cubic feet in all when the additional gas obtained from further heating the coal residue (from which the primary gas was obtained) was taken into account. The most interesting feature of the experiment, however, is the manner in which the increased volume of gas is obtained. This is shown as follows :—

Volume composed of :—		
Primary gas	4,500	cubic feet.
Increase of volume due to degradation	495	,, ,,
Gas expelled from low temperature coke residue	5,000	,, ,,
Gas due to gasification of tar	1,205	,, ,,
Total yield	11,200	cubic feet per ton.

With regard to the final tar as yielded by Dessau vertical retorts, Davidson has shown that 1 gallon when gasified will produce 68 cubic feet of gas having a candle-power of 17·35. In the ordinary way the yield of tar from coal carbonized for prolonged periods at high temperatures varies from 9 to 12 gallons per ton, whereas with a gas make approaching only 5,000 cubic feet per ton the tar recovered would be in the neighbourhood of 20 to 22 gallons. The difference between these two figures represents the quantity of tar which under modern conditions is transformed into permanent gas and free carbon. The character of the tar is, moreover, considerably affected. When the gas has been subjected to the prolonged influence of secondary heat a tar of a distinctly benzenoid character results, whilst when the decomposition is limited—as with modern methods—the tar consists largely of derivatives comprised in the paraffin series.

The primary objection to intermittent systems of carbonization is the manner in which the quality of gas evolved undergoes deterioration as the period of distillation proceeds. Thus during the first quarter of an hour there is a burst of gas of good quality very much resembling the semi-primary gas given in the table on page 415. Although carried out some years ago, the experiments of L. T. Wright on the extent of deterioration still prove most instructive. The following figures obtained by Wright give an excellent idea of this effect :—

Composition of Gas at Various Periods of Charge

	Period from Commencement (*Approximate*).				
	10 minutes.	1½ hours.	3½ hours.	5½ hours.	
Hydrogen	20·10	38·08	50·68	67·12	per cent.
Methane	57·38	44·03	35·54	22·58	,,
Heavy hydrocarbons	10·62	5·98	3·04	1·79	,,
Carbon monoxide	6·19	5·98	6·21	6·12	,,
Carbon dioxide	2·21	2·09	1·49	1·50	,,
Sulphuretted hydrogen	1·30	1·42	0·49	0·11	,,
Nitrogen	2·20	2·47	2·55	0·78	,,
	100·00	100·00	100·00	100·00	

The results were, of course, obtained at lower temperatures than those now

prevailing, and under old-fashioned conditions of seal and vacuum, so that at the present day it would be unlikely that the nitrogen content would remain practically constant, and even show the reduction which Wright found after five and a half hours. In fact, in connection with the heavy twelve-hour charge the author, in an experiment carried out some five years ago, finds that with a ½-inch seal and 1½-inch "draw" the composition approximates to the following:—

	After 6 hours.	After 12 hours.
Hydrogen	45·2 per cent.	65·8 per cent.
Methane	22·9 „	1·4 „
Heavy hydrocarbons	4·1 „	nil
Carbon monoxide	6·3 „	15·2 „
Carbon dioxide	2·6 „	0·6 „
Nitrogen	18·0 „	16·6 „

So far as nitrogen only is concerned (determined by the direct method) the following figures are given as typical of those obtained under the rather severe and abnormal conditions quoted above:—

After 1 hour	11·6 per cent.	of nitrogen.
„ 2 hours	14·8 „	„
„ 3 „	16·4 „	„
„ 4 „	16·7 „	„
„ 5 „	17·5 „	„
„ 6 „	18·5 „	„
„ 7 „	19·7 „	„
„ 8 „	20·1 „	„
„ 9 „	20·2 „	„
„ 10 „	15·9 „	„
„ 11 „	15·2 „	„
„ 12 „	15·2 „	„

In the modern form of coke oven it is customary to carbonize the heavy charges, amounting in some cases to as much as 10 tons, for periods of twenty-four hours, or even longer. Under such conditions the deterioration becomes somewhat excessive towards the end of the period, as is shown by the following results, obtained by Simmersbach for a twenty-nine hour charge.

Hour of carbonization.	2	3	4	5	6	7	8	9	10	11	12	13	15	17	19	21	23	25	27
Gas analysis.																			
CO_2	3·3	3·0	2·3	2·5	2·2	2·0	1·4	1·9	2·3	1·3	1·5	2·0	1·9	1·8	1·1	1·05	0·8	0·7	1·0
C_6H_6	1·8	1·5	1·1	1·1	1·0	0·8	0·6	0·5	0·35	0·35	0·35	0·3	0·25	0·1	—	—	—	—	—
C_2H_4	4·0	3·5	3·1	3·2	2·8	2·5	2·5	2·0	1·75	2·05	1·85	1·8	1·8	1·9	1·2	1·0	0·6	0·3	0·3
O_2	1·05	0·8	0·6	0·6	0·5	0·5	0·2	0·2	0·2	0·1	0·2	0·2	0·15	0·25	0·15	0·05	0·05	0·1	0·3
CO	0·9	1·9	2·9	2·8	3·0	3·95	3·4	3·1	2·8	2·8	4·15	4·1	3·9	4·15	4·7	4·0	3·8	4·9	5·8
CH_4	36·65	36·1	34·5	34·5	33·6	32·4	35·65	33·45	31·2	32·4	33·4	32·45	33·2	30·6	26·1	21·15	18·95	12·2	4·7
H_2	42·5	44·6	48·8	47·8	50·1	50·75	53·65	50·55	47·1	51·5	50·65	49·75	53·4	51·6	55·75	58·95	61·9	67·0	70·0
N_2	10·0	8·6	6·7	7·5	6·8	7·1	3·6	8·3	14·3	9·5	7·9	9·4	5·4	8·6	11·0	13·8	13·9	14·8	17·9

The coke yielded contained 2·56 per cent. of volatile matter and 88·53 per cent. of carbon. The nitrogen, it will be noticed, is at a minimum (3·6 per cent.) at the eighth hour, but is five times this amount at the twenty-seventh.

LIGHT AND HEAVY CHARGES

Little more than a decade ago it was the recognized custom to employ light charges in the retort, and to work these off in short periods of carbonization. Six hours was looked upon as a convenient period, so that the retort could be filled four times during the twenty-four hours. When such systems are adopted the coal lies in a thin layer upon the floor of the retort, thereby leaving a large crown space unoccupied. By prolonging the period to either eight or twelve hours the labour entailed is curtailed by one-third or a half, and many further advantages accrue. With the six-hour charge the weight of coal distilled in a " through " retort of average cross-section was usually 6 cwts. ; and it may be taken as a rough rule that the number of cwts. shall be equivalent to the period of carbonization in hours.

Thus, a 6-hour charge consists of 6 cwts.
an 8-hour ,, ,, ,, 8 ,,
and a 12-hour ,, ,, ,, 12 ,,

In each case it will be seen that the weight of coal employed in twenty-four hours is approximately the same ; but whereas in the six-hour charge it has to be handled on four distinct occasions, with the twelve-hour charge only two handlings are necessary. The primary objection to the six-hour charge is, however, the excessive degradation and decomposition which takes place in the greater free space above the coal. Owing to the tendency of the gas to linger in the retort, and to its slow passage therethrough in contact with incandescent surfaces of carbon, the destructive influences are afforded exceptional facilities for working their evil. It must be remembered, moreover, that although decomposition by heat occurs in what may seem a minute space of time, in the ordinary way the thermal degradation of the hydrocarbons takes place very slowly in comparison with the rate at which many other chemical reactions occur. Thus an increased time of exposure tells heavily in this direction. As the bulk of gases travel along the free space to the outlet pipe, portions of them will be in contact with the sides of the retort, etc., where their temperature quickly rises to that of the surfaces, and it is here probably that the most intense degradation occurs. The gases towards the middle of the bulk, however, absorb the radiant heat traversing the space, and as the more complex compounds have a greater absorptive capacity for radiant heat than the simpler bodies, the tendency is for the more stable gases, such as methane, to remain unharmed whilst the complex vapours are split up. It is for this reason that the condensible vapours and gaseous hydrocarbons are of a distinctly benzenoid character with light charges. Furthermore, the excessive degradation gives rise to the deposition of free carbon, which, in turn, causes stopped pipes ; and naphthalene makes its appearance in undesirable quantities. The naphthalene formation may be explained by the fact that when subjected to excessive heat benzene probably polymerizes so that compounds containing condensed benzene nuclei are formed.

During the formation of such compounds hydrogen is evolved in some quantity, and accounts for the high percentage of this gas usually found in the resultant gas from light charges. With regard to the "free" carbon deposited, it is interesting to note that Colman considers that with still higher temperatures and with increase of time the above compounds yield more hydrogen and benzene nuclei of a still more complex nature, leading eventually to carbon itself. The molecule of solid carbon in all probability consists of a very large number of carbon atoms arranged as a honeycomb of condensed benzene nuclei. These complex substances, still containing some hydrogen, are black and infusible, and their physical properties are very closely akin to those of pure carbon itself.

As regards the extent of free space in the retort with varying types of charges, G. P. Lewis has given the following figures :—

22 inches by 16 inches ▭ retort, 6 cwt. charge ; space in crown = 65 per cent. of volume of retort.
" " " " 8 " " " " = 55 " " "
" " " " 12 " " " " = 32 " " "
Coke oven 9 feet by 1 foot 6 inches . . . . = 6 " " "

As illustrating the effect of varying the duration of charge upon the product obtained, Ferguson Bell gives the following comparisons :—

Duration of charge.	Weight of charge.	Gas made per ton.	Candle-power No. 2 Met.	Calorific value per cubic foot.
Hours.	Cwt.	Cubic feet.		B.Th.U. Net.
6	6	10,594	16·31	538·8
8	$7\frac{3}{4}$	11,245	15·59	518·9
10	$9\frac{1}{2}$	11,499	14·53	488·4
12	$11\frac{1}{2}$	11,463	14·77	484·4

The principle of the intermittent heavy charge has recently been carried to further lengths by the installation of large horizontal retorts having a cross-section of 24 inches by 20 inches, and capable of carbonizing about a ton of coal in twenty-four hours.

To sum up, the merits of the heavy charge as compared with the results from partly filled retorts may be enumerated as follows :—

(1) Considerably curtailed carbonizing costs.
(2) Less degradation, and, therefore, less naphthalene and free carbon,
(3) Few stopped pipes.
(4) More ammonia.
(5) Better coke of a denser nature, and less breeze.
(6) More tar of a better and thinner quality.
(7) Less retort carbon.
(8) Less sulphur in the form of CS_2, etc.

Some doubt seems to exist as to the question of fuel. Whilst some authorities

imply that the heavy charge is more extravagant in this direction, this would by no means appear to be the rule. The "make per mouthpiece" per day shows some falling off, owing to the fact that with the heavy charge the final hours of the period are largely yielding only the residual gases from the coke—comparatively small in volume, and which are not evolved to the same extent in the short carbonization periods. With the heavy charge, it is, of course, essential that the periods of charging of the various units should be so arranged that the resultant mixture of gas obtained is more or less constant throughout the twenty-four hours.

THE COMPOSITION OF TOWNS' GAS

The composition of the gas supplied varies to some extent in different localities in accordance with the methods of manufacture adopted. The smaller and medium-sized undertakings for the most part distribute straight coal gas only, although in some instances the character of this may be altered by some form of steaming the charge which has recently become popular. The chemical constituents of ordinary straight coal gas are given below, but it should be borne in mind that the proportions of the various constituents given are liable to variation, particularly so as far as the quantity of carbon dioxide, nitrogen, and oxygen is concerned.

Composition of Normal Straight Coal Gas (unstripped).

	Per cent. by volume.	
Hydrogen	47·0	
Methane	27·5	
Unsaturated hydrocarbons	3·5	
Carbon monoxide	7·75	
Carbon dioxide	3·5	
Nitrogen	10·5	14·25
Oxygen	0·25	
Calculated calorific power	518 B.Th.U. gross.	

Prior to 1914, when oil for the enrichment of water gas could be obtained comparatively cheaply, it was customary to employ from 2 to 2½ gallons of oil per 1,000 cubic feet of water gas made. Under such conditions the carburetted water gas produced had an illuminating power of some 17 candles, and it was customary to distribute a gas consisting of from 70 to 75 per cent. of straight coal gas and 25 to 30 per cent. of carburetted water gas. In such cases the composition of the final gas would approximate to the following:—

Composition of Coal Gas and Carburetted Water Gas Mixture

	Per cent. by volume.	
Hydrogen	44·0	
Methane	22·0	
Unsaturated hydrocarbons	5·8	
Carbon monoxide	16·5	
Carbon dioxide	3·5	
Nitrogen	8·0	11·7
Oxygen	0·2	
Calculated calorific power	545 B.Th.U. gross.	

When a gas of the above-mentioned quality was distributed official requirements demanded that the illuminating power should not be lower than 14 candles. To-day, of course, the position has completely changed; and, with the passing of the illuminating power standard, the highly enriched grade of water gas has completely disappeared. The majority of undertakings provided with water gas plant now employ them very largely for the production of blue water gas or a semi-enriched gas (having a calorific power of from 380 to 420 B.Th.U.) in the manufacture of which from 0·75 to 1 gallon of oil per 1,000 cubic feet is used. Accordingly, the gas most commonly supplied to-day by all the larger undertakings consists of a mixture of from 75 to 80 per cent. of straight coal gas and 20 to 25 per cent. of blue water gas. In some instances the proportion of blue water gas is raised to 40 per cent. or more. The question of the production of water gas *in situ* by steaming the charge is discussed later.

COMPOSITION OF MIXED GAS CONSISTING OF 80 PER CENT. STRAIGHT COAL GAS AND 20 PER CENT. BLUE WATER GAS

	Per cent. by volume.	
Hydrogen	48·0	
Methane	22·2	
Unsaturated hydrocarbons	2·8	
Carbon monoxide	13·8	
Carbon dioxide	3·7	
Nitrogen	9·3	13·2
Oxygen	0·2	
Calculated calorific power	482 B.Th.U. gross.	

The effect of adding a further proportion of a combustible diluent (in this case blue water gas) is shown by the following analysis. It should be noted that whereas as compared with the above analysis the calorific power is, of course, reduced, the actual proportion of inert constituents undergoes slight reduction.

COMPOSITION OF MIXED GAS CONSISTING OF 70 PER CENT. STRAIGHT COAL GAS AND 30 PER CENT. BLUE WATER GAS

	Per cent. by volume.	
Hydrogen	48·5	
Methane	19·5	
Unsaturated hydrocarbons	2·5	
Carbon monoxide	16·83	
Carbon dioxide	3·80	
Nitrogen	8·70	12·67
Oxygen	0·17	
Calculated calorific power	458 B.Th.U. gross.	

The composition of the saturated and unsaturated hydrocarbons in coal gas will necessarily vary in accordance with the coal carbonized and the method of carbonization adopted, as an instance of which may be quoted the difference found in the case of the vertical retort (when paraffinoid characteristics prevail) and the horizontal retort which tends towards the production of benzenoid products.

F. S. Sinnatt [1] and L. Slater have determined the relative proportions of the olefines present as follows :—

	Per cent. by volume of total olefines. I.	II.
Ethylene	84·0	84·3
Propylene	13·4	11·8
Butylene	1·75	2·35
Amylene	0·97	1·54

The most comprehensive analysis of an average sample of straight coal gas (in which, however, incombustible constituents are somewhat excessive) has been given by Lessing [2] :—

	Per cent. by volume.		B.Th.U. per cubic foot of constituent at 60° and 30 in. moist gas.	B.Th.U. per cubic foot of total gas at 60° and 30 in. moist gas.	
Saturated Hydrocarbon Gases :					
Methane	22·68		992	224·96	
Ethane	1·53		1,730	26·47	
Propane	·31		2,207	6·20	
		24·52			257·63
Unsaturated Hydrocarbon Gases :					
Ethylene	2·89		1,559	45·06	
Propylene	·29		2,301	6·67	
Butylene	·05		3,042	1·52	
Acetylene	·10		1,452	1·45	
		3·33			54·70
Vapours :					
Benzene	·72		3,738	26·91	
Toluene	·13		4,378	5·69	
Xylene, etc.	·22		5,099	11·22	
Naphthalene	·01		5,783	·58	
Carbon bisulphide	·03		1,240	·37	
		1·11			44·77
Other Gases :					
Carbon monoxide	12·69		318	40·35	
Hydrogen	37·73		320	120·74	
		50·42			161·09
Inert Gases :					
Carbon Dioxide	4·07		..	..	
Oxygen	1·09		..	..	
Nitrogen	15·46		..	..	
		20·62			
		100·00		518·19	518·19

[1] Soc. Public Analysts, 1920.

[2] *Gas J.*, CXLV, p. 489.

THE EFFECT OF BENZOL STRIPPING

The process of washing coal gas,[1] for the recovery of the aromatic vapours, which was demanded by the exigencies of war has now been very largely discontinued by gas undertakings, although it is still, of course, in operation at coke-oven establishments. The commercial aspect of benzol recovery has been considerably altered by the modern method of selling gas on the basis of therms instead of in cubic feet. If straight coal gas is completely stripped, for instance, the aromatic vapours removed would represent approximately 1 per cent. of the total volume of the gas. Normally, 2 gallons per ton of coal are extracted, and whereas pure benzol has a calorific value of 163,000 B.Th.U. per gallon, the crude mixture removed from coal gas has an average calorific power of 130,000 B.Th.U. per gallon, and 2 gallons represents about 100 cubic feet of gas. Accordingly, the revenue from benzol sold in various forms may be approximately contrasted as follows :—

2 gallons crude spirit @ 1*s.* 2*d.* (net)	= 28*d.*	per ton of coal carbonized.
100 cubic feet of benzol @ 5*s.* per 1,000 cubic feet	= 6*d.*	„ „ „
260,000 B.Th.U. @ 16*d.* per therm	= 41·6*d.*	„ „ „

While, therefore, it was commercially advantageous to extract benzol from the gas while the cubic-foot basis of selling remained in force, it will be noted that, as heat units are now sold, the benzene has a far greater value if sold in the gaseous form.

With regard to the effect of benzol extraction on the quality of coal gas it has been shown that the loss in calorific power is approximately 4·5 per cent. when 2·1 gallons of crude spirit is extracted per ton of coal, 7 per cent. when 2·5 gallons are extracted, and 8 per cent. when 3 gallons are recovered.

L. J. Willian [2] states that in America the average yield of light oils is about 3 gallons per ton of coal carbonized, but this undoubtedly refers to the gas produced from coke ovens. He states that the light oils recovered have approximately the following composition : Benzol 50 to 60 per cent., toluol 12 to 13 per cent., solvent naphtha 10 to 12 per cent., heavy naphtha and wash-oil 13 per cent. This investigator has carried out extensive tests in order to determine the effect of " stripping " on the quality of gas. With a plant dealing with 100,000 cubie feet of coal gas per day, he obtained data showing a loss of 63 per cent. of the candle-power (Met. No. 2 burner) and 6·2 per cent. of the calorific power (B.Th.U. gross), whilst the naphthalene decreased 80 per cent., and the carbon bisulphide 50 per cent.

Willian has also investigated the effects produced by stripping carburetted water gas, but the effectiveness of such a procedure depends entirely upon the quantity of oil which is employed in the carburation of the gas. The temperature prevailing in the carburettor influences the result. Temperatures between 700° and 760° C. appear to produce the maximum amount of toluene. Higher tempera-

[1] For detailed particulars of the plant employed, etc., the reader is referred to *Benzol*, by S. E. Whitehead (Benn Bros., Ltd.).

[2] *American Gas Inst. News*, Dec., 1917.

tures will tend to increase the benzene, while lower temperatures produce paraffins and olefines. The recovery of light oils from water gas in this country, though attempted in the early days of the war, has not been followed up, partly owing to the paraffins present in the recovered spirit, and also on account of the attenuated nature of the carburetted water gas which has resulted from the shortage of gas-oil. Willian's figures show that, with thorough scrubbing, the crude spirit recovered from carburetted water gas amounts to about 10 per cent. of the oil used, and consists of benzol 35 per cent., toluol 25 per cent., solvent naphtha 10 per cent., heavy naphtha and wash-oil 30 per cent. The loss of candle-power due to scrubbing was 50·8 per cent., and of calorific value 4·2 per cent.

Some interesting figures relating to the effect of tar on the proportion of benzene, etc., in the gas have been given by Sainte Claire Deville,[1] who shows that the tar tends to absorb the benzene at the commencement of the carbonizing period but throws it off towards the end of the charge :—

	Gas prior to entering Condensers and Purifiers.	Gas at outlet of Condensers and Purifiers.
	Benzol in grains per cubic foot.	
First hour of carbonization	21·4	17·3
Second „ „	19·3	15·4
Third „ „	12·3	18·8
Fourth „ „	4·0	19·1

The extent to which the benzol recovered from coal is enhanced by the process of stripping the gas is illustrated by the following figures :—

	Pounds per ton of coal carbonized.	
	Benzene.	Toluene.
Recovered from tar	0·4	0·130
Recovered by tar-washing process	1·5	0·75
„ „ oil-washing process	10·0	3·50

THE EFFECT OF STEAMING THE COAL CHARGE

Opinion as to the relative economy of producing a mixed gas in two operations or of generating it in a single operation by producing water gas *in situ* is still divided. The process of steaming the coal charge was in its early days almost solely confined to the intermittent system of vertical retorts when it became customary to admit steam during the last two hours of a 12-hour charge. In recent years, however, ideas as to the essential qualities of towns' gas have been considerably modified, with the result that a remarkable advance has been made with the system as applied to continuously operated vertical retorts. The operation of steaming is particularly elastic, it being possible to control the results obtained within a wide range by regulating the quantity of steam admitted and the temperature of the retorts. In general, it may be said that the arrangement consists of passing superheated steam into the coke-extractor chamber through a $\frac{1}{8}$-inch nozzle and at a pressure of 40 lb. per square inch.

[1] *Gas J.*, CXLVII, p. 392.

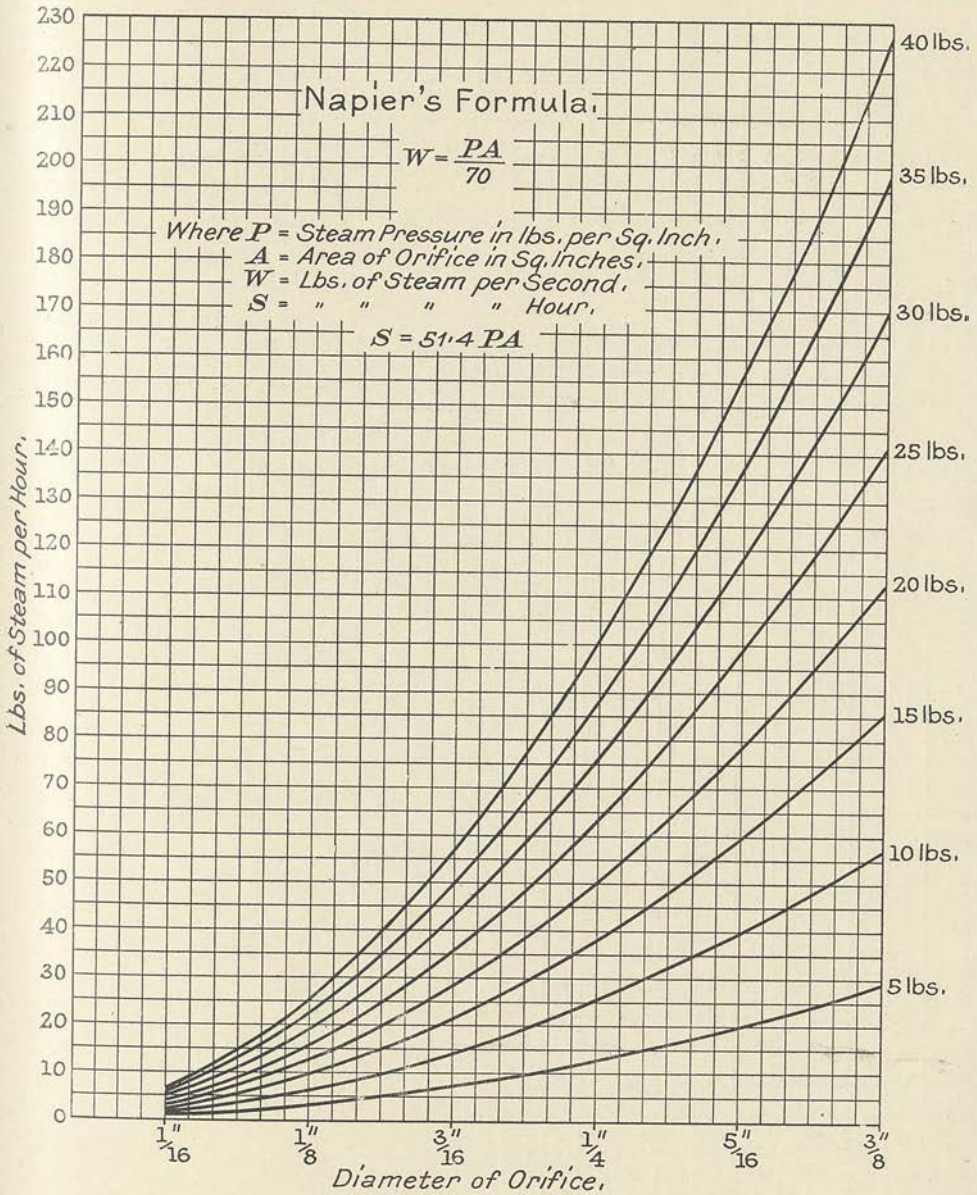


FIG. 261.—CHART SHOWING FLOW OF STEAM AT VARIOUS PRESSURES THROUGH DIFFERENT SIZED ORIFICES.

An idea of the increased volume of gas which may be obtained by the employment of steam is given by the following table, which has been compiled from results obtained by J. West [1]:—

[1] *Gas J.*, CXL, p. 563.

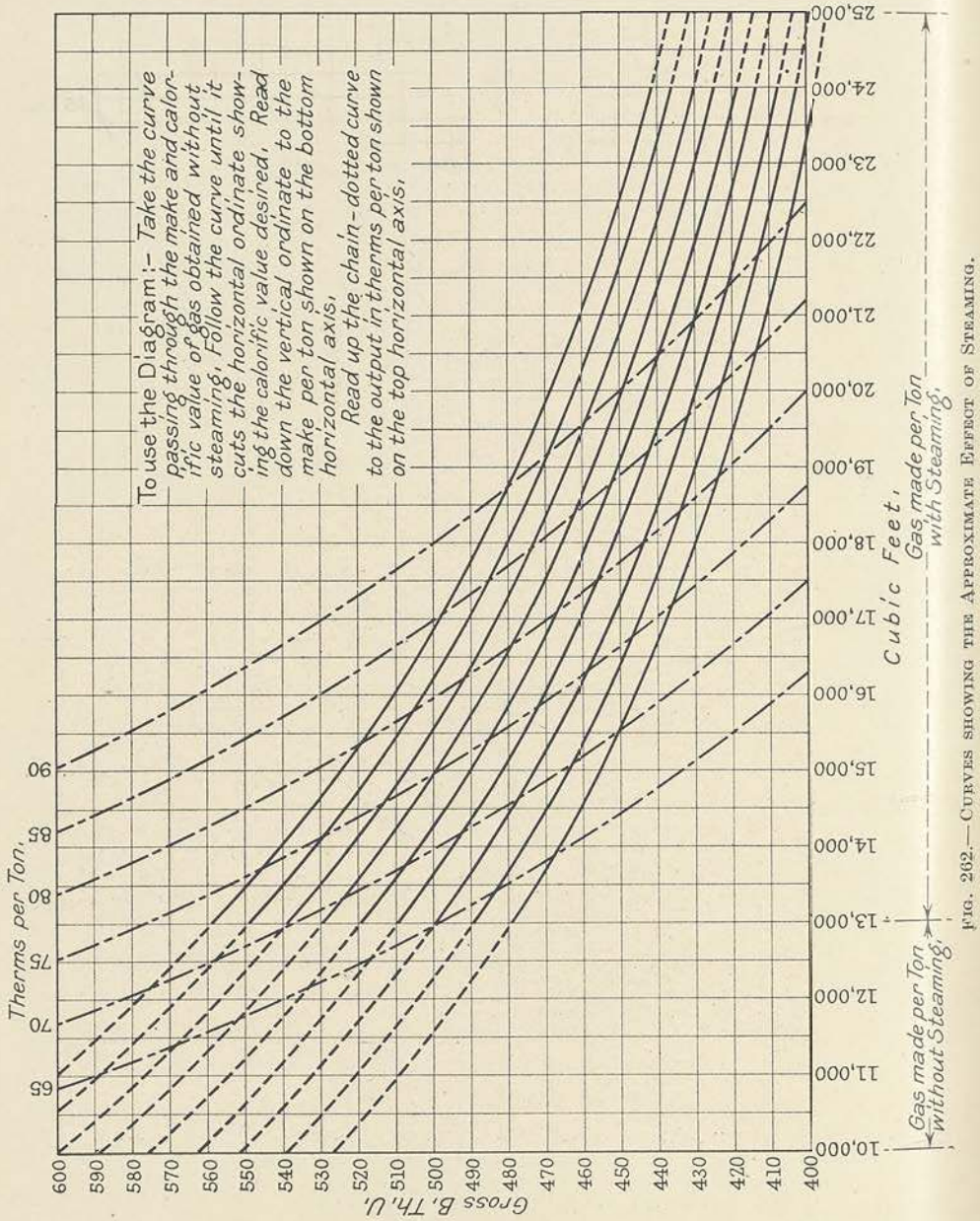


FIG. 262.—CURVES SHOWING THE APPROXIMATE EFFECT OF STEAMING.

EFFECT OF STEAMING IN CONTINUOUS VERTICAL RETORTS

	Without steam.	With steam at 25 lb.	With steam at 40 lb.
Gas, per ton of coal (cubic feet) . .	14,989	17,759	21,684
Calorific power (gross B.Th.U.) . .	503	460	442
Tar, per ton (dehydrated), gallons .	17·4	18·2	18·6
Liquor (10 oz.), per ton, gallons . .	39·7	42·4	40·3
B.Th.U. (gross) per ton of coal . .	7,538,461	8,169,140	9,584,328

Probably the most important work in connection with the process is that which has been published by the Gas Investigation Committee of the Institution of Gas Engineers.[1] In considering the results of the tests it should be remembered that the coal used was comparatively poor from the gasification standpoint, so that they do no necessarily represent the maximum results obtainable. Five complete tests were carried out, and the volume of gas per ton of coal increased (as the amount of steam was increased) from 10,384 cubic feet to 21,849 cubic feet. At the same time the gross calorific power of the gas decreased from 544 B.Th.U. per cubic foot with no steam admitted to 410 B.Th.U. with maximum steaming.

The composition of the gas made changed gradually with increasing amounts of steam in such manner that the volume of hydrocarbons per cent. decreased from 2·3 to 1·6, and methane from 28·5 to 14·5; while the amounts of carbon dioxide increased from 2·2 to 6·6 per cent., and carbon monoxide from 10·3 to 17·9 per cent.; the hydrogen remained almost constant at 48 to 50 per cent. by volume. The total number of heat units in millions B.Th.U. made in gaseous form per retort per day increased from 15·94 gross to 26·70, but in the last test the figure fell to 24·94 since the increase in the amount of potential heat energy per ton in gaseous form was more than counterbalanced by the reduction in the amount of coal carbonized per retort per day.

One of the most important considerations in connection with steaming is that of coke yield. Definite figures of the actual amount of coke remaining for sale are particularly difficult to obtain, but from the Gas Investigation Committee's results it would appear that for each additional 6,570 cubic feet of gas made beyond the yield of straight coal gas 1 cwt. of coke is consumed. As regards the actual weight of coke sold the following figures are extracted from reports made by the engineers of gasworks in various parts of the country where continuous vertical retorts are in use.

COKE SOLD PER TON OF COAL CARBONIZED. STEAMED VERTICAL RETORTS

	Cwts. Coke sold per ton of Coal.
1. Uddingston	8·53 (9·25 cwt. without steaming)
2. Macclesfield	9·50
3. Nelson	8·26
4. Helensburgh	7·93 (8·8 cwt. without steaming)

[1] *Proc. Inst. Gas Eng.*, June, 1920.

As regards the effect of the size of nozzle and the pressure at which steam is supplied the following figures (extracted from tests carried out at Uddingston gasworks) are instructive :—

INFLUENCE OF NOZZLE SIZE AND STEAM PRESSURE ON RESULTS

Size of nozzle.	Steam pressure (lb.).	Gas yield, cubic feet per ton of coal.	Calorific power, B.Th.U. gross.
$\frac{1}{16}$-inch	5–6	9,870	560
$\frac{1}{16}$-inch	25–30	13,554	500–520
$\frac{1}{8}$-inch	25	15,487	506
$\frac{1}{4}$-inch	10–12	14,450	480–500
$\frac{1}{4}$-inch	25	17,500	430–450

Where steaming is employed considerable use will probably be found for the chart given in Fig. 261, which shows the quantity of steam (in lb. per hour) which is passed by different sized orifices at a number of different pressures. Again, an idea of the increased quantity of gas per ton of coal which may be expected with different types of coal (the straight gas yield of which is known) may be gathered by reference to the curves (specially prepared by Mr. John West), shown in Fig. 262.

The general effect of steaming, and the modifications resulting from the variation of the quantity of steam admitted, is well shown by the following series of figures which have been compiled from the series of five tests carried out at the Uddingston gasworks by the Gas Investigation Committee.[1]

TABLE SHOWING EFFECT OF VARYING QUANTITY OF STEAM ADMITTED

Test No.	I.	II.	III.	IV.	V.
Diameter of nozzles (inch)	—	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$
Steam pressure at nozzles (lb.) . . .	No steam	Normal	5·16	10·02	15·20
Steam, per cent. on coal used . . .	—	13·3	22·1	32·7	44·8
Gas made per ton of coal (cubic feet) .	9,367	12,666	15,222	17,814	19,593
Calorific power, B.Th.U. gross . . .	544	482	447	436	410
Coke *made* per ton of coal (cwts.) . .	11·90	11·54	11·13	10·55	10·34
Tar (dry) per ton of coal (galls.) . .	13·20	16·40	16·80	20·40	21·20
Liquor (10 oz.) per ton of coal (galls.) .	38·80	39·30	41·10	45·10	46·80
Sulphate per ton of coal, 24½ per cent. (lb.)	34·40	34·80	36·40	39·90	41·40
B.Th.U. per ton of coal (in millions) .	5·096	6·105	6·804	7·767	8·033

Apart from the substantial increase obtained in British Thermal Units per ton of coal, the remarkable increase in the yield of tar and ammonia should be noted. This is no doubt due to the fact that secondary reactions are largely prevented from occurring, partly owing to the fact that the volatile products are rapidly

[1] See *Proc. Inst. Gas Eng.*, June, 1920.

swept from the retort by the scouring action of the steam, while the state of dilution existing affects the position of gaseous equilibrium. Cobb has suggested that ammonia is formed by the action of steam in breaking down complex nitrogen compounds. It should be understood that in the above table the figures given for coke yield represent the total coke made. In this instance the retorts were heated by surplus coal gas, thus no coke was employed as fuel.

The effect of various degrees of steaming on the ultimate composition of the gas is well illustrated by the analyses which accompany the five tests already quoted.

Effect of Steaming on Composition of Gas

Test No.	I.	II.	III.	IV.	V.
Steam, per cent. on coal used	Nil	13·3	22·1	32·7	44·8
Analysis of gas (per cent. by vol.):					
Hydrogen	49·5	49·5	48·9	48·8	48·3
Methane	28·5	23·5	19·0	16·8	14·5
Unsaturated hydrocarbons	2·3	1·8	1·8	1·8	1·6
Carbon monoxide	10·3	13·8	16·4	17·4	17·9
Carbon dioxide	2·2	3·3	3·6	5·1	6·6
Nitrogen	6·8	7·5	9·4	9·2	10·1
Oxygen	0·4	0·6	0·9	0·9	1·0
Total inert constituents	9·4	11·4	13·9	15·2	17·7
Calorific power, B.Th.U. gross	544	482	447	436	410

If the above percentages are converted into cubic feet of each constituent per ton of coal it will be observed that not only have hydrogen and carbon monoxide been generated but the hydrocarbons have also been augmented. Thus :—

Cubic Feet per Ton of Coal Carbonized

Test No.	I.	II.	III.	IV.	V.
Methane	2,669	2,976	2,892	2,992	2,841
Unsaturated hydrocarbons	215	228	274	320	313

It will be observed that the quality of the extra gas tends to fall with increasing quantities of steam, and the problem arises as to what percentage steaming may be carried before the desirable limit is passed. Much must depend upon the class of coals employed, but it should be noted that with steaming at 32·7 per cent. not only has the calorific power of the mixture fallen to 436, but inerts are present in the proportion of over 15 per cent. To conform, therefore, with present-day ideas as to the most economic gas to supply, it would appear that it is not advisable to exceed 30 per cent. of steam on the weight of coal used.

The main difficulty when steaming is carried out on a high percentage basis

would appear to be that of maintaining an adequate temperature in the retorts, more especially in the lower sections where the endothermic nature of the water gas reaction is most marked. The importance of temperature on the composition of the gas yielded by the water gas reaction is well illustrated by the figures given by L. J. Willian[1]:—

Effect of Temperature in Water Gas Reaction

Temp. ° C.	Per cent. of steam decomposed.	Composition of gas, per cent. by volume.		
		Hydrogen.	Carbon monoxide.	Carbon dioxide.
670	8·8	65·2	4·9	29·8
760	25·3	65·2	7·8	27·0
837	41·0	61·9	15·1	22·9
955	70·2	53·3	39·3	6·8
965	94·0	48·8	49·7	1·5
1,070	99·4	50·9	48·5	0·6

The above figures clearly indicate that as steaming is progressively increased there must essentially be a corresponding rise in the proportion of carbon dioxide in the gas unless means are found to maintain the retort at temperatures sufficiently high to permit of a maximum decomposition.

Downward Steaming

The general practice when steaming the coal charge has been to admit the steam to the base of the retort so that a scouring action on the products evolved from the coal is effected. A method,[2] however, has been introduced by T. Settle in which the usual upward steaming from the base is replaced by a downward stream admitted near the upper end of the coal charge. In this case the steam is superheated and passes at a pressure of 30 lb. into the gas outlet fixed to the retort. The supply is so arranged, in fact, that instead of impinging on the coke with a high velocity, as in the more common methods, the steam approaches the charge at a slow speed and is equally diffused over the whole cross-section of the retort. Continuous downward steaming, however, is not carried on, but the supply is turned into each charge in succession, over the last three hours of a 12-hour distillation period. The retort at this period contains, of course, coke and breeze only, and the top gas outlet is closed so that the steam has to travel downward through the hot coke, the products due to it passing thence by a special connection to the base of an adjoining retort, through which they travel upwards through the coal charge and thus to the gas outlet. Each retort therefore receives during the period of distillation three hours' steaming downwards and three hours' treatment with blue gas upwards. The advantage of the highly heated upwards stream of blue gas is that a diluting

[1] *Proc. New England Assocn. Gas Eng.*, 1919. [2] See page 165.

effect upon the rich gases takes place without loss or absorption of heat; moreover, the speed of travel towards the gas outlet is greatly accelerated, thus curtailing secondary action.

So far as the yield of B.Th.U. per ton of coal is concerned some remarkable results have been obtained at Truro gasworks, the main features of which are shown below:—

CARBONIZING RESULTS FROM DOWNWARD STEAMING

	I.	II.
Steam pressure, lb.	20	25
Gas yield per ton of coal	16,860	17,483
Calorific power (B.Th.U. gross)	489	503
Coke made per ton of coal, cwts.	12·94	12·97
B.Th.U. in gas per ton of coal (in millions)	8·242	8·805
Type of coal	Whitwood	Wigan Arley

ATMOSPHERE IN VERTICAL RETORTS

The modern vertical retort lends itself admirably to an adjustment of "atmosphere." This fact has led to important attempts to modify both liquid and gaseous products by adjusting the conditions of atmosphere in accordance with the results desired. Hydrogen may be readily brought into the retort, either in the form of debenzolized coal gas, as blue water gas, or by the generation of water gas *in situ* by the injection of steam. J. W. Cobb [1] has said that the action of a scouring gas in the retort may be regarded in two ways. Even an inert gas, such as nitrogen, would not be without effect, because it would wash the volatile products out of the pores of the coke, assist their volatilization by lowering their concentration in the vapour phase, and hurry them away from the region of decomposition. So light a gas as hydrogen has a great power of diffusion, and it is therefore even better able to penetrate the pores and perform these duties. The general effect of the ascending stream of gas to be anticipated is that of increasing the yield of gas and of the lighter constituents in the tar. In so far, however, as the secondary products of carbonization are concerned (in which are included benzene, toluene, and other valuable products for the manufacture of dyes and drugs), the plant which excels in the rapid removal of products without any considerable decomposition may have its disadvantages. The suggestion is made, therefore, that carbonizing plant might be so modified that, whereas conditions would prevail which would ensure a high yield of gas and paraffinoid condensed products, the gas should be accorded secondary heating, which would ensure the volatile hydrocarbons being obtained in the benzenoid form.

The tendency for paraffins to predominate when ordinary grades of gas coal

[1] Wm. Young Memorial Lecture, Sept., 1918.

are employed in continuously operated vertical retorts, has prompted Perkin and West [1] to develop a system by means of which the hydrocarbons, particularly those remaining in the tar, may, if desired, be transformed largely into the benzenoid variety. The method, it is claimed, provides a means whereby a higher yield of coal tar and of low-boiling aromatic hydrocarbons may be obtained under high temperature conditions, with a corresponding diminution of hydrocarbons of the aliphatic series, the presence of the latter in the lower fractions of the tar adding to the difficulty of purifying the benzol and toluol. Perkin and West state that if a gas of moderately low quality—such as " stripped " coal gas—be passed into the lower end of the retort at such a rate that it is able, after traversing the incandescent coke zone, to carry the volatile matter from the partially carbonized coal through the relatively cool coal (which is just entering the hot zone of the retort) without the volatile matter becoming condensed in the cool coal in any degree, then not only is the amount of tar distilled increased in volume, but its specific gravity is decidedly lower. In this process the stream of low quality gas is admitted beneath the coke-extractor worm; and, as the rate of supply of the subsidiary gas is of importance, it is regulated by increasing the vacuum exerted by the exhausters on the main gas outlet, or by admitting gas under pressure. The tar is found to contain an additional proportion of benzene, toluene, xylene and phenols, with a corresponding diminution in the yield of paraffins.

THE TEMPERATURE THROUGHOUT THE CHARGE

The temperatures prevailing throughout the carbonizing mass vary to some extent with the weight of the charge, and it is generally found that whereas with the light charge in the horizontal retort the hottest zone is that in contact with the bottom and sides of the retort, with complete filling the hottest portion will be that forming the surface of the coal. The pyrometric observations of Bond, recorded in the proceedings of the Institution of Gas Engineers, are of considerable interest and throw much light on the conditions prevailing. This investigator has shown that the solid residue tends to divide into two distinct layers, and he recorded temperatures at the three zones (*A*, *B*, and *C*, Fig. 263) for varying periods of the charge. At the zone *A* the temperature at the commencement of the charge was 675° C.; at the end of the first two hours, when 37 per cent. of the total gas had been evolved, it was 800° C.; whilst after four and a half hours a maximum of 1,000° C. was attained. As regards the zone *B*, at the centre of the charge, after the coal had been distilling for two hours the temperature was approximately the same as at the base of the charge, but never exceeded the latter. At the commencement of carbonization the temperature of the core—as would be

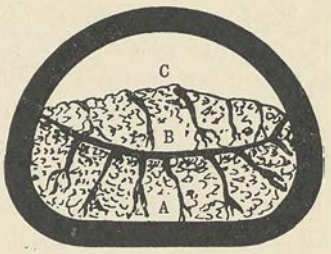


Fig. 263.—Temperatures at Various Zones of Charge.

[1] Eng. Pat. 114937/1917.

expected—was only 440° C. These results all refer to a charge 6 inches in depth. Considerable variation was found when the thickness of the coal layer was increased to 12 inches. In this case the temperature of the core at the commencement was no more than 94° C., but as carbonization proceeded a gradual increase was noticeable, until after eight hours there was only a slight difference between the base and the core of the charge. At this period the hottest portion of the charge was the surface, which had risen to about 1,065° C.

The following table, compiled from figures given by G. P. Lewis, gives a useful insight into the conditions of temperature obtaining during an eight-hour charge :—

		Time after commencement of charge.								
		Hours.								
		½	1	2	3	4	5	6	7	8
		Degrees Fahrenheit.								
Light charge (6 inches thick)	Bottom	1,290	1,360	1,460	1,700	1,850	1,870	1,870		
	Centre	1,110	1,250		1,650	1,900	1,830	1,830		
	Top	930	1,100	1,360	1,600	1,740	1,760	1,850		
Heavy charge (12 inches thick)	Bottom	1,110	1,170	1,290	1,380	1,440	1,470	1,560	1,690	1,890
	Centre	200	210	300	410	500	610	1,080	1,470	1,870
	Top	1,380	1,470	1,560	1,590	1,620	1,690	1,780	1,870	1,920

With regard to vertical retorts of the continuous type, at the point of combustion the temperature is about 1,300° C., and at the base of the retort it is approximately 1,100° C. It must not be lost sight of that in the vertical retort progressive heating may be employed, whereas in horizontal systems this is not practicable. By such heating, the prevailing temperatures of the various portions of the retort may be varied and the charge subjected to differing intensities of heating as it travels downwards. Thus we get the two types of heating, namely, top and bottom, in the first of which the upper portions of the retort are subjected to the most severe temperatures, the lower portions being more highly heated in other systems. The conditions prevailing in vertical retorts are illustrated in Figs. 264 and 265. Whilst in continuous systems the relative positions of uncarbonized coal, the viscid layer surrounding it, and the coke zone remain practically constant, this is not the case with intermittent systems, in which the pasty envelope gradually closes in towards the centre of the charge. With continuous charging, even if top heating be adopted, the upper portions of the mass will still be relatively cool, so that the primary gases coming away at low temperatures are subjected to the minimum of degradation. With intermittent working, however, it is essential to heat the base of the retort more highly, for in this way the lower portions of coal are carbonized in advance of the upper, and thus a freer passage through the central core is assured. The coke,

moreover, is subjected to a maximum temperature just before leaving the retort, so that a considerable proportion of the volatile matter is expelled from it. That this is desirable is shown by tests carried out by Davidson, who found that even "well-burned-off" coke will give off quite a large amount of gas. Taking an ordinary coke containing 1·97 per cent. of volatile matter, it was shown that on further heating this would yield an additional quantity of gas equal to 2,900 cubic feet per ton of coke, the composition of the gas being as follows :—

Hydrogen . .	86·8 per cent.
Methane . .	2·05 ,,
Carbon monoxide .	6·5 ,,
Carbon dioxide .	0·6 ,,
Nitrogen . .	4·05 ,,

The temperatures prevailing in vertical retorts are now largely governed by the extent to which steaming is carried on. The following table [1] is extracted from actual readings taken at Uddingston gasworks with Glover-West retorts :—

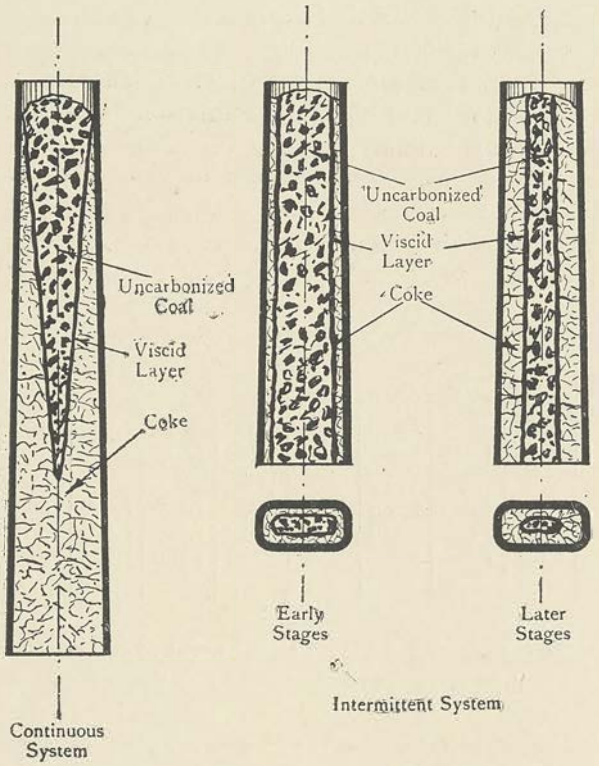


FIG. 264.

FIG. 265.

TEMPERATURES IN VERTICAL RETORT SETTINGS
(Degrees Centigrade)

	No steaming.	Steaming, 13·3 per cent.	Steaming, 22·1 per cent.	Steaming, 32·7 per cent.	Steaming, 44·8 per cent.
Waste gas flues	876	902	964	910	930
Circulating flues—middle . . .	1,089	951	1,095	1,081	1,065
,, ,, —bottom . . .	1,141	1,005	1,163	1,175	1,126
Combustion flues—top	1,180	—	—	1,207	—
,, ,, —bottom . . .	1,218	1,131	1,085	1,150	1,033
Secondary air flues—top . . .	755	700	646	637	585

[1] *Proc. Inst. Gas Eng.*, June, 1920.

The Travel of Gas in Vertical Retorts

So far as the path by which the gas finds its exit from the horizontal retort is concerned, when once a ring of hot coke has been formed around the cool coal core the only way of escape for the products is through this heated zone. In both types of vertical retorts, however, matters are different, and the volatile constituents may leave either by way of the cool central core, or by evolution from the outer layers of the pasty envelope they may travel upward through the heated coke. The former, owing to the absence of excessive degradation, is, of course, the most desirable outlet, and Bueb is of the opinion that with intermittent vertical systems the gas takes this course. Colman, however, holds the view that Bueb's hypothesis is only true to a very limited extent, except in cases where no pasty envelope is formed—as with shales and non-caking coals. Colman corroborated his views by analysing the gas from various portions of the retort, with the following results :—

	Gas drawn from coal core.	Gas drawn from coke zone.	Final gas obtained.
Hydrogen	45·3 per cent.	59·0 per cent.	53·5 per cent.
Methane	37·2 ,,	20·2 ,,	28·0 ,,
Carbon monoxide	8·8 ,,	12·9 ,,	11·9 ,,
Carbon dioxide	5·9 ,,	3·0 ,,	3·2 ,,
Unsaturated hydrocarbons	2·0 ,,	1·9 ,,	2·3 ,,
Oxygen	nil	nil	nil
Nitrogen	0·6 ,,	3·2 ,,	1·3 ,,

The marked resemblance of the final gas to that obtained from the coke zone will be noticed.

Vertical retorts, though having fully established their claims in many directions, are still passing through a stage more or less of evolution, and therefore it is inopportune to discuss their relative merits as carbonizing agents compared with the time-honoured horizontal retorts. One cannot do better than quote the views of an authority who has had every opportunity of experimenting with all kinds of plant. His opinion is that " on summing up the respective balance-sheets, very little difference may be found between the two competitive systems, and local circumstances may settle the question one way or the other."

CHAPTER XIII

THE CONDENSATION OF COAL GAS

ALTHOUGH the operation of condensation might appear to be one of extreme simplicity, this is by no means the case ; for the character of the final products obtained is appreciably influenced by the manner in which the gas is dealt with at this stage. Condensation may be best defined as the reduction of the gas to normal temperatures, and the simultaneous removal of all those substances which are not permanent gases at such temperatures. In the main, the apparatus employed for the purpose is of a simple nature, and merely embodies the principle of exposing large surface areas to the action of a cooling agent. On gasworks the cooling medium employed is either air or water, or both. The atmospheric condenser was a common feature of gasworks in the past, and it is still to be found in many of the smaller and medium-sized works. As a cooling agent, however, water is infinitely more efficient. When a temperature drop of 10° Fahr. is required, the capability of water (per square unit of surface exposed) to bring about the reduction is eleven times as great as that of air, and when the temperature drop increases to 50° Fahr. the proportional efficiency is more than 200 to 1. In addition, the water-cooled condenser is easily regulated, so that a more or less constant outlet temperature may be obtained whether the apparatus is working up to its full capacity or not.

ATMOSPHERIC CONDENSERS

Condensers of the atmospheric type are of no stereotyped construction, and in the case of some small works are often made up from odd lengths of pipe and connections which the manager may have at his disposal. In general, however, the chief standard varieties in common use may be classified as follows :—

(*a*) Horizontal types.
(*b*) Vertical types.
(*c*) Annular types.
(*d*) The battery condenser.

The horizontal condenser shown in Fig. 266 frequently takes the form of an extended foul main which is carried in zigzag fashion from end to end of one of the retort-house walls. As blockages from naphthalene or pitchy deposits are likely to occur at times, it is essential that flange connections should be used, so that clearing may be easily effected. The condensed liquids flow down the sloping pipes in the

same direction as the gas. In the general way this procedure—when slow travel is assured—would seem to be quite effective in the removal of naphthalene. In conjunction with the steel foul main, steel is also being employed to a large extent in the construction of condensers. The horizontal condenser shown in the sketch is constructed in spiral form, and differs from the most simple type in that it rests upon its own stanchions. A common type of vertical air condenser complete with gas and tar outlets is shown in Fig. 267. The annular atmospheric condenser (Fig. 268) has in the past assumed a good deal of importance, and is probably the most satisfactory example of these types, in that the intensity of cooling is to some extent under control. As can be seen from the sketch, the gas passage in the tall vertical

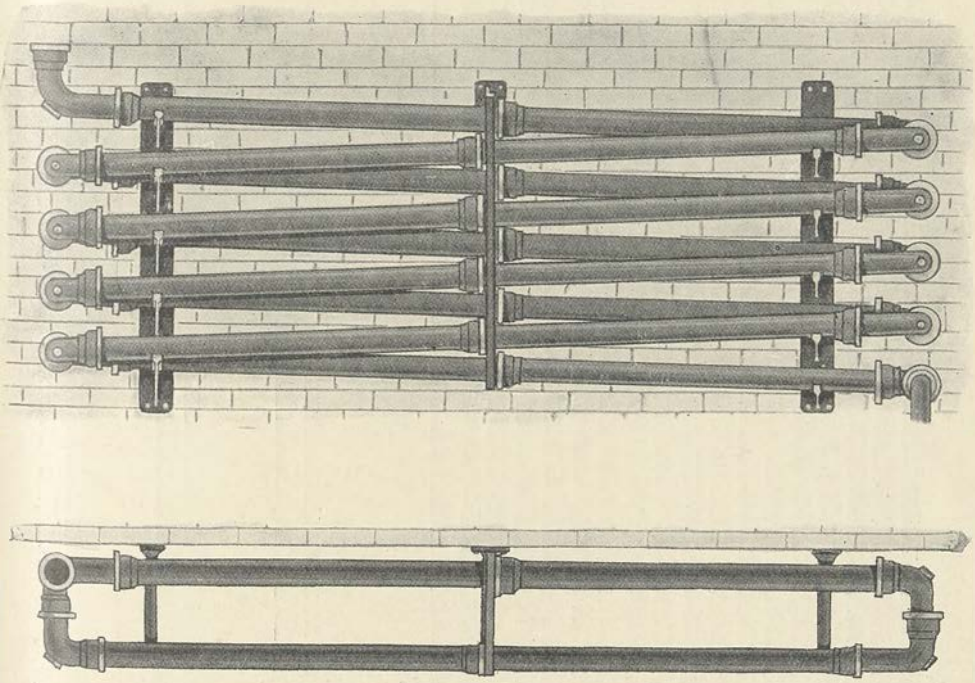


FIG. 266.—HORIZONTAL CONDENSER.

cylinders is annular in form, hence both an inside and outside surface are exposed to the cooling effect of the air. The diagonal side pipes convey the warm gas to the upper ends of each annular cylinder, and in this way a comparatively strong draught is caused to ascend the inner air tube. Butterfly valves or dampers are fitted to the top of each vertical air pipe, so that the amount of cooling can be regulated in accordance with requirements. These valves are usually operated by means of a hand chain reaching to the ground. Occasionally this type of condenser is found with the diagonal pipes omitted, the cylinders being connected by short horizontal branches, in which case the gas travels up and down the cylinders alternately.

The annular condenser shown in the figure is the improved Walker type, and may be composed of any number of tubes. It will be noticed that the inner cylinder is coned, so as to increase the annular space at the bottom. In this way stoppage due to tarry deposits is avoided. The base of the annular space is also given a fall, so that tar may run away readily to the seal-pot. Annular condensers should,

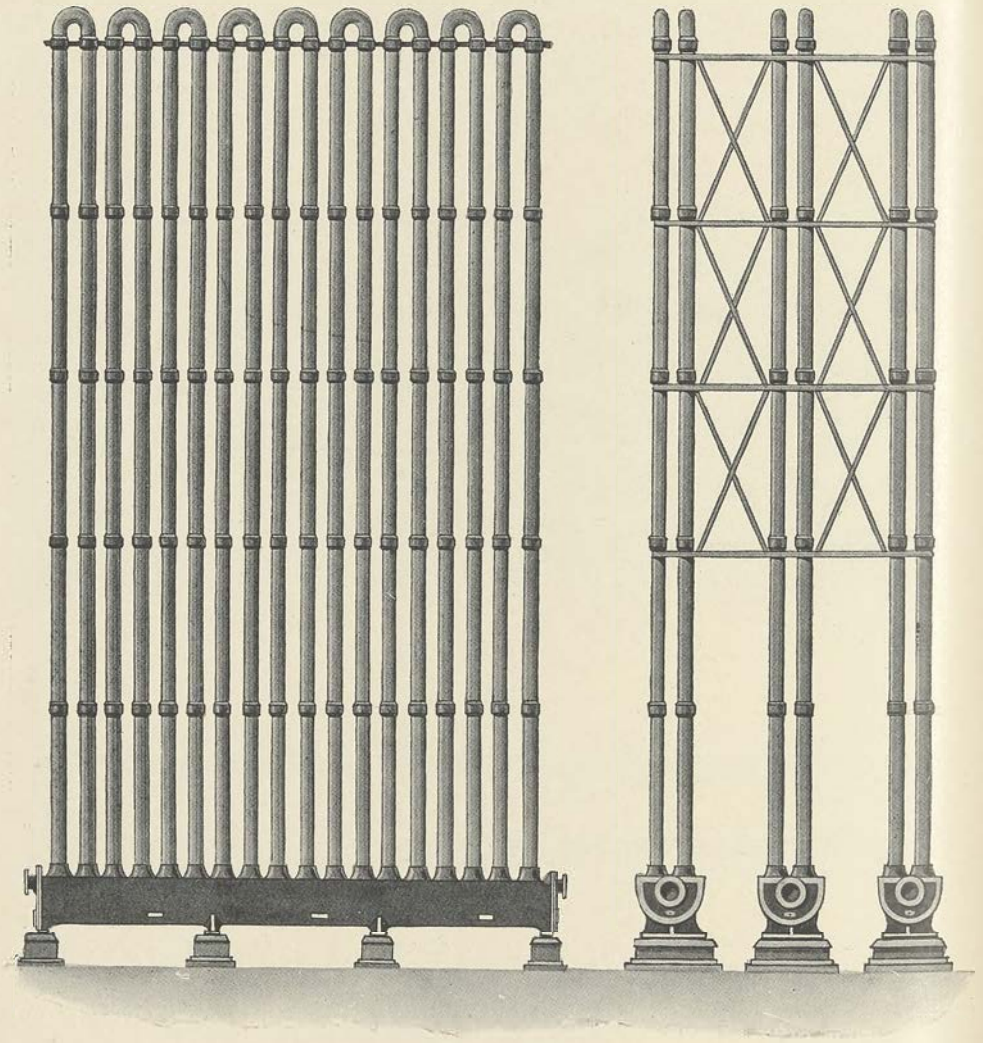


FIG. 267.—VERTICAL CONDENSER.

whenever possible, be fixed in a moderately sheltered position so that they are not exposed to the extremes of climatic conditions. As regards their size, one rule (given by R. and J. Dempster) states that the allowance of superficial cooling surface should be 150 to 200 square feet per 1,000 cubic feet of gas passing per hour.

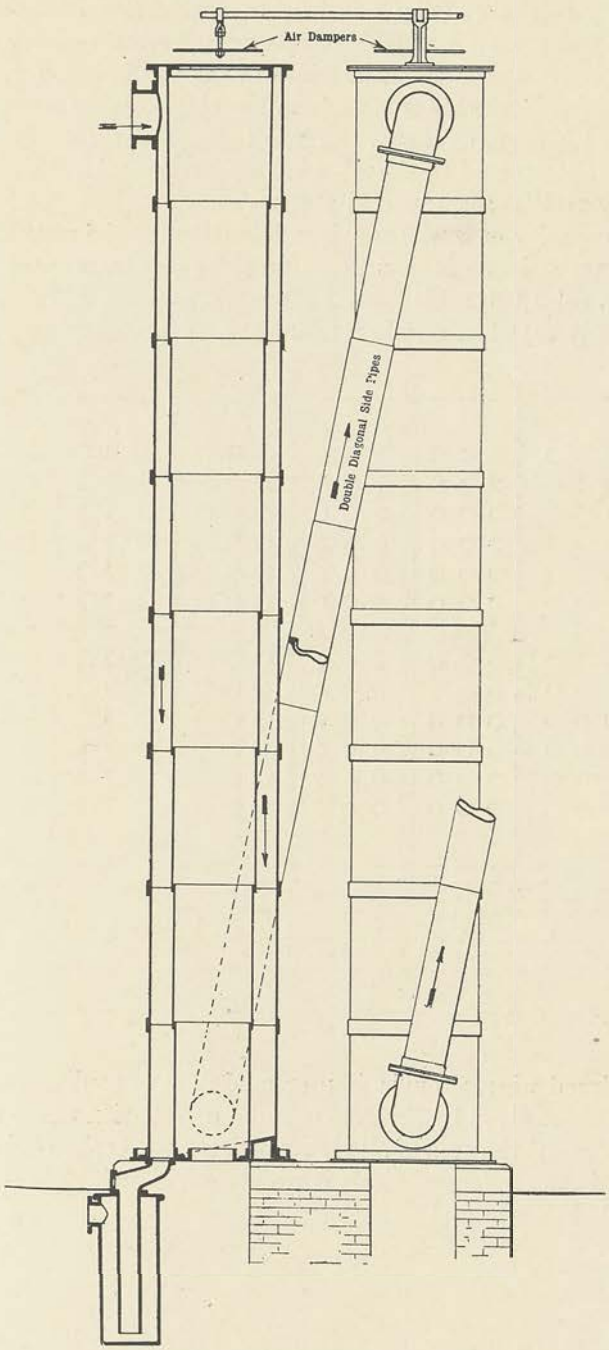


FIG. 268.—ANNULAR CONDENSER.

The battery condenser (Fig. 269) is of somewhat novel construction. It consists of a long and narrow box divided internally by baffle-plates which cause the gas to take a circuitous course. The width of the box is usually about 2 feet, and small tubes passing from side to side form the chief cooling surface. The ends of these tubes are left open, so that a current of air readily passes through. In addition, the obstruction caused by the tubes has some effect in breaking up and throwing down the tarry vesicles suspended in the gas.

So far as capacity of condenser plant is concerned, the most reliable rule from which to form an estimate is that which provides an allowance of 5 square feet of superficial area per 1,000 cubic feet of gas made per diem. This is sufficient (but not extravagantly so) when cast-iron mains and apparatus are employed, and may

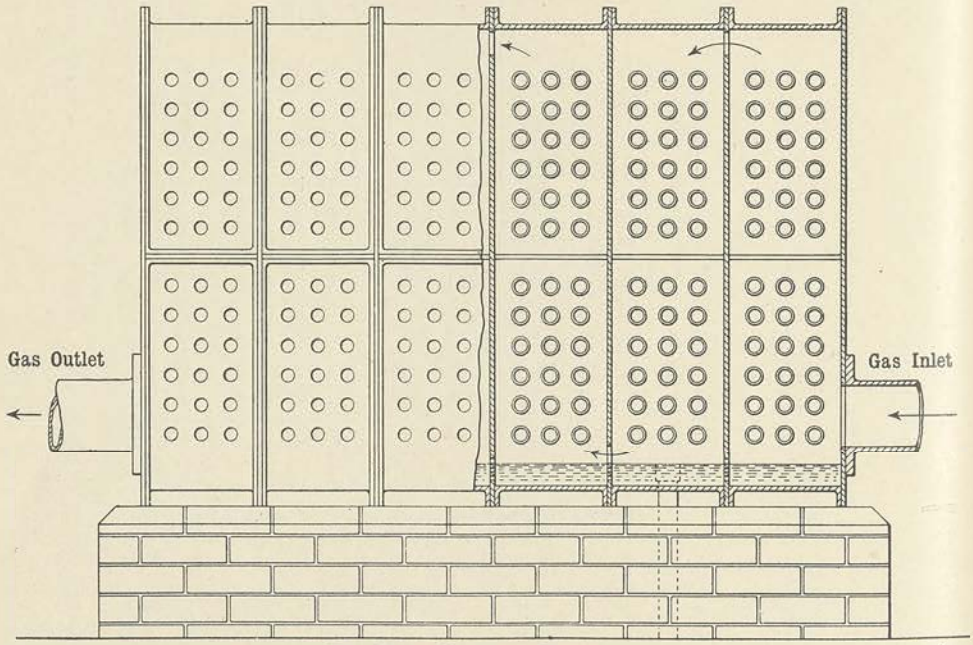


FIG. 269.—BATTERY CONDENSER.

be slightly reduced when wrought iron or mild steel is used. It must be borne in mind that the figure given by this rule includes (in addition to the areas exposed by the actual condenser) the area of all piping between the outlet of the hydraulic main and the inlet of the condenser. This is readily calculated. The following relate to pipes commonly in use as foul mains :—

6-inch	pipe.	Each foot run	exposes an	area of	1·57 square feet.
9-inch	,,	,,	,,	,,	2·35 ,,
12-inch	,,	,,	,,	,,	3·14 ,,
15-inch	,,	,,	,,	,,	3·92 ,,
18-inch	,,	,,	,,	,,	4·71 ,,
24-inch	,,	,,	,,	,,	6·28 ,,

Many other rules exist for computing the capacity of condensers. One based on the quantity of coal states that 100 to 120 superficial feet should be allowed for every ton carbonized per diem. Another rule, based on thoroughly sound principles, but difficult of application in practice, says that 4 square feet of surface should be allowed per gallon of water yielded per ton of coal. In order to preclude the too sudden condensation of gas there was in past years a generally recognized formula stipulating that of the total length of foul main 20 feet of length per inch diameter of the pipe should be under cover in the retort house. The rule, however, has lost its significance in present-day practice. As regards the dissipation of heat it may be assumed that this will amount, approximately, to 1 B.Th.U. per minute for each superficial foot of cooling surface exposed to the air and for each degree (Fahr.) above atmospheric temperature.

WATER CONDENSERS

Water condensers as now employed are almost solely constructed from riveted mild-steel plates (which form the outer shell) and steel or wrought-iron tubes. There are two distinct types at present in use, namely :—

(*a*) Multitubular condensers.
(*b*) Water-tube condensers.

Although both types possess their respective advantages, it is now generally recognized that, except in cases where the condensing water is exceptionally clean,

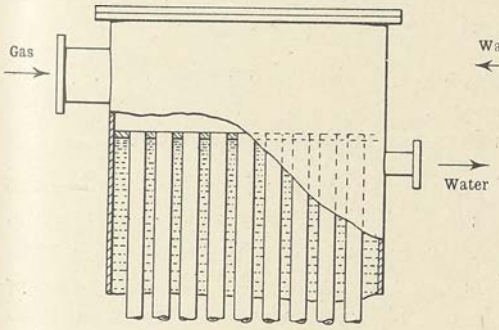


FIG. 270.—MULTITUBULAR CONDENSER.

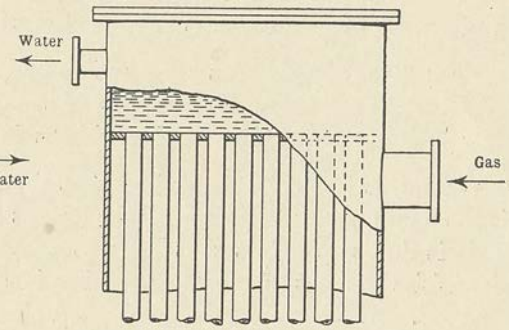


FIG. 271.—WATER-TUBE CONDENSER.

the water-tube condenser is to be preferred. The outstanding distinction between the multitubular and water-tube condenser is that in the former the water passes outside and around the tubes which carry the hot gas, whereas in the latter type the opposite is the case. The difference is clearly seen by reference to Figs. 270 and 271. It will be realized that when any deposit is likely to take place it is far preferable to have this within the tubes, which can be readily cleaned, rather than in the chamber surrounding them. Thus when only muddy water pumped from rivers or canals is obtainable there should be no hesitation in adopting the water-tube system. On the other hand, if the incoming gas is particularly dirty and

contains an undesirable quantity of heavy tar vesicles, the outer chamber is liable to obstruction from this cause. In the calculation of the area of cooling surface required it should be remembered that the actual surface to be considered is that with which the gas is in contact. Hence when the gas travels inside a tube the interior surface must be taken, but when the gas is surrounding the tube the exterior surface is considered. From this it will be seen that the water-tube type gives more condensing area for the same number of tubes. Mention has already been made of the combined atmospheric and water-cooled condenser. This in reality amounts to nothing more or less than a condenser of the water-tube type. In this case it will be seen that the outer casing is available as an atmospheric cooling surface, whereas in the multitubular condenser this function is lost, owing to nearly cold water (instead of hot gas) being in contact with the shell. J. S. Haug has pointed out that the upkeep of the multitubular condenser as regards painting is much more expensive, due to what is commonly called " sweating," which is occasioned by the condensation of moisture from the air on the cold shell. In the case of the water-tube condenser the shell is hot, and condensation, therefore, does not occur in this manner.

So far as the actual condenser capacity required for a given works is concerned, the general allowance for all types of water-cooled apparatus may be taken as 3 square feet of cooling surface per 1,000 cubic feet of gas passing per maximum diem. In the case of the multitubular type of condenser a deduction (calculated on the rule already given for air-cooled apparatus) may be made for the surface of the outside shell, whilst for all types the length of foul main should be considered, as previously pointed out. To determine the efficiency of a condenser and its ability to deal with a given set of conditions it is necessary to consider :—

(*a*) The average inlet temperature and the desired outlet temperature.
(*b*) The condition of saturation of the gas.
(*c*) The rate of transmission of heat from the surfaces employed.

First, it has to be recognized that the aqueous vapour with which the hot gas is saturated accounts for by far the largest share of the total work of condensation. This is due to the fact that the water vapour has to be deprived of considerable quantities of heat, the same applying in some measure to the liquefiable hydrocarbons. A. F. Browne has estimated that of the total work of condensation 87 per cent. is accounted for in removing aqueous vapour, and 13 per cent. in cooling permanent gases and in condensing liquefiable hydrocarbons. Crude gas, although deprived of a large portion of the aqueous vapour it originally contained, is still in a state of saturation when it leaves at the condenser inlet. If this were not the case the process of condensation would be a trifling matter. The actual number of heat units to be extracted can be arrived at by ascertaining the weight of water vapour present in the gas passing at the inlet, and, similarly, the weight of water vapour present at the outlet. The difference will give the weight of water condensed out of the gas. This figure multiplied by the thermal units to be liberated per pound of water between the inlet and outlet temperatures will give the total amount of heat which is to be eliminated. The ability of a surface to transmit heat varies to

some extent, not only with the difference between the temperatures involved, but with the condition of the surface, *i.e.* whether clean or coated. Haug, in careful experiments, found that when the difference in temperature between the two surfaces (*i.e.* the heat potential) was 30° Fahr., the heat transmission amounted to approximately 6 B.Th.U. per square foot of surface per minute under average working conditions. It must be remembered, however, that as temperature differences decrease the unit given will slowly decrease, and *vice versa*.

THE DESIGN OF CONDENSERS

Several types of water-cooled condensers are in use to-day, but in many cases the difference is only a matter of detail. Older patterns having cast-iron shells are still in evidence, but in general the construction will conform to that shown in Fig. 272. This condenser may be used singly or in batteries, and some means should always be provided where-with the flow of gas and water may be reversed. So far as general dimensions are concerned, the height of the apparatus should be from two to five times the diameter. For smaller condensers 2-inch water tubes may be employed, but the 3-inch is preferable for all larger types. A point to remember is that the length of the tube should not be such as to make it structurally weak; it is as well to confine the ratio of length to diameter within the limit of 80 to 1. The larger tubes are certainly more easily kept free from stoppage and are more readily cleaned, but there is some limit to their size in that as the diameter increases the cooling surface per unit area of ground surface is curtailed. As regards length, it is as well to confine this within the limits of manufacturers' stock sizes, otherwise additional expense will be incurred. The 20-foot tube is, perhaps, most suitable for all the

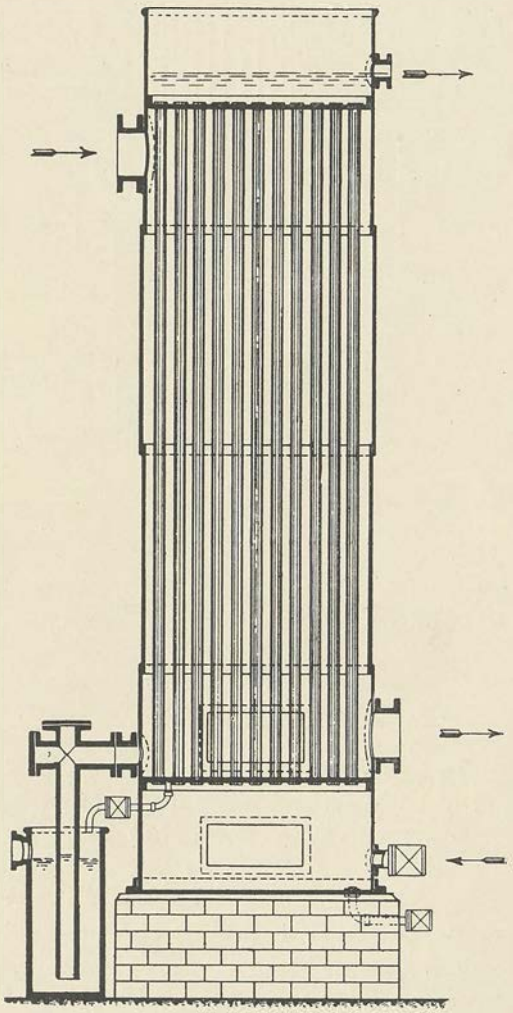


Fig. 272.—Typical Water-tube Condenser.

larger condensers. In shape the modern water condenser is nearly always cylindrical, this section facilitating the building together of the mild steel plates forming the shell. Moreover, the shell of the multitubular type has to withstand the stresses due to water pressure, and the cylindrical shape is better able to do so. Only in the case of the largest condensers is it advisable to work to a rectangular section, and then only in those instances in which the saving of ground space is a consideration. So far as the spacing of tubes is concerned there is no hard and fast rule, but it is as well to remember that the free space in the shell should not be too greatly encumbered; otherwise stoppage will quickly result. A good basis to work upon is that of arranging the tubes so that they occupy about 18 per cent. of the total area of the tube sheet. For water gas this should be increased to 25 per cent.

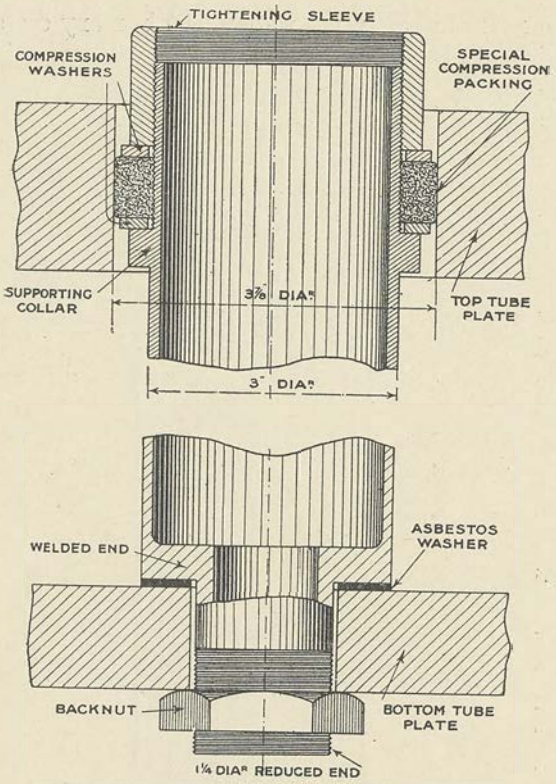


FIG. 273.—DEMPSTER'S SPECIAL TUBE-JOINT.

The modern tubular condenser is most frequently made with the tubes expanded into the top and bottom tube plates; but, in order that expansion and contraction of the tubes may take place without undue straining of the joint, special methods of making the latter are often employed. It will be appreciated, moreover, that some considerable difficulty is entailed in removing an expanded tube when renewals become necessary. The special tube-joint employed by R. and J. Dempster is shown in Fig. 273.

In all modern condensers means should be provided whereby the direction of flow of both gas and water may be reversed, the cold-water inlet always being in counter-current to the flow of hot gas.

THE CARPENTER CONDENSER

Dr. Carpenter, in dealing with large units of gas, adopts the hydraulic form of condenser, consisting of a series of vertical cooling tubes placed in a cylindrical vessel containing water. The tops and bottoms of the tubes are connected by gas chambers, and the gas is made to flow upwards through the tubes in one vessel and down-

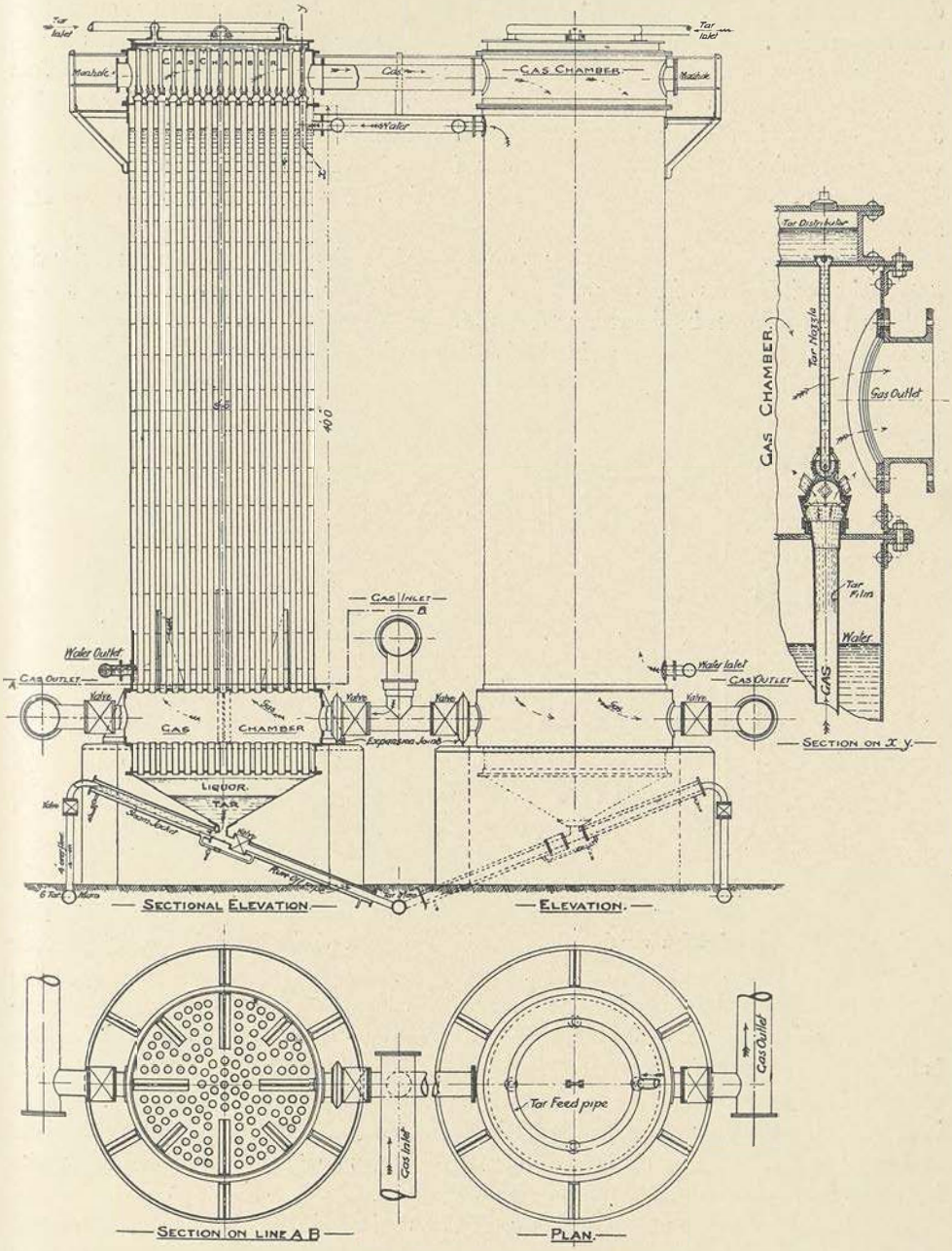


FIG. 274.—CARPENTER'S REVERSIBLE CONDENSER.

wards in the second one. The arrangement of connections and valves is such that the direction of flow of the gas can be reversed when desired. The pair of con-

densers shown in Fig. 274 are capable of dealing with about four million cubic feet of gas per diem. The cold water enters the condenser near the point of exit of the cooled gas and flows up one vessel and down the other in a direction opposite to that of the gas, the outlet for the water being near the inlet for crude gas. By varying the amount of circulating water a more uniform condensation is obtained under the varying conditions of the atmosphere than is possible in the ordinary air condenser. The tubes are 3 inches diameter inside and 40 feet long, expanded into the top and bottom tube plates.

For the purpose of eliminating a large portion of the naphthalene and for the prevention of deposits in the tubes, tar-spraying devices are fitted on the top of every tube, as shown in the enlarged detail. This consists of a tar-distributing box at top, with scaled nozzles provided with " spreaders " or crown castings for distri-

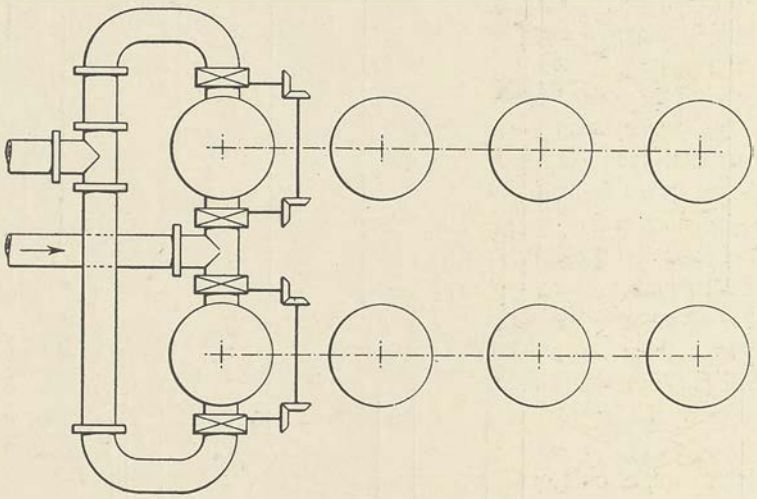


Fig. 275.—Connections for Carpenter's Condenser.

buting a thin film of light tar down the inside surfaces of the gas tubes, the warm tar being pumped into the upper box for this purpose. The gas on ascending or descending slowly through the tubes is washed by this means, and any deposition of naphthalene flows away along with the condensed tar and liquor into a receptacle provided for it in the lower portion of the vessel. A steam-jacketed seal pipe and a run-off pipe are provided as shown. The heated water, after passing through the condensers, is usually circulated through separate air-cooling towers and used continuously over and over again. In most cases tar spraying is not carried on continuously, but for short intermittent periods throughout the day.

The condensers are usually arranged in batteries of any number up to twelve, and are connected up so as to be reversible, as shown in Fig. 275. It will be seen that any possibility of error in operating the valves is guarded against by coupling up the latter by means of gearing. The water valves are arranged in precisely the same manner as those for the gas.

SPECIAL APPARATUS

Special types of condensers are now found which differ both in construction and working from the conventional plant. For instance, the condenser may now be made to carry out the function of a primary washer, the gas being brought

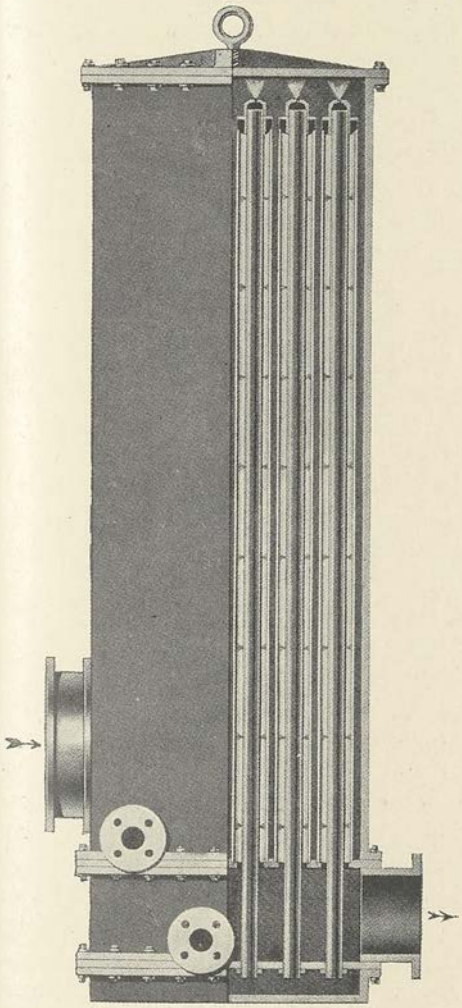


FIG. 276.—THE CHRISTOPHER CONDENSER.

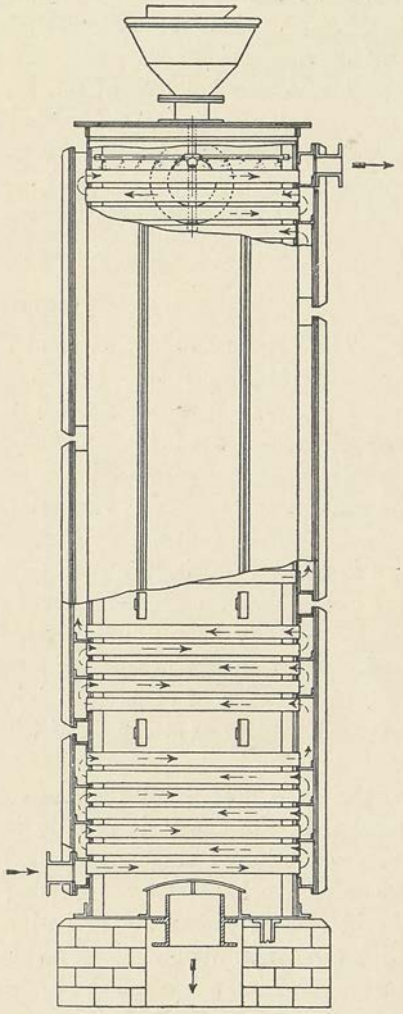


FIG. 277.—WATER-TUBE BATTERY CONDENSER.

in contact with water as well as with water- or air-cooled surfaces. The Christopher condenser, Fig. 276, is designed so that the gas is sprayed during the operation of cooling. It consists of a series of concentric tubes so arranged that the gas, passing downwards through the annular space between the tubes, is divided into a thin film, and is thus brought into intimate contact with the exterior surface of the inner

tube, and the interior surface of the outer tube. For gasworks purposes the washing liquid employed is water, although for special purposes oil or thin tar may be utilized. The flow of gas through the condenser may be reversed so that, instead of entering at the top and passing down the annular space, it may enter at the bottom when it passes vertically between the tubes to the upper part of the tube chamber. It will be observed that sprays are fitted at the top of the water tubes as well as at equidistant points throughout their lengths; but in normal instances the top sprays and the upper side sprays only are put into operation.

A water-cooled type of battery condenser is shown in Fig. 277. The condenser is rectangular in shape, preferably built up from steel plates, and is divided by baffles into separate compartments. Water is admitted at the bottom, passing in a zigzag course through the apparatus in an opposite direction to the gas. By means of a "tumbler" attachment at the top weak liquor may be sprayed intermittently on the exterior of the water tubes, thereby assisting to wash the gas.

THE THEORY OF CONDENSATION

The primary object of condensation is not merely that of cooling the gas to atmospheric temperature, but to ensure that the bulk of the constituents which are not permanent gases at normal temperatures are separated out. By the law of vapour pressures it is known that the saturation content of a gas decreases correspondingly with any reduction of temperature, and that the gas is unable to hold in suspension any excess of vapours above the quantity corresponding with its vapour pressure at the reduced temperature. Accordingly, as the temperature of the hot gas is reduced during its passage through the condenser, a considerable portion of the excess vapours (in the form of steam and liquefiable hydrocarbons) is deposited. As has already been pointed out, it is the aqueous vapour which accounts for the greater portion of the work of cooling entailed.

In the case of coals containing a high proportion of moisture or which yield a large quantity of steam on distillation, the condensation apparatus may be almost entirely occupied in dissipating the heat arising from the formation of steam. Owing to the extremely finely divided condition in which many of the particles are suspended in the gas it is usually impossible to bring about their entire separation by a reduction of vapour pressure by cooling. For this reason the gas is frequently accorded mechanical treatment with the object of removing all traces of solid or liquid matter before its arrival at the wet purification plant. Gradual cooling, with the strict avoidance of "shock," is generally looked upon as the ideal to be secured, for in such cases the hydrocarbons are thrown down in sequence, and there is but slight danger of depriving the gas of a portion of the more valuable constituents which it is capable of retaining at normal temperatures. In connection with this point Butterfield says that with rapid cooling supersaturation of the gas with certain condensible vapours occurs, whilst other less readily condensible constituents are dissolved or mechanically abstracted by the flushing action of the condensate. He points, moreover, to the probability of the selective action of radiant heat coming into play, and says that radiation from relatively cool walls lowers the temperature

of the liquid and solid particles and the more complex gases, whereas more permanent gases are unaffected by it, and are cooled only by contact with cool surfaces.

In considering the principles of condensation, the question of the removal of aqueous vapour may be dismissed, as it is inevitable that the whole of this must be eliminated, with the exception of that portion with which the gas is saturated at normal temperatures. So far as the hydrocarbon condensate is concerned, it is of advantage to sub-divide this in the following manner :—

(*a*) Heavy tars.
(*b*) Medium tars.
(*c*) Light tars and oil fog.

Of the total quantity of tar obtained, about 60 to 65 per cent. will be deposited in the hydraulic main, and this portion is largely of a heavy character. The medium tars, of a somewhat lower specific gravity, are the next constituents to be thrown down. The greater portion of these will be accounted for during the passage of the products through the main connecting the hydraulic with the condenser, whilst the lighter tars and extremely fine vesicles known as the " oil fog " may travel considerably further. In cases where condensation capacity is insufficient or the apparatus is improperly controlled, considerable quantities of the heavier tar fog will be found to travel forward to the scrubbers, so that eventually stoppage occurs. From the point of view of the retention in the gas of the maximum quantity of the hydrocarbons, the slow travel and gradual temperature drop associated with the horizontal atmospheric condenser cannot be improved upon. In general, the temperature of the gas in the hydraulic main varies between 60° and 70° C. (140° and 158° Fahr.). Although this temperature is below the boiling point of the suspended tarry vapours the latter are prevented from depositing owing to their being carried forward mechanically by the moving bulk of gas. The constituents most liable to deposition are benzene, toluene, certain naphthas, and, to some extent, xylene, which have an important effect on the ultimate illuminating power of the gas. A well-established rule of condensation states that the minimum temperature to which gas is reduced should not be lower than 10° C. (50° Fahr.). Dr. Carpenter has stated, however, that rapid condensation with a comparatively big temperature drop has been shown in practice to have very little effect on quality. The experiment which this authority conducted were carried out with gas which had been subjected to an extremely sharp drop of from 60° C. to 5° C.

The whole problem of condensation turns on the point as to the affinity possessed by tar, both in the liquid and " fog " conditions, for absorbing certain low boiling hydrocarbons present in the gas. Gas as it leaves the hydraulic main may be looked upon as being partly saturated with naphthalene, although with modern systems of carbonization and heavy charges the quantity present has been considerably reduced. There is little doubt that the heavier tars and tar " fog " with which the gas is in contact in the initial lengths of the foul main possess a marked affinity for naphthalene. At the same time prolonged contact must inevitably result in the absorption of low-boiling constituents. Authorities on condensation are, therefore,

chiefly in conflict as to whether gas and tar should be separated at the earliest possible moment, or whether prolonged contact between the two should be permitted. As already stated, the heavy tars and high-boiling constituents are mostly separated out in the hydraulic main, although some portion of these is carried still farther forward by mechanical action. There can be little dispute, however, that such tars are detrimental from the point of view of quality, and should be isolated from the gas with all possible speed. For the same reason a tar seal in the hydraulic main is to be avoided. The solvent action of the heavy tar vesicles becomes more pronounced as the temperature drops. Thus removal of the heavy fog at an early stage is probably desirable, leaving the lighter qualities to exert their action as a naphthalene solvent.

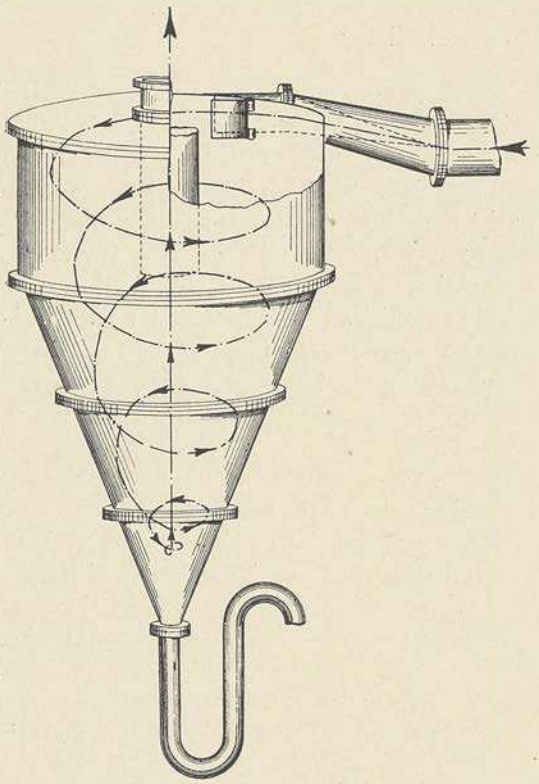


Fig. 278.—Colman's "Cyclone" Tar Extractor.

Colman states that heavy tar fog when allowed to go forward to the condensers affects the removal of the naphthalene solvents in two ways—one favourably and the other adversely. On the one hand, it removes from the gas the vapours of the light oils, and thus tends to prevent them from reaching the cold end of the condenser, where their action on naphthalene would be most pronounced. On the other hand, such fog as gets forward to the cold end mixes with the light oils which separate there, thus increasing their content of naphthalene and impairing their ability to take up more of this substance. The complete removal of naphthalene can only be effected by the action of solvents which are not already saturated with the product. It would seem, however, that one of the most effective methods of dealing with the crude gas is to eliminate the heavy tars and heavy fog at an early stage, and to ensure the passage of the light oil fog as far forward as the outlet of the condenser. Some form of mechanical action has the most effective results in breaking up and throwing down the heavier vesicles, and Colman has successfully applied the principle of centrifugal force in his "Cyclone" apparatus. This machine, shown in Fig. 278, is usually interposed in the foul main at a point about half-way between the hydraulic main and the condensers. It consists of a wrought or cast-iron cylinder, to the

bottom of which is connected an inverted conical chamber, having a seal pipe attached to its lower end. The gas inlet is rectangular and enters the cylinder at a tangent. It contains, moreover, a flap valve by means of which the velocity of the gas is regulated. A whirling motion is thus set up, so that the tarry vesicles are thrown against the sides of the vessel by centrifugal force, broken up, and run off to the seal. The gas, meanwhile, finds its outlet by way of the central vertical pipe. In one instance it was found that in passing through the separator the gas gave up about $3\frac{1}{3}$ gallons of liquid per 10,000 cubic feet, of which 60 per cent. was tar and 40 per cent. liquor. This indicates that the amount of tar fog present was 2 gallons per 10,000 cubic feet. It resembled a thin liquid oil tar of the nature of that produced in the manufacture of water gas. The extractor is made in sizes varying from 3 feet to 10 feet in diameter.

The advocates of the retention of the heavy tars in contact with the gas point out that as the temperature falls the disposition of the tar to absorb naphthalene increases, hence contact at the lower temperatures is desirable. At the same time it must be remembered that there is a corresponding increase in the capacity of the tar for absorbing the low-boiling constituents. In some cases the " counter-current " principle has been introduced ; that is to say, the tar thrown down in the condensers is run backwards towards the hydraulic main, so that gas and tar are travelling one against the other. In Dr. Carpenter's system tar is sprayed down the individual condenser tubes ; in addition, more or less abrupt condensation is arranged for, so that the naphthalene is partially removed and washed out of the apparatus by the tar.

At Brunswick gasworks a regular system of tar washing has been instituted for the purpose of removing, not only naphthalene, but a portion of the sulphur compounds as well. Tar from an overhead tank, after undergoing filtration, is made to fall in fine streams down the annular space of the condenser limbs. The cold inflowing tar chills the gas, forming a fog, which is removed by the descending stream together with almost all the naphthalene, the greater part of the CS_2, and a part of the H_2S. The approximate quantity of tar used is $3\frac{1}{4}$ gallons per minute, which reduces the temperature of 3,500 cubic feet of gas from 50° to 30° C. It is stated, moreover, that the illuminating and calorific values of the gas are affected favourably by the treatment.

Whatever methods may be employed in the condensation of coal gas, it must be remembered that illuminating power has in the present day lost almost all of its former significance ; hence the retention in the gas of the maximum quantity of low-boiling constituents is not now so imperative. The greater the proportion of these hydrocarbons in the gas, however, the greater will be the latitude afforded for attaining the best results from carbonization ; and from the point of view of economics the valuable constituents should be retained in the gas to as great an extent as possible.

THE EFFECT OF CONDENSATION

Purely from the standpoint of quality there can be no doubt that the gradual condensation as effected by the air-cooled condenser is preferable to the more drastic effect of water-cooled apparatus. This is instanced by the fact that, for the same temperature drop, the condensates from the two types of condenser show considerable difference in character. The tar thrown down in the water-cooled condenser usually contains a comparatively high proportion of benzene and toluene with a small proportion of solvent naphtha. With the air condenser, however, the proportion of benzene hydrocarbons is usually quite small, while the condensate is more or less rich in fractions of the solvent naphtha description.

Coudelou has referred to some interesting experience gained while he was comparing the relative efficiencies of two distinct systems of condensers. Both were of the water-cooled type. The first was fitted with vertical tubes and the speed of gas travel was 8·20 feet per second, the average time of passage being 24 seconds. In the second case the speed of gas travel was 1·2 feet per second, and the time of passage about 40 seconds. In the first case naphthalene troubles were rife, and in the second case they were absent. This may therefore be taken as an interesting illustration of the defects resulting from too great a speed of gas travel through the condenser, a condition usually arising from the apparatus being too small for the duties it is called upon to perform.

The effect of sudden condensation upon the quality of carburetted water gas has been well illustrated by experiments conducted by C. S. Heath in America. The following table gives a comparison between the distillation tests of two condenser tars taken from different works. In the case of the first works the gas was taken in the ordinary way first through hot scrubbers and thence to the condensers. In the second instance the scrubbers were absent, and the gas was condensed immediately on leaving the superheater. The effect of this abrupt cooling on the presence of light oil in the tar will be readily seen from a comparison of the analyses :—

Percentage of oils in tar.	Gasworks No. 1.	Gasworks No. 2.
Water	1·8	3·0
Light oils to 170° C.	1·2	4·5
Heavy oils to 230° C.	23·0	26·5
Oils to 270° C.	23·5	18·0
Oils to 315° C.	17·0	13·2
Pitch, residue	33·5	34·8
Specific gravity	1·067	1·066
Free carbon	0·60	0·71

As would be expected from the high proportion of light oils in the tar collected from No. 2 Gasworks there was a sudden decrease in both calorific power and candle power of the gas after the latter had passed the condensers.

THE EXTRACTION OF TAR

On coke-oven works it is customary in some cases to wash the gas for the removal of the suspended tar. In the Otto-Hilgenstock system the vesicles are actually thrown down by spraying the gas coming from the foul main with more tar, as shown in Fig. 279. It is understood, however, that the tar spray has now been abandoned in favour of a mixed spray of tar and liquor. In spite of the many mechanical appliances now to be had, the complete removal of all traces of tar from coal gas is rarely effected before the wet purification plant is reached, and the most successful means for attaining this end would still seem to be that of bubbling the cooled gas through a bath of liquid, rather than by the introduction of apparatus embodying the principle of "wire-drawing" or friction. Of the tar extractors operating on the latter principle, the Pelouze and Audouin is probably the most generally utilized. The machine consists of an outer cylindrical casing with the gas inlet entering through the centre of the base. A bell, suspended from an overhead pulley (or in later designs from a central shaft, as shown in Fig. 280), passes over the inlet pipe and has its base sealed in liquor. The weight

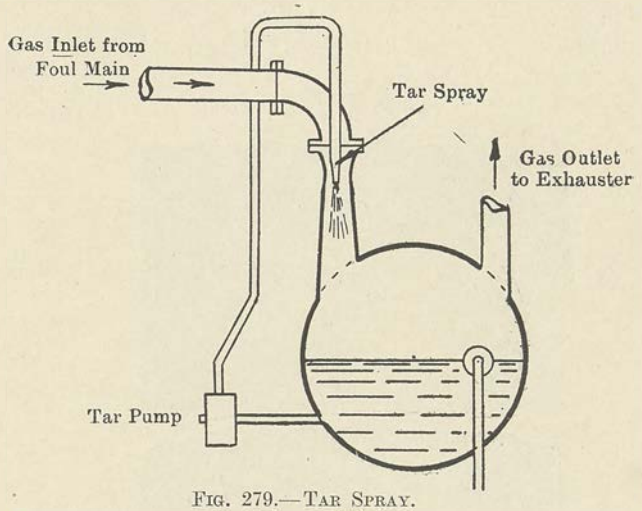


FIG. 279.—TAR SPRAY.

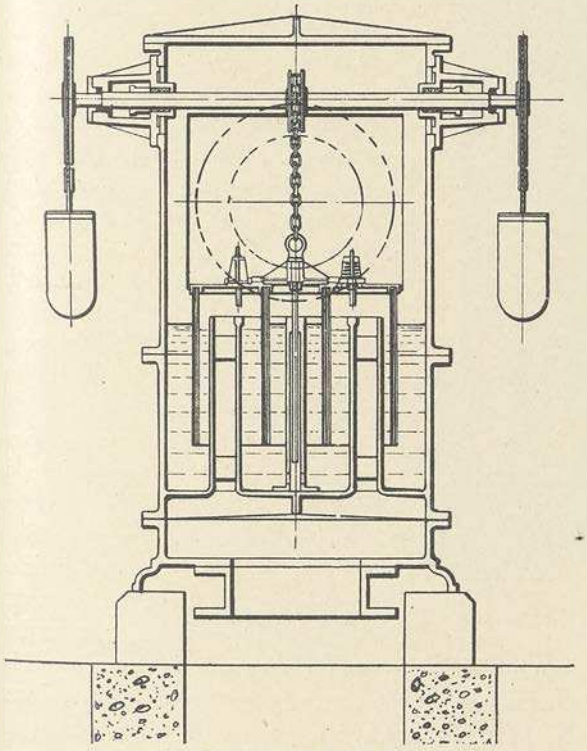


FIG. 280.—"P AND A" TAR EXTRACTOR.

of the bell is counterbalanced by loading the wheels on the shaft, as shown. This floating bell is composed of a cast-iron polygonal top, having cast-steel posts depending from each corner. The spaces between the posts are filled in with bundles of perforated and slotted plates spaced a short distance apart, the perforations being so arranged as thoroughly to baffle and break up the gas on its outward passage. Safety valves are fitted on the drum top so that in the event of the suspension chain breaking a gas outlet will be provided. The action of the machine is automatic, in that the extractor surface exposed to the gas varies in accordance with the quantity of gas passing through the mains.

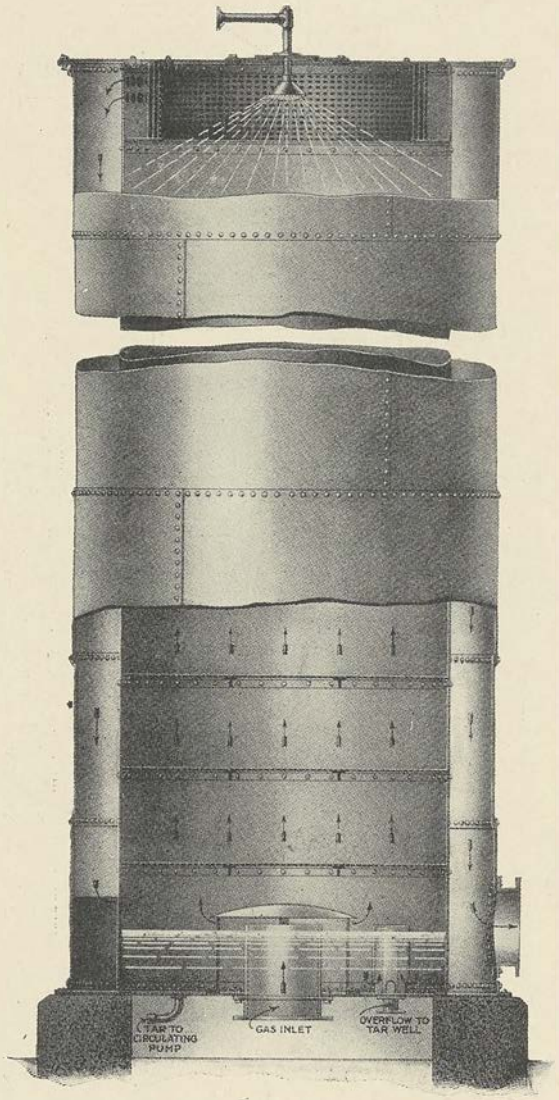


FIG. 281.—DEMPSTER'S PRIMARY EXTRACTOR.

Several forms of apparatus for tar removal, many of which are employed as primary extractors, are now to be found. There is no question, of course, that it is preferable to remove the suspended tarry vesicles at as early a stage as possible, and while the gas is still warm; although this condition does not apply in the case of the light oil fog which should be permitted to remain in the gas up to the condenser outlet. A description has already been given of a favourite form of primary extractor, namely, the "Cyclone." Another type, operating on a different principle, is shown in Fig. 281. This extractor consists of a central chamber around which is a sub-divided annular space. The central chamber is of large area, and is provided with special screens through which the gas must pass as it ascends. The suspended vesicles in the gas are deposited on the screens, the liquid thrown down dripping from one screen to another and assisting in the process of washing the gas. In addition, a central spray is fitted at the top of the chamber. Thin tar is passed

through the spray, and assists in keeping free the openings in the screens. Around the top portion of the central chamber is fitted a series of screens by means of which any excess of tar is removed, the gas then passing out by way of the annular chamber, being cooled slightly by contact with the outer shell, but at the same time preserving a higher and fairly even temperature within the central chamber. The lower part of the central chamber forms a tar receiver from which the warm tar may, if so desired, be pumped in continuous circulation throughout the apparatus.

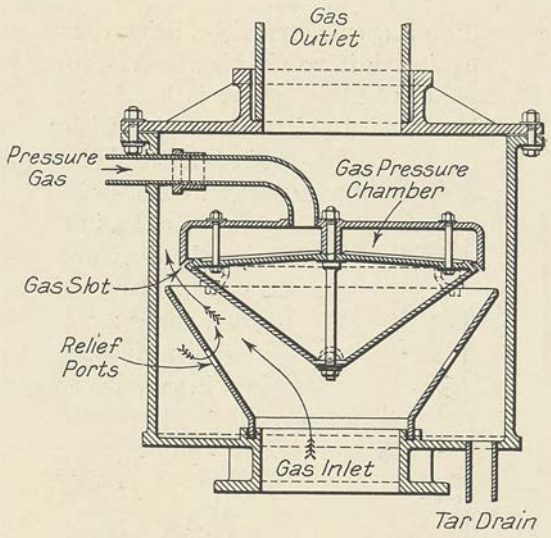


FIG. 282.—THE FISHER-FIDDES TAR EXTRACTOR.

The Fisher-Fiddes extractor, Fig. 282, is an adaptation of the principle employed in the removal of dust from hot producer gas. The hot stream of gas is passed through a rapidly moving film of clean gas, whereby the suspended particles are caused to impinge against a plate, being separated by this process and running to a special collection chamber. The gas enters at the bottom of the extractor and passes up a coned passage at the top of which it meets a film of gas issuing at a high velocity from a narrow slot stretching round the periphery of a pressure chamber. The tar particles are deflected against the side of the main casing at an angle of about 45 degrees, and they rapidly form a film which itself assists in arresting further particles. The best position for the apparatus is just prior to the exhausters, a connection being taken from the exhauster outlet to the pressure chamber, and the gas pressure being reduced to 12 inches of water. At Tottenham gasworks the following results[1] were obtained from a series of tests :—

Test.	Gas passed. Cubic feet.	Extracted Gallons.	Extracted per million cubic feet.
A.	186,000	7	35·0 gallons.
B.	750,000	22	29·0 ,,
C.	5,000,000	191	38·0 ,,
D.	3,500,000	72	20·6 ,,
E.	5,500,000	249	45·0 ,,
		Average . .	33·5 gallons.

[1] *Gas Journal*, CXXXIX, p. 20.

ELECTRICAL PRECIPITATION

Electrical precipitation is the process for removing suspended particles from a gas by electrifying the particles statically, and then separating them from the gas by attraction to a surface charged with an opposite potential. A discharge of positive electricity manifests itself as a brush reaching out from the discharging surface, the suspended particles being electrified, while the gas itself is unaffected.

The principle introduced has been borrowed from methods employed in connection with smelter furnaces, where it has been customary to bring about precipitation of solid suspended particles escaping with the gases by means of a direct current high-tension electrical discharge. Investigations have shown that under certain conditions it is possible to throw down the suspended tarry vesicles in crude coal gas under identical conditions.

The installations, or treaters, that have been developed commercially are of two principal types, the pipe treater and the plate treater, the general action of both types being similar.

In operation, insulated wires are suspended down the centres of the pipes in the pipe treater and between the plates in the plate treater.

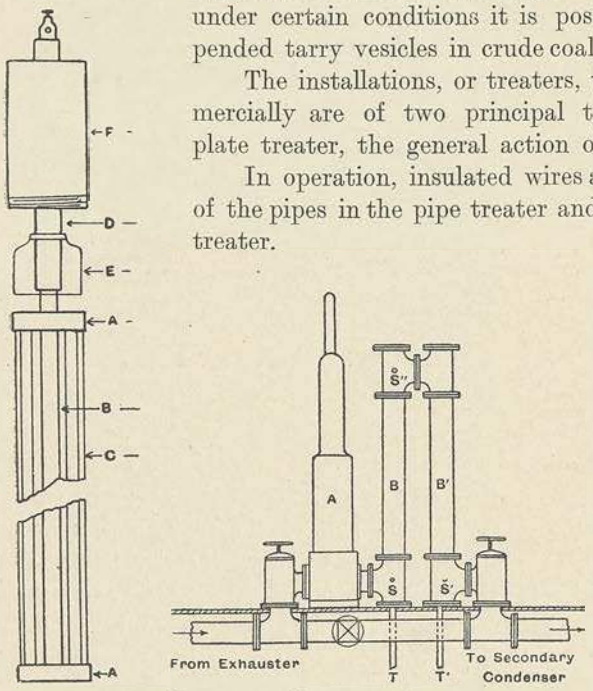


FIG. 283.—ELECTRICAL DISCHARGE APPARATUS.

The most common diameter of pipe, or distance between plates, is about 12 inches. The potential that must be maintained for such distances varies with the chemical composition of the gas and with the temperature, from, say, 50,000 to 100,000 volts.

As the gas passes through the pipes or between the plates, suspended particles, either liquid or solid, are electrified by the discharge from the wires. The negatively electrified particles are then repelled from the negative wire and attracted to the surface of the plate or pipe that is charged positively.

The apparatus as employed by Professor White, of Michigan University, consists essentially of specially constructed electrodes suspended within a gas-tight chamber (Fig. 283). The chamber is composed of a cast-iron inverted U-tube, constructed from 8-inch pipe covered on the outside with a jacketing of felt. Each of the arms of the U-tube is 9 feet long, and these form precipitating chambers. An electrode is suspended from the apex of each arm, and is made up from two cast-iron discs connected together by a light piece of gas pipe, while extremely fine discharge wires are afterwards stretched from disc to disc. The discs are 4 inches in diameter,

and each electrode—of the squirrel-cage pattern—has an effective length of 5 feet 8 inches. So far as contact time is concerned, it is estimated that the speed of the gas passing through the electrode chambers is about 30 feet per second, and the experiments have shown that the time of exposure to the electrical discharge, which is under half a second, is ample for the removal of the last visible traces of tar. Incidentally, it has been found that in addition to bringing down the whole of the tar this electrical purifier has certain desirable effects in the direction of minimizing the trouble arising from the deposition of naphthalene. For tar removal the apparatus has been interposed at a point where the temperature is in the neighbourhood of 60° C.—that is, at a very early period in the foul main. Where naphthalene exists in the crystalline state the solid particles may be expelled in the same manner as the vesicles of tar. For naphthalene removal, however, a second electrode is placed at a point where the temperature is at its lowest.

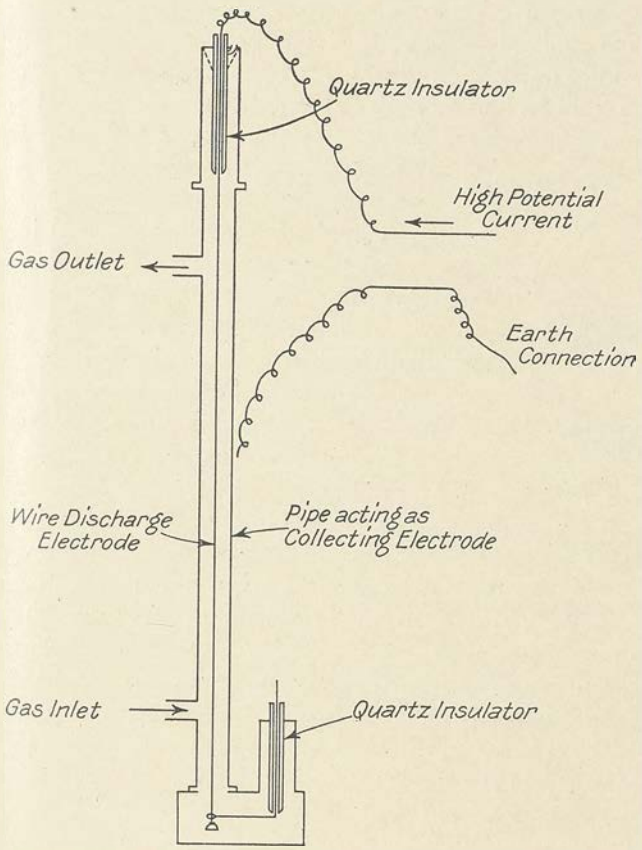


FIG. 284.—TREATER CHAMBER FOR ELECTRICAL PRECIPITATION.

A thorough examination of the possibilities of electrical precipitation has recently been made by J. G. Davidson,[1] who points to the fact that the main difficulty associated with the process is one of insulation. In order to provide against the failure of insulation, Davidson employed the apparatus shown in Fig. 284. The treater chamber consisted of an iron pipe 21 feet high and 10 inches in diameter, and it was provided with fused quartz insulators as shown. From filtration experiments which were made to determine the efficiency of cleaning on a large coke-oven works it was found that the gas from the treater contained from one to three milligrammes per cubic foot, whereas gas from the outlet

[1] Report No. 3, Canadian Council for Scientific and Industrial Research.

of the tar extractors of ordinary construction showed from eight to nineteen milligrammes of tar per cubic foot.]

ESTIMATION OF TAR FOG IN GAS

It is only with considerable difficulty that the tar fog present in gas can be estimated. The conditions prevailing in the main conveying the gas almost preclude a really accurate determination of the tar present; but, from the practical standpoint, a test which has a comparative value is of considerable utility to the gas engineer. In practice, the only suitable method of estimating tar-fog in gas is by processes of filtration, the crudest application of which is to hold a piece of blotting paper or white linen over the end of a lantern cock connected to the gas main. For the everyday purposes of the gas engineer a visual comparison of the kind will usually suffice to show how the extraction plant is performing its duty, and by elaboration of the same idea a roughly quantitative test may be devised.

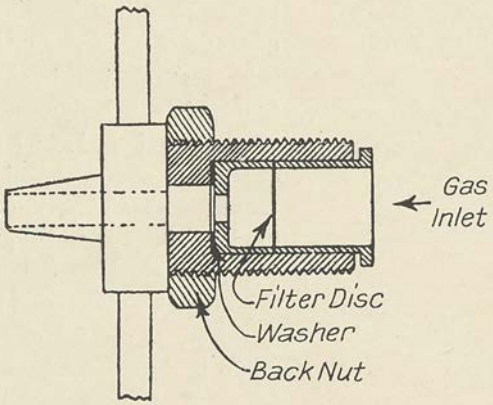


FIG. 285.—EDWARDS' TAR FILTER.

The most important work on the subject has been carried out by A. Edwards,[1] who employed a method whereby the gas is filtered through a disc of filter paper (Fig. 285) cut to a diameter of 1·8 cm. and exposing 2 sq. cm. of filtering area. The volume of gas which has to be passed through the filter paper to give a stain within measurable limits varies from 80 to 9,000 c.c., according to the proportion of tar fog present. The method employed is a visual one, which has been made quantitative as well as comparative. If the area of the stain (A) on the filter paper is known, also its density (D), the weight of the tar to give unit density on unit area (T), and the volume of the gas (V), then the quantity of tar fog present in the gas is :—

$$\frac{A \times D \times T}{V}$$

The result may be expressed in grains per cubic foot, or grains per cubic metre, according to the particular units taken.

T is determined by suspending the tar, collected at the point considered, in solvent naphtha or similar colourless liquid, and measuring the density in a glass cell with parallel sides. If then W is the weight of tar taken, V the volume of solvent in which W is dispersed, V_c the volume of the cell, A the area of the side of the cell, and D the density of tar and liquid in the cell, the weight of tar to give unit density if spread over unit area is :—

[1] *Journal Soc. Chem. Ind.*, 1918, 35 T.

$$\frac{W \times V_c}{V \times A \times D} = T.$$

To ensure a fairly representative sample of the gas the sampling must be rapid, in order to prevent the falling out of the larger tar particles. With this object, the difference of pressure between the two sides of the disc should be from 12 to 24 in. water column, depending on the resistance of the paper disc. Speed is also necessary to complete the removal of the finer particles of fog by impingement within the pores of the filter paper. One disc only is necessary, as a second one placed in series with the first and spaced by a metal liner is invariably unstained. The stain is always confined to the receiving surface of the first disc. Where the gas is under low pressure an aspirator is used to give the required pressure difference.

As before stated the volume of gas to be passed through the filter paper to give a stain within measurable limits varies from 80 c.c. to 9,000 c.c., depending upon the proportion of tar fog present.

The following interesting series of results obtained upon gas streams on works where different manufacturing methods were employed have been given by Edwards :—

	Coal Gas.	Grains per cubic foot.
A.	Outlet condensers following seal in hydraulic mains	30
B.	Outlet condensers following part sealed and part dry mains with retort-house governors	15
C.	Outlet P. and A. tar extractors following A.	0·25
D.	Outlet rotary exhausters following dry mains and condensers . . .	8
E.	Outlet rotary exhausters following B.	6
F.	Outlet turbo exhausters following B.	0·6
G.	Outlet Livesey washers following D.	0·6
H.	Outlet P. and A. tar extractors following E.	0·17
I.	Outlet P. and A. tar extractors following F.	0·14
J.	Outlet ammonia washers or scrubbers horizontal revolving type following G.	0·4
	Water Gas, Partly Carburetted.	
K.	Outlet rotary exhausters following relief holder	2·3
L.	Outlet Crossley tar extractor following K.	0·17

It will be observed that retort-house governors have an appreciable effect on the tar fog, and the rotary exhausters remove a fair proportion of the remainder. Turbo-exhausters reduce the amount to as low a figure as Livesey washers following rotary exhausters. Pelouze and Audouin machines carry the removal to finer limits.

CHAPTER XIV

NAPHTHALENE IN COAL GAS

To the majority of gas engineers the naphthalene question is still one of extreme importance, chiefly owing to the fact that no really definite solution of the trouble has yet been reached, while matters have not been improved by the modern practice of curtailing or eliminating altogether the oil formerly used with a fairly free hand for the carburation of water gas. It is enough to say that modern methods of carbonization have certainly tended to lessen the trouble, but the whole problem stands on somewhat unsatisfactory ground—so much so that a method which is effective at one works may be absolutely useless at another.

The amount of naphthalene in coal gas varies considerably, in accordance with the coal made use of and the system of carbonization employed. The following, however, may be taken as exemplifying the average quantities at the various stages of manufacture when horizontal retorts containing moderately full charges are in use and no special method of extraction is employed :—

Inlet of condensers	60–80	grains	per 100	cubic feet of gas.
Outlet	20–25	,,	,,	,, ,,
Outlet of purifiers	8–15	,,	,,	,, ,,

On the other hand, tests on the gas stream coming from a system of intermittent vertical retorts [1] have shown the following figures for naphthalene :—

Outlet of primary condenser	9·9	grains	per 100	cubic feet.
Outlet of Pelouze and Audouin condenser	7·5	,,	,,	,,
Outlet of secondary condenser	7·0	,,	,,	,,
Outlet of washers	3·5	,,	,,	,,
District gas	3·2	,,	,,	,,

The results obtained from continuous vertical retorts are still lower, as is instanced by the figures obtained at the Droylesden works of the Manchester Corporation :—

NAPHTHALENE IN PURIFIED GAS, GRAINS PER 100 CUBIC FEET

Lancashire coal	2·77
Yorkshire coal	1·98
Derbyshire coal	2·35

[1] *American Gas Institute News*, Sept., 1917.

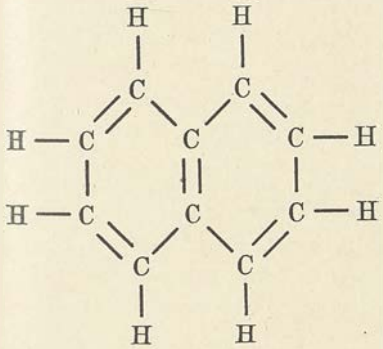
FORMATION OF NAPHTHALENE

The greater proportion of naphthalene produced in the carbonization of coal is obtained in the tar distillates, the average total quantity yielded being approximately 0·3 per cent. by weight of the coal, or from 6 to 7 lb. per ton of coal dealt with. The quantity of the product formed, however, depends very largely upon the system of carbonization and the treatment to which the evolved gases are subjected. Accordingly, while the tar from horizontal retorts may contain 10 per cent. by weight of naphthalene, that from continuous vertical retorts frequently shows no more than 5 to 7 per cent. In general, the warm crude gas derived from horizontal retorts contains naphthalene equivalent to from 1 to $1\frac{1}{4}$ lb. per ton of coal carbonized.

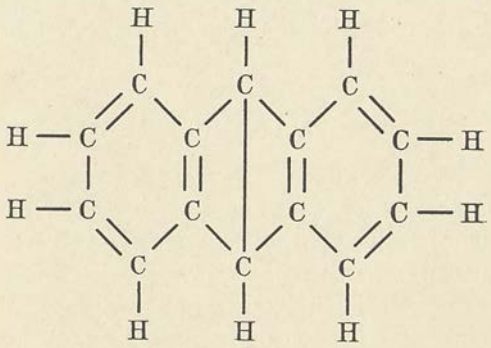
It must be realized that naphthalene is not formed as a direct distillation product from the coal itself, but that it is the result of secondary influences which affect the gas during its passage from the retort. Under the influence of heat many hydrocarbon vapours have a tendency to form naphthalene, and it seems that this tendency is the greater the higher the proportion of carbon in the compound.

According to Lewes the hydrocarbons to a great extent leave the coal as vapours of condensible hydrocarbons; the breaking-down of these to such simple gaseous compounds as ethylene, already formed, into acetylene and methane, and the polymerization of the former into higher compounds then occurs. Bodies like naphthalene and anthracene have such great stability that when once formed they resist any effort to decompose them again by heat.

Naphthalene formation may be explained by the fact that when subjected to excessive heat benzene probably polymerizes, so that the following compounds containing condensed benzene nuclei are formed :—



Naphthalene.



Anthracene.

During the formation of such compounds hydrogen is evolved in some quantity, and probably accounts for the high percentage of this gas usually found in the resultant gas from light charges. With regard to the "free" carbon deposited, it is interesting to note that Colman considers that with still higher temperatures and with increase of time the above compounds yield more hydrogen and condensed

nuclei of a still more complex nature, leading eventually to carbon itself. The molecule of solid carbon in all probability consists of a very large number of carbon atoms arranged as a honeycomb of condensed benzene nuclei. These complex substances, still containing some hydrogen, are black and infusible, and their physical properties are very closely akin to those of pure carbon itself. Rhead and Wheeler, it may be noted, have pointed out that both graphite and amorphous carbon yield on oxidation a compound with the characteristic benzene nuclei in its constitution.

Some of the reactions which are responsible for naphthalene formation and which have been given by various authorities [1] are set down below :—

(1) $5\,C_2H_4 = C_{10}H_8 + 6\,H_2$.
(2) (*a*) $2\,CH_4 = C_2H_2 + 3\,H_2$. (*b*) $3\,C_2H_2 = C_6H_6$.
(*c*) $2\,C_6H_6 = C_{10}H_8 + 2\,C + 2\,H_2$.
(3) (*a*) $2\,C_6H_6 = C_{12}H_{10}$ (Diphenyl) $+ H_2$. (*b*) $C_{12}H_{10} + C_2H_4 = C_{14}H_{10} + 2\,H_2$.
(4) $3\,C_6H_6 = C_{14}H_{10} + 4\,C + 4\,H_2$.
(5) (*a*) $C_6H_6 + C_2H_4 = C_6H_5C_2H_3 + H_2$.
(*b*) $C_6H_5C_2H_3 + C_2H_4 = C_{10}H_8 + 2\,H_2$.

The most important work on the subject is undoubtedly that carried out by J. W. Cobb,[2] who has studied the mode of decomposition of single constituents of the gas, chief attention having been given to benzene and toluene. The results obtained by this investigator are more fully referred to in the chapter on Carbonization, but briefly his conclusions clearly indicate that there is a tendency for hydrogen, which is the predominant product of carbonization, to reduce the single-ring benzene compounds to benzene, but at the same time to preserve the benzene nuclei intact. A similar action of hydrogen on the attached groups of more complicated ring compounds most probably accounts for the production of naphthalene and anthracene. Hence the formation during high temperature conditions of the horizontal retort of a considerable quantity of the aromatic hydrocarbons and naphthalene, with a corresponding decrease in the yield of paraffins and phenols.

VAPOUR PRESSURE OF NAPHTHALENE

A knowledge of the vapour pressure of naphthalene in coal gas is of primary importance to gas engineers, for this permits an estimate to be made of the actual quantity of naphthalene which gas at a definite temperature will carry, and the quantity it will deposit when cooled from a higher to a lower temperature. The amount of naphthalene required to saturate a given volume of gas at definite temperatures has been determined by both Allen [3] and Schlumberger.[4] The results of these two authorities have been carefully checked by J. S. G. Thomas between temperatures of 0° and 60° C., and while Thomas is in substantial agreement with the figures given by Schlumberger, he differs at temperatures below 30° C. from results obtained by Allen.

[1] *American Gas Institute News*, Sept., 1917.
[2] *Gas World*, Sept. 7, 1918, p. 127.
[3] *J. Soc. Chem. Ind.*, 1900, 209.
[4] *J. für Gasbeleuchtung*, 1912, p. 1257.

The following table has been compiled from the results and curves given by Thomas :—[1]

NAPHTHALENE SATURATION OF COAL GAS

Temperature.		Grains per 100 cubic feet.		Pounds of naphthalene contained in a million cubic feet of dry gas.[2]
Cent.	Fahr.	Dry Gas.[2]	Wet Gas.[2]	
0	32	1·85	0·55	2·64
5	41	3·26	1·11	4·66
10	50	5·59	1·98	7·99
15	59	9·39	4·02	13·4
20	68	15·5	7·93	22·1
25	77	25·2	14·2	36·0
30	86	40·3	34·5	57·6
40	104	98·5	101·9	141
50	122	227	252	324
60	140	497	552	710

The effect of water vapour upon the degree of saturation will be observed from a comparison of the figures for wet and dry gas. Between 0° and 30° C. the saturation vapour pressure of naphthalene in moist gas is less than that in dry gas. At about 40° C. the saturation in both gases is identical, while above 40° C. the saturation naphthalene content of wet gas is rather greater than that of dry gas. The difference has been ascribed to the condensation of a skin of water upon the naphthalene in the case of moist gas.

Neglecting the factor of supersaturation, the above table indicates that a million cubic feet of dry gas cooled in the mains from 20° C. (68° Fahr.) to 15° C. (59° Fahr.) may deposit 8·7 lb. of naphthalene; or if the same volume of gas was cooled from 20° C. to 10° C. the quantity deposited might be 14·1 lb.

It must be emphasized that the above figures should not be applied in order to calculate the quantity of naphthalene which might be deposited for any definite temperature drop in the coal-gas condensers. The figures relate solely to the evaporation of naphthalene *into* coal gas, and the problem of naphthalene condensation introduces other factors which require entirely separate investigation. A point of considerable importance in gas engineering arises on account of the lower values of the saturation naphthalene content of coal gas obtained by Thomas for temperatures up to 30° C. as compared with the values given by Allen; for on the basis of the latter's figures no trouble should arise from naphthalene in the district mains so long as the gas as distributed contains less than 10 grains of naphthalene per 100 cubic feet. In point of fact, assuming that the lowest gas main temperature met with is about 5° C. (40° Fahr.), the amount of naphthalene required to saturate

[1] *J. Soc. Chem. Industry*, 1916, 506.

[2] Measured at temperature of the experiment and pressure of 760 mm.

the gas is only some 3 grains per 100 cubic feet. This consideration should therefore be sufficient to emphasize the necessity for employing means at the works to reduce the naphthalene content to certainly not more than 3 grains per 100 cubic feet.

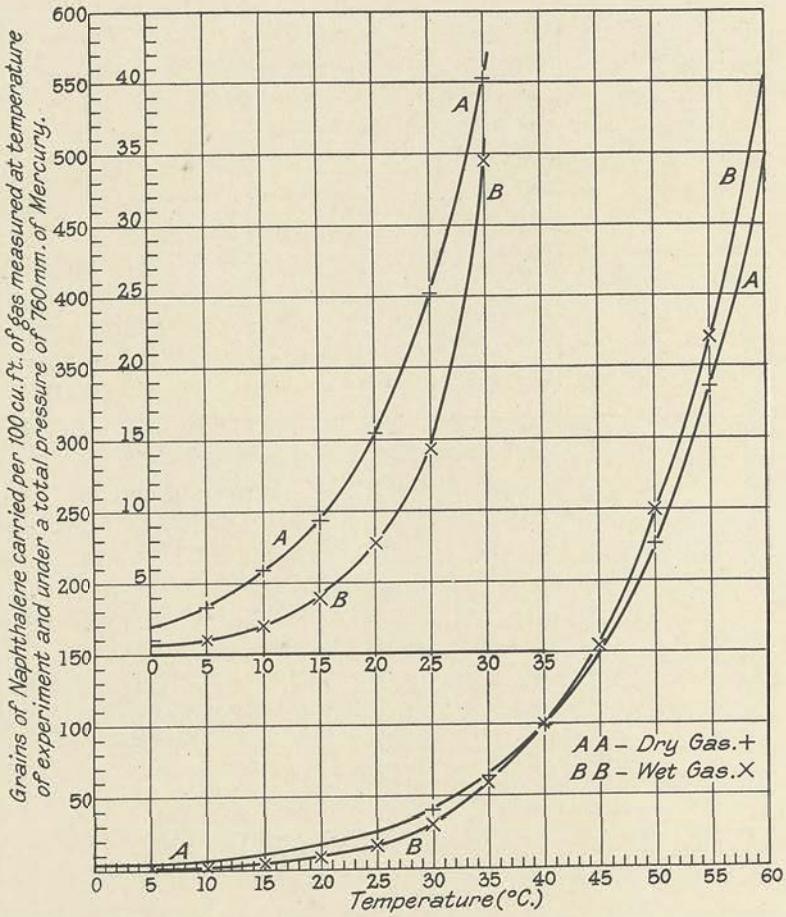


FIG. 286.—CURVES SHOWING NAPHTHALENE SATURATION OF COAL GAS (THOMAS).

Thomas has shown that the number of grains of naphthalene (W) sufficient to saturate 100 cubic feet of dry coal gas at normal temperature and pressure may be calculated at any temperature in the range 0° to 60° C. by the formula—

$$\log_{10} W = 14{\cdot}2739 - \frac{3812{\cdot}34}{\theta} - 0{\cdot}02593 \log_{10} \theta,$$

where θ is the absolute temperature Centigrade.

MEANS OF DEALING WITH NAPHTHALENE

The methods which have been introduced for the prevention of naphthalene deposition may be summarized as follows :—

(*a*) The employment to the best advantage of the process of condensation; including shock condensation, or abrupt cooling, involving a wide temperature drop.

(*b*) Treatment of the gas by means of special solvents employed in a washer, scrubber, or mechanically-operated apparatus.

(*c*) Carburation of the gas with suitable oils in such a way that they act as so-called " carriers " of naphthalene.

(*d*) The passage of the gas through a special porous medium which will absorb naphthalene.

(*e*) Deposition of naphthalene with the aid of an electrical discharge (*see* page 456).

In addition to the above it may be pointed out, as a matter of historical interest, that one of the early investigators, Bremond, found that naphthalene is set free whenever there is condensation of the aqueous vapour in the gas, that its deposition is preceded by the deposition of water, and that gas deprived as far as possible of aqueous vapour does not deposit naphthalene. Bremond therefore dried his gas by passing it through a vessel containing a desiccating material. It is said that a good deal of success attended this method; but the experiments were only carried out on a comparatively small scale. As a present-day parallel, however, may be quoted the custom of some engineers to cover the water in gasholders and station meters with a surface film of oil so as to prevent further saturation of the gas with water vapour at these points. It is claimed that condensation in the district mains (probably attended by the deposition of naphthalene) is thus curtailed. Such a possibility is indicated by the lower saturation naphthalene content of moist gas compared with dry gas at temperatures below 40° C. as determined by Thomas.

Condensation as a Factor

So far as the process of condensation affects the problem of naphthalene it must be borne in mind that this portion of the plant merely plays a preliminary part and must not be expected to effect entire elimination of the product from the gas. This is particularly the case with the gas from horizontal and inclined retorts, for in those instances where the whole of the gas produced is derived from continuous vertical retorts it should be possible to reduce the naphthalene content to a safe figure without recourse to any plant other than the condensers.

It is necessary to recall that warm crude coal gas as it is found at the inlet of the condensers contains not only naphthalene but a mixture of low-boiling vapours which may be classed as naphthas, the boiling-points of many of which very closely approach the boiling-point of naphthalene (218° C.). Accordingly, when the temperature of the gas is reduced by the condensers, these vapours are deposited in addition to the naphthalene. The light naphthas are, moreover, solvents for naphthalene; thus some portion of the product is carried

away in solution to the seal-pots of the plant. The efficacy of the treatment obviously depends upon the quantity of naphthalene in the crude gas and upon the proportion of the naphtha vapours present. It is in this direction that gas produced in horizontal and inclined retorts differs from that derived from continuous vertical retorts; for, in the former case the quantity of naphthalene is comparatively high, while the lower-boiling naphthas are usually present in small proportion only. On the other hand, with continuous vertical retorts the proportion of naphthalene is small; and, owing to its paraffinoid nature, the gas usually contains a high proportion of the lower-boiling constituents. There should therefore be little difficulty —providing sufficient temperature drop is effected—in reducing the naphthalene content of gas from continuous verticals to a safe figure by passage through the condensers.

In viewing the problem from the standpoint of the horizontal retort it is necessary to remember that a moderately high content of naphthalene will still be present after the process of condensation as it is ordinarily carried out; but the extent of the trouble which this quantity is likely to give is, again, very greatly dependent upon the proportion of low-boiling naphthas which also remain in the gas after the condensers. For instance, provided that the low-boiling vapours are present in such quantities as to introduce what may be described as a state of equilibrium with the naphthalene, then no trouble need be anticipated when the gas is subjected to lower temperatures in the district mains. In such cases the two constituents will separate out together, the naphthalene will be dissolved in the naphtha condensate, and both will be carried to and collected from the syphons. Unfortunately, however, gas from horizontal retorts, even when full charges are employed, possesses decidedly benzenoid characteristics. In other words, in comparison with vertical retort gas, the proportion of low-boiling vapours is small. Consequently, after condensation, the proportion of low-boiling constituents to naphthalene is invariably such that the condition of equilibrium previously referred to is seldom found in practice. Perhaps no better instance of this is required than the conditions which are so frequently found in condensers of ample size and capacity which effect a temperature drop above the normal. It frequently happens that large deposits of solid naphthalene are found adjacent to the outlet pipes of such condensers, showing that the proportion of low-boiling condensible vapours in the gas is insufficient to dissolve the whole of the naphthalene produced by drastic cooling of the kind.

So far as the removal of the condensible constituents is concerned it is found in practice that a portion of the lower-boiling substances and lighter tars are immune from the effect of condensation *per se*; and owing to their physical condition they are carried forward in a state of mechanical suspension. Accordingly, if the gas is not subjected to thorough mechanical treatment, such as wire-drawing or primary washing, the "oil fog" may travel some considerable distance. This, in fact, from the point of view of naphthalene removal, is desirable, for it is when the gas is at the lower temperatures that the solvent action of the light oil fog is most effective. On the other hand, the heavy tar vesicles and heavy fog should be removed by employing some such device as the Cyclone extractor (Fig. 278) at an

early stage in the foul main, for if allowed to remain these tars will subsequently bring down with themselves the greater part of the light oil fog and thus preclude it from exerting its full influence on naphthalene. The heavier constituents of the tar, moreover, are moderately active absorbents of aromatic hydrocarbons, so that the longer they are permitted to remain the more pronounced will their "stripping" action be.

Inadequate Condenser Plant

Some engineers at the present day are still of the opinion that "shock" or abrupt condensation provides one of the best solutions of the naphthalene question. The author's experience has prompted him to form the opinion that drastic cooling and sudden abnormal temperature drops may—except, perhaps, in the case of the largest works—prove remedies which are in the main too drastic. The effects arising from such treatment will be fully appreciated from what has previously been said; but a policy of extremes in either direction must be avoided and inadequate cooling is to be deprecated far more than is excessive cooling. In fact, insufficiency of condenser capacity is probably responsible for the majority of naphthalene troubles. The condenser, as will be appreciated, is a piece of apparatus considerably influenced by climatic conditions, more especially if it be of the atmospheric type. When the plant is put down in the first place its capacity is invariably computed on the maximum day's production of gas. Normally, this occurs in the winter time when the weather conditions are more effective from the condensation standpoint; but it must be remembered that the yearly load curve is tending more and more to level up, so that the capacity which may be ample for a maximum winter day may fall measurably short of that essential for a maximum summer day. Accordingly, during the summer months the proportion of naphthalene in the gas is frequently at its highest; although, owing to the higher average temperatures prevailing, no greater inconvenience may then be suffered. There is no question, however, that many of the stoppages occurring during the winter months are largely due to the indiscretions committed during the summer months. Although, therefore, the policy of rating condenser capacity on the basis of so many superficial feet of cooling area per unit make of gas (*see* page 440) is sound within limits, such theoretical rules should always be checked when the plant is in operation by ensuring that at all periods of the year the condenser outlet temperature is capable of being maintained at a reasonably low figure, say 20° to 25° C. as a maximum.

Treatment of the Gas with Solvents

Secondary treatment of the gas for the removal of naphthalene is not by any means universally carried out, but it is to be recommended in the majority of cases where the gas is produced from horizontal or inclined retorts. A question which is still at issue is as to whether it is preferable to extract the naphthalene by some process such as washing with solvents at the works, or whether it is more effective to admit special "carriers" to the district mains. If it is a question of starting *de novo* there can be no doubt that the best policy is to attack the problem at the fountain-head and ensure that no gas containing naphthalene enters the district

mains. Naphthalene troubles are, however, in no small measure due to old deposits in the mains, so that the most thorough removal at the works does not in any way guarantee immunity. For this reason many engineers prefer to treat the gas in the mains, while a combination of both processes is certainly ideal.

There are many substances which are suitable solvents for naphthalene, although the majority of those which absorb naphthalene also absorb the aromatic hydrocarbons. Bayer [1] has given the following figures which he obtained as the results of using a light oil for the purpose:—

Composition of Wash-oil, Per Cent. by Weight

	Before use.	After use.
Water	0·0	5·2
Benzol	0·4	14·9
Light oils	67·6	2·7
Middle oils	25·0	15·4
Naphthalene	3·9	19·1
Heavy oils	3·1	42·7

As regards the naphthalene solvent power of the most readily available substances for the purpose the following figures have been given:—

	Per cent. of naphthalene absorbed.
Creosote oil	3·1
Gas oil	5·8
Tar oil	9·74
Water gas tar	23·50
Benzol	24·90

Some interesting results obtained on a large scale in connection with gas washing for naphthalene removal have been given by Macleod and Henderson.[2] In this case the solvent employed was a coal tar distillate which yielded the following fractions on distillation:—

Below 100° C.	23·5 per cent.
100°–170°	4·5 ,,
170°–185°	63·5 ,,
Residue and loss	8·5 ,,
Specific gravity at 15°	1·000

The effect of treating the gas with this oil is shown below:—

	Naphthalene. Grains per 100 cubic feet.		Make of gas per ton of coal.	Condenser Temperatures °C.	
	Inlet of washer.	Outlet of washer.		Inlet.	Outlet.
I	19·7	6·7	10,498 cubic feet	43	18
II	15·2	6·7	10,352 ,, ,,	49	18
Average	17·45	6·7	10,425 ,, ,,	46	18

[1] *J. für Gasbeleuchtung*, 1911, p. 496. [2] *J. Soc. Chem. Industry*, November, 1913.

With the object of avoiding the partial absorption of the aromatic hydrocarbons from the gas it is customary in some instances to pre-benzolize the wash-oil by adding from 4 to 5 per cent. of benzol to it. In this way equilibrium is brought about between the vapour pressure of the benzene in the gas and the vapour pressure of the benzene in the oil.

The South Metropolitan Gas Company have installed a very complete system for naphthalene removal by scrubbing all the gas with anthracene oil in horizontal washer-scrubbers before it leaves for the district. The oil used shows normally the following test on distillation :—

Drop point	280° C.
280° to 325° C.	32 per cent. by volume.
325° to 360° C.	49 „ „
Residue	19 „ „

Originally the oil, which may take up so much as 8 per cent. of aromatic hydrocarbons in cold weather, was pre-benzolized before use ; but the stripping effect was not found to be material once a condition of saturation had been obtained, hence the addition of benzol is no longer carried on. The wash-oil is practically free from naphthalene when first admitted to the washer, and the quantity of fresh oil added is determined by the test for naphthalene on the outlet gas. The process is remarkably effective, showing an efficiency of 100 per cent., with but the barest trace of naphthalene in the finished gas, and frequently no trace whatever. The spent oil running away from the plant is heated and treated meanwhile with steam. The process amounts to revivification, the naphthalene and lower-boiling constituents being removed in this way, and the oil then being ready for further service. The spent oil from the washer-scrubbers normally contains about 5 per cent. of benzene and light naphthas. The quantity of oil used varies with the season and the efficiency of the washer, but it approximates to 25 gallons per million cubic feet of gas.

The author has for some years employed a light oil from carburetted water-gas tar as a washing medium, the treated gas being practically free from naphthalene. In this case the crude gas is dealt with, a scrubber of ordinary construction and filled with boards being interposed for the purpose just prior to the final ammonia scrubber. This position is, perhaps, the most advisable owing to the fact that the gas issuing from the naphthalene scrubber holds in mechanical suspension a certain amount of light oil fog which is eliminated by the water scrubber, and is not therefore carried forward to the dry purifiers.

The light tar used is in reality an oil which separates in the tar storage tank from the heavier tar and rises to the surface. The distillation test of the tar oil used is as follows :—

Water-Gas Tar Oil (Freed from Water)

	Per cent. by volume.
Up to 200° C.	nil
200° to 300° C.	48
300° to 360° C.	23
Residue	29

Specific gravity, 0·947. Free carbon, trace. Naphthalene, nil.

A point to bear in mind is that water-gas tar used for naphthalene washing should contain a high naphtha content and preferably no naphthalene. Accordingly, the carburettor and superheater of the water-gas plant should not, if possible, be operated at temperatures greater than 750° C. (1,400° Fahr.), for up to this temperature practically no naphthalene results from the cracking of the American petroleum commonly used for enrichment. In past years it was customary to operate both carburettor and superheater at temperatures of from 900° to 980° C., and whereas this may have been necessary for complete fixation of the vapours when considerable quantities of oil were used, it is no longer so now that the amount of oil per 1,000 cubic feet of gas has been curtailed by more than half.

Extraction during Benzol Recovery

It is a somewhat remarkable fact that in the earlier period of the war, when the " C " process of tar-washing was introduced, there was in many instances a marked tendency for naphthalene troubles to increase. This may be explained by the fact that the removal of benzene and its homologues from the gas deprived the latter of constituents which have a solvent action on naphthalene, while at the same time the very fact that gas and tar came into intimate contact set up conditions which were favourable for an exchange of naphthalene from tar to gas. The recognized oil-washing process has been followed by variable results in the same direction, but so long as the correct grade of wash oil is employed with intelligence there is no reason why it should not be instrumental in reducing the naphthalene content of the gas. The process of " stripping " the gas certainly extracts a portion of the low-boiling naphthas, and for this reason there is every necessity to ensure that the naphthalene is reduced to a much finer content than that which would be considered " safe " with an unstripped gas. The first precaution is to ensure that the temperature of the stripping vessel is little above that of the atmosphere. In other words, both gas and wash-oil should be properly cooled before coming in contact with each other, otherwise if the tar or oil used contains naphthalene it will give this up to the gas. In some gasworks where benzol removal from the gas is or has been carried on it has been customary to split the main stream of gas and to strip one stream only. This practice, from the naphthalene standpoint, is probably to be condemned, for with partial scrubbing the naphthalene content of the final gas may still be moderately high, whereas the low-boiling vapours have been reduced to an extent which render them insufficient to act as solvents for such a quantity of naphthalene.

As regards the effect of the process of benzol stripping on the amount of naphthalene in the gas the following figures have been given by L. J. Willien [1]:—

[1] *Proc. American Gas Inst.*, Dec., 1917.

	Naphthalene, grains per 100 cubic feet of gas.		Loss per cent.
	Before scrubbing.	After scrubbing.	
Coke-oven gas (590 B.Th.U.) . . .	24·6	8·8	64·2
Coke-oven gas (508 B.Th.U.) . . .	27·1	6·9	74·6
Coal gas (544 B.Th.U.)	7·8	1·6	80·0

The effect of temperature upon naphthalene extraction is shown by the following figures which refer to a stream of coal gas of two million cubic feet per day, treated in a rotary washer-scrubber with green oil:—

Temperature of Wash-oil. ° Fahr.	Naphthalene, grains per 100 cubic feet.	
	Before washing.	After washing.
75	16·2	6·9
76	11·2	7·9
77	19·0	10·8

General experience shows that the naphthalene content of the gas is reduced by 75 per cent. when the latter is thoroughly scrubbed with an oil containing practically no naphthalene.

Many benzol plants are now fitted with a primary or vapour condenser, through which the hot still-vapours pass in counter-current to the benzolized washing oil. If an outlet is provided at the base of this primary condenser, and the high-boiling condensates are run off to a separator tank, it will be found that they consist essentially of water, naphthalene, and naphthas. The water and naphthalene may be separated direct, or, to carry the process a stage further, it is profitable to erect a small secondary still in which the naphtha portion may be dealt with. If the distillate is collected, cooled, and run to a shallow settling-tank, the remainder of the naphthalene may be recovered, while the liquid portion will consist largely of naphtha, which may be sold direct as such or returned to the debenzolized oil-tank. Such a process forms, in the author's opinion, the nucleus of what may become a recognized method for naphthalene removal and recovery in the future.

The Use of Solvents

One of the most effective means of eliminating naphthalene trouble in the district mains and services is to ensure that the gas distributed contains a sufficient proportion of suitable solvents. The solvents may be present as a fine atomized mist which is carried forward in mechanical suspension by the gas, or they may be present as vapours produced from suitable spirit or light oil treated in a special form of carburettor.

There are a number of liquids which may be employed for the purpose of

increasing the naphthalene solvents in the gas. A point to bear in mind is that the best liquid is not necessarily that which has the lowest boiling-point. In fact, the higher the boiling-point, within reasonable limits, the more permanent will the effect be. As explained above, two alternative methods of adding solvents present themselves, namely :—

(*a*) Addition by spraying, or thorough atomization of the solvent.

(*b*) Addition by carburation, or evaporation of the solvent into the gas.

It is essential, of course, that the liquid employed should be as free as possible from naphthalene ; and, although various coal-tar and carburetted water-gas tar distillates are quite suitable, preference is usually shown nowadays for a light paraffin oil or kerosene. From the point of view of their naphthalene solvent power ordinary coal-tar naphthas are preferable to paraffin, but the latter is more readily obtainable at a reasonable cost and possesses the great advantage of containing no naphthalene whatever.

When the solvents are injected into the main gas stream care should be exercised to ensure that the spray is placed at the centre of the main and not at its periphery, and from the point of injection onwards there should be as long a length of straight main as possible. Sharp bends or abrupt changes of direction occurring adjacent to the point of spraying may be responsible for deposition of the oil mist before it has had time to become thoroughly dispersed throughout the gas volume. The most suitable place for the insertion of the spray is at some convenient point in the district main just prior to its leaving the works, although in aggravated cases or straggling districts it may be necessary to arrange for local sprays at some distance from the works.

On the Continent it has been customary in some instances to atomize a light tar oil into the crude gas as it issues from the condensers. The oil employed consists of 60 per cent. distilling over between 100° and 180° C., and 35 to 40 per cent. between 180° and 230° C. This can be readily atomized at ordinary temperatures, the mist being removed prior to the wet purification by means of P. and A. tar extractors. It is claimed that naphthalene may be entirely eliminated by this process.

When a solvent is introduced into the district mains the first essential is to ensure that it will carry effectively throughout the whole system. Paraffin, and many of the other common solvents, should be atomized and not vaporized, for they have a comparatively low vapour pressure, and, if vaporized, will not remain in the gas for any length of time. Although, in the author's opinion, the solvents are preferably admitted to the district main, it may be pointed out that in some instances the spray is fitted at a point between the station meters and the gasholders.

Of the special spraying methods introduced, may be mentioned that of Botley, who injects about 4 gallons of thoroughly atomized paraffin oil per million cubic feet of gas. This investigator found that the oils most suited for enriching purposes are not the best for naphthalene washing ; thus petroleum is more efficient than a light spirit or benzol. When the system is in use, a dark green oil is pumped from the street syphons, this being recovered and made use of on the works for lubrication, or, in some cases, recarburetting. The recovered portion amounts to about 25 per

cent. of the original quantity used. The temperature at which the oil mist is injected is of some importance, a degree or two above that of the gas in the mains being most satisfactory. It may be mentioned that the quantity of solvent given above was that employed at a time when coal gas was of a very much richer nature than at present, and when, therefore, the proportion of natural carriers was very much higher. With present-day gas, accordingly, it will usually be found necessary to add at least 10 gallons of the solvent per million cubic feet.

C. Wood, at Bradford gasworks, employs a spray of the form shown in Fig. 287, the solvent being supplied to the spray at a pressure of 70 to 80 lb. per square inch. The solvent used is paraffin, having a boiling-point of 165° C. About 10 per cent. of the total oil injected is deposited, the condensate having a boiling-point of from 174° to 179° C. Colson adopted the practice of washing the gas in a Livesey washer with an oil specially prepared from tar. The distillate used had an average specific gravity of 0·996 and was obtained at temperatures between 170° and 215° C., being of the nature of creosote. It was not necessary to fill the washer completely with the solvent, and a depth of a few inches on the surface of the liquor was found to be sufficient. Leather made use of creosote oil for eliminating naphthalene, but took the precaution to pre-benzolize it. Once saturated with naphthalene the oil may be distilled, when the benzene and toluene are recovered with the light oils. The naphthalene is then eliminated by means of live steam, and the residue remixed with the benzene distillate and returned to the washer. R. de la Boulaye experimented with a number of substances, ranging from methyl and ethyl alcohol to heavy oils, in order to determine their relative merits as solvents for naphthalene. Finally he concluded that the best remedy for naphthalene was abrupt condensation and the ultimate use of a benzol or heavy oil spray in the mains before the gas left for the district. The practice adopted by Ferguson Bell is somewhat uncommon. The gas whilst in a warm state is washed with warm tar, and at the outlet of the washers and scrubbers it is further treated with a naphtha oil.

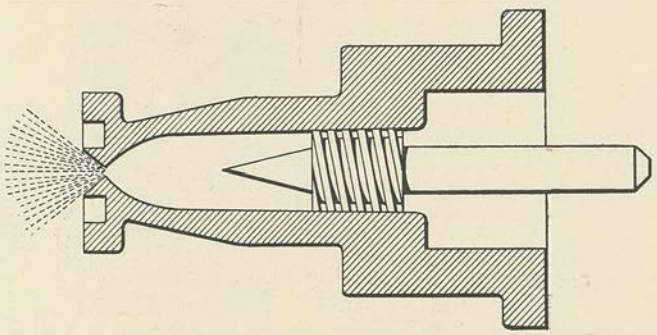


Fig. 287.—Spray for Naphthalene Solvent.

Carburation with Solvents

Carburation of the gas with spirits or low-boiling solvents is not now effected to the same extent as formerly owing to the present high cost of suitable liquids. The advantage of using such spirits as benzol is that they have a comparatively high

vapour pressure, and remain, therefore, as a permanent vapour in the gas. Higher boiling solvents such as paraffin may be employed in vaporizers; but, as pointed out above, atomization in such cases is to be preferred. When paraffin is utilized in a vaporizer it will be found that some of the higher-boiling constituents do not evaporate, and they flow away from the apparatus.

One type of carburettor which has been employed is shown in Fig. 288. The carburettor is connected with the gas main at the outlet of the works, the main being provided with a throttle valve so that about 10 per cent. of the gas distributed can be passed through the vaporizing chamber. The illustration shows the solvent storage drum, the overhead supply tank, and the vaporizing chamber in cross-

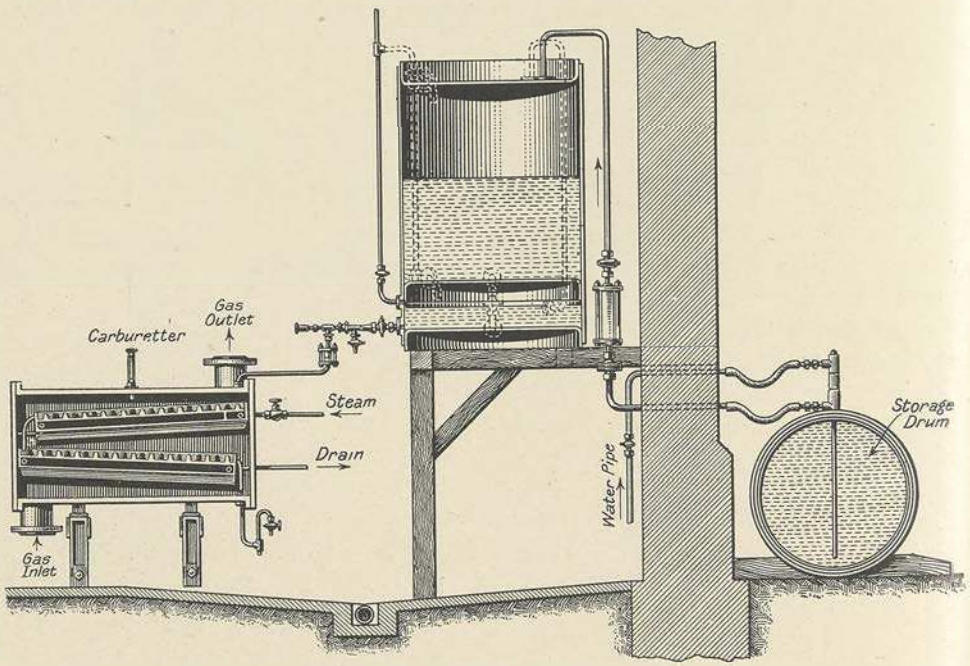


Fig. 288.—Apparatus for Carburation of District Gas.

section. It will be noted that water pressure is employed for transferring the solvent from the drum to the overhead tank. When solvents, such as paraffin, of moderately high boiling-point are used, the distance from the outlet of vaporizing chamber to the gas main should be as short as possible, for the character of the oil mist produced is favourably influenced by a moderately sudden temperature drop of the hot by-passed gas. The introduction of carburetted water gas undoubtedly went some considerable way towards lessening the naphthalene evil, although opinions differ considerably as to its utility in this direction. A great deal, however, depends upon the method of manufacture of the water gas, and more particularly upon the temperature to which it is subjected during its passage through the superheater. If the superheater is maintained at temperatures much above the normal the gas will

largely be deprived of its solvent properties, owing to the over-cracking of the oils upon which these properties depend.

Ab-der-Halden [1] has studied the effect of artificial carburation and has reached the following conclusions :—

(1) When a coal gas saturated with naphthalene at a given temperature is artificially carburated, it can be cooled below this temperature without the naphthalene solidifying, as it is retained in the form of a gaseous solution by the carburating vapours.

(2) The efficiency of the treatment depends on the boiling-point of the carburating agent and not on its chemical composition, and the best results are obtained with oils boiling between 80° and 90° C.

(3) The cooling-point of the treated gas up to which the naphthalene will not solidify out depends on the quantity of the carburating agent used.

(4) The influence of carburating coal gas supersaturated in naphthalene is the more marked the greater the content of the naphthalene in the original gas.

Carburetted water gas, however, has suffered in quality as a result of the enormous advance in the cost of oil occasioned by the world shortage. To-day it contains seldom more than one-third of the solvents which characterized it in pre-war days, and little assistance in the way of naphthalene troubles must now be expected from it. In fact, the use of oil in most cases has been discontinued altogether, with the result that the mixed gas as distributed under such conditions is particularly poor in low-boiling vapours.

THE ESTIMATION OF NAPHTHALENE IN COAL GAS

Colman and Smith's method depends upon the fact that naphthalene is removed from the gas when the latter is passed through an aqueous solution of picric acid, the naphthalene being precipitated as naphthalene picrate ($C_{10}H_8$, $C_6H_3N_3O_7$) and free naphthalene. The apparatus consists of five bottles, the first having a capacity of 4 oz., the second 10 oz., the remaining three being of 2 oz. capacity. The first is charged with a solution of citric acid which serves to remove any ammonia in the gas, the second contains 100 c.c. of one-twentieth normal picric acid, the third and fourth 25 c.c. each of the same solution, while the fifth serves to retain any splashings carried over. The fifth bottle is connected to the meter inlet. The gas is then passed through the bottles at the rate of 0·5 to 1 cubic foot per hour, until 10 cubic feet have passed. The contents of the 2 oz. bottles are then transferred to the 10 oz. bottle, and all connecting tubes are washed out with as small a quantity of water as possible. An india-rubber stopper fitted with a glass tube, sealed at the bottom, but having a small hole in the side, is then tightly inserted in the 10 oz. bottle, the hole in the side of the tube being just below the bottom of the stopper. The bottle is then evacuated with the water pump as completely as possible, and the glass tube is drawn up so that the hole is well within the rubber stopper, thus sealing the bottle tightly. The bottle is placed in a bath of warm water, the latter being heated to

[1] *Chimie et Industrie*, Jan., 1920.

boiling. The bottle is occasionally shaken, and heating is continued until a clear solution is obtained. After cooling the whole of the naphthalene picrate will crystallize out in fine needles.

The contents of the bottle are washed into a 250 c.c. measure, and are made up to this volume with water. The whole is then filtered. One hundred c.c. of filtrate are taken, a few drops of lacmoid solution are added, and the whole is titrated with decinormal soda solution until the colour changes from a brownish yellow to a greenish tint. The 50 c.c. burette supplied with the apparatus reads off directly the number of grains (uncorrected) of naphthalene per 100 cubic feet of gas. This reading divided by the tabular number gives the corrected value. If an ordinary burette is used the result may be calculated as follows:—

Two hundred and twenty-nine parts of picric are combined in the picrate with 128 parts of naphthalene, therefore the quantity of picric acid formed multiplied by $\frac{128}{229}$ gives the quantity of naphthaline in the volume of gas passed through the meter.

CHAPTER XV

EXHAUSTING MACHINERY

ALTHOUGH the exhauster has only come into universal use during comparatively recent years its invention extends back to quite the early days of gas production, the scientific apparatus employed to-day having been gradually evolved from an exceedingly crude beginning. The necessity for some such apparatus first became apparent when the original cast-iron retorts began to give way to those made from more porous substances. The idea of drawing off the gas from the retorts by the creation of a vacuum seems to have first occurred to an engineer named Grafton, about the year 1839. The machine which this investigator made use of was extremely inefficient, consisting of an ordinary wet-gas meter with the inlet and outlet reversed and having the drum driven by power. The notion, however, paved the way for more suitable apparatus, with the result that ten years later the exhauster had become a familiar feature of the larger works. Nowadays, this machine, in various forms, is to be found on all gasworks with the exception of the very smallest, where the cost of installing and operating it would not be commensurate with the saving entailed by its introduction. Where the limit, so far as the size of the works is concerned, should be placed is a matter for argument. It is frequently stated that any works making two million cubic feet of gas or over per annum can profitably instal exhausting plant. When faced with actual facts, however, such a proposition does not bear examination, and, unless exceptional circumstances intervene, the use of the exhauster on works making less than four or five million cubic feet per annum is not to be recommended.

Consideration of an actual case is sufficient to emphasize this point. For instance, consider a works making five million cubic feet per annum. When working without an exhauster the gas made per ton of coal would probably average 9,500 cubic feet, whilst the introduction of the exhauster might account for an increased yield of from 800 to 1,000 cubic feet. In consequence, the coal consumed annually would be reduced from 525 to 480 tons, *i.e.* a saving of 45 tons.

Capital Outlay :—	£	*s.*	*d.*
Engine, exhauster, valves, foundation	200	0	0

N.B.—If no building is available for this plant, an additional outlay (say £80) would be entailed.

Charges to be met (annual) :—	£	s.	d.
Interest, depreciation, repairs, and renewals, 14 per cent. on £200	28	0	0
Gas consumed by engine, say 3,000 cubic feet per week at 4s. 6d., cost into holder	35	2	0
Oil, stores, etc., per week 4s.	10	8	0
	£73	10	0

Resultant Saving :—	£	s.	d.
45 tons of coal at net cost price (after allowing for residuals) of 32s.	72	0	0
Wear and tear on carbonizing plant, owing to reduced quantity of coal used, at 4s. per ton	9	0	0
	£81	0	0

The balance, it will be noticed, is extremely small, although a good deal will depend upon the distance of the works from a point of delivery for materials, and consequently the price at which coal can be obtained at works. No saving of labour can be contemplated, for on works of such a size a single man only is employed for carbonization. Moreover, the question of labour may operate against the employment of the exhauster, owing to the necessity for the man in charge to have some knowledge of mechanical plant. On the other hand, the exhauster offers undoubted advantages in such directions as the control of gas quality, the reduction of scurf, etc.

Exhausters now employed on gasworks are almost universally of the rotary type, although those operating on the reciprocating principle and designed on the lines of an ordinary steam pump were in common use in days when the rotary machine had not been brought to its present stage of perfection. Primarily, the function of the exhauster, in whatever form it may be used, is that of withdrawing the gas from the retorts by the creation of a vacuum, to avoid the formation of an excessive pressure therein, and eventually to propel the gas through the remainder of the apparatus and into the holders, thus causing the latter to rise. So far as the conditions of the operation of the exhauster are concerned the vacuum induced on the inlet must be sufficient—

(*a*) To overcome the seal on the dip-pipe, if a seal is employed.

(*b*) To overcome frictional losses arising from the passage of the gas along the foul main.

(*c*) To overcome the resistance offered to the gas by the condenser.

In normal working and when dry mains are not in use, the hydraulic seal amounts to about half an inch, whilst the frictional losses in the foul main may be equal to 1 inch of water pressure, and the resistance of the condensers to 2 inches. Accordingly, on the larger works it is usual to maintain an average vacuum of about 4 inches of water at the exhauster inlet. On the outlet, the pressure to be overcome varies in accordance with the resistance offered by the apparatus following and the quantity of gas passing at the time. In the aggregate, it may vary between 8 inches to 10 inches on a small country works to as much as 50 inches of water on the largest plants, but in average cases it will be accounted for somewhat as follows :—

PRESSURE CONDITIONS THROUGHOUT THE APPARATUS

Retorts	Level-gauge.						
Hydraulic main	½ inch to 1 inch vacuum.						
Exhauster inlet	4 inches vacuum.						
„ outlet	30 „ pressure.						
Tar extractor, outlet	26 „ „	Pressure thrown by	tar extractor,	4	inches.		
Washers, outlet	24 „ „	„	„	washers	2	„	
Scrubbers, outlet	22 „ „	„	„	scrubbers	2	„	
Purifiers, outlet	9 „ „	„	„	purifiers	13	„	
Station meter, outlet	8·5 „ „	„	„	meter	0·5	„	
Holder, inlet and outlet	8·5 „ „	„	„	holder	8·5	„	
					30	inches.	

From the above it will be seen that the forcing of the gas through the dry purification material and the raising of the holder bell account for the greatest portion of the work which the exhauster has to perform against back-pressure. At times the physical condition of the purifying material may give rise to considerably increased pressure, when the offending vessel must be shut off, or a tier of oxide "slipped" by drawing the slides specially provided for this purpose.

TYPES OF EXHAUSTERS

In considering the mechanical details of exhausters it is advisable to classify the various types under the following headings :—

(*a*) Reciprocating types.
(*b*) Rotary types.
(*c*) Steam jet types.
(*d*) Turbo-exhausters and high-speed machines.

Reciprocating machines operated on the pump principle need be given no further notice as they are now obsolete. Rotary exhausters of various types are almost exclusively used at the present day, whilst the most recent development of the same principle is the turbo-exhauster. The first attempt to construct a practicable rotary exhauster was made by Beale in 1850, and this machine, with important modifications and refinements, has served as a model for the modern apparatus. About the same year G. Jones introduced a blower operating on the Roots' principle, but for gasworks purposes the machine has not gained much favour in this country, although in America it seems to be preferred. Some years later the Beale exhauster was much improved by Gwynne & Co., who introduced two overlapping blades instead of the single one originally employed. The Gwynne-Beale exhauster is shown in Fig. 289. The blades pass through slots cut in the inner drum, which is revolved from the source of power. The extremities of the blades are provided with steel-cased pins which are fitted into segments. The segments travel in grooves cast in the end covers of the drum, so that when the inner drum revolves the blades are drawn in and out, thus sucking in the gas from one port and discharging at the second. The main defect of this exhauster was the

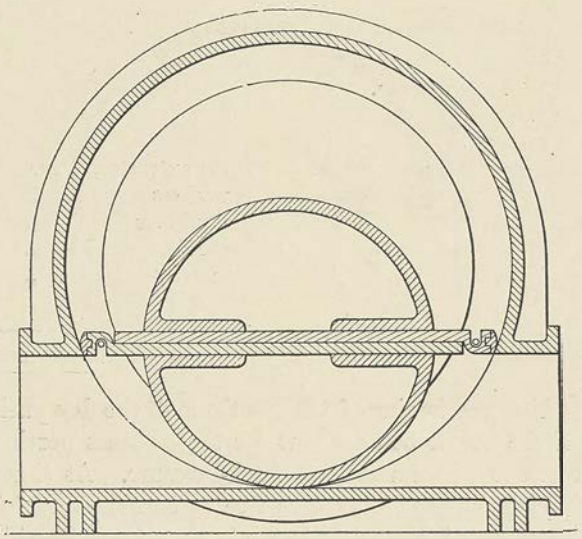


FIG. 289.—GWYNNE-BEALE EXHAUSTER.

large amount of friction produced by the guiding segments running at a high speed, whilst the compound slide required frequent renewal. The machine was therefore soon displaced by an improved form, also due to Beale, in which the guiding segments were eliminated. The blades in the new type (Fig. 290) were guided from the centre of the outer casing by the use of a block running on a central shaft fixed in one of the end plates. The two slides were then cast in one piece, and the frictional losses so reduced as to lessen the driving power required to about two-thirds of that of the original machine. A feature of the machine is that the outer casing is not bored to a true cylinder, but is oval in shape, this being necessary owing to the slightly eccentric movement of the blades which slide on the centre block.

MULTIPLE BLADE EXHAUSTERS

The primary objection to exhausters of the two-blade type is the irregularity of the vacuum they produce on the inlet side, particularly when running at slower speeds. In order to avoid such oscillation the exhauster with more than two blades was introduced about the year 1879; and owing to the many advantages offered

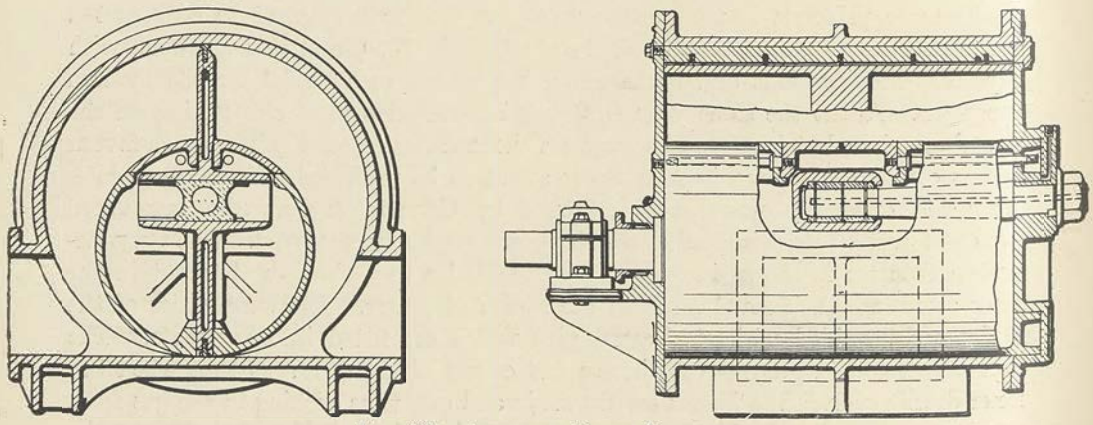


FIG. 290.—IMPROVED BEALE EXHAUSTER.

the multiple type is by far the most common in use at the present time. Stated briefly, the advantages which the multiple machine possesses over the two-blade type are as follows :—

(*a*) For the same size an increased capacity is obtained, amounting to about 30 per cent. with the three-blade type and 40 per cent. with the four-blade type, as compared with the two-blade machine.

(*b*) The oscillation is considerably reduced.

(*c*) The outer cylinder is a true circle, consequently no special boring machinery is required.

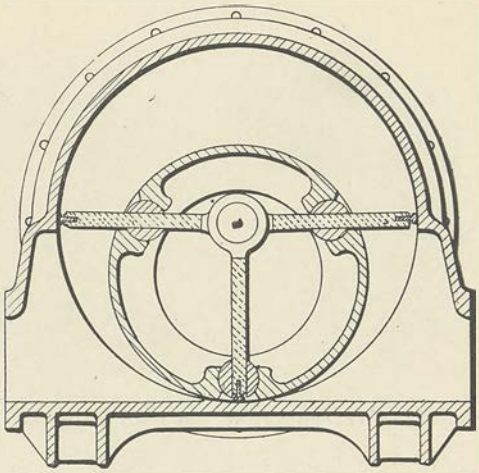


FIG. 291.—3-BLADE EXHAUSTER.

(*d*) The whole machine is more easily constructed.

On the other hand, as is often pointed out, the increase in the number of blades is obtained only by reducing the extent of the wearing surfaces, and some engineers state that the three- or four-blade machines have their disadvantages in cases where the back-pressure at the outlet is considerable and where high speed is necessary.

The design of the two-blade machine is such that it is capable of dealing with very high pressures, due to the small number of parts and the method in which the load is taken. Taking the slide in position shown in Fig. 290 it is readily seen that at the time of maximum pressure the pin is under its minimum strain, and the reaction due to the load on the exposed part of the slide is transferred to the other side of the driving drum where the maximum of wearing surface can be provided, with consequent reduced wear. With a three- or four-blade machine with the slide in the same position, the pin is under maximum stress, and the load on the roller face is very heavy, due to the load on the slide and the reaction from the pin.

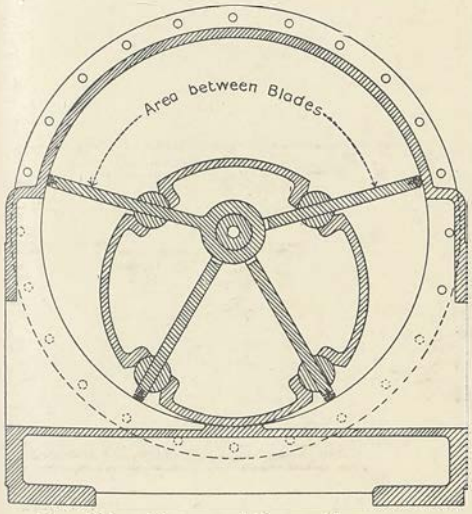


FIG. 292.—WALLER 4-BLADE EXHAUSTER.

Moreover, in the design of the multiple machine it is often found that very large rollers have to be used in order to obtain adequate wearing surface at this point. For high speed and high pressure many engineers consider the two-blade machine to be ahead of any other, and this type

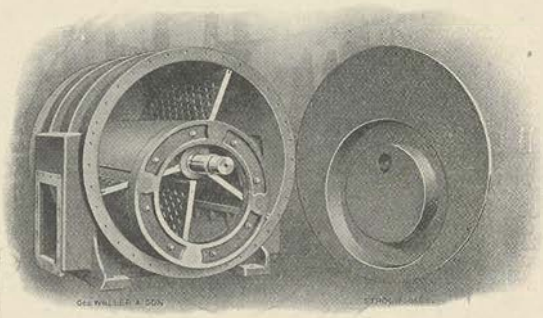


FIG. 293.—WALLER EXHAUSTER WITH END-PLATE REMOVED.

of exhauster is now made for working against pressures up to 10 lb. per square inch.

Typical examples of the multiple exhauster are shown in Figs. 291 and 292. The outer drum is bored truly cylindrical, whilst the internal drum (which is about two-thirds the diameter of the external casing) is fitted with three or four small rolls which are slotted out to take the blades, and oscillate in the bearings according to the movement of the blades. The ends of the rolls project beyond the width of the inner drum and are supported in bored recesses in the end covers. The blades are hinged on a shaft which is central with the outer drum, and which extends the whole length of the cylinder and is supported in a deep boss on the back cover, and secured by a nut. To facilitate lubrication this spindle is bored down its entire length. The driving shaft is cast on to the inner drum and projects through a gland and stuffing box in the inner cover. In order to reduce the losses by "slip" the tips of the blades are fitted with T-shaped strips which are forced against the inner periphery of the drum by spiral springs. The construction of these exhausters will be readily seen by referring to Figs. 293 and 294.

The number of blades fitted bears some relation to the capacity of the exhauster; and, in general, all machines dealing with less than 5,000 cubic feet per hour are fitted with two blades; all above this capacity and up to 25,000 cubic feet per hour are of the three-blade type; whilst four blades are fitted for sizes larger than this. The smallest rotary exhausters made are 3 inches internal diameter and 3 inches long, but these are seldom used for anything beyond adding air to the dry purifiers or for compressing purposes. They are of the two-blade type, running at about 500 revolutions per minute, and having a gross output of about 115 cubic feet per hour. The largest exhausters manufactured, which are chiefly employed on coke-oven works, have a capacity of about 450,000 cubic feet per hour,

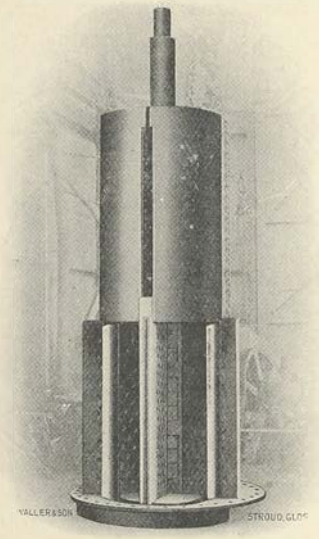


FIG. 294.—EXHAUSTER, SHOWING INNER DRUM PULLED AWAY FROM BLADES.

and are 5 feet in diameter. They are almost invariably driven by electricity, as shown in Fig. 295.

Methods of Driving

Some years ago it was the common practice to drive the larger exhausters by means of belting, but the method is now fast giving way to the direct-coupled system. The belt drive is objectionable owing to the possibility of the belt slipping, in which case the exhauster may stop abruptly, on account of friction between the blades and the case. The cost of driving power is, of course, the chief consideration in the case of the small works, and as steam power is frequently not available in such cases, a gas engine drive through a countershaft and belting is the only alternative. An advantage attending this method is the possibility of driving liquor and other pumps from the same countershaft. (A recommendation for the use of the exhauster in small works—and one which can scarcely be gauged in terms of money—is that a greater pressure may be maintained on the district mains, thus the annual quantity of gas consumed may undergo augmentation.)

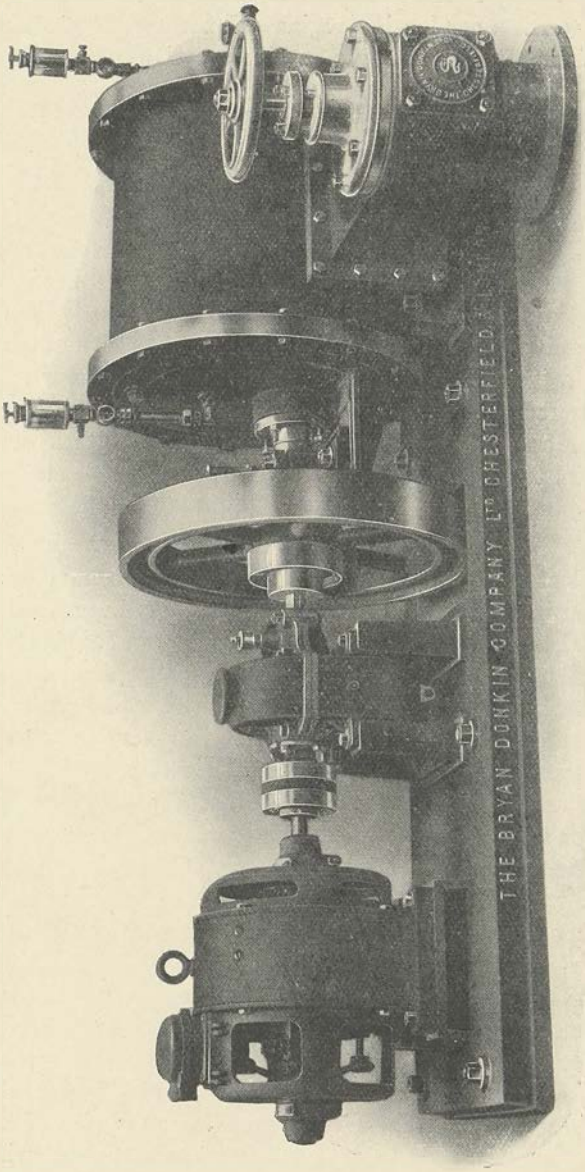


Fig. 295.—Electrically Driven Exhauster Installation.

On the larger and medium-sized works, where an ample supply of steam is always at hand, exhausters are frequently driven by reciprocating or turbine steam

engines. Many devices have been introduced with the object of ensuring efficiency and economy. With the larger exhausters it is always profitable to instal a compound engine, owing to the considerable saving it effects in steam consumption. On the larger works a condensing engine still further increases the efficiency of steam consumption. When, however, a single cylinder engine is installed some attention to the valve setting is necessary. All exhauster engines may be operated with a comparatively early " cut-off," and the admission of steam for the whole length of the stroke must be looked upon as unjustifiable extravagance. In the majority of cases the " cut-off " may be arranged at half-stroke, though many engines will be found working at three-quarters or seven-eighths. The later " cut-off " probably emanates from the fact that some engineers are of the opinion that closure at any earlier period is conducive to unsteady running; but if the fly-wheel is of sufficient proportions this will not be found to be the case. Cases are known where engines are running at a quarter " cut-off," and with no undesirable effect on the " draw." When a " cut-off " is used, however, a rather larger engine is necessary; and for high-pressure steam it is certainly advisable to fit an expansion gear, so that a sharper and earlier effect may be obtained. With very low-pressure steam it is essential to work with admission during the whole stroke.

Electrical Driving

Electrically operated gasworks exhausters have as yet been adopted only in isolated instances in this country. Speaking in general, there is frequently a good case for the employment of electrical power in almost any other department of the works, but with the usual rather primitive generating plant so frequently found on a gasworks it will usually be better policy to drive the exhausters by other means. In the first place, with the usual electrical plant considerable fluctuations of pressure are common, whereas the maintenance of a uniform pressure is essential if the exhauster is to be operated effectively. It has been said that in order to ensure an even pressure it is essential to employ a battery of accumulators in conjunction with the generating plant on account of the steadying effect produced. Every engineer who is familiar with electrical stoking machinery knows that at some period or other his plant is temporarily put out of action by the blowing of a fuse or some such common mishap, and while this is of comparatively little importance in the case of intermittently worked plant, it is a matter of considerable importance where the continuously running exhauster is concerned. Certainly, continuity of supply may be ensured by a proper arrangement of the switch gear; but, for all that, an additional responsibility is introduced from which the more common methods may be said to be free. Thus, from the point of view of reliability, tendency to breakdown, etc., the electric drive is not to be compared with the single-cylinder steam engine or gas engine. From the standpoint of economy and efficiency, however, there is little question that the electric motor is superior for the purpose, particularly when compared with the average form of non-condensing steam engine employed. A difficulty with the electric motor which is frequently overlooked is that if it is direct coupled to the exhauster it must (unless a turbo-exhauster is used) be built

for running at a very low speed. Electric motors of normal construction, however, are built to run at high speeds, consequently the special type required is very costly, and also very much heavier and larger than the normal type. The question of governing, too, is one which must be given due consideration, for although the "throttle" method as applied with the steam-driven machine may be employed (by arranging for speed variation by means of a shunt regulator), it is probably better, in order to avoid anything in the nature of complications, to maintain a constant speed and to effect governing by the ordinary by-pass method.

Exhausters—more especially those of the turbo pattern—driven by steam turbine have been more in evidence lately, and their development has probably been the result of the successful operation of water-gas blowers by this means. The chief merit of this type of exhauster is its ability to maintain an absolutely constant suction whatever the volume of gas delivered. In order to maintain this uniformity the speed of the turbine is varied within wide limits by means of an automatic governor. The turbine, of course, produces a much steadier turning moment than the reciprocating engine, and, in general, collateral advantages are to be found in the economy of fuel consumption and the low charges for maintenance.

Running Speed

It is not generally realized that when regulating an exhauster the speed to be considered is not the actual number of revolutions performed by the drum per minute, but the peripheral speed of the tips of the blades. For a given number of revolutions per minute the peripheral speeds of (say) a 6-inch drum and a 4-feet diameter drum would be widely different, the blade tips travelling at a greatly increased linear velocity in the latter case. In both cases, however, the peripheral speeds should be approximately equal, and for exhausters of all sizes there is very nearly a constant peripheral speed, which should vary only between the limits of 650 and 850 feet per minute. Thus a 9-inch exhauster running at 275 revolutions per minute gives a peripheral speed of 650 feet per minute, and a 3-foot machine running at 70 revolutions per minute has also a peripheral speed of about 650 feet per minute.

Governing the Capacity

There are two standard methods of governing exhausters:—

(*a*) By inserting an automatically controlled by-pass between inlet and outlet.

(*b*) By automatically throttling the steam supply, or controlling the electric current.

When a gas-engine drive is employed the first method only is practicable, as the speed of the engine cannot be varied to any great extent by the ordinary means of governing employed. Schemes for effecting this have certainly been suggested; but, at the most, the result is only partial, and the most convenient arrangement is to work the engine in conjunction with a countershaft to which a stepped pulley is fitted.

The ordinary arrangement of governing with a by-pass valve is shown in Fig.

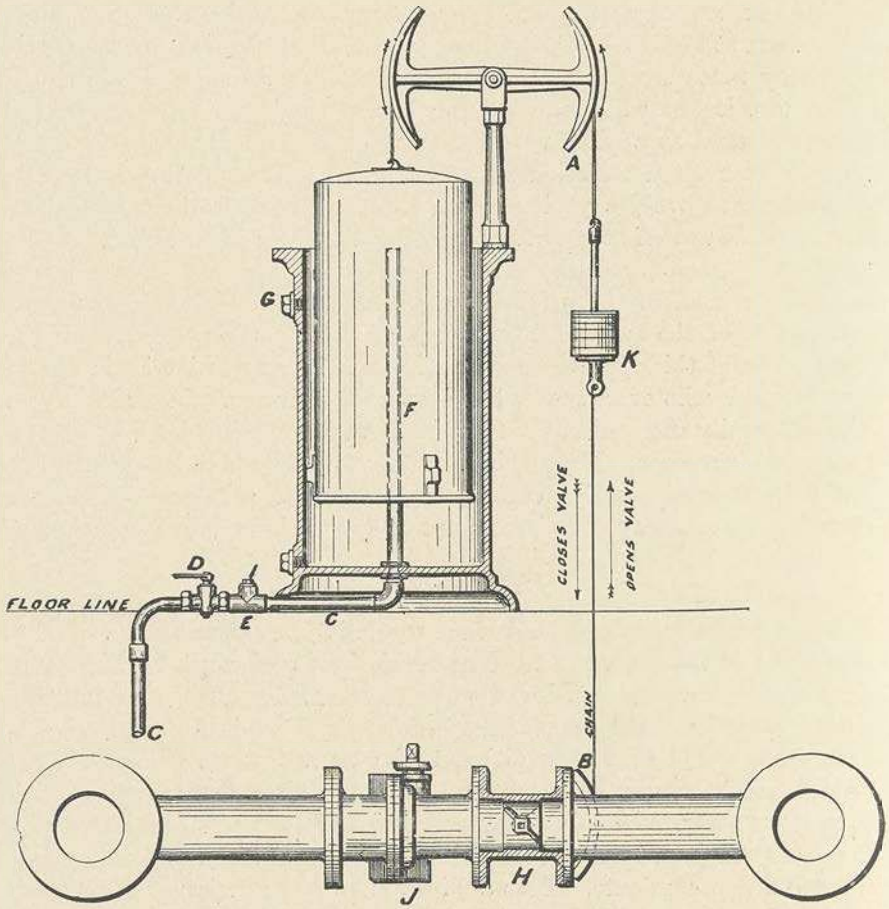


FIG. 296.—EXHAUSTER GOVERNING BY BY-PASS.

296. The inlet and outlet of the exhauster are connected by a short length of pipe in which an ordinary butterfly valve, attached to a quadrant (Fig. 297) is inserted. The quadrant is then attached by a chain and lever to the bell of a small gasholder which is connected by a small service pipe (*F*) to the inlet main of the exhauster.

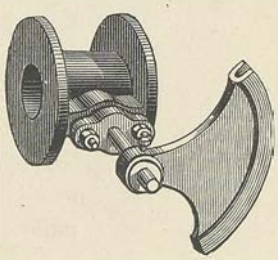


FIG. 297.—QUADRANT AND VALVE.

The quantity of gas coming away from the retort house varies to some considerable extent at different periods of the day. Accordingly, the intensity of vacuum produced will also vary in ratio to the amount passing if the speed of the exhauster is permitted to remain constant. In this type of governing the speed of the engine is maintained fairly constant, and at a sufficient velocity to take the maximum quantity of gas coming from the retorts. When the quantity passing along the foul main undergoes reduction the vacuum becomes momentarily increased;

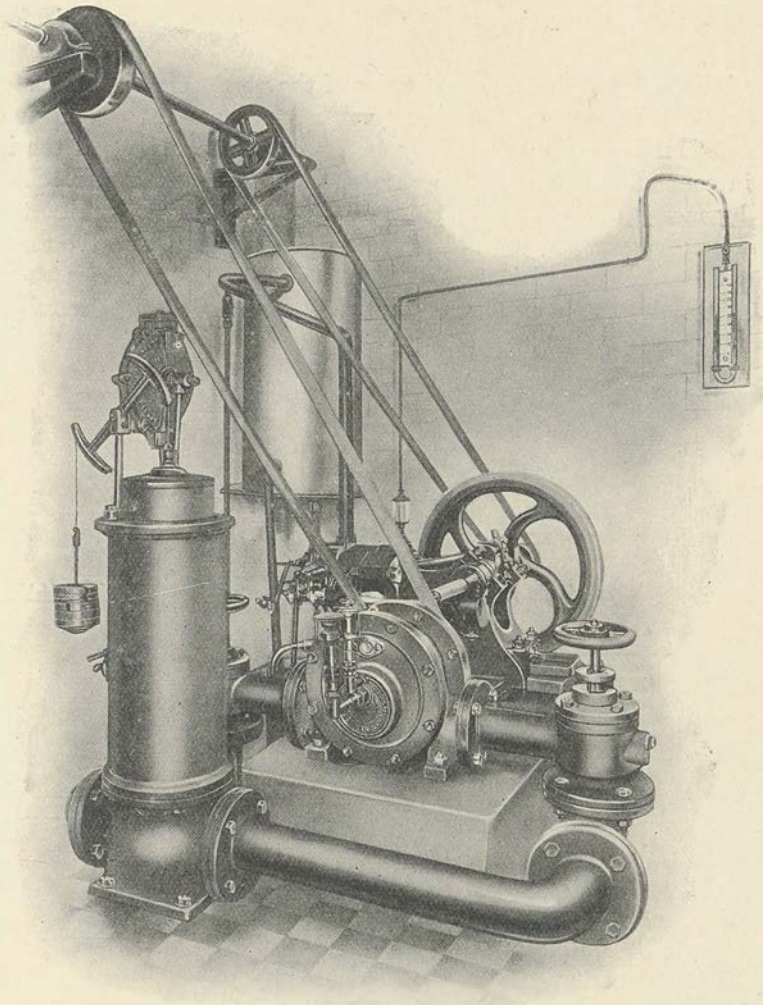


FIG. 298.—COMPLETE EXHAUSTER INSTALLATION SUITABLE FOR A SMALL WORKS.

accordingly, the holder bell drops and operates through its link motion to open the by-pass valve. In this way gas is sucked back from the outlet to the inlet, and compensates for the falling off in the quantity coming from the retorts—thus the original vacuum is maintained. In the same way, as the quantity of gas passing along the foul main increases the vacuum momentarily decreases, with the result that the holder bell rises and closes down the by-pass valve until the normal " draw " is given. The method is certainly effective, but care is necessary to see that the exhauster is running at a sufficient speed to deal with the *maximum* quantity of gas likely to pass at any time from the retorts, for the governor cannot increase the speed of the engine should this be insufficient at any period. Fig. 298 shows a

complete gas-driven exhausting plant with by-pass governor suitable for a small works.

There is little doubt that, when the size of the plant permits, exhauster governing can be most effectively carried out by varying the speed of the engine employed for driving. This is simply effected by employing a gasholder bell the interior of which is in communication with the vacuum side of the exhauster. Buoyancy is imparted by means of air-floats placed at the base of the bell, whilst the upward or downward movement of the bell is conveyed by link motion to the throttle valve of the engine. Briefly explained, the operation of the governor is as follows:—Should the quantity of gas passing to the inlet of the exhauster decrease, then the

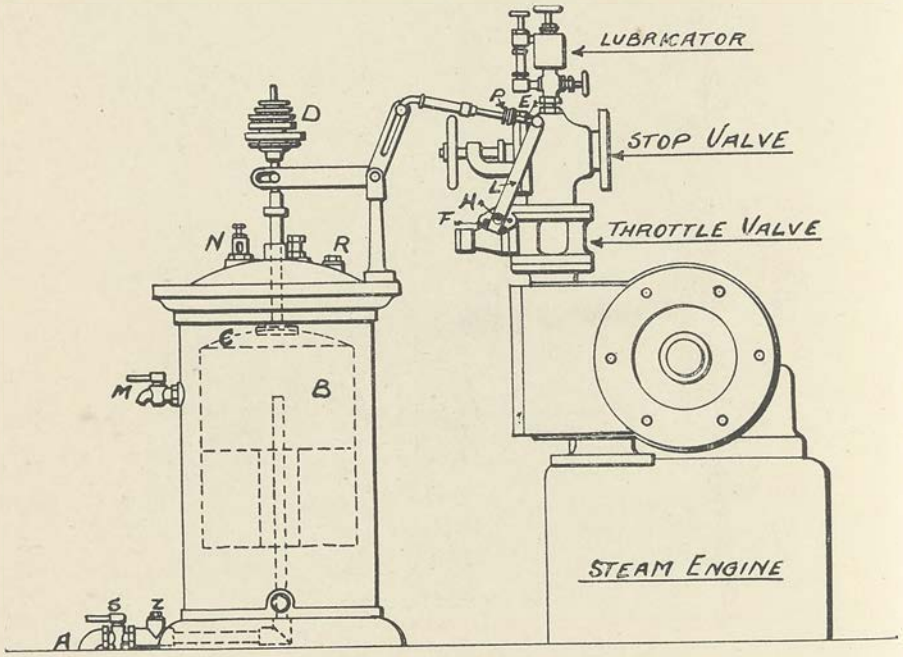


FIG. 299.—EXHAUSTER GOVERNING BY THROTTLE.

intensity of vacuum in the inlet main will increase. But the service pipe (*A*, Fig. 299) transmits this increase of vacuum to the interior of the bell, which, accordingly, is pulled downwards. The downward movement of the bell then operates through the link-motion to close the throttle valve (*H*) slightly so that the speed of the engine is reduced in accordance with the amount of gas coming along. In the same way, when the quantity of gas increases, the vacuum on the inlet falls, with the result that the bell ascends and opens the steam throttle to the required extent. By adjusting the cock placed at *R*, on the top of the bell, the rate at which the bell rises and falls may be regulated. In some instances steadiness of movement is assured by introducing the principle of the "dash-pot."

In laying down exhauster installations it is frequently arranged that both

by-pass and throttle governors shall be provided. On large works where a number of exhauster units are employed, there is no necessity for a by-pass governor, for, according to the make, exhauster sets are started up or shut off and the whole of the governing can be done by steam regulation. On small and medium-sized works, however, where only duplicate machines are in use, a single exhauster has probably to deal with the maximum winter and minimum summer make. In this case the exhauster is usually installed to allow room for future extension ; consequently, without the by-pass governor it would have to run at an inconveniently low speed when dealing with the minimum make. In such cases it is preferable, therefore, to supply a by-pass governor, which is adjusted from time to time according to the season, while the throttle governor controls the speed of the engine according to the varying makes during the twenty-four hours. Waller's latest form of hydraulic governor is shown in Fig. 300.

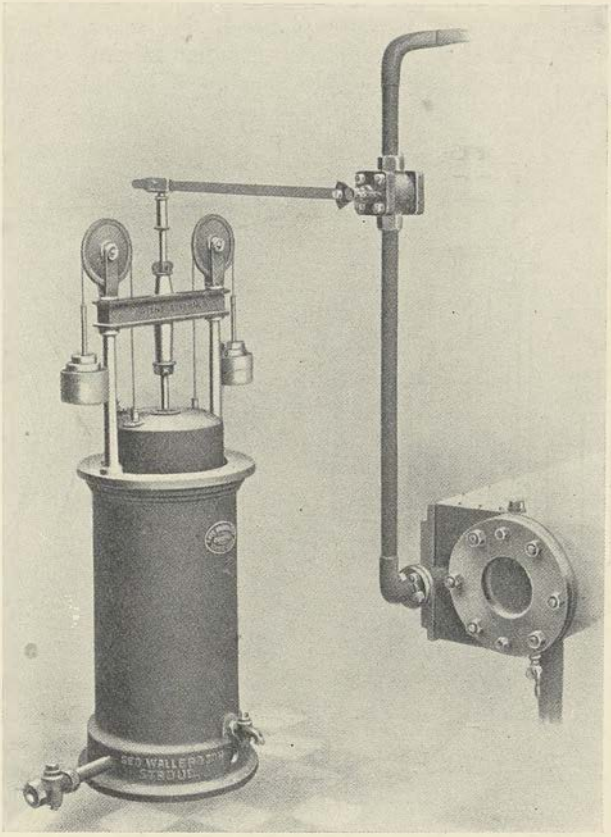


Fig. 300.—Waller's Hydraulic Governor.

The Lubrication of Exhausters

The lubrication of the exhauster is a point requiring very careful attention, for endless trouble may follow the use of unsuitable oils. For most purposes the best lubricant is a mixture of refined creosote and mineral oil—one part of the former to three of the latter. A heavy oil should always be used, also an oil that will act as a solvent for the tar, such as a good mineral oil, rather than a vegetable oil which will thicken with the tar. The temperature of the gas, the quantity of suspended tar, and whether the gas is clean or foul, are all important factors from the point of view of lubrication ; and experience is, perhaps, the most reliable guide. When the exhausters are preceded by tar extractors it will be found preferable to use an ordinary engine oil of good quality. The tar vesicles present in the gas possess very important properties in relation to the lubrication of the exhauster, and it is

important to ensure that the necessary fluidity of the tar is maintained. Dr. Carpenter has emphasized the value of the tar present by showing that, when the exhausters are placed prior to the condensers in sequence, no lubricating oil whatever is necessary.

Special apparatus for the lubrication of exhausters is now nearly always employed. The forms most generally made use of are :—

(*a*) Ordinary self-contained drip-feed.

(*b*) Pressure system, embodying the use of a reservoir from which the oil is expelled by the pressure of gas at the outlet of the exhauster.

(*c*) Mechanical appliances, such as miniature pumps driven by gearing or belting from the exhauster shaft.

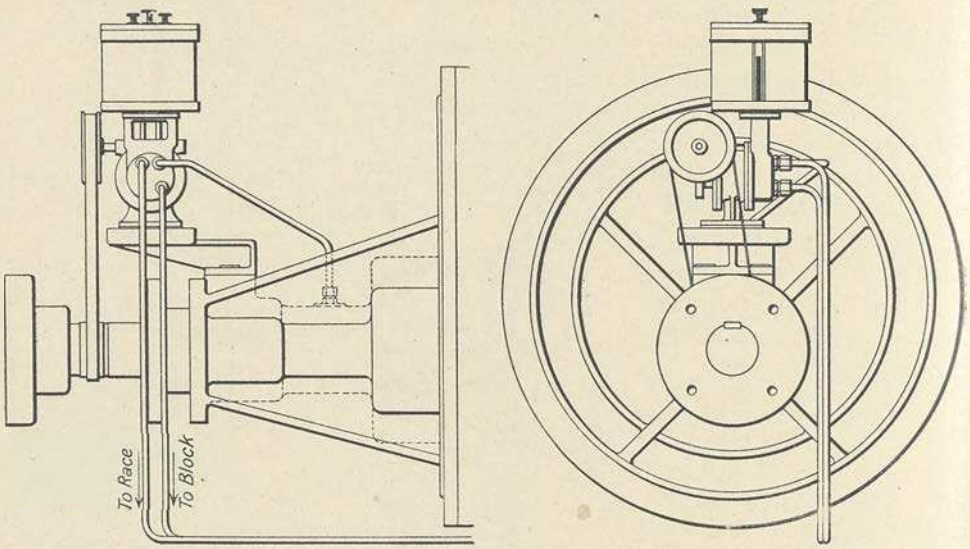


Fig. 301.—Mechanical Lubricator for Exhausters.

The several points at which an exhauster should be lubricated depend largely upon the type of the machine. Taking, however, as an instance one of the three- or four-blade types such as Waller's (Fig. 292), it will be seen that the inner drum is supported and rotates in recessed covers, therefore lubrication is required at these points. The hinges upon which the blades are carried upon the central spindle are lubricated by means of an oil hole provided by boring through the whole length of the spindle, oil being forced through this duct by an automatic or hand pump. In the case of the old pattern two-blade Beale exhauster the inner drum is supported by the shaft, which is carried in outside bearings ; these require lubrication, as do the segments which rotate in grooves in the covers. The latest pattern Beale machine is provided with a recessed back cover which requires lubrication, the driving shaft is supported by an outer bearing which must also be lubricated, whilst the steel spindle supporting the centre block upon which the blades rotate is pro-

vided with a hole for injecting oil. When possible, a continuous flow of oil, as given by one of the mechanical lubricators, should always be arranged for, this being very much more effective than an intermittent supply. The distribution must, moreover, be uniform, as a dry portion where contact occurs quickly results in heating and subsequent erosion of the surfaces.

Water as a Lubricant

The scarcity and high price of ordinary lubricating oils during the war led to an attempt to use water for the purpose. The practice has been adopted with considerable success in France,[1] where it has been shown that the principle is entirely satisfactory so long as the water employed is chemically pure and free from suspended matter. The water may be supplied through ordinary drip-feed lubricators, or by means of a small pump. The rate of flow should be from 90 to 100 drops per minute for an exhauster having a capacity of about 200,000 cubic feet per day, and it is stated that if the machine is to stand idle for any length of time a small quantity of oil should be admitted in order to prevent rusting. Guillet states that instead of water it is preferable to use ammoniacal liquor, since a hard water, under the action of ammonia and carbon dioxide in the gas, forms a deposit which may give rise to trouble. With ammoniacal liquor no derangement occurs; in fact the interior surface of the exhauster takes a high polish.

The following results were obtained from an electrically driven exhauster when lubricated by oil and water respectively:—

	Oil.	Water.
Power absorbed (watt hours)	7,500 ..	5,000
Temperature	30° C. ..	20° C.

Precautions against Stoppages

Owing to the seizure of a bearing, the slipping of a belt, the burning out of a fuse, or some other unlooked-for cause, an exhauster is liable to pull-up at short notice. This, of course, should not occur if the machine is properly attended to; but, nevertheless, it is an emergency which must always be provided for. In addition to duplicate plant some means should be provided for guarding against the undue pressure which would otherwise be thrown upon the retorts and the apparatus between them and the exhauster. A usual method is to insert in a by-pass pipe connecting inlet and outlet a safety flap-valve such as that shown in Fig. 302. In the ordinary way the outlet pressure holds the valve against its seatings, but should the exhauster stop the inlet pressure will, after a time, exceed that on the outlet, so that the valve is forced open, giving a free way for the gas. It will be realized, however, that only temporary relief is afforded before the pressure of the whole apparatus will be thrown on the retorts. The flap valves are usually fitted with a handle, as shown, so that they may occasionally be jarred in order to ensure that sticking will not occur.

On the rare occasions when the exhausting plant breaks down it is unreason-

[1] *J. des Usines à Gaz*, Jan. 20, 1918.

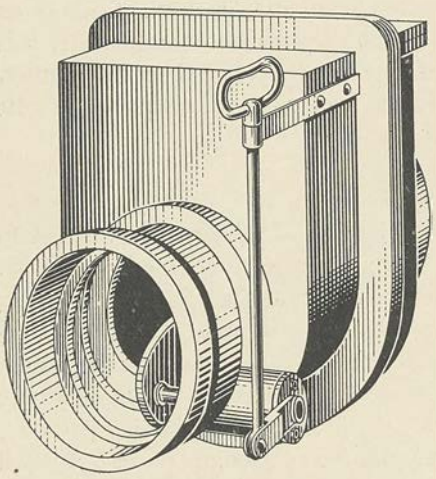


Fig. 302.—Safety Flap-Valve.

able to expect that no loss of gas whatever need take place, and the most simple and safe means of providing against such a contingency is that of inserting a safety seal in the main leading from the retort house to the exhauster. This seal can be regulated to some definite depth—usually about 6 to 8 inches—thus only a small pressure will be exerted upon the apparatus before the gas blows away. The seal should be arranged at some point in the open where there will be no chance of the escaping gas igniting. In making use of a seal of this kind it is necessary to ensure that the blow-off pipe is sealed to a greater depth than the maximum possible "draw" at this point; otherwise air will be sucked in.

Calculation of Capacity

Figures given by makers for the capacity of exhausters denote the amount of gas passed at normal temperature. The exhauster has, however, to deal with an amount of gas varying from 5 to 10 per cent. in excess of this rated quantity. In addition, "slip" past the blades is a fairly considerable item, for which further allowance has to be made. The amount of "slip" occurring is entirely dependent upon the difference of pressure between the inlet and outlet of the exhauster, and is independent of speed. But it may be taken as a general rule that as speed increases the proportional "slip" undergoes reduction. In calculating the capacity of exhausters it is customary to make an allowance of 15 to 20 per cent. for "slip," according to the size of the machine.

The calculation of the capacity of an exhauster is not so simple as might at first sight be supposed. Considering an ordinary four-blade machine it must be remembered that the capacity is not the whole space swept out by each blade per revolution. The amount of gas carried forward by each pair of blades is the greatest volume which exists at any time between the two blades. By reference to Fig. 303 it can be seen that at each revolution a volume of gas having a cross-sectional area equal to the shaded portion of the figure is carried from inlet to outlet by each pair

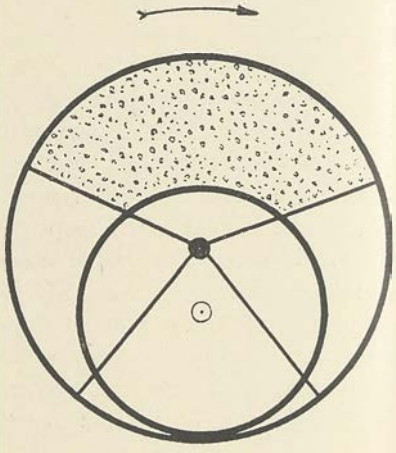


Fig. 303.

of blades ; and in one revolution of the exhauster this volume is taken in and delivered four times. When considering a two- or three-blade machine the volume between the blades (for a given size) is, of course, greater than with the four-blade ; but then it is only displaced two or three times in one revolution instead of four times.

For a four-blade exhauster the following method of calculating capacity may be used, but it cannot be said to be closely accurate when very large or very small sizes are under consideration.

Let D = the inside diameter of outer drum in feet.
L = length of drum in feet.
N = Revolutions made per minute.
Q = Cubic feet of gas passed per hour.

Then $Q = 65\ D^2LN$.

This gives the gross capacity, from which 20 per cent. should be deducted for "slip."

The capacity of modern exhausters has been increased to a certain extent by the introduction of relief-port passages which enable the blades to continue drawing for a longer period and provide a greater area for the issuing gas. It is questionable, however, whether these passages are perfectly satisfactory.

Driving Power Required

The motive power is the largest item in the running costs of exhausters. As regards the horse-power required for any one installation it is almost impossible to lay down a hard and fast rule, for so much depends upon the conditions under which the plant is working. A mere table of powers is, therefore, apt to be misleading. The power varies considerably ; for instance, an exhauster made to pass 100,000 cubic feet per hour at its standard speed would have about 65 to 70 per cent. efficiency if working against 30 inches to 60 inches back-pressure. If, however, the machine was put to work to pass 25,000 cubic feet per hour, the power required could not be taken in the same ratio to the gas passed, for the amount of power lost would bear a much larger ratio to the gas passed than in the first case. Hence the efficiency of the machine when dealing with small quantities will be much lower. There is no fixed rule as to what to allow for efficiency in such cases, and much depends on the type of machine under consideration. In practice, it is usual to treat each case on its merits, to suit the prevailing conditions. Some idea of the probable horse-power required may, however, be obtained from the following table, compiled by E. B. Donkin :—

HORSE-POWER REQUIRED TO PASS GAS AGAINST VARIOUS PRESSURES.
(Friction of Exhauster neglected.)

Capacity per Hour.	TOTAL PRESSURE OF GAS IN INCHES OF WATER.										
Cubic feet.	6	9	12	15	18	20	24	30	36	40	50
5,000	0·08	0·12	0·16	0·19	0·24	0·26	0·31	0·39	0·47	0·53	0·66
10,000	0·16	0·24	0·31	0·39	0·47	0·53	0·63	0·79	0·95	1·05	1·31
15,000	0·24	0·36	0·47	0·58	0·71	0·79	0·94	1·18	1·42	1·58	1·97
20,000	0·31	0·47	0·63	0·79	0·95	1·05	1·26	1·58	1·90	2·10	2·63
25,000	0·39	0·59	0·79	0·98	1·18	1·31	1·58	1·97	2·37	2·63	3·29
30,000	0·48	0·71	0·94	1·18	1·42	1·57	1·89	2·36	2·83	3·15	3·94
40,000	0·62	0·94	1·26	1·58	1·90	2·10	2·52	3·15	3·78	4·21	5·26
50,000	0·79	1·18	1·58	1·97	2·36	2·63	3·15	3·94	4·73	5·25	6·57
60,000	0·94	1·41	1·89	2·36	2·84	3·15	3·79	4·73	5·67	6·30	7·89
80,000	1·24	1·84	2·52	3·16	3·80	4·20	5·04	6·30	7·56	8·42	10·5
100,000	1·58	2·37	3·16	3·94	4·73	5·26	6·31	7·89	9·47	10·5	13·15
150,000	2·37	3·54	4·72	5·90	7·09	7·87	9·46	11·8	14·2	15·8	19·7
200,000	3·16	4·74	6·32	7·88	9·46	10·5	12·6	15·8	18·9	21·0	26·3
250,000	3·95	5·92	7·90	9·85	11·8	13·1	15·7	19·7	23·6	26·2	32·9
300,000	4·74	7·11	9·48	11·8	14·1	15·7	18·9	23·6	28·4	31·5	39·4

The additional allowance for friction will vary from 40 to 100 per cent. of the figures given by the above table. As an illustration of this item, the following examples are given :—

PERCENTAGE TO ADD TO POWERS GIVEN IN ABOVE TABLE IN ORDER TO FIND HORSE-POWER TO DRIVE EXHAUSTER

Capacity per Hour.	Back-pressure.	Add to previous Power.
10,000 cubic feet	12 inches	100 per cent.
20,000 „ „	18 „	90 „
50,000 „ „	24 „	70 „
100,000 „ „	30 „	50 „
200,000 „ „	36 „	45 „
300,000 „ „	50 „	40 „

Thus for an exhauster passing 100,000 cubic feet against 30 inches back-pressure an engine of about 12 b.h.p. would suffice, although it is always as well to allow an additional margin of 25 per cent., bringing the total brake horse-power up to 15.

STEAM-JET EXHAUSTERS

Steam-jet exhausters working on the injector principle are comparatively rare features of the modern gasworks in this country, although they continue to find

a certain amount of favour on the Continent. First introduced by Cleland, the steam jet was afterwards improved by Körting, and is seen in Fig. 304. Steam at about 50 lb. pressure is projected through a series of truncated cones gradually increasing in size. The gas is drawn in through spaces at the nozzles of the cones and is carried forward by the pressure of the steam. Care should be taken to ensure that dry steam only is used, and this is afterwards extracted from the gas by condensing apparatus. The capacity of the exhauster may be regulated within comparatively wide limits by an adjustable needle-valve at the steam inlet, and by a movable sleeve which opens or closes the gas inlet ports. The chief merits of this type of exhauster are that pulsation is entirely avoided, and there are no constantly moving mechanical parts to give rise to wear and tear. On the other hand, there is the expense of providing additional condensers, whilst steam consumption is high. The jet may be interposed at various points in the series of apparatus. In some cases it is preferred to place it in the

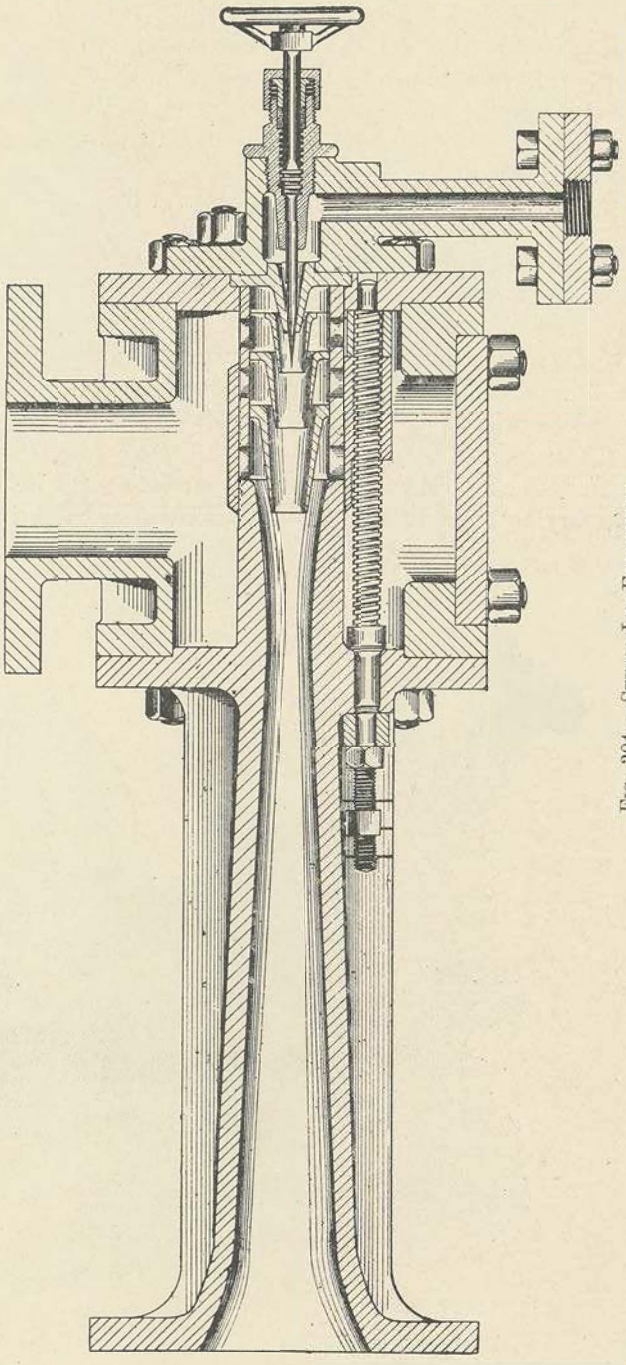


Fig. 304.—Steam-Jet Exhauster.

foul main, almost immediately after the hydraulic main, others make use of it after the condensers, but at Gloucester it was used just prior to the dry purification plant. Some advocates of the steam-jet exhauster have said that it gives rise to a direct increase in illuminating power equal to as much as three-quarters of a candle. It is difficult, however, to see on what grounds such a gain in quality could take place.

Turbo-Exhausters

The chief drawback to the ordinary rotary exhauster is the necessity for a considerable amount of rubbing contact and the large frictional area brought into play, with a consequent reduction in efficiency. In recent years these difficulties have been overcome by the introduction of the high-speed machine working on the fan principle and providing large clearances. A further advantage offered by the centrifugal fan exhauster is its greater volumetric capacity in proportion to the floor-space occupied.

In order to deal with pressures commonly met with on gasworks, it is generally necessary to build these machines with two or more impellers which rotate on a

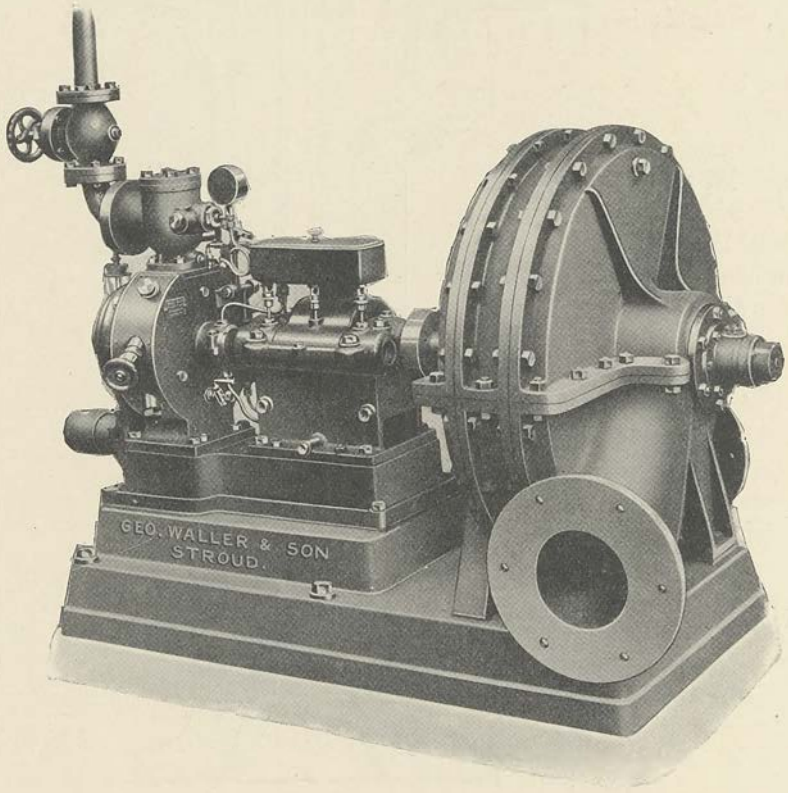


Fig. 305.—Two-stage Waller Turbo-Exhauster.

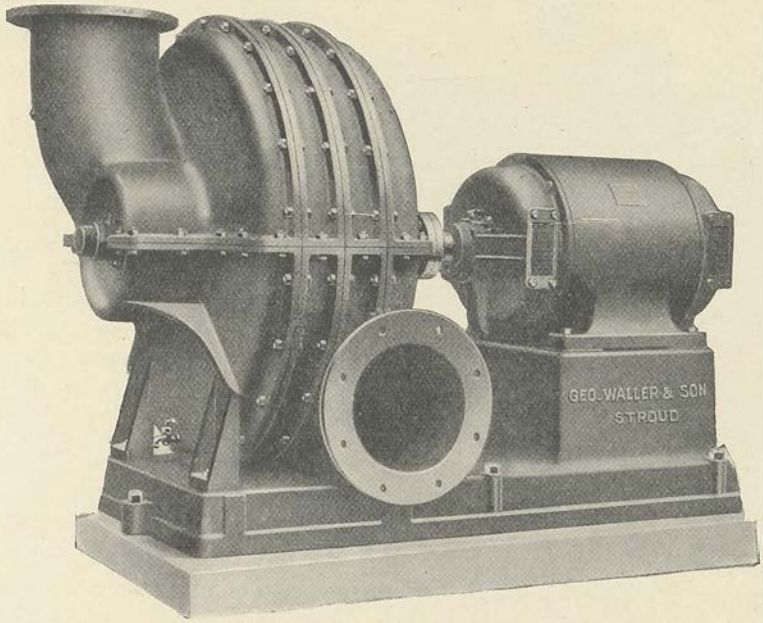


FIG. 306.—THREE-STAGE WALLER EXHAUSTER.

common axis but in separate cells. By means of suitable passages the gas is passed from cell to cell in series until it is discharged from the machine at the requisite pressure, this pressure being the sum of the amounts by which it is increased at each stage. The intensity of this increase of pressure per stage is dependent upon the diameter and speed of the impellers, and also upon the specific gravity of the gas at the time of its being passed through the machine. Constructional difficulties inherent to this type of exhauster restricted its use at one time to works with a large output. So far it has been found impracticable to build them in sizes which will deal with the requirements of small or medium-sized works with the efficiency and reliability which characterize the ordinary rotary type.

As might be expected the several designs now to be had differ considerably, but many are based on the principles of Professor Rateau, who has devoted considerable time to the study of the subject. Figs. 305 and 306 show the Waller type of turbo-exhauster, the two-stage machine being driven by steam turbine, and the three-stage by electrical motor. The impellers of these machines are built up from steel plates bolted to a cast-iron centre, whilst the spindles are of steel, running at the driving end in white metal bearings with oil-ring lubrication, the outer ends running in ball bearings. A ball bearing is also provided at this end to take up the axial thrust of the spindle due to the pressure of the gas on the impellers. The exhauster and prime mover are mounted on a cast-iron box section. The machine shown in Fig. 305 is driven by a de Laval turbine running at 4,000 revolutions per minute, and will pass 50,000 cubic feet of gas per hour against a pressure of 30 inches. The larger machine (Fig. 306) is rated for a capacity of 170,000 cubic feet

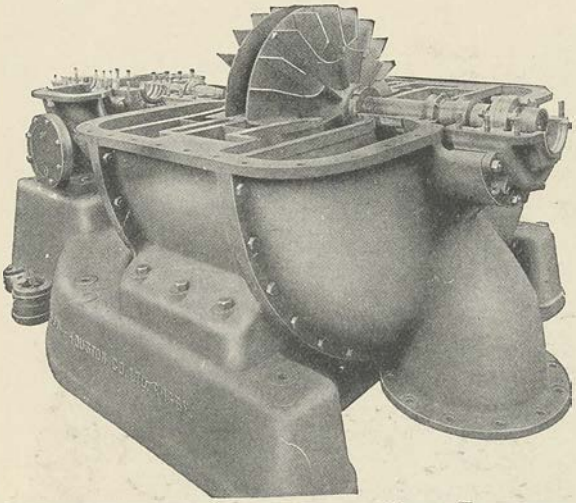


FIG. 307.—BRITISH THOMSON-HOUSTON TURBO-EXHAUSTER.

per hour against a pressure of 24 inches. Owing to the high speed at which turbo-exhausters have to run, they are particularly suited for being driven direct by electric motor or steam tubine without the employment of intermediate gearing. Another type of fan exhauster is shown in Fig. 307. This is the British Thomson-Houston machine driven by a Curtis impulse-type steam turbine through a flexible coupling. The exhauster is of the two-stage type, and is capable of dealing with 500,000 cubic feet of gas per hour against a pressure of 40 inches. In this case the impellers are placed back to back in order to eliminate end-thrust. Fig. 308 shows one of the impellers, which are solid steel castings, the blades and hub being in one piece, with the exception of the inlet ends which, being twisted to allow free entry of the gas, are mounted on a small extension hub. On leaving the impeller the gas passes through a series of exit guide blades, which convert the velocity head into pressure head. As regards initial cost this is, on an average, about 50 per cent. less than that of an ordinary rotary installation of the same capacity. Owing to the high rate of speed, pulsation with this type of exhauster is almost entirely eliminated.

The construction of the Sturtevant rotary blowers and exhausters is illustrated in Figs. 309 and 310. The exterior cast-iron casing is composed of two hollow cylinders partially intersecting, on either side of which are intake and discharge openings. Inside the casing are two rotors, one of which, the impeller, is made up of three diamond-shaped bars, joined together by a central web, the whole being keyed to a central driving shaft. As the impeller revolves, three separate pockets are formed in the space between the casing and the stationary core, thus carrying the gas from the inlet to the discharge. The idler rotor does no actual work, but successively provides spaces to receive and pass the impeller blades to

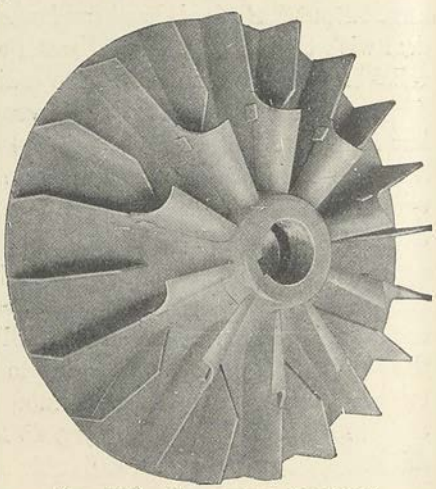


FIG. 308.—EXHAUSTER IMPELLER.

the suction side of the machine without letting gas pass back from the pressure side. The machines may be governed by regulating the speed in accordance with the quantity of gas passing, or by means of the by-pass.

A typical Rateau turbo-exhauster is shown in Fig. 311. Although these machines run at high speeds the wear and tear is negligible, the wheels revolving in the casing without touching it. The bearings supporting the impeller shaft are provided with large oil reservoirs and ring lubrication for medium speeds, and with forced lubrication for high speeds. Where the shaft passes through the casing stuffing boxes of special design are provided, these ensuring gas tightness and practically no friction, with the result that little or no loss of power occurs.

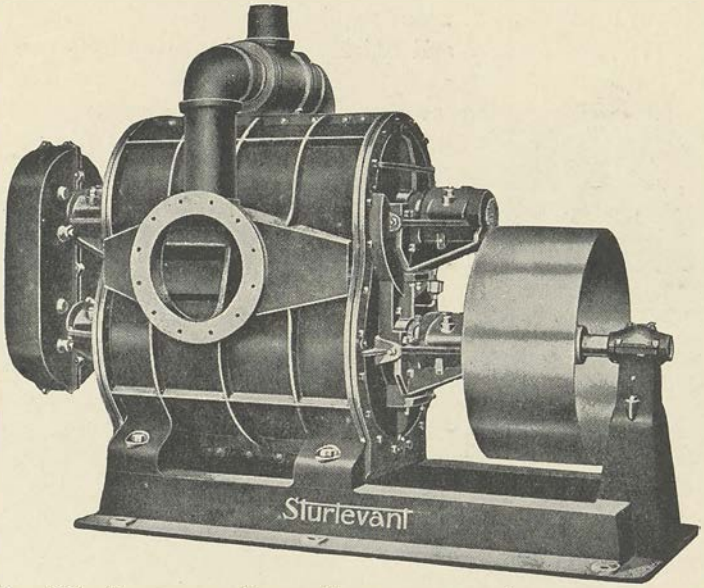


FIG. 309.—STURTEVANT ROTARY EXHAUSTER WITH AUTOMATIC BY-PASS.

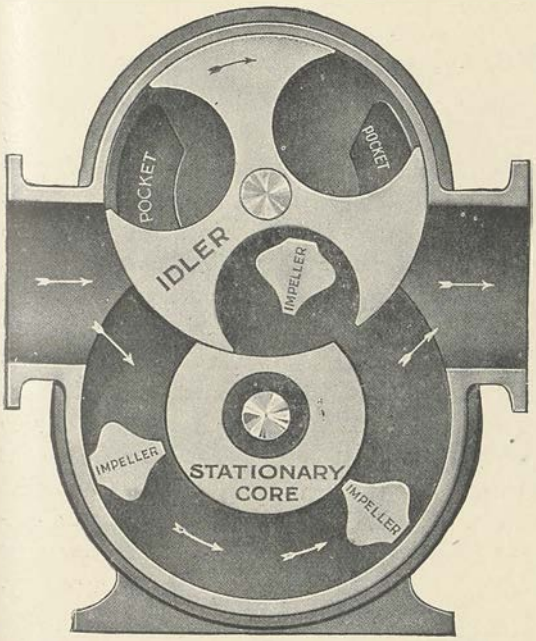


FIG. 310.—SECTION THROUGH STURTEVANT ROTARY EXHAUSTER.

The special advantages of the high-speed rotary turbo-exhauster may be enumerated as follows :—

(1) Efficiency at least 70 per cent.

(2) Low wear and tear, due to absence of internal rubbing parts.

(3) Absence of pulsation.

(4) Silent running.

(5) Large range in capacity with but small variation in efficiency.

(6) Small ground space required.
(7) Access easily and quickly gained to working parts.

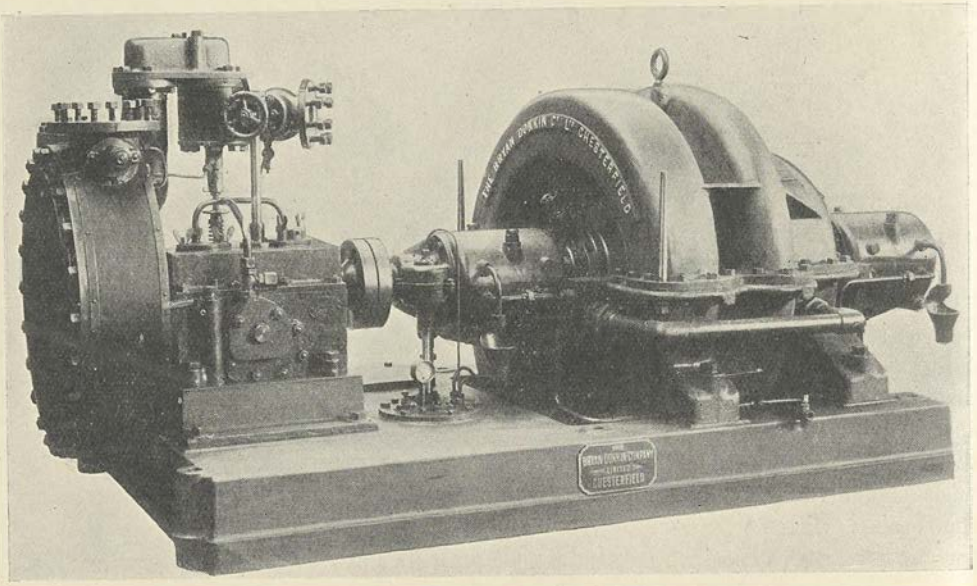


Fig. 311.—Rateau High-speed Exhauster driven by Steam Turbine.

EXHAUSTERS PRIOR TO CONDENSERS

The position of the exhauster is entirely arbitrary. In almost all cases, however, it will be found in sequence between the condensing and washing plant. Some engineers prefer to place the machine either before the condensers (so that condensing takes place under pressure), or after the washers (so that both condensers and washers are under a vacuum). The practice of condensing under pressure has assumed some importance, and finds a stout advocate in Dr. Carpenter. The problem of the most effective means of lubricating an exhauster is always a vexed one, and is said to be more troublesome when the light oil tars have been removed from the gas in the process of condensation. When, however, the exhauster is placed prior to the condensers, so that it is operated at a temperature of about 60° C., no lubricant is necessary, the condition of the gas being sufficiently oily to ensure smooth running of the machine. By placing the exhauster at a point nearer to the hydraulic main a shorter length of main under vacuum is assured, so that there is less probability of the intake of air through defective joints. The disadvantage attached to exhausting hot gas is that owing to its increased temperature the bulk of the gas is augmented, hence additional exhauster capacity is necessary. If the average temperature of the gas is about 60° C., the additional capacity required (compared with the ordinary practice of exhausting at 20° C.) will amount to about 15 per cent.

CHAPTER XVI

THE PRELIMINARY PURIFICATION OF COAL GAS

THE purification of coal gas commences directly the gas reaches the hydraulic main, by which time it has undergone a considerable drop in temperature. At this point some of the impurities will be washed from the gas by the deposition of a portion of the aqueous vapour and by its passage through the hydraulic seal. The impurities in crude coal gas at this stage may be summarized as follows :—

(1) Suspended tarry matter and condensible hydrocarbons.
(2) Ammonia.
(3) Sulphuretted hydrogen.
(4) Carbon disulphide and other sulphur compounds.
(5) Carbon dioxide.
(6) Hydrocyanic acid, usually spoken of as cyanogen.
(7) Naphthalene.

Of these, the last three can scarcely be classified as impurities, and there is no statutory obligation to remove either these or No. 4. Whilst it is in all cases to the engineer's own interest to reduce the naphthalene content to such a quantity as can be carried by the gas without deposition, the removal of cyanogen and sulphur compounds is (owing to the very small quantities in which they are present) not so imperative, and is only carried out in rare instances. Carbon dioxide, though frequently classified as such, is in no sense an impurity, but may be looked upon as an inert diluent having a deteriorating influence upon the illuminating and heating values of the gas (*see* page 582).

In the preliminary purification of coal gas by wet methods it is the removal of a portion of the sulphuretted hydrogen and carbon dioxide with which we are chiefly concerned. At the same time the last traces of suspended tar must be eliminated. In order to understand the principles upon which the process is based, it is necessary to consider the nature of the various substances present in the crude gas, *i.e.* whether they are acid or alkaline. Thus we have :—

Ammonia—alkaline.
Carbon dioxide—acidic properties.
Sulphuretted hydrogen—acidic properties.
Hydrocyanic acid—acid.

In the first instance, advantage is taken of the powerful affinity possessed for ammonia by water which, at normal temperature and pressure, is capable of absorbing about 780 times its own volume of ammonia gas. Thus, treatment of the crude gas with water, in special vessels known as washers and scrubbers, affords a ready

means of removing this impurity. Water also possesses some affinity for carbon dioxide and sulphuretted hydrogen, but its capacity in this direction is but slight, one volume absorbing about three and a quarter volumes of sulphuretted hydrogen, or one volume of carbon dioxide. Carbon disulphide gas is also soluble in water, but to a very small extent, amounting to about one-thousandth part of the volume of water. Advantage is taken of the fact that the ammonia solution formed, being of an alkaline nature, is capable of ready reaction with the acid impurities in the gas. Thus carbon dioxide, the strongest acid present, and sulphuretted hydrogen, are absorbed, with the formation of certain definite salts which are themselves soluble in the water. In the ordinary sense ammoniacal liquor consists of water containing in solution a certain proportion of these salts.

It is necessary to emphasize that the quantity of ammonia which water can absorb is not entirely dependent upon temperature, for solubility also varies in direct proportion to the pressure of the ammonia gas. If pure ammonia gas is in contact with water at normal temperature and pressure, then the water is capable of absorbing an amount equal to 780 times its own volume. In crude gas, however, the proportion of ammonia to the whole volume is trifling, hence the pressure it will exert is only in proportion to the extent of its presence. For instance, if ammonia is present to the extent of one per cent. of the whole, then the pressure it exerts will amount to merely 0·01 atmospheres, at which pressure very little affinity exists between it and the water. It is this fact which explains the necessity for using a comparatively large quantity of water per ton of coal carbonized (*see* page 508), and shows why the question of time contact is one which must be considered in the design of washers and scrubbers.

Ammonia in crude coal gas is usually found to the extent of about 1·5 per cent. by volume, and of this amount from a third to one-half will have been washed out by the aqueous vapour and will have been deposited by the time the gas has reached the outlet of the condensers. In this respect the figures of Hunt, who found the distribution of ammonia as follows, are of interest :—

Ammonia removed by condensation	42·7	per cent. of total.
„ „ first scrubber	43·3	„ „ „
„ „ second „	14·0	„ „ „

W. S. Curphey [1] has more recently stated that of the total ammonia at least 50 per cent., and probably 60 per cent., is found in the virgin liquor.

When gas containing sulphuretted hydrogen and carbon dioxide comes in contact with a solution of ammonia, the amount of the acid gases absorbed may be sufficient to give rise to a neutral or normal salt, or absorption may continue until the ammonia solution contains about 20 per cent. more of the acids than is sufficient to give the neutral salts. Hence, both acid and normal salts result as follows :—

Ammonia and Carbon Dioxide—

(1) $2\,NH_4OH + CO_2 = (NH_4)_2CO_3$ (ammonium carbonate) $+ H_2O$. Normal.

(2) $NH_4OH + CO_2 = NH_4.HCO_3$ (ammonium bicarbonate). Acid.

Ammonia and Sulphuretted Hydrogen—

(1) $2\,NH_4OH + H_2S = (NH_4)_2S$ (ammonium sulphide) $+ 2H_2O$. Normal.

(2) $NH_4OH + H_2S = NH_4.HS$ (ammonium hydrosulphide) $+ H_2O$. Acid.

[1] *Alkali Report*, 1916, p. 29.

Actually, the acid salts are not formed direct, as shown above, but from further absorption of acid gases by the normal solutions, as follows :—

$(NH_4)_2CO_3 + H_2O + CO_2 = 2\,NH_4HCO_3$.

$(NH_4)_2S + H_2S = 2\,NH_4HS$.

THE COMPOSITION OF GAS LIQUOR

The liquor deposited in the hydraulic main and condensers is generally characterized as " virgin liquor," which signifies that the water in which the salts are dissolved emanates from the coal and not from external sources. In the ordinary way the yield of virgin liquor varies from 10 to 14 gallons per ton of coal carbonized. The hydraulic main liquor differs considerably from that obtained in the washing plant, chiefly owing to the fact that the temperature at this point (about 60° C.) renders many of the compounds which are found at the lower temperatures unstable. Thus the salts formed as in the above reactions, *i.e.* the carbonates and sulphides, are present in only small quantities, there is little free ammonia in comparison with the amount in the scrubber liquor, and fixed ammonia salts may predominate.

Ammonia in gas liquor may be combined in two distinct ways, first as easily decomposable compounds such as carbonates and sulphides and, secondly, as more stable compounds which will not undergo decomposition by heating, but which require the addition of a caustic alkali to displace the ammonia from them. In the former case, the ammonia is combined with the weaker acidic gases CO_2 and H_2S and is known as " free " ammonia. In the latter case it is combined with stronger acids, such as hydrochloric and sulphuric, and is then denoted " fixed " ammonia. The " fixed " ammonium salts in gas liquor are the outcome of the combination of ammonia with the minor impurities in the crude gas and are derived to some extent from oxidation. In general, the final mixture of gas liquor obtained in the storage well contains from 75 to 80 per cent. of the " free " salts and from 20 to 25 per cent. of " fixed " salts, the possible constituents being as follows :—

THE COMPOSITION OF GAS LIQUOR

Water containing in solution :—

Ammonium	carbonate	" Free " ammonia 75 to 80 per cent. of total ammonia.
,,	bicarbonate	
,,	carbamate	
,,	sulphide	
,,	hydrosulphide	
,,	cyanide	
,,	polysulphide	
,,	chloride	" Fixed " ammonia 20 to 25 per cent. of total ammonia.
,,	sulphocyanide	
,,	sulphite	
,,	thiosulphate	
,,	sulphate	
,,	ferrocyanide	
,,	acetate	

Also phenols, amines and other nitrogenous bodies.

It does not follow that gas liquor will contain every one of the above salts; in fact, some of those included are only met with on rare occasions. Ammonium carbamate, $CO(ONH_4)NH_2$, is deposited as a white solid when CO_2 and ammonia meet. It is easily soluble in water, but is probably present in only minute quantities in gas liquor, for, when dissolved, it is soon converted into carbonate. As regards the "fixed" salts, these are largely accounted for by ammonium chloride, which owes its presence to the common salt (sodium chloride) present in the original coal. The amount of salt varies considerably according to the class of coal used, the maximum proportion in the coal being about 0·25 per cent. Ammonium chloride is a particularly unwelcome compound, for, in addition to its deleterious effects on the fireclay of the retorts,[1] it has—in the gaseous state—a marked corrosive action on the steelwork of the hydraulic main, etc. When deposited in the solid state it may give rise to considerable trouble, due to the stoppage of pipes, and in some cases special means have been introduced for dealing with it.[2]

Ammonium cyanide is present only in traces, and is frequently absent altogether. The ferrocyanide is also of rare occurrence, so much so that, during an examination of various liquors extending over a period of five years, conducted by the chief inspector under the Alkali Act, it was only identified with certainty on one occasion. Ammoniacal liquor is considerably affected by oxidation, so that its ultimate constituents are influenced in some degree by the amount of oxygen present in the gas. A process of gradual oxidation from one compound to another takes place, the final salts obtained depending upon the extent to which the oxidation has occurred. Ammonium polysulphide and thiosulphate are the first products of oxidation, these being formed from ammonium sulphide, although, in the case of the former, the action is more mechanical than chemical. Oxidation, then, proceeds progressively, so that in turn the thiosulphate, sulphite and, lastly, sulphate are formed, whilst in certain cases free sulphur may be deposited. The sulphite is usually only present in faint traces, which is probably accounted for by the fact that solutions of polysulphide and sulphite react to form sulphide and thiosulphate: $(NH_4)_2S_2 + (NH_4)_2SO_3 = (NH_4)_2S + (NH_4)_2S_2O_3$. At the same time ammonium thiosulphate may be formed by reaction between the sulphite and sulphide: $4\,(NH_4)_2SO_3 + 2\,(NH_4)_2S = 3\,(NH_4)_2S_2O_3 + 6\,NH_3 + 3\,H_2O$. Lunge asserts that ammonium polysulphide cannot exist in ordinary ammoniacal liquors, since it reacts with sulphites and cyanides. At one time there was some doubt as to whether gas liquor contained any actual free ammonia (*i.e.* dissolved NH_3), but investigators such as Gerlach and Tieftrunck have shown this to be the case. Owing to the fact that acetylene is of a slightly acid nature, ammonium acetate (CH_3COONH_4) may in some cases be found in gas liquor. When liquor is distilled with an alkali (lime) for the manufacture of sulphate of ammonia, the final traces of ammonia are seldom expelled, so that some slight loss, amounting, under best conditions, to about 0·1 per cent., is inevitable. This is in some measure due to the fact that certain of the ammonia-bearing compounds (such as the amine bodies) require rather more energetic treatment to bring about complete decomposition.

[1] *See* Chapter VI, page 217. [2] *See* Chapter VIII, page 273.

From the foregoing remarks, it will be gathered that the final composition of ammoniacal liquor depends upon—

(*a*) The class of coal carbonized.

(*b*) The amount of salt in the coal.

(*c*) The temperature of distillation.

(*d*) The means employed for separating liquor and gas.

(*e*) The temperature to which the liquor is subjected.

(*f*) The amount of oxygen in the gas, the amount of air drawn in on the inlet side of the exhauster, and the extent to which the liquor is exposed to the atmosphere.

Item (*d*) is one which is frequently overlooked, and may have come considerable influence on the amount of ammonia present in the crude gas. For instance, when tar towers are in use the ammonia in the gas at the outlet of the condensers is frequently lower than 200 grains per 100 cubic feet, in contrast with about 300 grains when the system of a separate draw-off to each hydraulic is installed. The reason would appear to be that in the case of tar towers the maintenance of the seal is ensured by running liquor into the tower alone. When weir valves or other individual means are in use the liquor is usually laid on to each hydraulic, and by giving rise to splashing sets free ammonia, which is accordingly carried forward by the gas. In the ordinary way the hydraulic main liquor contains about 50 per cent. of its ammonia in the fixed form, chloride and sulphocyanide predominating. At the present day, however, it is a growing practice to circulate the liquor repeatedly through the hydraulics, and in such cases the fixed content will be considerably increased, so that it may amount to as much as 80 per cent. of the ammonia present.

The proportion of ammonia contained in gas liquor is in reality quite small. In normal cases the total ammonia varies from 1·5 to 2 per cent., being apportioned as follows:—

Free ammonia	1·2 to 1·6 per cent.
Fixed ammonia	0·3 to 0·4 „ „

As regards CO_2 and H_2S the following figures may be taken as illustrating average conditions:—

CO_2 in gas liquor	1·3 to 2 per cent.
SH_2 „ „	0·1 to 0·6 „ „
Sulphur „ „	0·5 to 0·7 „ „

It is difficult to lay down any hard and fast figures in connection with the manner in which the ammonia is distributed, but in general it will be accounted for somewhat as follows. The manner in which the sulphur is combined is also given.

Distribution of Ammonia in Gas Liquor

"Free"	Ammonium sulphides	6 per cent. of total ammonia.
	„ carbonates	74 „ „ „
"Fixed"	„ chloride	15 „ „ „
	„ sulphocyanide	1·75 „ „ „
	„ thiosulphate, sulphite, etc.	3 „ „ „
	„ sulphate	0·25 „ „ „

DISTRIBUTION OF SULPHUR IN GAS LIQUOR

Sulphur combined with free ammonia as sulphides	55 to 75	per cent. of total.
„ „ „ fixed ammonia as sulphocyanide	15 to 25	„ „
„ „ „ „ „ as sulphate	1 to 5	„ „
„ „ „ „ „ as thiosulphate	5 to 15	„ „
„ „ in other forms (polysulphide, etc.)	1 to 5	„ „

The ammonia present in coal gas has provided the gas engineer with a simple means of eliminating the chief impurities in the gas, but there is a limit to the extent of the purification which can be carried out through its agency, for the amount of the alkali present in crude gas is only in the neighbourhood of 1·5 per cent. by volume. Of this, about one-fourth to one-fifth is combined as fixed salts, thus the surplus available for the removal of sulphuretted hydrogen and carbon dioxide amounts to about 1·2 per cent. Together the H_2S and CO_2 in the crude gas (excluding any CO_2 which may be drawn in from the furnace) total about $2\frac{1}{2}$ per cent. by volume, thus the ammonia available is theoretically sufficient for removing only about one-half of these impurities. At the outlet of the condensers the impurities in coal gas will be present in approximately the following proportions :—

IMPURITIES IN COAL GAS AT OUTLET OF CONDENSERS

	Grains per 100 cubic feet.	Per cent. by volume (average).
Ammonia	200 to 300	0·75
Sulphuretted hydrogen	500 to 900	1·0
Carbon dioxide	900 to 1,400	1·5
Sulphur compounds	35 to 45	
Hydrocyanic acid	60 to 80	
Naphthalene	20 to 25	

THE ABSORPTION OF CARBON DISULPHIDE

As previously pointed out, water absorbs only about one-thousandth part of its own volume of carbon disulphide ; and, in the usual way, from 2 to 4 grains of this impurity are removed from the gas during its passage through the washers and scrubbers. The reduction of carbon disulphide by treatment with liquor has for long been a subject of investigation, and the extent to which the compound may be absorbed, also the actual chemical manner in which its removal is effected, have given rise to a good deal of discussion. In the first place, it is by no means certain (as is so often stated) that CS_2 is directly absorbed by ammonium sulphide with the formation of ammonium thiocarbonate, according to the equation—$(NH_4)_2S + CS_2 = (NH_4)_2CS_3$. Tilden states that an interaction takes place between carbon disulphide and ammonia whereby a sulphocyanide and sulphide are formed, but heat is necessary for the reaction—$4\ NH_3 + CS_2 = NH_4SCN + (NH_4)_2S$. The same authority states that combination of the two gases may give rise to ammonium sulphocyanide and thiocarbonate—$4\ NH_3 + 2\ CS_2 = NH_4SCN + (NH_4)_2CS_3$. The actual manner in which the CS_2 is removed is, however, not at all clear, and whilst it appears to unite with ammonium sulphide on the lines of the first of the reactions shown above it seems essential that polysulphides or free sulphur should be present ; for the two substances do not combine when in the pure state. The carbon dioxide

in the gas, moreover, would have detrimental effects from the point of view of CS_2 removal; for it tends to dissociate ammonium thiocarbonate and to set free the sulphur compound. Some express the opinion that ammonium polysulphide is alone the agent by means of which the CS_2 is removed.

Although all attempts at the reduction of sulphur compounds by treatment with liquor have been attended with somewhat erratic results, there seems little doubt that some reduction may be affected by dealing with the gas whilst in its hot state. One method of treatment is thoroughly to wash the gas with hot liquor in the hydraulic main, the liquor being circulated and recirculated so that only the surplus flows away. Lunge states that the liquor from the hydraulic main is especially suited for wet purification, for it contains some considerable quantities of free ammonia (*i.e.* NH_3) owing to the far-going dissociation of the "free" salts—carbonate and sulphide. It is probable, therefore, that some absorption of CS_2 may take place owing to the presence of uncombined ammonia in the liquor, and after the manner of Tilden's equations already referred to. No great reliance can, however, be placed in the method. It has, in consequence, not been generally undertaken on gasworks.

So far as the difference of constitution of the liquor from the hydraulic main and of the final product obtained in the storage well is concerned, Meyer and Hempel have given the following interesting table:—

	Liquor from Storage Well.	Liquor from Hydraulic Main.
Total ammonia	1200·6 grains per gallon	405·7 grains per gallon
"Free" „	984·5 „ „ „	204·1 „ „ „
"Fixed" „	216·1 „ „ „	201·6 „ „ „
Ammonium carbonate . . .	2468 grains per gallon	332 grains per gallon
„ sulphide . . .	193 „ „ „	51 „ „ „
„ thiosulphate . .	86 „ „ „	30 „ „ „
„ sulphite . . .	Traces	Nil
„ sulphate . . .	16 „ „ „	16 „ „ „
„ chloride . . .	517 „ „ „	505 „ „ „
„ sulphocyanide .	127 „ „ „	70 „ „ „
„ ferrocyanide . .	6·2 „ „ „	2·3 „ „ „
„ cyanide . . .	8·3 „ „ „	2·4 „ „ „
Uncombined ammonia . .	7·4 „ „ „	73·0 „ „ „

METHODS OF OPERATING WET PURIFICATION PLANT

The most efficient manner of operating washers and scrubbers is to ensure that the gas on first entering the apparatus is treated with the strongest liquor obtainable, whilst in each subsequent vessel the liquor circulated becomes gradually weaker until, in the final scrubber, clean water is employed. Where circumstances permit it is preferable that the decarbonating vessel be worked with hydraulic main liquor,

as this contains a large proportion of uncombined ammonia, available for the removal of CO_2 and H_2S. Considerable care should be taken in order to prevent the passage forward of tar to the ammonia washers. At the inlet to the washing plant this impurity should be reduced to as low as 2 grains per 100 cubic feet of gas. Davidson has said that the crude gas in the hydraulic main contains as much as 8,000 grains of tar per 100 cubic feet.

The effect of submitting the gas to clean water in the final scrubber is to remove practically the last traces of ammonia from the gas, whilst the water is converted into a weak liquor (from 1 to 2 oz. strength), which, mixed with that flowing from the condensers and hydraulic mains, is passed down the previous portions of apparatus and finally worked up to the desired strength. Herring says that the weak liquor has a slightly greater affinity for the sulphuretted hydrogen, but as its strength increases the carbon dioxide exerts its superior affinity, actively combines with the free ammonia, and breaks up some of the already formed sulphide, giving, instead, ammonium carbonate. Thus in certain of the washing vessels evolution of sulphuretted hydrogen may occur.

As regards the amount of water (other than that formed from the distillation of the coal) which is necessary in order to effect the wet purification of gas, the author finds that with Durham coal the flow through the final scrubber amounts to from 10 to 13 gallons per ton of coal carbonized. With this quantity the ammonia in the outlet gas is reduced to 0·5 grains per 100 cubic feet. Some years ago it was considered that the water required for complete removal of ammonia should be 3 gallons per ton of coal used ; but much must depend upon the nature of the coal, the systems of carbonization and condensation, and the type of scrubber in use.

WASHING AND SCRUBBING APPARATUS

The arrangement of the wet purification plant conforms to no regular rules, so that the apparatus and the method of working it vary considerably, in accordance with the tastes of the engineer. Formerly, the removal of ammonia was effected by the use of no other energy than the pressure of the gas itself ; but, recently, mechanical devices, necessitating the use of external driving power, have come into favour. The latter apparatus is commonly known as the washer-scrubber, owing to its ability —due to increased efficiency—to perform the greater portion of the work of these two vessels.

Washing plant may be taken to embrace those portions of the apparatus in which the gas is actually caused to bubble through seals or to pass through weirs of liquor. In scrubbing plant, on the other hand, the gas comes in contact with a wetted surface of coke, boards, or other suitable material. In the design of the washer, the depth of the seals employed, or the resistance offered (and, accordingly, the effectiveness of the machine for removing ammonia) must be balanced against the back-pressure thrown, and in no case should the latter exceed 3 inches for a single machine. Washers are invariably operated with liquor of the maximum strength, whereas in the scrubbers, liquor of a weaker quality is circulated.

To-day, the washer introducing the principle of wire-drawing and bubbling has come into very general use, for not only is such apparatus efficient from the point of view of the removal of the gaseous impurities, but it provides an admirable means of eliminating tar where this may have travelled forward to the wet plant. There are numerous types of this style of washer, but probably the most noteworthy is that designed by the late Sir George Livesey, and employed extensively throughout

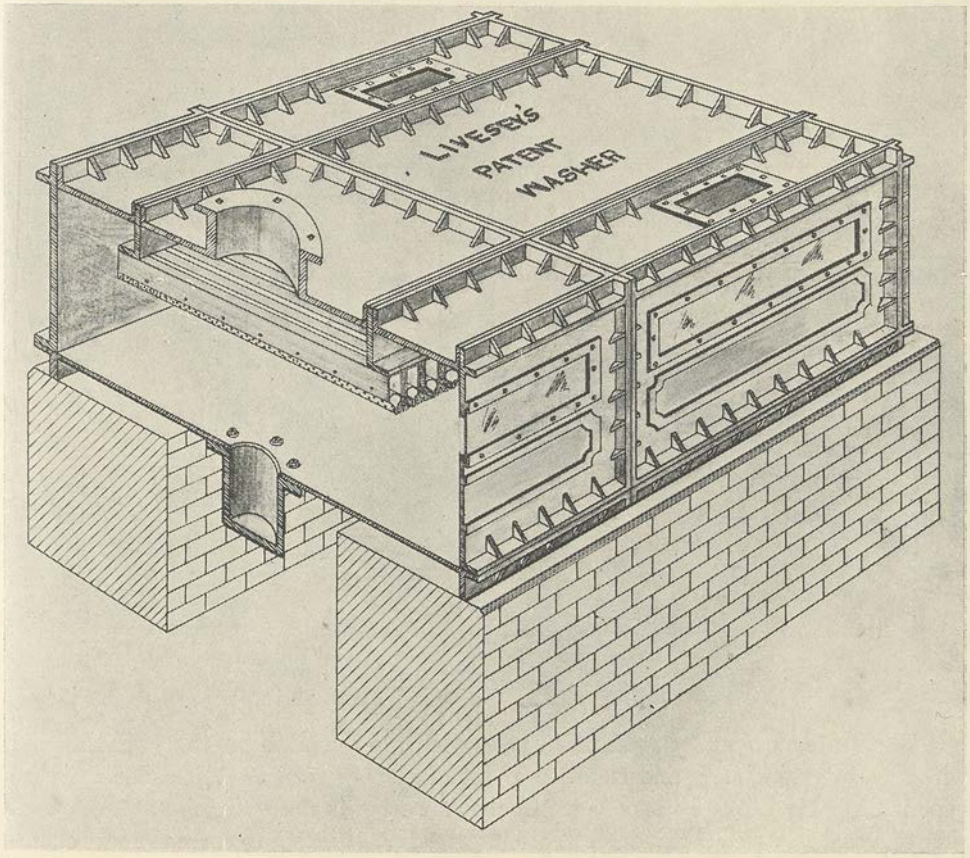


FIG. 312.—THE LIVESEY WASHER.

the world. The apparatus is shown in Fig. 312. It consists of a rectangular cast-iron outer case, the upper portion of which forms an inlet chamber. To the lower flanges of the inlet chamber is fastened a series of wrought-iron pear-shaped tubes, an enlarged section of which is shown in Fig. 313. It will be noticed that whereas the space between these tubes is in communication with the inlet chamber, the interior of the tubes is connected with the outlet chamber. Thus the gas has free access to the intermediate spaces, passes downwards through them, and depresses

the liquid until it (the gas) finds an outlet through the perforations in the bent plate and thence upwards into the space above the plate, whence it travels to the outlet chamber. The bubbles of gas in passing through the liquor into the tube space convert the surface into a foam, thus the most thorough contact of gas and liquor is assured. In order to prevent the gas passing direct from the inlet to the outlet chamber the ends of the intermediate spaces are securely closed up. The perforations in the tubes are usually one-twentieth of an inch in diameter, and so placed that there are about thirty to the square inch. The washer will be found to work most effectively when the depth of liquor is such that it rises to an inch above the top of the pear-shaped plates, in which case 3 inches of pressure is thrown.

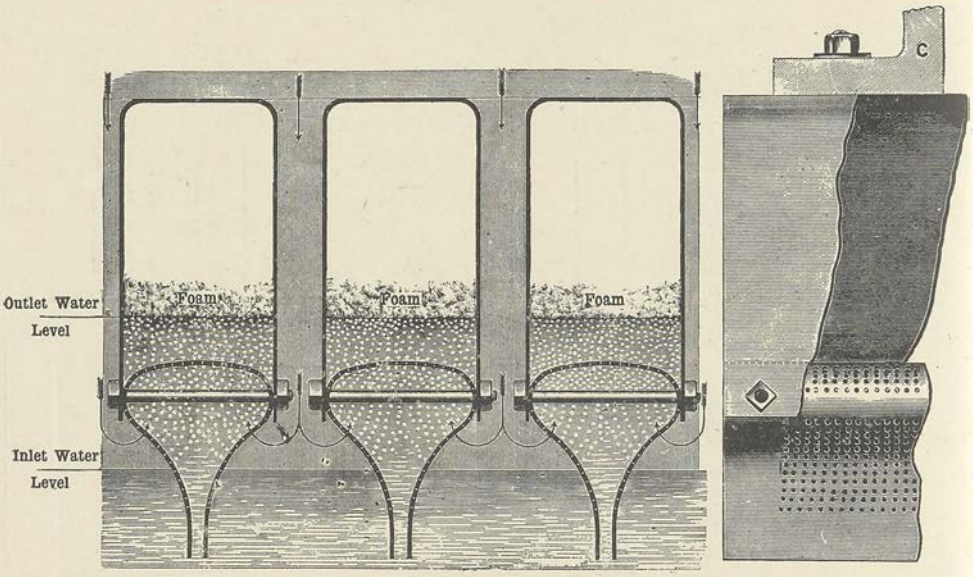


Fig. 313.—Livesey Washer, Detail of Perforated Plates.

There are now many washers in use which are operated on the bubbling and wire-drawing principle; and from the point of view of tar extraction efficiency the type is probably not to be excelled. Cockey's washer is shown in Fig. 314. It consists of a cast-iron vessel divided off by horizontal partitions into three or more chambers. The gas entering at the base travels upwards through a vertical pipe to the top of which is fitted a hood. The gas meets the hood and is then deflected downwards through four openings in the horizontal plate and passes through the liquor. It then travels past several serrated edges which are sealed in liquor, and afterwards finds its way to the next chamber. The liquor flows from the top chamber downwards; and the depth of the seals may be regulated as desired.

Dempster's washer is shown in Fig. 315. It is composed of a series of cast-iron trays placed one above the other, the trays having a number of narrow openings, with raised edges. These openings are covered with hoods having serrated edges.

and each tray contains liquor in which the serrations of these hoods are sealed. The weaker liquor enters at the top and flows round the hoods, as shown in the

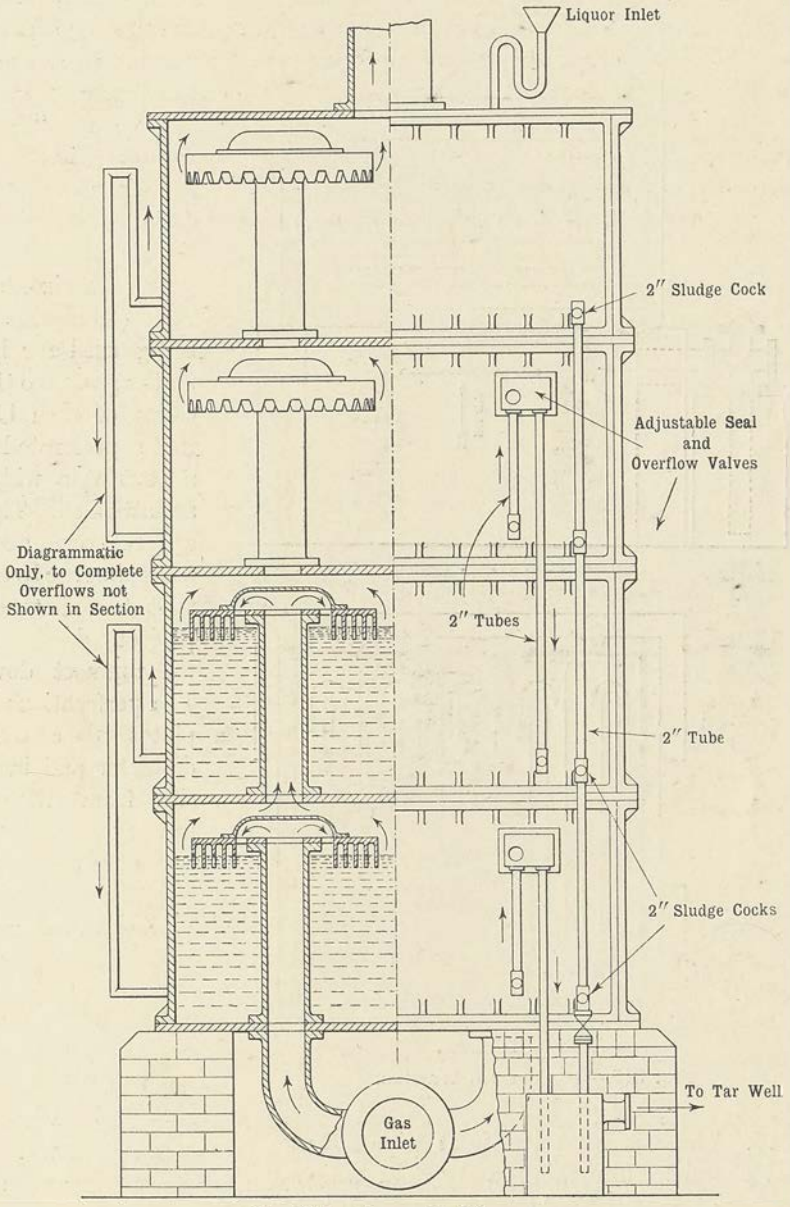
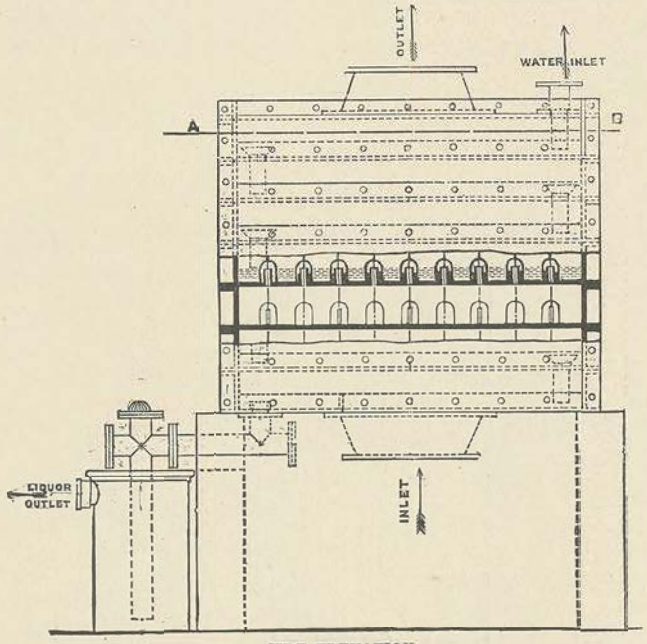
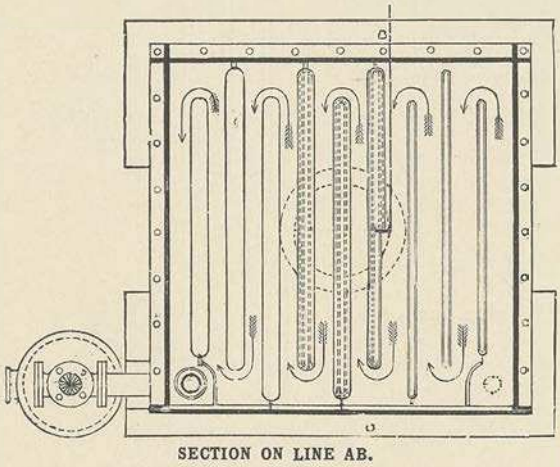


FIG. 314.—COCKEY'S WASHER.

sectional plan, thence overflows to the section below, and finally is drawn off at the base of the vessel. The gas enters at the bottom and passes upwards through the



SIDE ELEVATION.



SECTION ON LINE AB.

FIG. 315.—DEMPSTER'S WASHER.

in Fig. 317. The gas from the inlet pipe enters a central chamber, branching away from which are a number of longitudinal troughs, open at the bottom but closed at the far end. The level of the liquor in the cast-iron external shell is such that the lower ends of the troughs are sealed, openings in the bottom tray and through the liquor-sealed serrations of the hoods until it passes to the outlet at the top.

The "Multiple" washer (Fig. 316) is an American type. It is designed on lines very similar to the Livesey type, horizontal inverted U-section troughs being used for breaking up the gas. To the lower edges of each U-trough three perforated plates, set out at a wide angle, are attached. The plates are set one above the other, but are so arranged that the distance they project decreases from the topmost downward. The perforations in these plates decrease in diameter and increase in size from the bottom upwards, whilst their edges are serrated.

The principle of Walker's washer is shown

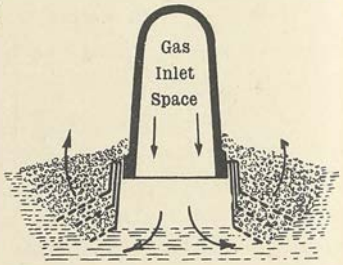


FIG. 316.—THE "MULTIPLE" WASHER.

and whilst the bottom edges are perforated there are a number of narrow slots in the side of the troughs through which the bulk of the gas passes. In general, the washer forms a distinct piece of apparatus; but, if desired, it may be fitted in the base of a scrubber, as seen in Fig. 329.

In some cases the functions of tar-extracting, washing and scrubbing are merged into one vessel, known as a purifying machine. In the Walker apparatus (Fig. 318) the gas is first treated in the lower portion of the vessel, which contains a washer

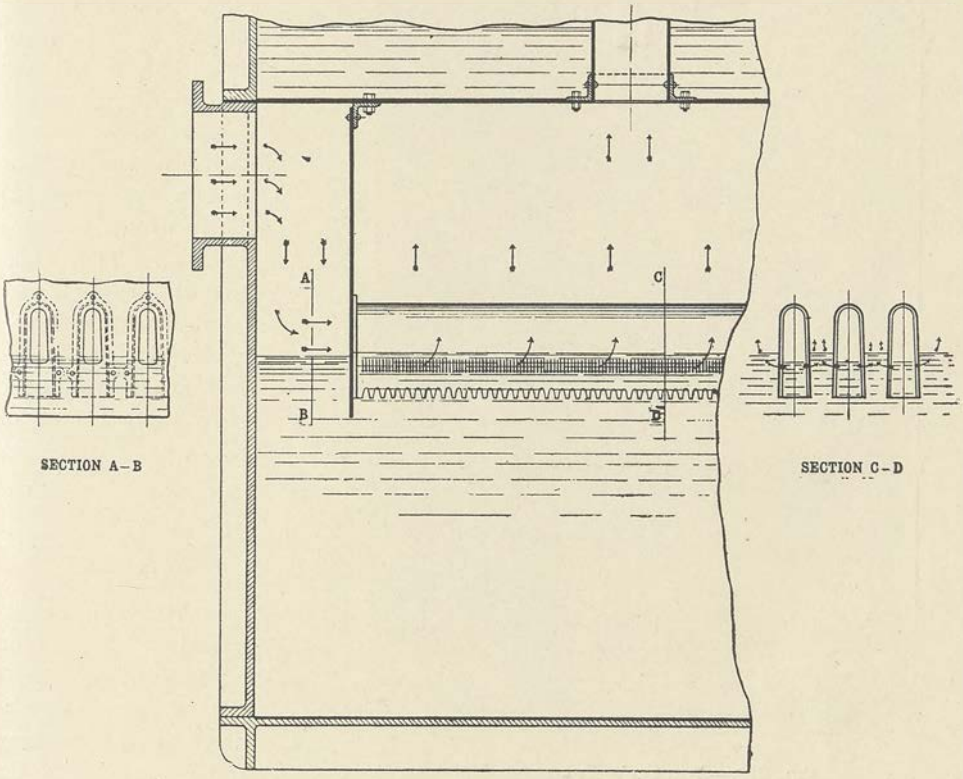


FIG. 317.—WALKER'S WASHER.

similar to that shown in Fig. 317. It then travels upwards to the next compartment, where it comes in contact with strong liquor distributed over devices containing wetted boards. The gas then travels through a number of superimposed tiers of such boards and is taken off at the top of the machine. A vertical shaft passes through the centre of each of the boxes containing the boards, the ends of the shaft being connected to rocking levers carried from pivots on the top of the machine. The rocking levers are operated by a small engine placed at ground level, and by means of these levers the boxes are raised and lowered about every ten seconds. The boards contained in the boxes are, in this way, frequently immersed in the liquor contained

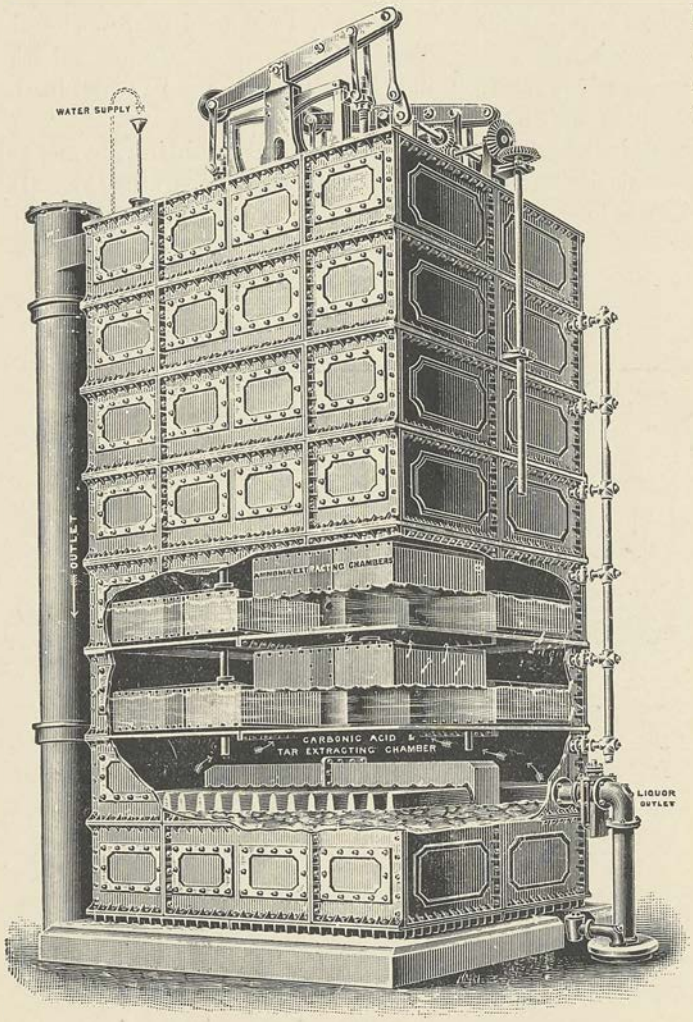


FIG. 318.—WALKER'S PURIFYING MACHINE.

in their respective compartments, and are then exposed in their wet condition to the crude gas. Effective contact with a large area of wetted surface is thus ensured. Clean water is admitted to the top of the machine at the rate of 10 gallons per ton of coal carbonized, and flows out at the base as a liquor of from 16 to 22 oz. strength. The back-pressure thrown by the apparatus is extremely small, amounting to little more than 1 inch of water.

MECHANICAL WASHER-SCRUBBERS

Plant of this description has been introduced with a view to combining the functions of the washers and scrubbers. On the majority of the larger works some apparatus of the kind is now to be found. The increased efficiency of ammonia extraction obtained is largely dependent upon the large area of freshly wetted surface with which the gas is brought in contact, also the "breaking-up" effect of the mechanically-operated portions. The primary objection to machines of this type is the necessity for employing motive power, whilst the introduction of running parts accounts for some expenditure on wear and tear. At the same time, the capacity of the machines for dealing with a definite quantity of gas is considerably less than that necessary with the ordinary type of washing and scrubbing plant; thus, when a large stream of gas is to be treated, substantial saving in capital outlay will be effected by the employment of the washer-scrubber. There are several

types of washer-scrubber now in use, but in many cases a strong resemblance is shown. Essentially, the machines consist of a series of cylindrical bays, made from cast-iron, and bolted together so as to form a number of compartments. A rotating shaft carrying some form of agitating gear runs through the centre of the cylinder. The crude gas entering at one end passes out at the further end of the cylinder deprived of the greater portion of its ammonia, while clean water (flowing in at the opposite end to the gas) travels from bay to bay, being converted into a liquor of gradually increasing strength. In the most effective machines, clean water running into the final bay will be worked up to a liquor of about 12 oz. strength by the time it reaches the opposite end of the cylinder.

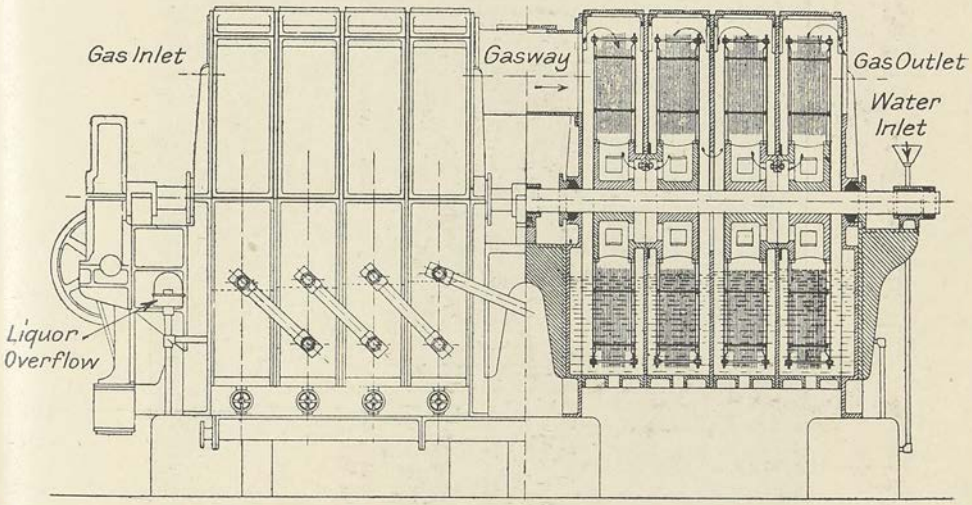


FIG. 319.—KIRKHAM, HULETT AND CHANDLER'S "STANDARD" WASHER-SCRUBBER.

Modern washer-scrubbers may be classified into two distinct groups :—

(*a*) Horizontal types.

(*b*) Vertical centrifugal types.

Type (*a*) was introduced many years ago by Paddon, and although it is still very much in evidence on gasworks, there is some tendency for the more effective centrifugal type to take its place. Of type (*a*) the original machine of Kirkham, Hulett and Chandler (Fig. 319) is, perhaps, the best known. In its latest and improved form it consists of a number of concentric cast-iron rings bolted together and divided into separate compartments by means of circular division plates having openings in the centre to permit of the passage of the gas. The machine is constructed in two sections with intermediate bearings at the centre, whilst a connecting main from section to section is provided for the passage of the gas. In the original machine the central shaft was carried on bearings inside the washing chambers, which rendered the bearings extremely difficult of access, and frequently resulted

in the fracture of the shaft. The washing appliance consists of bundles of corrugated wrought-iron sheets, the corrugations of alternate sheets crossing one another diagonally. The bundles (Fig. 320) are attached together so as to form a complete circle, and are fixed to the central shaft by means of double collars. The collars are made of such a size as to obstruct the direct passage of the gas from bay to bay and to cause it to take a circuitous path in contact with the wetted bundles. In order to preclude still further the possibility of "slip" a special arrangement of lead rings is fitted so as to bear upon the collar and completely close any gas way

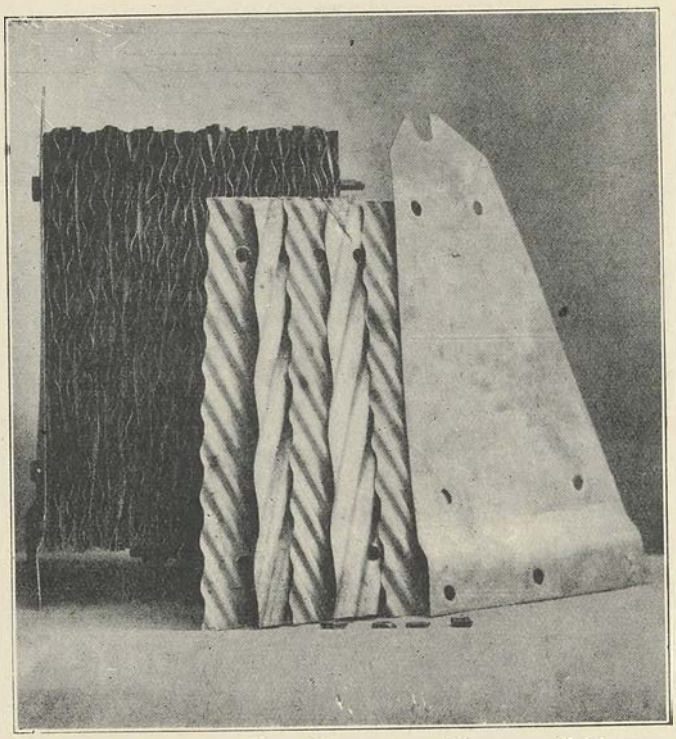


FIG. 320.—CORRUGATED-IRON BUNDLE FOR "STANDARD" MACHINE.

except through the bundles. The arrangement is clearly seen in Fig. 319. The liquor flows from bay to bay by means of the external sloping pipes shown, its usual depth being rather less than one-third of the diameter of the machine. When the machine is used for cyanide extraction the corrugated-iron bundles are replaced by a somewhat similar pattern made from wood.

The Whessoe washer-scrubber (Fig. 321) is very similar in construction to that described above, and is, in fact, worked on the same lines as the Kirkham and Chandler machine. Wooden bundles are used, and the machine is divided into four sections and driven from the centre of the shaft instead of from one end.

Holmes' washer-scrubber is now made in two sections, as shown in Fig. 322.

and is so arranged that either the whole or only one-half of the machine may be used at one time. In its later form it is driven from the centre of the shaft, and by withdrawing the coupling bolts one-half of the shaft only is revolved. The scrubbing appliance differs from that in other machines in that it consists of a number of brushes made from foreign bass and attached to a framework carried from the central shaft. The gas in passing from bay to bay finds a path between the bristles of the brushes and is, accordingly, subjected to most intimate contact with the liquor.

Clapham's "Eclipse" washer-scrubber was one of the first to be introduced and is still in common use, although some modification has taken place as compared with the original machines. It is particularly of interest in view of the unique means employed for bringing the crude gas in contact with wetted surfaces. The outer case is not cylindrical, the lower portion being rectangular and the upper half semi-circular. The shell, as in other machines, is divided into a number of compartments in which cylindrical cases (made from cast iron) and having perforated back and front plates, revolve. These cases, which vary in number from 8 to 12, contain several compartments, all of which are filled with wooden balls. The balls are kept in position in the cases by means of sheet-iron cover plates arranged round the

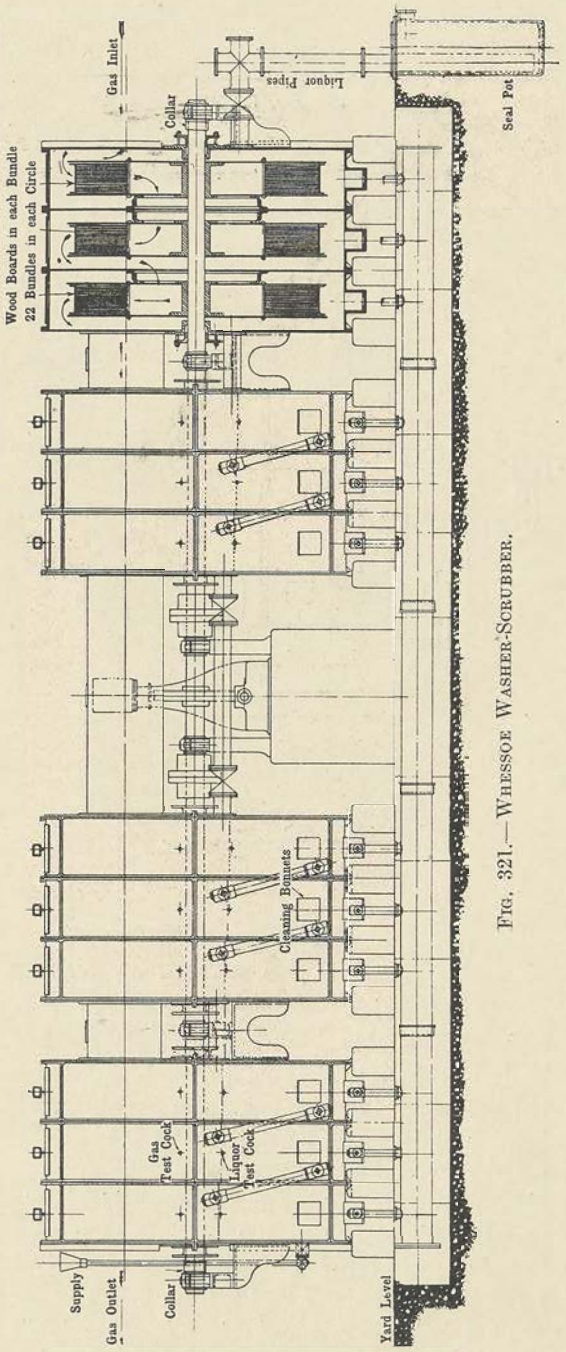


FIG. 321.—WHESSOE WASHER-SCRUBBER.

periphery. The balls vary from $1\frac{1}{4}$ inches to 2 inches in diameter, according to the size of the machine. They are made from hard sycamore, and each has a hole, half an inch in diameter, bored through the centre. The machine is so arranged that the gas is caused to travel in contact with the balls, and thus becomes thoroughly subjected to the action of the liquor. In some cases a series of perforated buckets have been fixed upon the cases, and so arranged that they pick up the liquor and discharge it over the balls when at the top of their circular course.

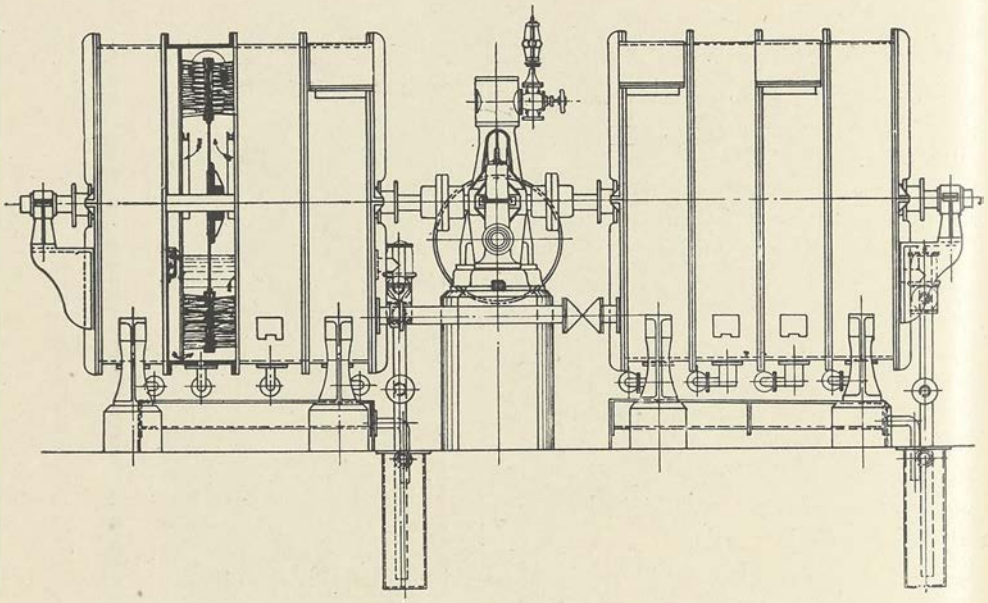


FIG. 322.—HOLMES' WASHER-SCRUBBER.

CENTRIFUGAL WASHER-SCRUBBERS

Centrifugal washer-scrubbers are of comparatively recent introduction, and differ considerably from the machines previously described. First, they are essentially of the vertical type, having a series of vertical compartments through which the gas passes in sequence. The best known in this country is that made by Kirkham, Hulett and Chandler, illustrated in Fig. 324. It consists of a cylindrical cast-iron vessel divided into a number of chambers through which passes a vertical shaft. To this shaft are attached specially shaped trays, which, revolving at a speed of about 100 to 150 revolutions per minute, lift up and spray the washing liquid so as to bring it into intimate contact with the ascending stream of gas. The number of chambers varies from two to ten, according to the purpose for which the apparatus is required; but, in general, the machines composed of a small number of chambers are employed for naphthalene washing, spraying an oil instead of gas liquor. The construction of the trays is best seen from Fig. 325. Each tray

is composed of a perforated rim, whilst depending from the bottom are four bent tubes, the sides of which are also perforated. As the shaft revolves the liquid is forced up the bent tubes into the trays, whence it is flung by centrifugal force across the gas space, rebounding again from the outer walls of the cylinder, and once more coming in contact with the gas. The gas is admitted into the lowest washing chamber, passes through the spray to the central opening in the bottom of the second chamber, thence through the second spray, and so on into the third and subsequent chambers. The washing medium is admitted at the top of the vessel, flows through the centre openings from chamber to chamber, and is finally run off at the bottom. In an eight-chamber machine clean water admitted at the top will be discharged as 16 oz. liquor, and—if so desired—the last traces of ammonia may be removed. This washer is equally suitable for the extraction of cyanogen from the gas. When used for this purpose the sprayers are made entirely of cast iron. For naphthalene removal the machine is constructed of from 2 to 6 chambers, but one machine may be used for both purposes, arrangements being made so that one or two chambers are supplied with water gas tar or other solvent

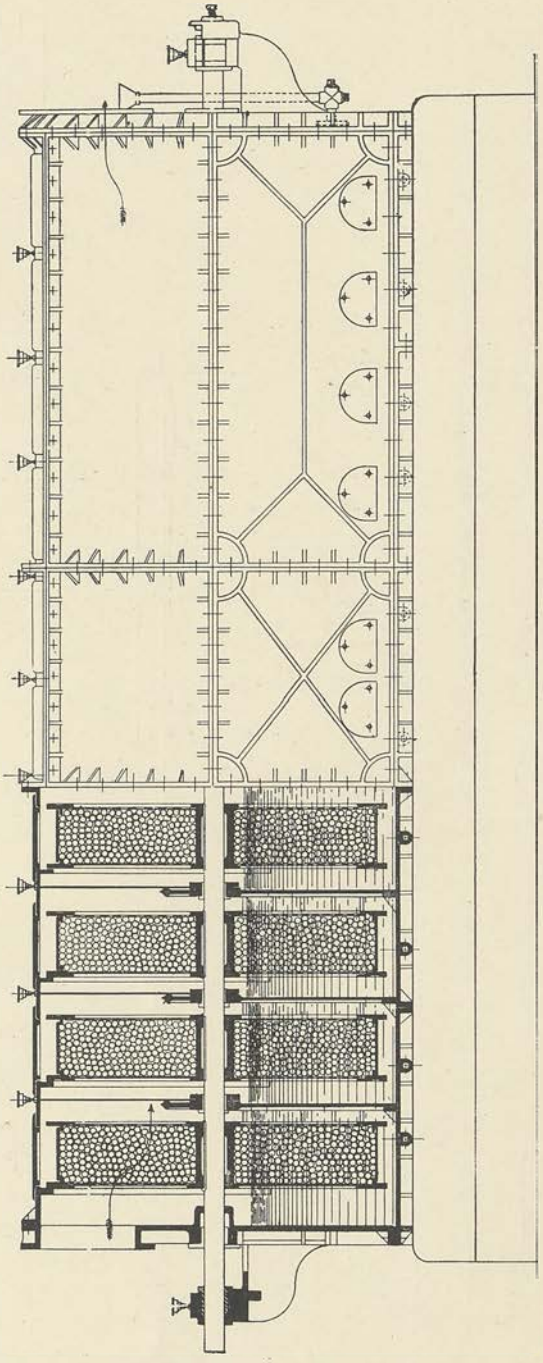


Fig. 323.—Clapham's Eclipse Washer-Scrubber.

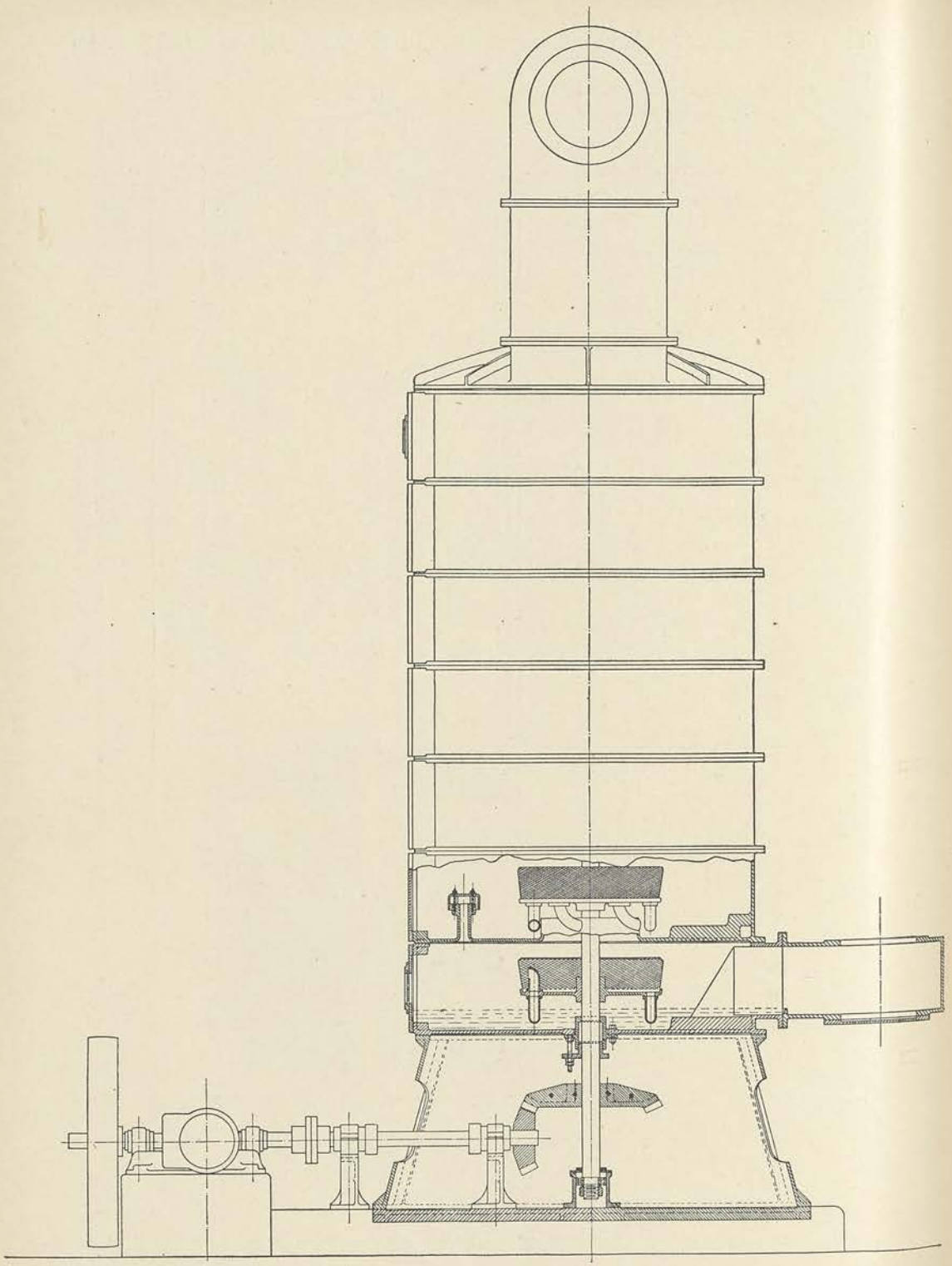


FIG. 324.—KIRKHAM, HULETT AND CHANDLER'S CENTRIFUGAL WASHER-SCRUBBER.

whilst the remainder are operated with liquor. The upper chambers should preferably be used for naphthalene removal, and the lower ones for ammonia extraction.

The Dempster-Feld washer (Fig. 326) is similar to that described above in so far as it consists of a number of superimposed chambers, through which passes a vertical shaft rotating at a speed of about 120 revolutions per minute. The spraying device, which is similar in all chambers, and is shown in detail in Fig. 327, is composed of a number of cones, varying from six to twelve, attached to the shaft by means of a cast-iron hub. The lower ends of the cones are so arranged that they dip into the liquor contained in the dish-shaped channel in the base of the chambers. As the shaft

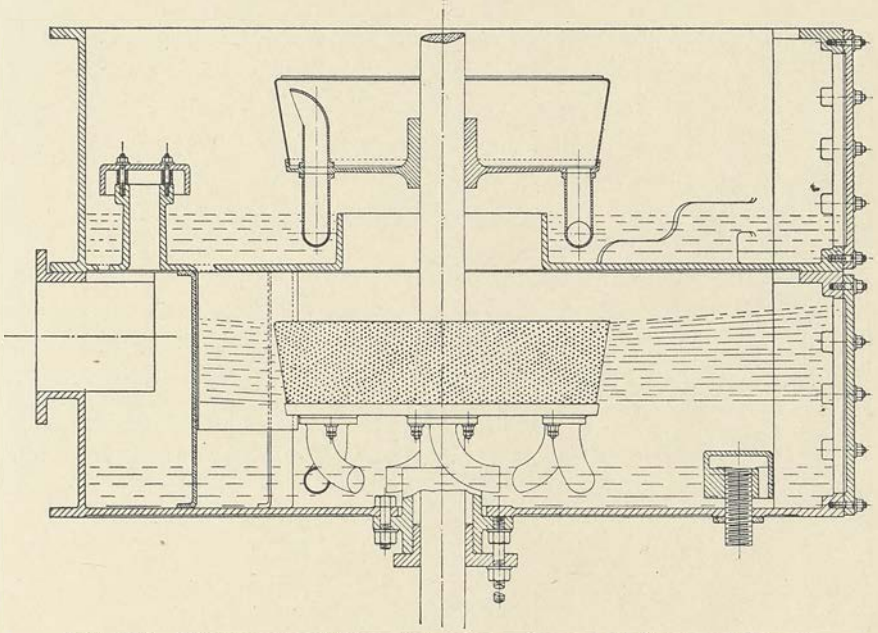


FIG. 325.—CENTRIFUGAL WASHER-SCRUBBER. DETAILS OF SPRAYING DEVICE.

rotates, the water is drawn up through the spaces between the cones, and is thrown off at a tangent at the upper edge with tremendous velocity, and passes across the gas space. The base of each compartment is provided with four apertures through which the gas travels from chamber to chamber, entering at the base and leaving at the apex. A machine dealing with 3 million cubic feet per day is only 5 feet in diameter and 23 feet high over all, which includes the height of the pier on which the machine stands. A baffle plate is fixed in the outlet compartment of the washer, which ensures the gas passing away in a dry state. The washers are made in sizes varying from 250,000 to 45,000,000 cubic feet of gas per 24 hours.

HORSE-POWER REQUIRED BY WASHER-SCRUBBERS

The power required to drive washer-scrubbers depends upon their size, the speed of running and the washing medium employed, *i.e.* weak or strong liquor,

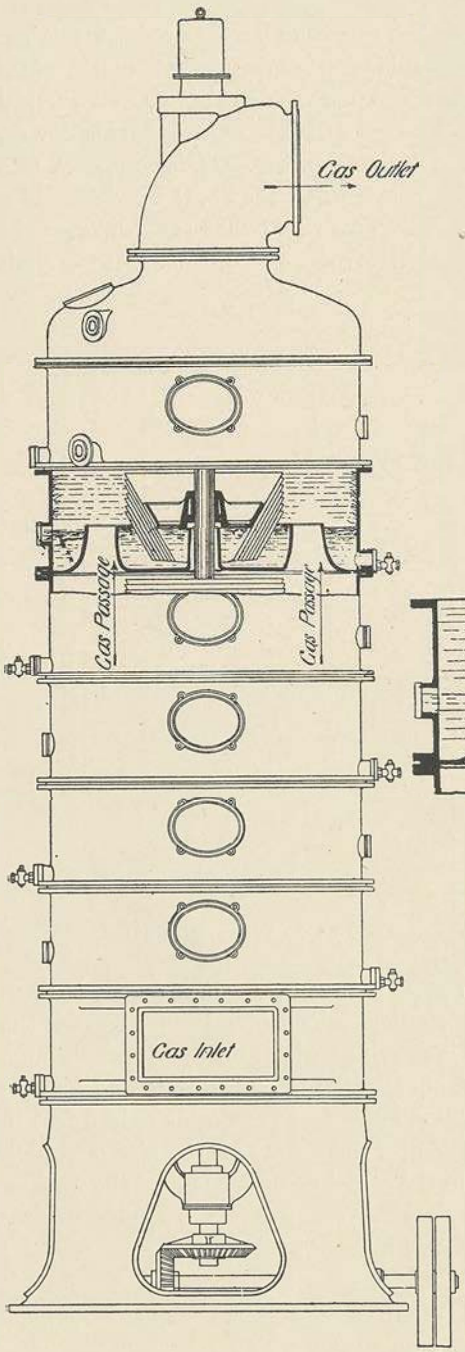


FIG. 326.—THE DEMPSTER-FELD CENTRIFUGAL WASHER.

tar or oil. Speed for speed the horizontal types absorb the larger amount of power, but owing to the very much greater rate at which the vertical machines travel they are usually rather more extravagant in this direction. The following figures (relating to the Kirkham, Hulett and Chandler washers) show the approximate powers required for various sizes of machines; but when installing driving plant for this purpose it is advisable to allow some further margin (say 20 per cent.) for contingencies.

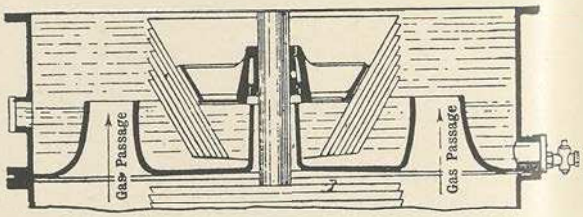


FIG. 327.—DEMPSTER-FELD WASHER SPRAYING CONES.

Cubic feet.	Horizontal.	Vertical.
500,000 per diem	3 h.p.	4 h.p.
1,000,000 ,, ,,	4 h.p.	5 h.p.
2,000,000 ,, ,,	5 h.p.	7 h.p.
3,000,000 ,, ,,	6 h.p.	10 h.p.

From this it will be seen that if electrical energy is used the cost per day for driving a 3 million cubic feet vertical machine would amount to 20*s.*, or about 0·08*d.* per 1,000 cubic feet of gas treated, or 1*d.* per ton of coal, with electricity at 1·5*d.* per unit.

SCRUBBERS

Scrubbers of some form or other are almost universally employed for removing the last traces of ammonia from coal gas. They consist either of rectangular or cylindrical vessels, the height of which is comparatively great in relation to the width or diameter. The ratio of height to diameter usually varies between $2\frac{1}{2}$ and 5 to 1, although in some instances it may be as much as 7 to 1, particularly in the case of scrubbers of comparatively small capacity. The cylindrical section is nearly always adopted, and the majority of scrubbers are constructed from cast-iron plates bolted together so as to form tiers. At the bottom of each tier or bay a grid is fixed to brackets cast on to the side plates whilst the gas outlet pipe, in many forms, passes down the centre of the vessel. Steel has been employed to some extent in the construction of scrubbers, the ring sections being riveted up

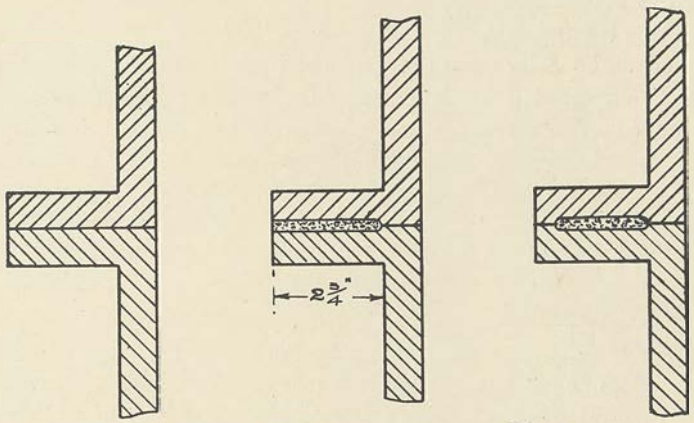


Fig. 328.—Typical Joints in Cast-iron Work.

by lap or butt joints, with external angles at the top and bottom of the sheet. Owing to its superior endurance against corrosion cast iron is, however, still preferred by the majority of engineers. Cast iron possesses, moreover, a secondary advantage in that the vessel is easily taken to pieces, and may be sold and re-erected elsewhere when it may have been outgrown by the increased output of the works.

In cast-iron work, as in common use for the construction of scrubbers, washers, tanks, purifiers, etc., three types of joint are found. These are shown in Fig. 328. It must be emphasized that although rust joints, composed of iron borings and cement (*see* page 248), are extremely strong they are not altogether desirable when such substances as ammoniacal liquor are being dealt with, so that faced joints should preferably be employed. For smaller scrubbers (say up to 5 feet diameter) the depth of the cast-iron plates is 4 feet, whilst above this size 5-feet plates are used. When the diameter of the scrubber is exceptionally large (over 30 feet) the flat cast-iron top becomes decidedly cumbersome, and is liable to sag. In

such cases it may be advisable to construct a domed top having a rise equal to one-sixth of its diameter and made from steel.

The function of the scrubber is to bring the partly purified gas in contact with large areas of wetted surface, and to this end the tower is packed with various materials which are laid on the grids at the base of each tier of plates. The type of packing required and its disposition have no little influence on the efficiency of the scrubber, hence considerable care should be given to this point. The chief points to be kept in mind when deciding upon the method of packing are the following :—

(1) A large area of exposed surfaces is required.

(2) The surfaces should be rough.

(3) Any tendency for the gas to " slip " must be avoided, and the stream should be broken up as far as possible.

(4) Initial cost of the packing material.

(5) The life of the material.

(6) Ease of cleaning out.

Brushwood and fascines were largely used as a packing in bygone days, but have now been superseded by layers of coke, wooden blocks, drain-pipes, grids, and boards on edge. As regards the relative areas exposed to the gas by these materials, Livesey has given the following figures :—

Coke	8½	square feet	per	cubic foot	of	scrubber capacity.
Drain-pipes, 3 inch diameter	17	,,	,,	,,	,,	,,
,, 2 inch ,,	21	,,	,,	,,	,,	,,
Boards on edge . .	31	,,	,,	,,	,,	,,

Dr. Carpenter has obtained extremely high efficiency by packing scrubbers with metal bundles somewhat similar to those employed in Kirkham, Hulett and Chandler's horizontal washer-scrubber (Fig. 320). There is little doubt, however, that, considering efficiency in conjunction with expense, it is difficult to improve on a packing composed of boards placed on edge. These should be rough sawn and arranged in chequer fashion, so as to give a sieve-like construction. The size of boards conforms to no hard and fast rule. The following may, however, be taken as affording satisfactory results :—

6-inch boards, ¼ inch thick, laid ¾ inch apart.

11-inch boards, ½ inch thick, laid ½ inch to ¾ inch apart.

A typical tower scrubber complete with board filling is shown in Fig. 329. In this case the bottom compartment forms a washer for the purpose of tar removal.

Board or grid filling for scrubbers is somewhat costly in the first instance, and where expense is of material importance tiers of coke may be substituted. Approximately, board filling will cost six times more than coke tiers, but it may be made use of over and over again. Whatever type of filling is employed it is essential that the upper surface of each layer should not be in contact with the underside of the grid supporting the layer above it, otherwise irregular distribution of gas and liquor, also increased back-pressure, will result. When the distance between the

tiers is 5 feet, at least 1 foot of clearance should be allowed, and when 4 feet, 6 to 9 inches is advisable.

Except in small works it is common to find scrubbers erected in pairs, whilst in the largest works there may be batteries of several. Whatever the number, it should always be arranged for the gas to come in contact with clean water before going forward to the purifiers. When two or more scrubbers are in use the last should be supplied with clean water alone, this running out at the base as a weak liquor, which is then pumped up to the preceding scrubber, and so on. When only one scrubber is available it should be so operated that the upper portion is supplied with clean water, whilst the lower tiers are treated with liquor from an intermediate spray.

An effective scheme has been introduced by Thos. Glover, and is illustrated in Fig. 330. The scrubbers are fitted with boards and are supplied with liquor which is previously passed through a strainer. The second scrubber is supplied with plate-glass windows placed opposite each other, so that if the vessel is carrying out its work effectively it is possible to see clearly through it from side to side. Half-way from the top weak liquor is sprayed on to the boards, whilst the upper half is supplied with clean water alone. The liquor flowing from the scrubbers passes through a

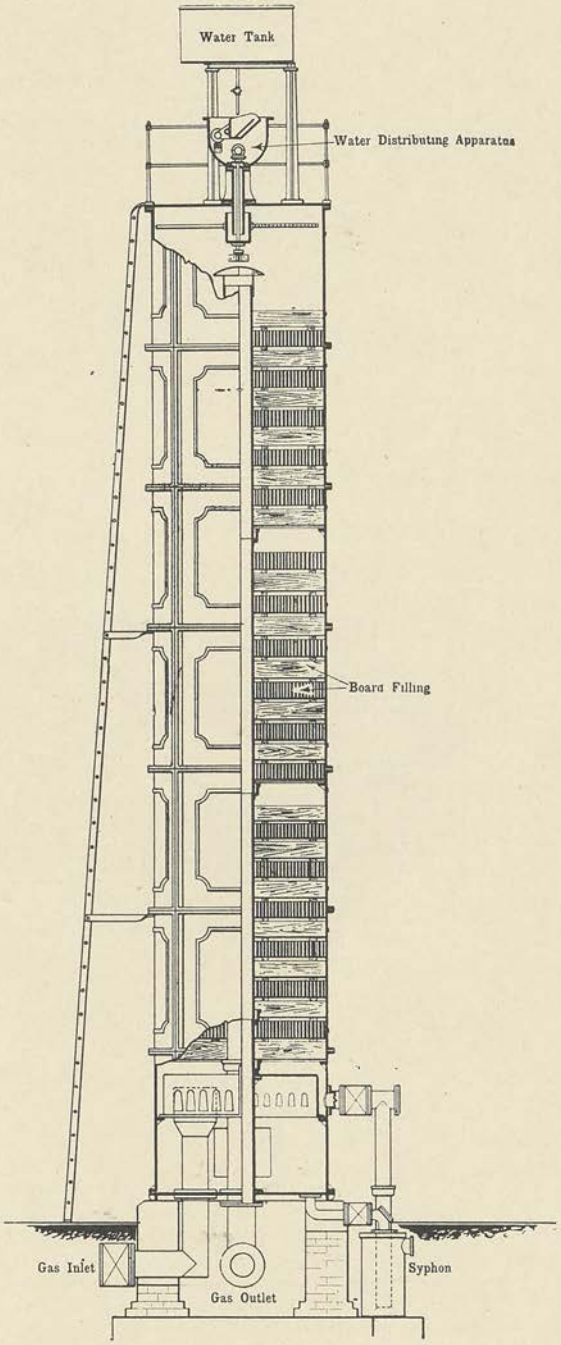


FIG. 329.—TYPICAL TOWER SCRUBBER WITH WASHER AT BASE.

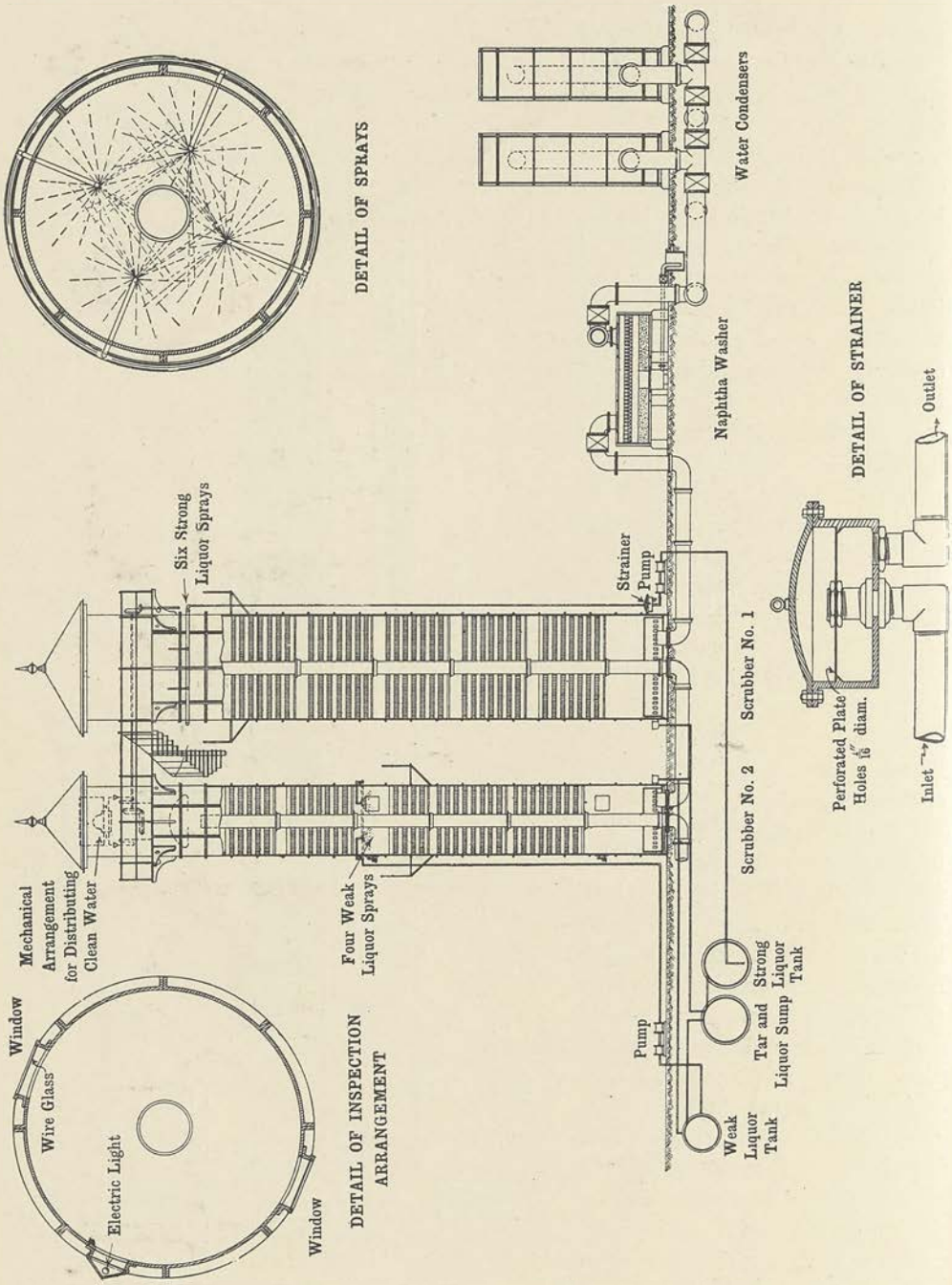


FIG. 330.—GLOVER'S SCRUBBER ARRANGEMENT.

sealed sight overflow. In this way the rate of flow is readily seen and ammonia loss is prevented.

LIQUOR DISTRIBUTORS

There are many types of liquor distributors or sprays now in use, the main object being that of ensuring a regular flow. It is also essential that the scrubbing liquid should be spread over the entire cross-section in uniform quantities, and atomized if possible. Liquor distributors may be classified into two sections, namely, those operated under pressure and those in which practically no head of water is available. Modern scrubbers should preferably be fitted with a main pressure box situated in the centre of the top cover plate of the vessel and from which arms radiate in various directions. The pressure of the liquor or water

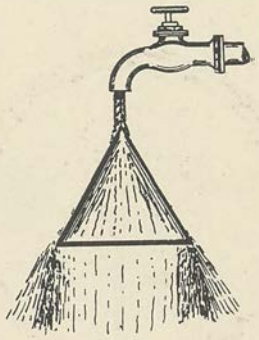


FIG. 331.—INVERTED CONE DISTRIBUTOR.

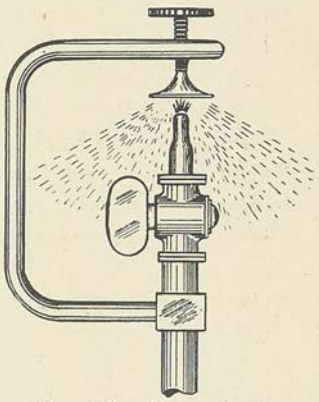


FIG. 332.—GURNEY'S JET.

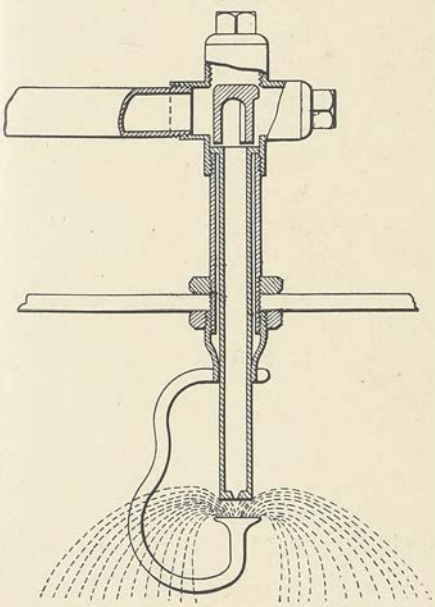


FIG. 333.—YOUNG'S SPRAY.

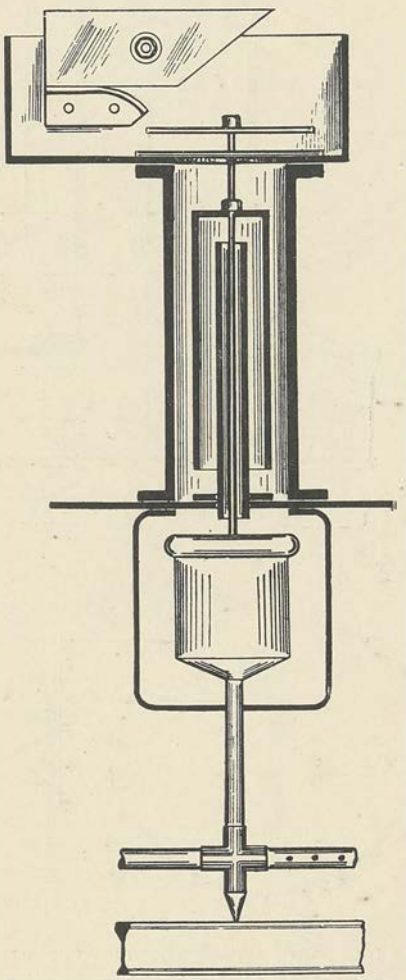


FIG. 334.—BARKER'S MILL OPERATED BY TUMBLER.

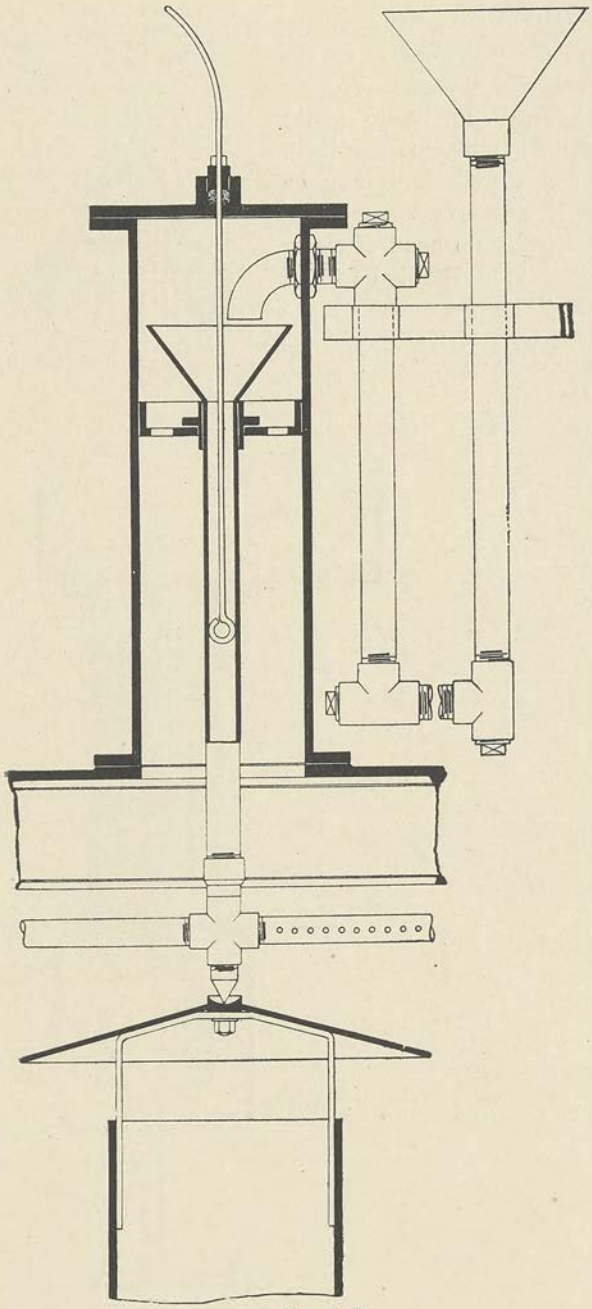


Fig. 335.

is then maintained by a suitable pump, and atomizers are spaced at intervals through the cover plate. For small works where no great pressure is available the best results will be given by some simple means such as the inverted cone (Fig. 331) or Gurney's jet (Fig. 332). The well-known principle of the Barker's mill is also very effective, but unless a certain amount of head is available the arms of the mill will remain stationary, with the result that local spraying will occur. On this account it is the general practice to employ the device known as the "tumbler," particularly when the amount of water entering the scrubber is so small as to be little more than a trickle. The sudden discharge of the tumbler, taking place at intervals, creates a certain amount of velocity head, which causes the arms of the mill to rotate for a short period. A complete installation of a tumbler and Barker's mill is shown in Fig. 334. Fig. 335 shows another means of operating the mill without the tumbler, and, consequently, is applicable where a moderately full stream of liquor is available. Fig. 336 shows an arrangement by means of which the sprayer arms, with the aid of suitable gearing, are revolved by a water wheel. Some engineers prefer to arrange for an intermittent flush of

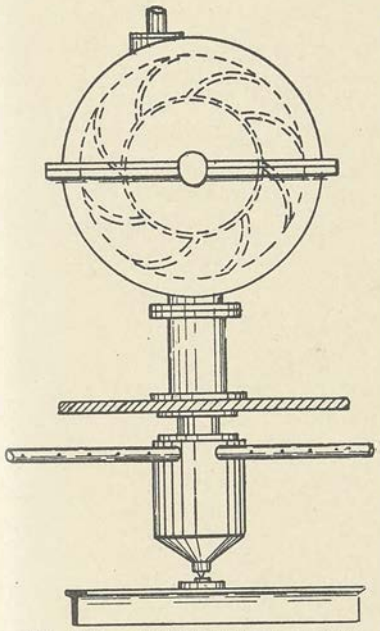


FIG. 336.—WATER WHEEL SPRAY.

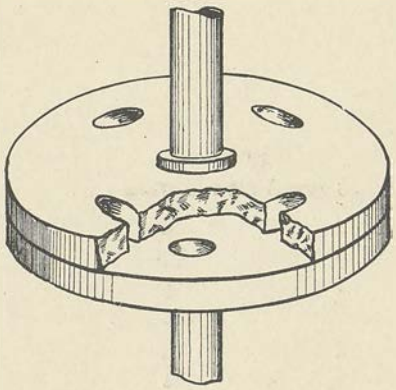


FIG. 337.—MANN'S DISCS.

liquor rather than a continuous flow, and in such cases the tumbler may be conveniently employed. Another means of providing for intermittent flow is by introducing the principle of Mann's discs (Fig. 337). The upper disc revolves whilst the lower remains stationary, so that when the holes in the discs coincide a flush of water or liquor is given.

THE CAPACITY OF WASHERS AND SCRUBBERS

The necessary capacity of the washing and scrubbing plant depends very largely on the type of apparatus employed. Owing to the introduction of more efficient plant the size of the vessels has undergone some considerable reduction of late years. For washers of the Livesey and similar types the following rule is reliable :—

Allow $\frac{1}{7}$ to $\frac{1}{5}$ cubic foot of capacity per 1,000 cubic feet of gas passed per diem.

The standard sizes of Livesey washers for dealing with various quantities of gas may be taken as follows :—

Gas dealt with per 24 Hours.	Length and Width of Washer.	Depth of Washer.
	ft. in. ft. in.	ft. in.
$3\frac{1}{2}$–4 million cubic feet	20 0 × 7 6	3 6
$2\frac{1}{2}$–3 „ „ „	15 0 × 7 6	3 6
$1\frac{1}{2}$–2 „ „ „	10 0 × 7 6	3 6
$\frac{3}{4}$–1 „ „ „	5 0 × 7 6	3 6
500–750,000 „ „	6 0 × 4 0	3 0
300–500,000 „ „	5 0 × 3 6	2 6
200–250,000 „ „	3 0 × 4 0	2 6
75–100,000 „ „	3 8 × 1 3	2 6

For mechanical washer-scrubbers an allowance of $\frac{1}{2}$ to $\frac{3}{4}$ cubic foot per 1,000 cubic feet of gas passed per diem may be made.

Scrubbers

When there is *no other* wet purification plant, a generally recognized rule for the capacity of tower scrubbers states that 9 cubic feet of volume should be allowed for every 1,000 cubic feet of gas passed per diem. For modern requirements, however, so great an allowance will in most cases prove unnecessary; but much depends upon the washing apparatus prior to the scrubbing plant. In the scrubbers slow contact is desirable, so that the gas should be in contact with the wetted surfaces for a period of from ten to fifteen minutes, as against about twenty seconds in the modern form of washer-scrubber. When associated with any form of mechanical washing apparatus 5 or 6 cubic feet of scrubber capacity per 1,000 cubic feet of gas per diem should prove ample. In some cases the gas issuing from the power-driven vessel is practically devoid of ammonia, and is merely passed through a small tower scrubber operated with clean water and working as a catch vessel. Such a scheme, however, is not to be recommended, unless ample safeguards are provided against the breakdown of the mechanical machine. Where no washer-scrubbers are in use the capacity allowed should be as much as 10 cubic feet per 1,000 cubic feet of gas per diem. This includes both washer and scrubber capacity in such cases where only board-filled washers and coke or board scrubbers are employed, and may be apportioned half to the one type of vessel and half to the scrubbers. When washers on the Livesey and such principles are introduced the scrubber allowance need be no more than 6 cubic feet per 1,000 cubic feet of gas per diem. In very small works where one tower scrubber alone, and no washer, is in operation, the allowance may wisely be increased to 12 cubic feet.

The following are the sizes of scrubbers which may be effectively employed for the removal of ammonia *where no other plant* (*i.e.* washers) is in use for this purpose. In giving the actual size of scrubbers this is the only case which can be readily dealt with, when no details of the washing apparatus are known.

Single Scrubbers

Gas made per Day.	Scrubber.	
	Diameter.	Height.
	ft. in.	ft. in.
20,000 cubic feet	3 6	24 0
40,000 „ „	4 6	32 0
60,000 „ „	5 0	36 0
80,000 „ „	6 0	35 0
100,000 „ „	7 0	35 0
150,000 „ „	8 0	35 0
200,000 „ „	9 0	40 0
300,000 „ „	10 0	40 0

TWO SCRUBBERS IN SERIES

		ft.	in.	ft.	in.	
100,000	cubic feet	5	0	30	0	each
200,000	„ „	6	0	35	0	scrubber
300,000	„ „	7	0	40	0	of these
500,000	„ „	9	0	40	0	dimensions.
1,000,000	„ „	12	0	45	0	
1,500,000	„ „	14	0	50	0	

It will be noticed that for the smaller scrubbers the ratio of diameter to height is very much greater than is the case with the larger capacity vessels. In the case of single scrubbers it will be seen that works making up to 300,000 cubic feet per diem have only been considered, as it is inconceivable that larger concerns than this would be provided with one scrubber alone. The same remarks apply to the two scrubbers, where the limit has been placed at $1\frac{1}{2}$ million cubic feet per day. It cannot be urged too strongly that the process of condensation should be carried out in an adequate and scientific manner. Effective condensation means an enormous reduction in the requisite scrubber capacity.

AMOUNT OF WATER REQUIRED

No hard and fast rule can be laid down in connection with the amount of water necessary to remove completely the ammonia from the gas. Much must depend on the amount of this compound present, and on the proportion of it which is eliminated and thrown down in the virgin liquor of the condensers, etc. It has been stated that, theoretically, the whole of the ammonia may be removed by admitting 3 gallons of water per ton of coal carbonized, but in practice such a result is never attained. In the ordinary way, the whole of the water employed is admitted to the final or clear-water scrubber, and in normal cases this amounts to 10 to 13 gallons per ton of coal carbonized. Much, however, depends upon the type of scrubber in use, coke filling requiring a greater quantity of water than is the case with board filling. Much variation is shown in the direction of water consumption, and the author can point to cases where, with no other washing apparatus but scrubbers in use, the quantity admitted amounts to only 4 gallons per ton of coal. The horizontal washer-scrubber does not effect any marked economy in water, and in most cases requires an amount equal to about 10 gallons per ton of coal. Vertical washer-scrubbers of the centrifugal type are, however, very much more efficient in this respect, and a small quantity of water, admitted at the top, will, if desired, remove the whole of the ammonia. At Salisbury it was found that with clean water admitted to a vertical machine at the rate of $3\frac{3}{4}$ gallons per ton of coal carbonized 90 per cent. of the ammonia present in the gas at the inlet was retained, whilst the water passed off as a 16 oz. liquor. Thos. Glover has given figures for the quantity of liquor which should be distributed in scrubbers in order that these vessels may perform their work most efficiently. He states that the liquor distributed per square foot of cross-sectional area of the scrubber should be 0·145 gallons per minute. This is less the clean water added to the final scrubber.

AMMONIA LOST THROUGH SCRUBBERS

Many engineers, nowadays, make a practice of allowing a very small amount of ammonia to travel forward from the scrubbers to the purifiers. In this way the oxide of iron is maintained in an alkaline condition and fulfils its functions more satisfactorily. The amount of ammonia permitted to travel forward varies from 0·5 to 1 grain per 100 cubic feet.

In making tests for the quantity of ammonia passing through the scrubber it is preferable to calculate the total ammonia loss rather than to state the quantity in so many grains per 100 cubic feet of gas. Only by considering the total quantity of gas passed can the actual loss, which should be stated in the equivalent of so many gallons of 8 oz. or 10 oz. liquor, be gauged. The following is the method of making the calculation :—

Total grains of ammonia lost per week

$$= \frac{\text{Gas made for week}}{100} \times \text{No. of grains per 100 cubic feet at scrubber outlet.}$$

In 1 gallon of 10 oz. liquor there are 1,522 grains of ammonia.

$\therefore$ Quantity of 10 oz. liquor lost (in gallons)

$$= \frac{\text{Total grains of ammonia lost per week}}{1{,}522}.$$

CONSERVATION OF AMMONIA

Although the quantity of ammonia recovered from coal is influenced considerably by the manner of carbonization, a consideration of even greater importance to the gas engineer is that of curtailing loss by evaporation and leakage. Exposed surfaces or streams of ammoniacal liquor evolve both ammonia and sulphuretted hydrogen, the extent of the loss depending largely upon temperature, although the more extensive the exposed surface the more rapidly will the dissolved gases be emitted. It is essential, therefore, that all seal pots or catch sumps should be fitted with tightly sealed covers, preferably water-luted, while the delivery pipes which convey liquor and tar to the storage well should be dipped below the lowest level of the liquid in the well.

The main contributory causes of low yields of ammonia may be stated as follows :—

(*a*) The indifference frequently displayed at the smaller works.

(*b*) Losses due to evaporation in imperfectly covered storage wells, seal pots, or from falling and splashing streams of liquor.

(*c*) Abnormally high ammonia content of effluent liquor escaping from sulphate of ammonia stills. The loss in this case is mainly due to insufficient quantities of lime being added, so that the whole of the fixed ammonia is not liberated.

As an instance of the manner in which the ammonia recovered varies at different gasworks the following figures[1] may be quoted :—

[1] Hollingworth & Fottrell, *Gas. J.*, March 9, 1920, p. 557.

AMMONIA RECOVERY AT GASWORKS, 1918

Pounds of Sulphate of Ammonia per ton of Coal.	Number of Works.	Coal Carbonized (tons per annum).
Between 40 and 45 lb.	2	14,228
„ 35 „ 40 „	3	32,766
„ 30 „ 35 „	12	623,328
„ 25 „ 30 „	41	2,492,311
„ 20 „ 25 „	119	3,984,768
„ 15 „ 20 „	119	2,835,001
„ 10 „ 15 „	98	1,714,941
„ 5 „ 10 „	28	322,481
Below 5 lb.	4	12,401

Highest average yield for the year . . . . . 43·0 lb.
Lowest average yield for the year . . . . . 3·7 lb.

So far as the prevention of ammonia loss in storage wells is concerned it has been shown that evaporation may be considerably reduced by covering the surface of the liquor with a very thin film of oil. Those undertakings making carburetted water gas may readily employ ordinary gas oil for the purpose, but the precaution must be taken to ensure that the suction from the liquor pump is always well below the surface of the liquor, otherwise the oil film may be drawn off. Once the surface has been covered the oil will remain effective for a considerable period, thus requiring very infrequent renewal.

LIQUOR PURIFICATION

Attempts have been made to dispense with dry purification plant by making use of the alkaline impurity (ammonia) for removing the whole of the remaining acid substances. As previously pointed out, however, the available ammonia in coal gas (after the condensers have been passed) amounts, theoretically, to very much less than the quantity necessary for extracting the acid impurities. It has been proposed to overcome the difficulty of this deficiency by causing the ammonia to perform its duties twice; in other words, having absorbed the acid impurities the resultant salts are decomposed in special apparatus, when the acid gases are expelled and the ammonia rendered available for further use. Purification systems based on such principles were introduced by Claus, also Laming, Livesey, and Hills. Although theoretically ingenious, their complicated nature prevented any development on a practical scale. During the war, however, renewed attention was given to the subject, owing to the fact that a demand arose for concentrated ammoniacal liquor; and in the preparation of this the liquor was treated in such a manner that, while the ammonia was retained, the sulphuretted hydrogen and carbon dioxide were expelled. Thus, the first condition necessary for complete liquor purification of the gas was fulfilled.

The Claus Process

The Claus process is of particular interest, in that it was tried on a fairly large practical scale at the Belfast gasworks, but was ultimately abandoned as unsuitable. Simply explained, the process consists of the following :—

1. The crude liquor (*i.e.* saturated with sulphuretted hydrogen and carbon dioxide) from the washers is passed through a series of towers, where it is submitted to the action of carbon dioxide gas. Sulphide of ammonia is, therefore, converted into the carbonate whilst sulphuretted hydrogen is liberated.

2. The sulphuretted hydrogen gas is then burned in a Claus kiln and yields sulphur.

3. The crude liquor, now consisting chiefly of ammonium carbonate, is passed into heating towers, in which its temperature is raised to from 85° to 95° C. In this way the CO_2 is expelled from the liquor to the extent of from 60 to 75 per cent. of the quantity in which it is present. This CO_2, or rather a portion of it, provides the CO_2 gas current mentioned under (1).

4. The partly purified liquor from which the CO_2 has been liberated is then distilled so that ammonia gas and the remaining ammonium carbonate are evolved.

5. The ammonia gas and ammonium carbonate vapour are then passed through cooling towers, when the carbonate sublimes to the solid state, leaving a comparatively pure ammonia gas.

6. Lastly, the ammonia is admitted to the stream of crude coal gas before the latter enters the washers.

In this way the original ammonia which has combined with CO_2 and H_2S in the crude gas is recovered in the gaseous form and caused to react once more with the acids. A surplus of ammonia is, of course, obtained, and may be converted into sulphate of ammonia in the ordinary way.

Although theoretically the expulsion of the acid gases is comparatively simple, in practice considerable loss of ammonia occurs unless the plant is designed with skill. The earlier investigators undoubtedly failed through lack of experience in plant design and operation, for under present day conditions it is possible to operate with a loss of 1 per cent. In practice, however, it has been shown that for complete removal of the sulphuretted hydrogen and carbonic acid from the gas so much as from four to six times the quantity of ammonia yielded by a ton of coal must be employed. Consequently, the working loss is multiplied by this extent.

Considerable light has been thrown upon the theory and practice of liquor purification by P. Parrish,[1] who states that, theoretically, 5·077 times the quantity of ammonia in the gas is the minimum quantity required for satisfactory working of the process. The same authority also states that as the volume and composition of the gas vary from day to day—even from hour to hour—these variations can only be satisfactorily met by maintaining in stock in the scrubbers or circulating tanks an excess quantity of caustic ammonia ; so as to provide against

[1] *Proc. Southern Assocn. Gas Eng.*, Nov., 1918.

any variations or contingencies that may arise. As to the design and arrangement of the plant this must embody the following essentials :—

(1) Adequate contact should be obtained between the coal gas and the re-circulated gaseous ammonia, in order to allow of the formation of the soluble ammonium compounds which are to be absorbed in the ammoniacal solutions and water being circulated. As the reactions involved necessitate time, as also does the absorption of the soluble ammonium compounds, the size of the vessels and the free space of the packing medium (assuming packed scrubbers are used) should be sufficiently large to allow of these desiderata being secured.

(2) The gas to be purified should be freed as effectually as possible from tar and hydrocarbons, which are likely to accumulate and eventually prevent the satisfactory and efficient working of the packing medium used.

(3) The relative merits and demerits should be carefully considered of (*a*) vertical scrubbers provided with suitable filling medium, which necessitate the installation of a series of bottom circulating tanks and pumps, and (*b*) horizontally disposed mechanical washer-scrubbers arranged in cascade form, in which a counter-current is established between the gas and re-circulated gaseous ammonia and the absorbing liquors and water.

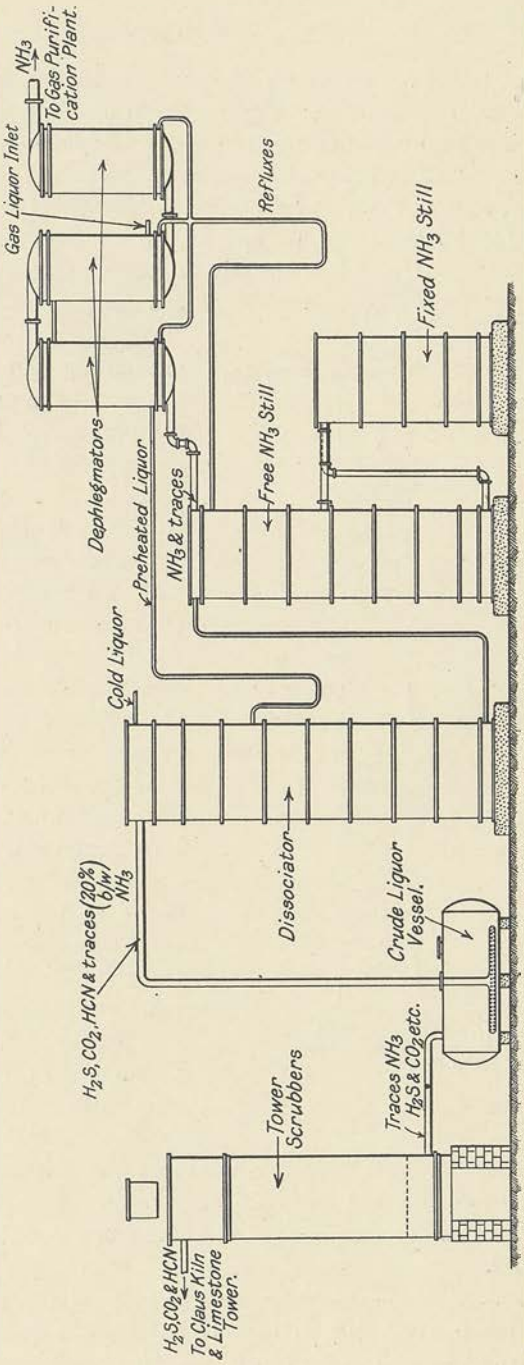


FIG. 338.—LAY-OUT OF SIMPLE LIQUOR PURIFICATION PLANT.

A simple type of plant as suggested by Parrish is illustrated in Fig. 338.

Davidson's Process

A recent process for the self-purification of crude gas is that introduced by Dr. W. B. Davidson. The principle of the process is on the same lines as those attempted by earlier experimenters, but it is operated in a more scientific manner. The process of separating the acid gases from the ammonia is carried on in a vertical still of the usual pattern, to the top of which the liquor is fed. The still is heated by steam introduced at the base, and whilst the ammonia is taken off at a point half-way up the column, the CO_2 and H_2S are expelled at the top. This separation of the ammonia and acid gases is made possible by graduating the temperature and pressure within the still—the pressure being so regulated that a comparatively high pressure is obtained in the portion of the still from which the ammonia is collected. After leaving the still, the gaseous ammonia is passed through absorbers to remove any traces of the acid gases, and is then re-mixed with the crude coal gas at any convenient point, such as the condensers or washers. From the washers, scrubbers, and condensers, the ammoniacal liquor is collected and returned to the still, whilst the surplus ammonia, being recovered in an extremely pure form, provides a valuable by-product. The working pressures in the still amount, as a minimum, to approximately 5 lb. per square inch at the point where the steam is applied; 4 lb. per square inch where the ammonia is withdrawn; and 3 lb. per square inch at the zone where the acid gases are removed. Higher pressures than these (worked in the same ratio) will, however, give more satisfactory results. Though not essential to the process, Dr. Davidson prefers to treat the gas which has passed the ordinary washers and scrubbers with a sludge of ferrous hydrate, prepared from iron chloride or sulphate and ammoniacal liquor. In this way the whole of the sulphuretted hydrogen may be removed. The process then resolves itself into the following:—

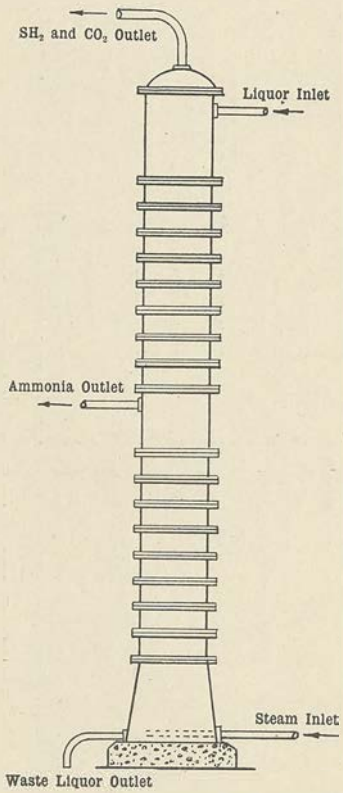


Fig. 339.—Davidson's Ammonia Still.

1. *Tar extractor.*—Tar in crude gas reduced to less than 2 grains per 100 cubic feet.

2. *Cyanogen washer.*—Iron sulphide sludge employed for removing cyanogen:— $FeS + 6\ HCN + 4\ NH_3 = (NH_4)_4FeC_6N_6 + H_2S$. Ammonium ferrocyanide is thereby formed, with the liberation of sulphuretted hydrogen.

3. *First ammonia washer.*—To which the ammonia gas liberated from the

liquor is admitted, thus extracting the bulk of the sulphuretted hydrogen and carbon dioxide.

4. *Second ammonia washer.*—In which water is used for removing any remaining ammonia, H_2S and CO_2. The H_2S is reduced to less than 0·02 per cent. by volume.

5. *Final washer.*—In the lower portion of this washer, a ferrous hydrate sludge is used to extract the last traces of H_2S and a further quantity of ammonia, as follows :—

Iron sulphate is treated with ammoniacal liquor to give ammonium sulphate: $FeSO_4 + 2\,NH_4OH = (NH_4)_2SO_4 + Fe(OH)_2$. The H_2S then combines with the iron hydrate formed: $Fe(OH)_2 + H_2S = FeS + 2\,H_2O$. The iron sulphide resulting from this reaction is afterwards made use of for absorbing cyanogen, as explained under heading (2). In the upper portion of the final washer, water or sulphuric acid is used for extracting the last traces of ammonia.

The Petit Process

This process is deserving of mention if only for the fact that the apparatus required consists merely of two ordinary washer-scrubbers. The first of the washers serves the purpose of absorbing the sulphuretted hydrogen from the gas (this being effected by the use of a special washing liquid), while in the second vessel revivification of the saturated liquor is brought about. The washing medium made use of is preferably potassium carbonate (K_2CO_3), which has the advantage that no precipitate is formed, so that the liquor always remains as clear as water. The gas after having the ammonia removed, but still containing carbon dioxide, is passed through the solution, when the carbon dioxide unites with the potassium carbonate in the presence of water to form a hydro-carbonate ($KHCO_3$). In addition, sulphuretted hydrogen is absorbed and yields a solution of potassium hydrosulphide, whilst the hydrocyanic acid is almost wholly eliminated and gives potassium cyanide.

After a time the original washing liquor becomes saturated with impurities, and is subjected to a simple process of regeneration, after which it is capable of further use. To effect revivification a stream of air from a blower is passed through the fouled solution, when the sulphuretted hydrogen and hydrocyanic acid are immediately liberated. It is interesting to note that an air blast would not liberate the impurities from a neutral solution, and in this case (owing to the original reaction with carbon dioxide) a bicarbonate salt is formed. In the Petit process the sulphur of the original coal may still be recovered as a by-product, and to this end it is customary to pass the air from the regenerator to a Claus kiln for the production of free sulphur. In general, the air after leaving the regenerator will contain about 2 per cent. of sulphur. It is found that a small amount of the carbon dioxide is also liberated by the blast; consequently the revivified solution is capable of taking up from the gas a further quantity of carbon dioxide in the next operation. The speed of the regeneration process may be appreciably increased if a small proportion of carbon dioxide is admixed with the air before its passage through the liquor. For this purpose a supply of waste gases may be taken from any con-

venient chimney and so regulated that the carbon dioxide is present in the air to the extent of about 3 per cent. Heating of the liquor up to 120° Fahr. accelerates the process considerably.

Ciselet and Deguide's Process

In this process[1] the purification of the gas is effected by means of a limited quantity of ammonia which is constantly and automatically regenerated during the operation. For this purpose the gas is treated with a liquid consisting of caustic ammonia in solution and lime in suspension. The ammonia reacts with the gas, the acid products of which it transforms into sulphide, cyanide and carbonate of ammonia, respectively, but in the presence of lime these ammonium salts give rise to a double decomposition with the lime and pass into calcium salts, while caustic ammonia is regenerated and thereupon continues its purifying action. The ammonia has, therefore, the function of a mere vehicle between the gases from which it removes the acid products, and the lime to which it imparts these products immediately thereafter, which also retains them definitely. As long as the quantity of lime is not exhausted, the same quantity of ammonia may continually serve for the purification of a continuous current of gas.

Briefly, the operation of the process is as follows:—The crude gas coming from the retorts is in the first place freed from tar in the ordinary manner. The acid constituents are then extracted. To this end, the gases are passed through suitable apparatus such as atomizers, in which they are placed in contact with a liquid containing caustic ammonia in solution and hydrate of calcium in suspension. This liquid, which may be prepared in a very simple manner by mixing lime-water with a solution of caustic ammonia or with ammoniacal liquor, reacts with the gases in two phases. The first phase is the absorption of the acid products by the ammonia:—

$$H_2S + 2\ NH_3 = (NH_4)_2S.$$
$$HCN + NH_3 = NH_4CN.$$
$$CO_2 + 2\ NH_3 + H_2O = (NH_4)_2CO_3.$$

The second phase is a double decomposition between the ammonium salts and the lime:—

$$(NH_4)_2S + Ca(OH)_2 = 2\ NH_3 + CaS + 2\ H_2O.$$
$$(NH_4)_2CO_3 + Ca(OH)_2 = CaCO_3 + 2\,NH_3 + 2\ H_2O.$$
$$2\ NH_4CN + Ca(OH)_2 = Ca(CN)_2 + 2\ NH_3 + 2\,H_2O.$$

The ammonia, therefore, does not remain in the state of a salt. It is constantly regenerated in the caustic state and can pursue its purifying action so long as the quantity of lime is not exhausted.

After some time it is advisable to eliminate the calcium carbonate, the precipitated mass of which increases rapidly. It is separated by filtration of the liquid which contains, in solution, the sulphide and cyanide of calcium and ammonia.

[1] Eng. Pat. No. 9780, 1917.

If desired, the ammonia may then be distilled off. As, however, after one operation, the liquor is not sufficiently saturated with sulphide and cyanide of calcium, it is preferable to add to it a further quantity of lime and to return it to the gas purification vessels. This cycle can be continued until the liquor is sufficiently saturated, after which the ammonia is expelled by distillation and used again in the purification of the gas.

Direct Methods of Recovery

During recent years some considerable attention has been given to the problem of recovering the ammonia resulting from the distillation of coal by direct means. In the ordinary way, this ammonia is wholly recovered in the form of an ammoniacal liquor, the liquor being subsequently worked up into sulphate of ammonia in a distinct plant. Chemists, particularly on the Continent, have endeavoured to obviate the necessity for providing a separate unit for working up the ammonia into commercial form, and have introduced processes for the "direct" recovery of the by-product in the ordinary course of gas-making. The "direct" methods now employed for the recovery of ammonia may be classified under two headings, namely :—

(*a*) Those in which the acid impurity, sulphuretted hydrogen, is utilized to form sulphate of ammonia.

(*b*) Those in which the crude gas is passed through a seal of sulphuric acid, thereby causing sulphate of ammonia to be deposited. These processes are sometimes referred to as "semi-direct" methods.

From the gas engineer's standpoint the ideal process is undoubtedly that which renders the use of sulphuric acid unnecessary. Although the practical difficulties attending such methods are many, a great deal of headway has been made. In fact Cobb, Feld, and Burkheiser have devised processes which from the theoretical standpoint are of exceptional interest, although they cannot be said to have as yet reached a stage which permits of their general application in practice.

The Burkheiser Process

In Burkheiser's process, the usual practice of extracting ammonia prior to sulphuretted hydrogen is reversed—the sulphur impurities being removed first. The *modus operandi* of the plant can be followed best by referring to the diagram, Fig. 340. The crude gas coming away from the tar extractor is first pre-heated by means of a steam coil. It then travels through a still, where the ammonia is expelled from any virgin liquor thrown down in the condensers, etc., and is carried forward by the crude gas. The sulphuretted hydrogen is then extracted by passing the gas through purifiers containing a special concentrated oxide of iron. This oxide has been subjected to a special process of roasting, by means of which the organic matter and moisture are removed, leaving the material in the form of small nodules. The activity of the oxide is so increased by this means that it is said to be capable of removing sulphuretted hydrogen at a speed thirty times greater than is the case with ordinary oxide. The apparatus is in two similar sections, one portion being used

for purifying the gas whilst the other is given up to revivification of the oxide. The two sections are reversed at intervals—the one which was revivifying doing the purification, and *vice versa*. After leaving the ammonia still, the gas passes through the special oxide of iron in the purifier and thence into the base of the

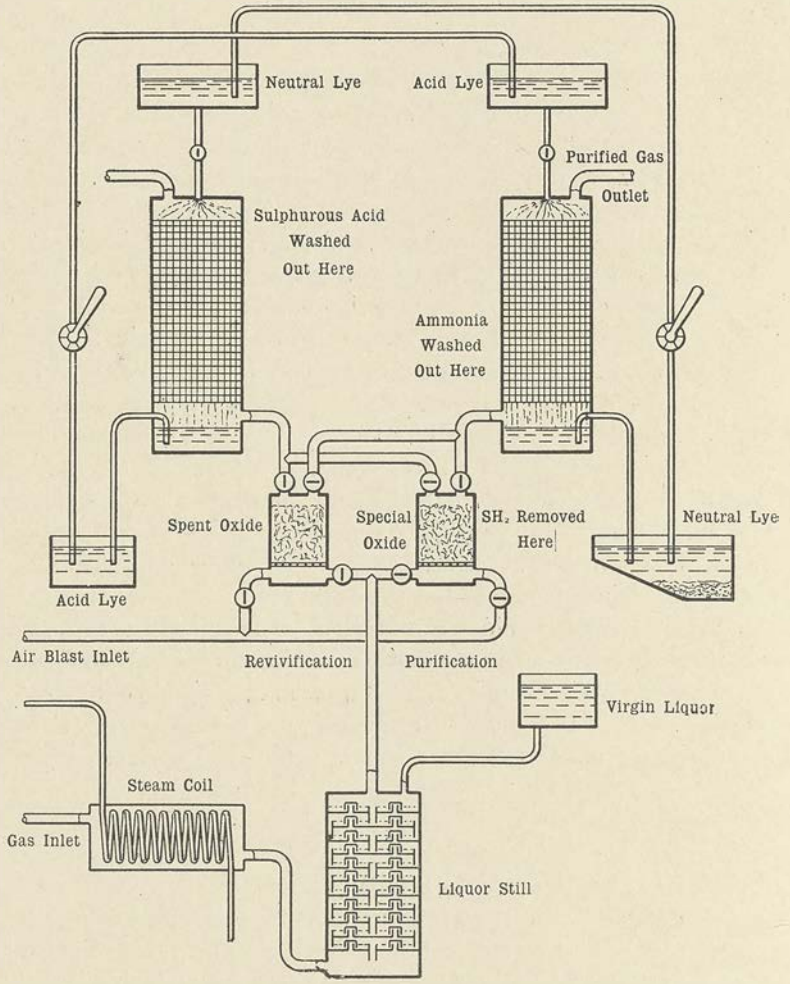


FIG. 340.—LINE DIAGRAM SHOWING BURKHEISER'S PROCESS.

ammonia washer. An acid solution is admitted to the top of the washer, and in this way the ammonia is neutralized and washed out from the gas. The neutral liquor, or lye, flowing from the washer is collected and used in the other side of the plant. The gas, free from all impurities, passes out at the top of the ammonia washer as shown.

When the oxide has absorbed its maximum quantity of H_2S, the gas is deflected

from the right-hand side, and is passed through the left-hand side of the plant, where the oxide (previously fouled) has been undergoing revivification; whilst the former purifying side is now submitted to a heated air-blast, so that this oxide may be revivified. Revivification is carried out by passing a powerful air-blast through the spent oxide, and the compounds of sulphur and iron are violently oxidized so that sulphurous acid is produced. The air-blast (laden with the acid) then passes to the washer, where it meets with a stream of neutral liquor produced in the other side of the plant—this absorbing the acid gases and running out as an acid lye from the bottom of the washer. This acid liquor is then pumped over to the opposite side of the plant, and is utilized for absorbing ammonia as before explained. A definite volume of liquor is thus kept in circulation, and becomes gradually charged with salt until the saturation point is reached, when the salt is deposited at the bottom of the neutral lye tank as ammonium sulphite and sulphate, the reaction being :—$H_2O + SO_2 + 2\,NH_3 = (NH_4)_2SO_3$ (sulphite). The sulphite is then oxidized into sulphate, taking up another atom of oxygen from an air-blast. For this purpose the apparatus shown in Fig. 341 is used, the sulphite being heated by a steam jacket and sublimed thereby.

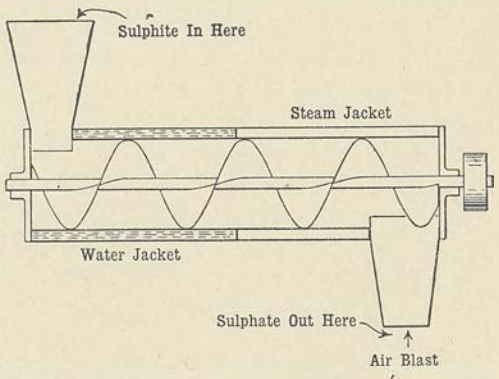


FIG. 341.—BURKHEISER'S OXIDATION APPARATUS.

The cylinder in which the worm conveyer works is jacketed for the first half of its length with cold water, and for the second half with steam. The sulphite, on reaching the heated portion, is volatilized and driven back by a blast of air entering at the outlet end, this air converting the sulphite into sulphate, which is then deposited. The principle of the apparatus is dependent upon the fact that ammonium sulphite is sublimed at temperatures below 100° C., whereas the sulphate is not. The salt thrown down in the liquor tank consists of about 67 per cent. sulphite, and the remainder sulphate.

In a process of this kind there is some liability to accident owing to over-heating during the revivification of the oxide. This, however, is guarded against by arranging a system of water-cooling for the oxide, also by ensuring the presence of water vapour in the blast. In practice, there is little fear of danger unless a temperature of 300° C. is exceeded; and in the Burkheiser plant the temperature rarely rises above 140° C. Moreover, as a safeguard, an electric alarm thermometer is fitted to the purifier undergoing regeneration.

In a process of this kind there is, of course, an excess of sulphur beyond that necessary to neutralize the whole of the ammonia. This surplus may be recovered for sale in various ways. The salt obtained by the process is of a somewhat inferior quality, owing to the incomplete nature of the oxidizing process, and, consequently, the presence of ammonium sulphite.

The war, unfortunately, rather interfered with the progress of processes of this kind; and, although the Burkheiser process is said to be in constant operation at the Tegel gasworks, it is to be noted that when tried at a gasworks in this country it proved a failure and was discontinued.

Parrish [1] has suggested that the original failure of the process was due mainly to two defects:—

(1) So far as the sulphur cycle is concerned, it was found that the introduction of heated air to the purifiers containing FeS, together with free sulphur along with iron oxide, led to the formation of soluble iron salts, such as $FeSO_4$. This fixation of the SO_2 was disastrous from two points of view. It represented the loss of acid gases and the inability to regenerate completely oxide of iron, except by special means which had not apparently been originally contemplated.

(2) The presence of H_2S in the gases from which ammonia was to be removed by the sulphurous acid solution resulted in the reduction of the H_2S and the precipitation of sulphur in the bath—thus impairing the quality of the ammonium salts produced.

Careful reflection on the various reactions involved in the Burkheiser process certainly leads to the conviction that, by suitable modification, the process could be operated successfully.

One of the directions in which modification will need to proceed is in the removal of the H_2S from the crude gas before absorption in the acid bath is effected. Certain portions of the Burkheiser process can be applied to ordinary gasworks practice. It is conceivable that if ammoniacal liquor were first desulphurized—the sulphur-freed ammoniacal liquor being next distilled to release the ammonia—the latter gas could be absorbed in an acid solution prepared by the absorption of SO_2 in water, such SO_2 being produced by the combustion of spent oxide. In this way there would be no necessity for the expensive Glover and Gay Lussac towers and acid chambers of the sulphuric acid plant. By pursuing this method, saleable ammonium salts could conceivably be produced.

The Feld Process

The Feld plant extracts ammonia and sulphuretted hydrogen simultaneously, at the same time oxidizing an amount of sulphuretted hydrogen equivalent to the ammonia in the gas. Sulphate of ammonia is yielded, whilst the surplus sulphur is obtained in the solid form. Within the last year or so, the plant has undergone some modification; the original process is, however, of considerable interest, and is described in outline below. For the sake of simplicity, the various stages in the working are sub-divided under different headings, so that there should be no difficulty in following out the scheme with the aid of the accompanying diagram (Fig. 342).

Process 1.—Gas containing NH_3 and H_2S is washed with a weak solution of ferrous sulphate. Sulphate of ammonia is formed, and sulphide of iron precipitated—

(*a*) $FeSO_4 + 2\,NH_4,OH = (NH_4)_2SO_4 + Fe(OH)_2$.

(*b*) $Fe(OH_2) + H_2S = FeS + 2\,H_2O$.

[1] *Proc. Southern Assocn. Gas Eng.*, Nov., 1913.

Process 2.—The iron sulphide liquor is treated with SO_2, which is obtained by the burning of sulphur. Free sulphur is precipitated, and soluble ferrous thiosulphate, thionate, and sulphate are formed—$2\,FeS + 3\,SO_2 = 2\,FeS_2O_3 + S$.

Process 3.—This liquor (FeS_2O_3) is again used for treating the gas—$2\,FeS_2O_3 + 4\,NH_3 + 2\,H_2S = 2\,FeS + 2\,(NH_4)_2S_2O_3$. The reaction this time is somewhat different. The ammonia and H_2S in the gas are again absorbed, whilst iron sulphide, together with some free sulphur, is precipitated—sulphate, thiosulphate, and thionate of ammonia being formed. The liquor is alternately treated with crude gas and SO_2 until it contains from 30 to 45 per cent. of ammonia salts.

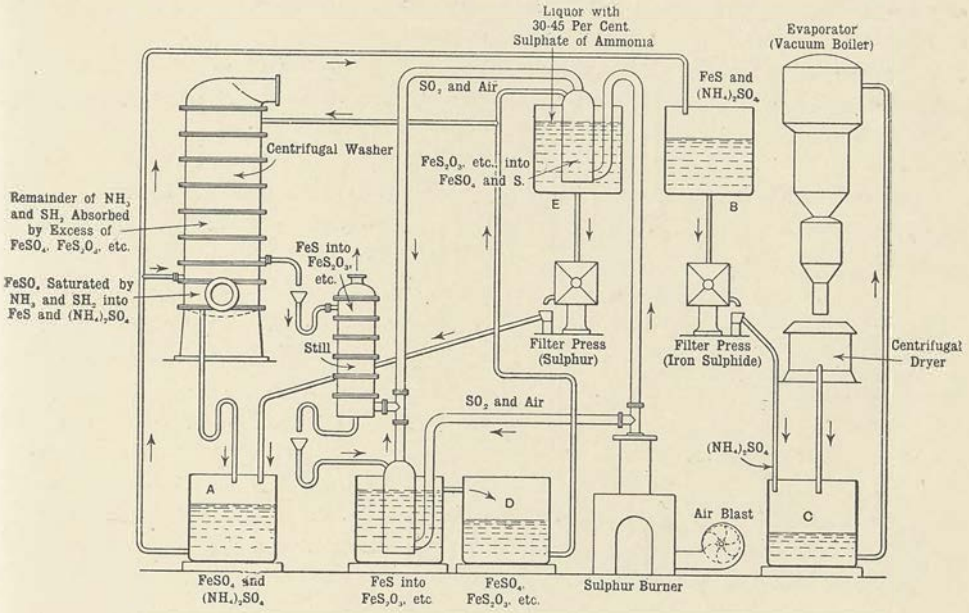


FIG. 342.—LINE DIAGRAM SHOWING PRINCIPLE OF FELD'S ORIGINAL PROCESS.

Process 4.—The liquor undergoes oxidation, by which process the thiosulphate and thionates are transformed into sulphate. To this end the hot liquor is treated with SO_2, and an excess of air. The ferrous sulphide is dissolved, and the ammonia all converted into sulphate, whilst free sulphur is precipitated—$2\,FeS + 2\,(NH_4)_2S_2O_3 + 3\,SO_2 + 2\,O_2 = 2\,(NH_4)_2SO_4 + 2\,FeSO_4 + 5\,S$.

Process 5.—The free sulphur is separated from the liquor by filtration.

Process 6.—The liquor coming from the filter-press, and containing the sulphate of ammonia, also sulphate of iron, is treated with the crude gas (containing H_2S and NH_3), by the action of which the ferrous sulphate is decomposed, forming again sulphate of ammonia and iron sulphide (*see* under Process 1). The iron is separated by filtration, and the liquor containing the sulphate is evaporated, leaving the salt behind—this being dried in a centrifugal machine.

Fig. 342 shows the plant complete. The washing liquor is pumped to the Feld centrifugal washer, and, on leaving, passes through the "still," being collected in the lower tank. Here (also in the still) the liquor meets with SO_2, which brings about the regeneration of the FeS into sulphates. As soon as the liquor contains 30 to 45 per cent. of ammonia sulphate, it is pumped to the upper tank, while the lower one is filled with fresh liquor. The salts are converted wholly into sulphates in this upper tank. The sulphur is then separated out in the filter press, and the liquor coming away from this is continuously pumped round and round into the lowest bay of the washer. The object of this is to precipitate completely the iron from the sulphate solution. The iron sulphide mud is then filtered out in the second press, and the liquor evaporated and dried.

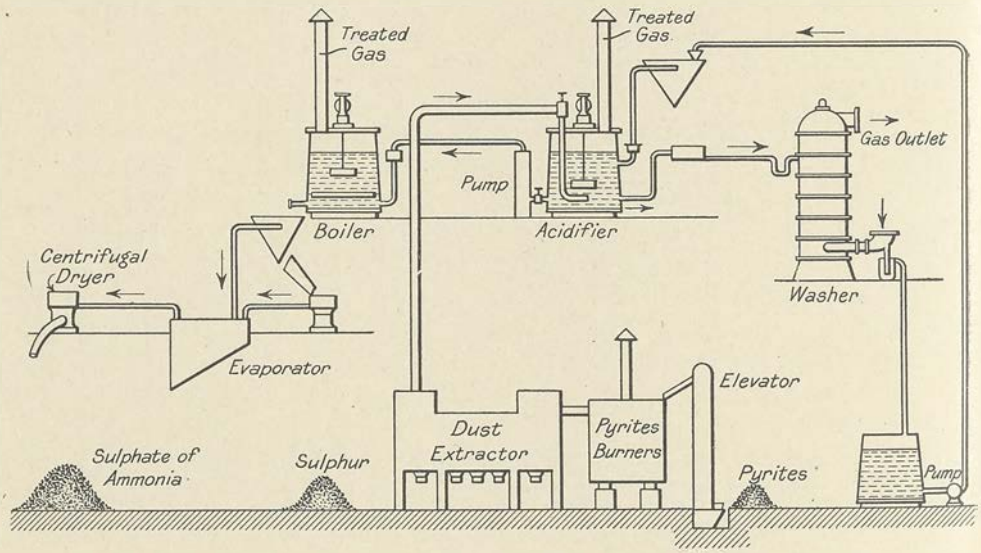


Fig. 343.— Diagram showing Operation of Feld Tetrathionate Process.

Owing to the difficulties attending the considerable dissociation tension of sulphites, Feld devised a process based on the oxidation of thionates, in its more recent form without the use of metal salts. In spite of the way in which the process has been scientifically perfected, in practice it has proved too cumbersome.

In this process the gas is washed with a solution containing ammonium tetrathionate which is prepared by the action of sulphur dioxide on ammonium sulphide (gas liquor).

The apparatus (Fig. 343) consists mainly of a washer, an acidifier, a boiling pan, an evaporator, and a sulphur (or pyrites) furnace. The gas, freed from tar and at a temperature of about 60° C., is admitted into the bottom of the washer, where it is washed by the descending stream of ammonium tetrathionate liquor. This takes up the ammonia and sulphuretted hydrogen from the gas, and is itself transformed

into thiosulphate, sulphur separating out. The effluent liquor is run into a tank, from which it is pumped into the acidifier, traversing, on its way, a collector in which a portion of the sulphur is deposited. In the acidifier the thiosulphate liquor is treated with sulphur dioxide, prepared by roasting sulphur or pyrites in the sulphur furnace, and which has been freed from dust in an electrical purifier, and cooled. The sulphur dioxide re-converts the thiosulphate into polythionate, which is returned to the washer. This cycle of operations results in the progressive enrichment of the polythionate ; and when the concentration has reached a certain stage, a portion of the liquor is pumped from the acidifier into the boiler, where the polythionate is decomposed by heat into sulphate, sulphur, and sulphur dioxide. In order to make certain that the liquor to be decomposed no longer contains any thiosulphate, sulphur dioxide may also be introduced into the boiler. The sulphate of ammonia liquor flows through a collector into the evaporator, where it is worked up into solid salt, this being discharged by an ejector into the whizzer. The sulphur retained in the collector is also put through a whizzer, the sulphate liquor thus recovered being run into the evaporator.

The various stages of the process, and the reactions which occur, are as follows :—

The crude coal gas is washed with a solution of ammonium tetrathionate, the reactions occurring being on the following lines :—

(*a*) $6\,NH_4OH + 4\,(NH_4)_2S_4O_6 = 5\,(NH_4)_2S_2O_3 + 2\,(NH_4)_2S_3O_6 + 3\,H_2O.$

(*b*) $3\,H_2S + (NH_4)_2S_4O_6 = (NH_4)_2S_2O_3 + 5\,S + 3\,H_2O.$

The tetrathionate lye which has been employed for washing is then treated with a current of sulphur dioxide. In this way the ammonium thiosulphate and trithionate formed are reconverted into tetrathionate—

(*c*) $2\,(NH_4)_2S_2O_3 + (NH_4)_2S_3O_6 + 2\,S + 3\,SO_2 = 3\,(NH_4)_2S_4O_6.$

When the tetrathionate lye becomes sufficiently concentrated it is heated, decomposition taking place with the formation of ammonium sulphate, free sulphur, and sulphur dioxide—

(*d*) $(NH_4)_2S_4O_6 = (NH_4)_2SO_4 + S + SO_2.$

The sulphur dioxide and a portion of the free sulphur are then used again in the earlier stages of the process. With German gas coal it has been found that sulphur exists in excess of that required for the formation of the sulphate of ammonia ; thus some considerable quantity of free sulphur also results as a by-product.

In the first instance the tetrathionate solution is prepared by the action of sulphur dioxide on gas liquor as follows :—

$$2\,(NH_4)_2S + 6\,SO_2 = 2\,(NH_4)_2S_4O_6.$$

Cobb's Process

One of the most promising processes for the direct recovery of ammonia is that introduced recently by J. W. Cobb. From the point of view of simplicity, the method has many advantages in comparison with its competitors. In this

case the gas is washed with a solution of zinc sulphate which, after performing its function, is regenerated for further use. Put briefly, the various stages of the process are as follows :—

(1) Crude gas is treated in a centrifugal washer with a solution of zinc sulphate—

$$ZnSO_4 + H_2S + 2\,NH_3 = (NH_4)_2SO_4 + ZnS.$$

(2) The sulphate of ammonia is filtered out and recovered by evaporation.

(3) The precipitated zinc sulphide is roasted, yielding zinc oxide and sulphur dioxide—

$$2\,ZnS + 3\,O_2 = 2\,ZnO + 2\,SO_2.$$

(4) The roaster gases containing sulphur dioxide, are then blown through water containing in suspension the zinc oxide from a previous roasting, zinc sulphate resulting from the reaction—

$$2\,SO_2 + O_2 + 2\,H_2O + 2\,ZnO = 2\,ZnSO_4 + 2\,H_2O.$$

One of the merits of the process is that tarry matter in the crude gas does not interfere, as it is destroyed during the roasting process.

Hemingway[1] has introduced a process for the elimination of hydrogen sulphide from gases by treating them in purifiers with iron carbonate, and he extends the process to the treatment of ammoniacal liquors. The process is carried out in such a manner that the ferrous carbonate is recovered for further use. When applied to the desulphurization of coal gas, the gas is passed through scrubbers in the usual manner, and ammoniacal liquor derived therefrom is conveyed to a tank and there treated with ferrous carbonate. The liquor having thus become "sweetened," and the iron salt having subsided in the form of sulphide, the sweet liquor (ammoniacal liquor deprived of its hydrogen sulphide) is run off to a still, or returned to the scrubbers; while the iron sulphide precipitate is converted into ferrous sulphate for use in the next stage of the process. The sweet liquor is conveyed to a second tank, and is there treated with the ferrous sulphate before referred to. The ferrous salt, absorbing carbonic acid, subsides as ferrous carbonate; and the sweet liquor (now containing a little extra ammonium sulphate) is run off to a still, while the ferrous carbonate precipitate is withdrawn for re-use in the first stage of the process. The ammoniacal liquor, draining from the precipitate, is led to the ammonia still as before. By the third stage of the process, ferrous carbonate is reproduced for use in the first stage, and the cycle of operations may be repeated without the introduction of further supplies of the ferrous salt, except so far as may be necessary for making good trifling losses in working.

Semi-Direct Processes

These processes, although, scientifically, not so perfect as those discussed above, in view of the necessity for introducing sulphuric acid, possess the advantage that they are comparatively simple in operation so long as certain necessary pre-

[1] Eng. Pat. 117387.

cautions are observed. The semi-direct plant to-day is mainly employed on coke-oven works, although a small number of gasworks now have the process in operation. Briefly stated, the advantages of the semi-direct method as compared with the ordinary separate distillation plant for recovering sulphate of ammonia are as follows :—

(*a*) No washers and scrubbers are required.
(*b*) Liquor storage wells may in many cases be dispensed with.
(*c*) Small steam consumption.
(*d*) Considerable saving in ground space and working costs.

On the other hand, experience shows that unless the plant is carefully operated and supervised the quantity of ammonia recovered may fall measurably short of the normal amount obtained under more general methods, while serious derangement [1] of the dry purifiers may result.

The best method for operating plants of this kind has been the subject of a special inquiry undertaken by W. S. Curphey,[2] who says that exact control of ammonia in the direct process is always a matter of difficulty. The ammonia content in the crude gas entering the bubbler is governed by the volume and temperature of the virgin liquor that separates in the hydraulic main and condensers, and when a long main is in use between the bubbler and purifier, condensation accompanied by absorption of ammonia takes place to a very notable extent.

Control by test, therefore, is the only satisfactory procedure.

Curphey states that the most serious sources of loss undoubtedly occur at the still, and at the bubbler, when crude gas is by-passed in quantity. Loss at the still is mainly due to deficiency of lime. The following tests are representative of the results obtained at one works :—

	Ammonia, per 100 parts of Spent Liquor.			Calculated loss of sulphate, lbs. per ton of coal.
	Free.	Fixed.	Total.	
1. (*a*) Lime feed defective	·007	·653	·660	5
(*b*) Lime feed defective	·009	·440	·449	3½
(*c*) Better feed ; reduced flow of liquor.	·030	·005	·035	·3
2. Lime feed repaired	·0025	·0003	·0028	·02

The loss due to by-passing of gas is more difficult to control, and in the winter months, with wet fresh oxide in use, must be serious. Thirteen grains ammonia per 100 cubic feet gas correspond to about 1 lb. sulphate per ton of coal carbonized. In the summer months 2 to 3 grains ammonia appear to be ample. In the winter months, hitherto 15 to 20 grains ammonia have been required.

The loss at the still is clearly preventable, if suitable qualitative tests are regularly applied, as they should be. The loss at the purifiers is in part preventable,

[1] *See* page 578.

[2] *Alkali Works Report*, 1916.

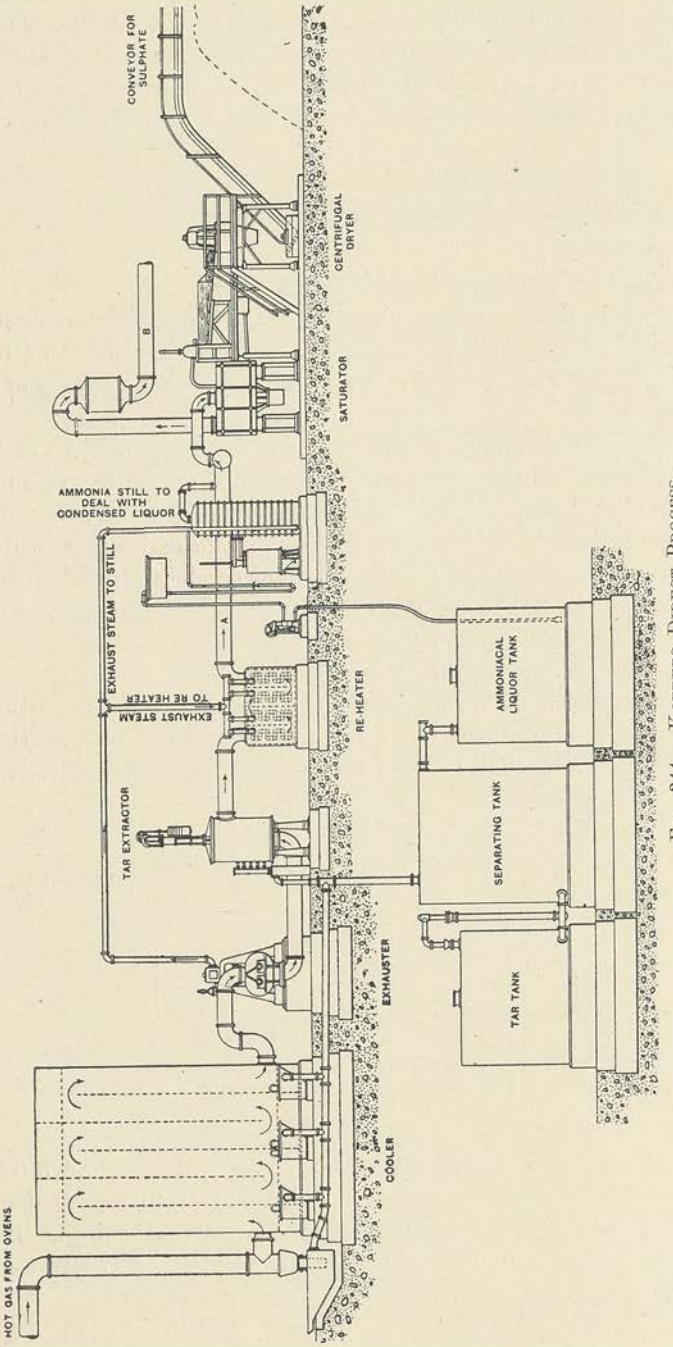


Fig. 344.—Koppers Direct Process.

and would be greatly reduced were it possible to maintain the oxide of iron in a fit condition.

Other points requiring attention in order to make the semi-direct process a success are the entire elimination of all tarry matter from the crude gas, and the maintenance of the acid bath at such a temperature as to permit of the formation of the salt.

In general, there are two alternative processes. In one the tar is separated at a temperature just above dew-point, the gases being conducted directly into the saturator, and the liquor in the saturator being maintained at a temperature so as to permit of sulphate manufacture by the application of external heat. A more successful method, however, is that in which the gases are cooled to atmospheric temperature for the complete extraction of tar, after which they are re-heated before passing into the saturator.

The Koppers system of semi-direct recovery is shown diagrammatically in Fig. 344. The hot gas coming direct from the ovens enters the coolers or condensers, where it is reduced in temperature to about 25° C. The gas then passes to the exhauster and is taken through a tar extractor of some efficient type. After the tar has been removed, the gas is led through the re-heater, where, by means of exhaust steam, its temperature is raised to about 55° C. The heated gas then passes to the saturator, where the ammonia is recovered from it by absorption in sulphuric acid. The sulphate as it is formed falls to the bottom of the vessel and is continuously removed by means of a steam or compressed air ejector. Finally, the sulphate is delivered to a centrifugal drying machine, in which the mother liquor is removed from it. The condensate thrown down in the coolers, also the overflow products from the tar extractor, are run to the separating tank, which is so arranged that tar and liquor can separate, owing to the difference in their specific gravities. The two products then flow into their respective storage tanks. The virgin liquor is finally pumped up into the ammonia still, where it is heated with steam and lime in the usual way. The ammonia, sulphuretted hydrogen, and carbon dioxide, resulting from the distillation of the liquor, are then admitted to the crude gas main at a point just preceding the saturator.

Fig. 345 illustrates a Wilton plant, from the outlet of the hydraulic main to the inlet of the dry purifiers, for the condensation of coal gas and the removal of tar and tar-fog, as well as for the recovery of sulphate of ammonia.

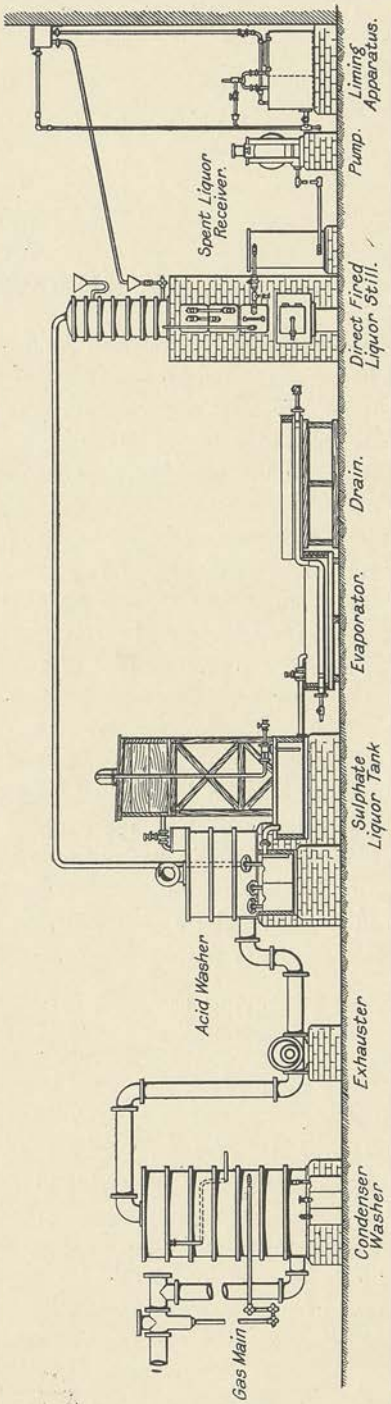


FIG. 345.—WILTON PLANT FOR SEMI-DIRECT RECOVERY.

CHAPTER XVII

THE RECOVERY OF CYANOGEN

THE presence of hydrocyanic acid amongst the products of the distillation of coal has been recognized for a number of years, and many and varied attempts have been made to effect its recovery on profitable lines. The amount of hydrocyanic acid occurring under normal conditions is, however, comparatively small, so that in many cases the working expenses of the process adopted have rendered recovery unprofitable, except in the case of the largest concerns. From a commercial point of view, cyanogen derives its value from the fact that the principal method of treating rocks and quartz for the recovery of gold is by the cyanide process, with or without amalgamation on copper plates. The *rationale* of the process is the crushing of the gold-bearing rock in a suitable machine, the admixture of the fines with water, so as to form a sludge, and, finally, the passing of this sludge over copper plates amalgamated with mercury. The fine gold then commixes with the mercury, whilst the residue of crushed ore flows away. The waste is known as " tailings." Periodically, that is after every three or four weeks, the copper plates are scraped, and the amalgam obtained is distilled in a retort, whence the mercury is evolved and the gold left behind. The mercury treatment is still employed in conjunction with cyanide, although in many cases the ore is treated direct and the amalgamation process is dispensed with. To-day, the greater portion of the gold output of the world is obtained by means of the cyanide method. Briefly, the process consists of two essential parts :—

(*a*) Dissolving the gold from the ore in a cyanide solution.
(*b*) Precipitation of the gold from the solution.

The mineral as won from the mines is primarily subjected to several sortings, and is then treated in large vats with a solution of sodium, or occasionally potassium, cyanide. An extremely weak solution is usually employed, owing to the fact that the greater the percentage strength of the cyanide the more easily are metals other than gold dissolved. The period of treatment generally varies from twelve to twenty-four hours, and in cases where the mineral may require extended contact the cyanide solution should be renewed every three or four days. Precipitation of the gold from the cyanide solution is usually carried out by means of zinc, the latter displacing the gold from the cyanide as follows :—

$$2\ NaAu(CN)_2 + Zn = Na_2Zn(CN)_4 + 2\ Au.$$

The process, however, is not so simple as might be supposed from the above brief outline, and many modifications have been introduced from time to time with the object of rendering the work more economical and of increasing the efficiency of recovery. In addition to being employed for the treatment of gold-bearing ores, cyanides find a limited use in the manufacture of dyes and paints, and in electro-plating.

CYANOGEN IN COAL GAS

The cyanogen in coal gas is almost wholly in the form of hydrocyanic acid, although some authorities say that it is also present as free cyanogen and ammonium cyanide. Hydrocyanic acid is produced by the combination of hydrogen, carbon, and nitrogen at high temperatures in the retort, and makes its appearance among the products at temperatures considerably higher than those at which primary ammonia is at a maximum (540° C.). It is probable that a portion of the ammonia itself is split up into its elements, hydrogen and nitrogen, these re-combining, with the addition of the carbon atom, to form hydrocyanic acid (HCN). As regards the original nitrogen in coal, it has been shown that less than 2 per cent. of this goes to form cyanogen, the quantity of the latter considerably increasing when high and extreme temperatures of distillation are employed (*see* page 386). The most favourable temperature in the retorts for the formation of cyanogen is said to be 1,200° C., and the maximum amount recoverable from a ton of English coal is about 1½ lb. of hydrocyanic acid, or about 10,000 grains.

Butterfield[1] states that German gasworks alone have yielded in recent years approximately 10,000 tons of ferrocyanide per annum, while the output of the British gasworks has not exceeded 5,000 tons. Were cyanogen recovery to be extended to all gasworks in this country, the annual output would amount to 24,000 tons of ferrocyanide or the equivalent in other cyanide products. Apart from any profit attached to the process (and there is no margin for extravagance in working expenses), it may be said that the removal of the hydrocyanic acid from the gas is followed by many indirect advantages not actually to be measured in terms of money, for the product is responsible for derangements in dry purification, and for the corrosion of steelwork, more particularly gasholder sheeting.

Cyanogen compounds may be found :—

(*a*) In the gas, chiefly as hydrocyanic acid.

(*b*) In the ammoniacal liquor, mainly as ammonium cyanide, ferrocyanides, and sulphocyanide.

(*c*) In spent oxide, chiefly as "Prussian blue" (ferric-ferrocyanide).

(*d*) In spent lime, as calcium sulphocyanide, and to some extent as calcium ferrocyanide.

(*e*) In spent liquor from the sulphate plant, as ferrocyanide compounds.

The chief processes nowadays, in this country at any rate, are those by means of which the cyanogen is extracted from the gas and recovered as either (*a*) ammonium

[1] *Gas World*, 1918, 62, 463.

sulphocyanide (NH_4SCN) or sodium ferrocyanide (prussiate of soda, $Na_4FeC_6N_6$). Ultimately the sulphocyanide or prussiate is converted into sodium cyanide for gold working processes; and, so far as this operation is concerned, recovery as prussiate is to be preferred.

Per se, the extraction of cyanogen as a distinct by-product will, in normal times, only prove profitable in the case of the larger gasworks. Indirectly, however, the removal of the compound from the gas presents many advantages, and if it could be generally extracted and turned to profitable account the task of the gas engineer would certainly be made easier. Apart from the fouling of gasholder water, and the corrosion of gasholder plates and other apparatus, the removal of the cyanogen is strongly to be urged, owing to its effect on the efficiency of the present-day purifying material. It is beyond all question that oxide of iron, whether natural or artificial, will remain in an active condition for a much greater length of time when the cyanogen is absent. Both Bueb and Guillet have shown that in some cases the efficiency of the "dry" purifiers may be increased by so much as 50 per cent. if the compound is extracted. Perthuis has pointed out that in certain circumstances cyanogen is responsible for a reaction in the purifiers which may cause the material in them actually to increase the sulphur impurities in the gas.

On works where no recovery plant for cyanogen is in use the bulk of the substance will be removed by the oxide or lime purifiers, although some slight reduction will take place during the passage of the gas through the wet purification plant. No definite statement can be made as to the amount of cyanogen which will pass through the oxide boxes. In many works the gas at the outlet of the purifiers shows only a trace, while in other cases as much as 8 to 10 grains of hydrocyanic acid per 100 cubic feet of gas will be found. The cyanogen, by combining with the iron salts, may be absorbed in the purifiers as ferrocyanides. In this way a portion of the active material is rendered inert so far as the absorption of sulphuretted hydrogen is concerned. Very much depends, however, upon whether the prevailing conditions are acid or alkaline. If formed, Prussian blue, by coating the granules of the oxide, exerts an effect far greater in proportion than the actual extent in which it is present. Spent oxide with a content of 25 per cent. of sulphur has been found to contain as much as 12½ per cent. of Prussian blue, although in normal cases the amount of the latter present will not exceed 4½ per cent. As regards the formation of Prussian blue in the purifying boxes the reactions taking place are by no means simple; but, when conditions permit, there seems little doubt that the ferric-ferrocyanide is the result of oxidation of a ferrous cyanide which is formed in the first instance. Thus the hydrocyanic acid reacts with the oxide of iron:—

$Fe_2O_3 + 4\ HCN = 2\ Fe(CN)_2$ (ferrous cyanide) $+ 2\ H_2O + O$, and by oxidation gives:—$18\ Fe(CN)_2 + 3\ O_2 = 2\ Fe_2O_3 + 2\ Fe_4, 3\ Fe(CN)_6$ (Prussian blue).

Many different opinions have been expressed as to the probable reactions accounting for the Prussian blue, and although the above seems reliable, it is open to question. Again, there is a likelihood that the hydrocyanic acid does not react with the active

material (Fe_2O_3), but with the iron sulphide, and the experiments of Leybold would appear to corroborate this, the mode of reaction suggested being as follows :—

$$FeS + 2\,HCN = H_2S + Fe(CN)_2,$$

the ferrous cyanide being finally oxidized to ferric-ferrocyanide as previously shown. The chief point to notice is that moisture or the admission of steam to the boxes will aid the formation of Prussian blue whilst free ammonia will prevent it. If, therefore, a small quantity of ammonia (about 1 grain per 100 cubic feet) is allowed to travel forward in the gas from the scrubber the formation of Prussian blue in any quantity will very seldom follow. The same effect, however, is not seen when an alkali such as lime is mixed in small proportion with the oxide in the purifiers, owing to the lime being quickly carbonated by the CO_2 coming forward with the gas.

W. S. Curphey[1] states that hydrocyanic acid is undoubtedly prejudicial to the efficient working of purifiers ; apart from any direct action it may have on sulphides of iron, liberating sulphuretted hydrogen, it reacts with oxide of iron in the presence of ammonia to form insoluble iron ferrocyanides and double ferrocyanides of iron and ammonium as well as ammonium sulphocyanide. If such reactions occur the oxide of iron is rendered inert, the reactive residue is coated over with insoluble bodies, and is rendered less porous. Moreover, the ammonia needed to neutralize the ferrous sulphate and to maintain the condition of mild alkalinity essential for efficient purification is fixed and prevented from performing its real function.

Curphey concludes that excess of moisture is the factor which favours the interaction of hydrocyanic acid and ammonia to form ferrocyanide and sulphocyanide. Thus, in the presence of moisture, ammonia and hydrocyanic acid are dissolved and brought into intimate contact with iron oxide and iron sulphide on the one hand, and with sulphuretted hydrogen and free sulphur on the other, and at a slightly raised temperature. Accordingly, Curphey suggests that the following reactions occur :—

(*a*) $2\,FeS + 6\,NH_4CN = (NH_4)_2Fe_2(CN)_6 + 2\,(NH_4)_2S.$

(*b*) (1) $(NH_4)_2S + 2\,S = (NH_4)_2S_3.$

(2) $(NH_4)_2S_3 + 2\,HCN = 2\,NH_4SCN + H_2S.$

THE RECOVERY OF CYANOGEN FROM THE GAS

As already stated, the cyanogen recovered as a by-product in the gasworks of this country is, without exception, removed from the gas alone. On the Continent the spent oxide is more frequently treated for this purpose ; but, in general, the class of coal employed gives higher yields of cyanogen than do English coals. Of the more important processes which have been adopted in this country the following

[1] *Alkali Works Report*, 1915, p. 23.

may be mentioned, although some have been discarded in favour of more modern methods :—

(*a*) The Foulis process (prussiate of soda).
(*b*) Wilton's process (prussiate of soda).
(*c*) The British Cyanides Company's process (sulphocyanide).
(*d*) The Davis-Neill process (prussiate of soda).
(*e*) The polysulphide process (sulphocyanide).

Other processes of interest are those of Ciselet and Deguide, and of the South Metropolitan Gas Company in collaboration with the Thann Chemical Manufacturing Company, of Alsace, and that of the Bartlett-Hayward Company of America.

The Foulis Process

The Foulis process was patented in 1892 and first put into operation at the Glasgow gasworks. Chloride of iron is made by dissolving scrap iron in hydrochloric acid in large vats, preferably made of slate. The iron chloride is then mixed with the requisite quantity of sodium carbonate so that iron carbonate results—

$$FeCl_2 + Na_2CO_3 = FeCO_3 + 2\,NaCl.$$

The iron carbonate is precipitated and the sodium chloride is run to waste. The iron carbonate is then removed to a further tank, where it is mixed with more sodium carbonate in the necessary theoretical quantities. The tank is provided with a stirrer and has an outlet leading into the first bay of a suitable washer-scrubber. The mixture is run direct into the washer and, combining with the hydrocyanic acid in the gas, is converted into sodium ferrocyanide, which is run away from the final bay as quickly as it is produced—

$$FeCO_3 + 2\,Na_2CO_3 + 6\,HCN = Na_4Fe(CN)_6 \text{ (sodium ferrocyanide)} + 3\,CO_2 + 3\,H_2O.$$

The crude ferrocyanide is evaporated nearly to dryness in pans, and when cool—and, consequently, solid—it is wheeled to the stores. In this condition it contains about 75 per cent. of sodium ferrocyanide. Oxidation of the $FeCO_3$ can be prevented by mixing in one bay of the washer-scrubber and by adding the whole of the sodium carbonate at one time.

Wilton's Process

In Wilton's process cyanogen is arrested in the process of scrubbing by adding to the rotary washer-scrubber an iron salt. It is more or less essential that the liquor in the washer-scrubber should be strong, *i.e.* about 16 oz., otherwise the whole of the hydrocyanic acid will not be arrested. Ammonium ferrocyanide is formed as follows :—

$$FeSO_4 + 6\,HCN + 6\,NH_4OH = (NH_4)_4Fe(CN)_6 + (NH_4)_2SO_4 + 6\,H_2O,$$

and is afterwards converted into Prussian blue by the addition of a further quantity of iron—

$$3\,(NH_4)_4Fe(CN)_6 + 2\,Fe_2(SO_4)_3 = Fe_4{,}3\,Fe(CN)_6 + 6\,(NH_4)_2SO_4.$$

British Cyanides Company's Process

The process of the British Cyanides Company, of Oldbury, recovers the hydrocyanic acid in the form of a sulphocyanide. The method consists essentially of the preparation of a solution containing ammonium polysulphide by the addition of coarsely powdered sulphur to ordinary ammoniacal liquor. A rotary washer-scrubber is employed for bringing gas and liquor in thorough contact, and the top of each bay is provided with a cup-shaped receiver having a closely fitting lid. These cups are periodically filled with the powdered sulphur, and the ammonium sulphide in the liquor combines with the free sulphur added to give ammonium polysulphides, $(NH_4)_2S_2$ to $(NH_4)_2S_5$. The process is dependent upon the fact that whereas hydrocyanic acid will combine with ammonium polysulphide, it will not react with ammonium sulphide. Ammonium sulphocyanide is formed in the washer, the liquor flowing out with a strength varying from 15° to 20° Twaddel. With the disulphide the reaction occurring is as follows :—

$$(NH_4)_2S_2 + HCN = NH_4SCN + NH_4HS.$$

Whilst the plant is in operation it is usual to test the liquor in the various bays of the washer-scrubber from time to time in order to ensure that it consists of ammonium polysulphide and not the sulphide. This may be done by adding a small quantity of acid to the liquor, when a decided precipitate of sulphur will be given if the polysulphide is present, whilst the sulphide will give practically no precipitate at all. In this system the hydrocyanic acid is extracted before the ammonia has been removed from the gas, as in this way the proportion of ammonium sulphide is increased and the efficiency of extraction rendered higher. To this end the plant is usually placed immediately after the exhausters, with some efficient form of tar extractor coupled up to its inlet.

It is found that by the British Cyanides process practically the whole of the hydrocyanic acid is removed from the gas, and the liquor may be readily worked up to a strength of from 3 to 4 lb. of ammonium sulphocyanide per gallon. As regards ammonia, the strength of the liquor may be as high as 40 oz., but 90 per cent. of the ammonia is present in the " fixed " state. In the case of some works the liquor is passed on to the sulphate plant and treated for the recovery of ammonia in the ordinary way, by the addition of lime. The lime then takes the place of the ammonia and gives rise to calcium sulphocyanide, which may be sold direct to the cyanide works, by whom it is converted into sodium cyanide. The conversion of ammonia into calcium sulphocyanide takes place as follows :—

$$2\,(NH_4SCN) + Ca(OH)_2 = Ca(SCN)_2 + 2\,NH_4OH.$$

It has been found that in addition to absorbing hydrocyanic acid some reduction of the carbon disulphide in the gas may take place as the gas travels through the plant. But whilst in some cases so much as 20 to 25 grains of CS_2 per 100 cubic feet was absorbed, at other times a reduction of only 1 to 2 grains was shown. No reliance can be placed upon the apparatus for this purpose. Colman, however, in a series of experiments, found that in no case was the CS_2 increased during the

passage of the gas through the washer, and an average reduction of 10 grains resulted from tests extending over some period. The exact manner in which the CS_2 is absorbed is not perfectly clear, but it may unite with the ammonium sulphide to give ammonium thiocarbonate (*see* page 506) as follows :—

$$(NH_4)_2S + CS_2 = (NH_4)_2CS_3.$$

The carbon dioxide in the gas is prejudicial to the absorption of CS_2, for it reacts with thiocarbonate and drives the CS_2 out of combination. When the CO_2 content in the gas is low the efficiency of CS_2 absorption should, therefore, be increased. The ammonium thiocarbonate gradually becomes converted into ammonium sulphocyanide in the washer—

$$(NH_4)_2CS_3 = NH_4SCN + 2\ H_2S,$$

so that in this way the carbon disulphide removed is turned to useful account.

The Williams Polysulphide Process

The British Cyanides Company have largely given up the process described above and have substituted for it a more efficient and economical method, known

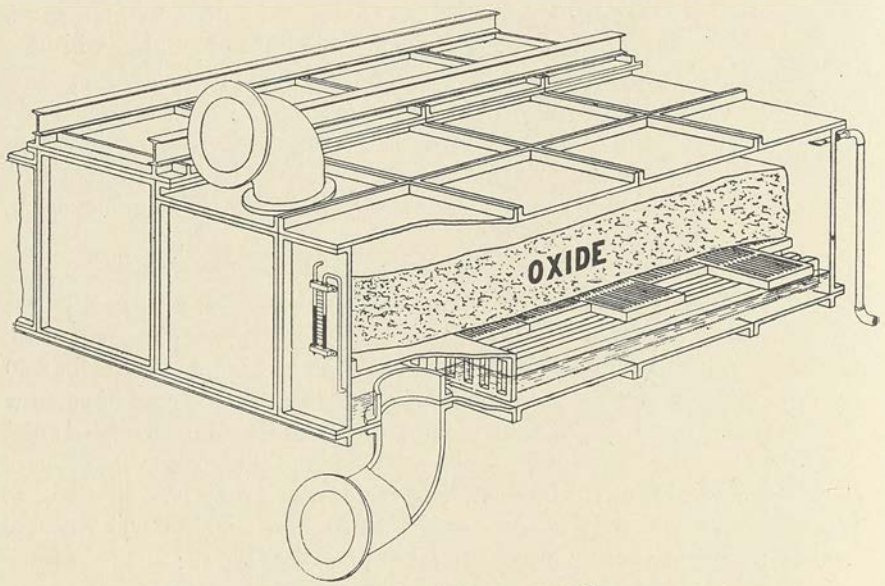


Fig. 346.—The Polysulphide Plant.

as the polysulphide process. In the newer process the hydrocyanic acid is recovered in the form of ammonium sulphocyanide, but the necessity of introducing a special supply of free sulphur is obviated by making use of the sulphur in spent oxide for the production of the polysulphides. A diagrammatic sketch of the apparatus is shown in Fig. 346. From this it will be seen that the vessel employed resembles

an ordinary dry purifier, access to which is obtained through portions of the top which are made removable on the lines of a Green's purifier. The inlet gas entering at the base of the vessel travels in the first instance through a tar extractor operated on the bubbling principle, the gas passing through the cyanide liquor which forms the seal. Above the tar extractor is arranged, on suitable brackets, a tier of ordinary wooden purifier grids which support a layer of spent oxide, evenly spread over the whole cross-section of the vessel, and about 24 inches in depth. The spent oxide used should preferably be of good quality, containing not less than 50 per cent. of sulphur. It is kept in a moist condition by a simple arrangement of sprays fitted around the four sides of the vessel at a point well above the oxide level. These sprays may be seen in Fig. 347, which shows a complete section of the box with the two inlets and outlets for the gas. A short period of spraying every day with water or a weak cyanide liquor is all that is necessary. In this way the polysulphide solution is formed within the interstices of the oxide bed, and is immediately converted into ammonium sulphocyanide by the incoming gas. The cyanide liquor, after trickling through the oxide mass, drops to the base of the vessel, from which it overflows to the storage tank by way of a seal. With regard to the actual formation of the sulphocyanide it would seem that a straightforward reaction on the following lines takes place—

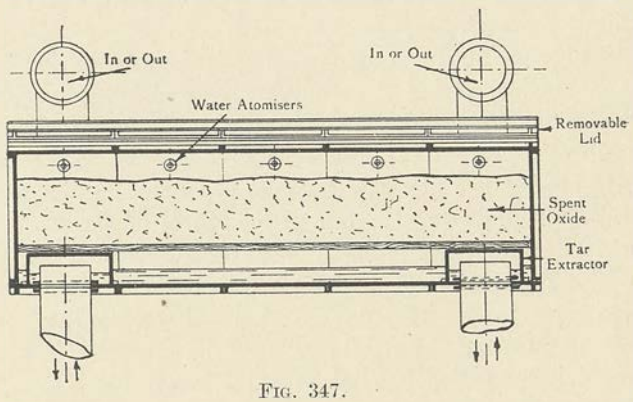


FIG. 347.

$$(NH_4)_2S_2 \text{ (ammonium polysulphide)} + HCN = NH_4SCN + NH_4.SH.$$

There is, however, some probability that a portion of the sulphocyanide is formed in two stages, with the intermediate production of thiocyanic acid. Thus ammonium polysulphide gives ammonium sulphide and thiocyanic acid as follows—

$$(1)\ (NH_4)_2S_2 + HCN = (NH_4)_2S + HSCN \text{ (thiocyanic acid)}.$$

The last-named then combines with more ammonia, in the form of the hydrate, to give the sulphocyanide—

$$(2)\ HSCN + NH_4OH = NH_4SCN + H_2O.$$

Probably the most surprising feature of the polysulphide process lies in the fact that although sulphur is inevitably required for the completion of the reaction, the spent oxide, after working for some period, shows no loss in sulphur content, and occasionally some increase is found. It would seem, then, that there is a simultaneous absorption of ammonia, sulphuretted hydrogen, and oxygen, and that—

as the oxide takes up sulphuretted hydrogen, which is eventually oxidized to sulphur—a continuous supply of free sulphur is automatically provided. The process would, in fact, be continuous but that the physical condition of the spent oxide necessitates periodical removal from the vessel and the substitution of a fresh layer. The period for which the material will remain in action varies under normal conditions between four and eight months. Six vessels now in operation at one gasworks have shown themselves capable of extracting practically the whole of the hydrocyanic acid over a period of six months without requiring remaking. The cyanide boxes are usually made either 20 or 25 feet square by 6 feet deep. The former size is capable of dealing effectively with 1½ million cubic feet of gas per diem, whilst the latter will take up to 2 million cubic feet. For larger volumes of gas the boxes are operated in parallel, although, when possible, it is preferable to arrange for two purifiers to be worked in series, so that the gas travels upwards through one and downwards through the second.

Figures obtained in actual practice show that one ton of spent oxide is capable of removing the whole of the cyanide from 350 tons of coal. One of the chief recommendations of the method is the manner in which the duties of washers, scrubbers, and dry purifiers are lightened. Of the ammonia contained in the crude gas entering the plant an average of from 30 to 35 per cent. is absorbed, the sulphuretted hydrogen shows a reduction of 35 per cent., whilst carbon dioxide falls off by from 5 to 12 per cent. No claim can be made for the absorption of carbon disulphide. It is essential to remember that there must be a small proportion of oxygen in the inlet gas. In general, this proportion varies between 0·2 to 0·6 per cent.; and—by oxidizing the iron sulphides in the purifier—gives rise to the free sulphur which is vital to the effective working of the process. The cyanide liquor flowing away from the plant varies in strength from 2½ to 3 lb. of ammonium sulphocyanide per gallon, and (after conversion to calcium sulphocyanide) it may be concentrated to any desired strength.

In some instances the ammonium sulphocyanide is treated direct with soda ash, in which case the product obtained is sodium sulphocyanide, having a strength of about 4 lb. of the latter compound per gallon of liquor.

The Davis-Neill Prussiate Process

The Davis-Neill process was first introduced at the Linacre works of the Liverpool Gas Company. The hydrocyanic acid is extracted from the gas by washing with a solution of ferrous carbonate and soda. The first step in the process is the preparation of the ferrous carbonate, which is made by mixing copperas (sulphate of iron) with ordinary soda ash (carbonate of soda)—

$$FeSO_4 + Na_2CO_3 = FeCO_3 + Na_2SO_4.$$

The mixture of ferrous carbonate and sodium sulphate is then passed through the first filter-press, in which the ferrous carbonate is retained as cakes. After thorough washing with clean water the cakes are removed to a second mixing tank or agitator, where they are intermixed with a further quantity of soda ash. The

resulting cream is then run into the first bay of any suitable washer-scrubber. On meeting with the gas the iron carbonate is converted into sulphide by the action of the sulphuretted hydrogen in the crude gas, whilst the hydrocyanic acid combines with the sulphide in the presence of sodium carbonate to form sodium ferrocyanide—

(*a*) $FeCO_3 + H_2S = FeS + CO_2 + H_2O$.

(*b*) $FeS + 2Na_2CO_3 + 6HCN = Na_4Fe(CN)_6 + H_2S + 2\,CO_2 + 2\,H_2O$.

In addition to sodium ferrocyanide certain quantities of other compounds, such as sodium and ammonium ferrous-ferrocyanide, are formed. For this reason the liquor undergoes further treatment, so that the whole of the cyanide may be recovered as a soluble prussiate. Leaving the washer-scrubber the liquor passes through a preliminary heater and then enters a still in which it meets with a strong solution of caustic soda. In this way the sodium ferrous-ferrocyanide is converted into sodium ferrocyanide as required—

$$Na_2Fe_2(CN)_6 + 2\ NaOH = Na_4Fe(CN)_6 + Fe(OH)_2.$$

The liquor obtained is then pumped through filter-press No. 2, in which any mud (chiefly consisting of iron sulphide) is retained. The cyanide solution, consisting in the main of prussiate of soda, but containing a small proportion of carbonate of soda, is then passed through an evaporator, and is finally recovered as yellow prussiate crystals. These crystals are afterwards washed with mother liquor from the finished crystallizing tanks, for the purpose of removing any impurities such as soda and sulphocyanides. The washed crystals are then treated in a re-dissolver, where the liquor they form is boiled for about 15 hours, before being run off to the finished crystallizing tanks. Slow cooling is desirable at this stage, otherwise small crystals will be formed.

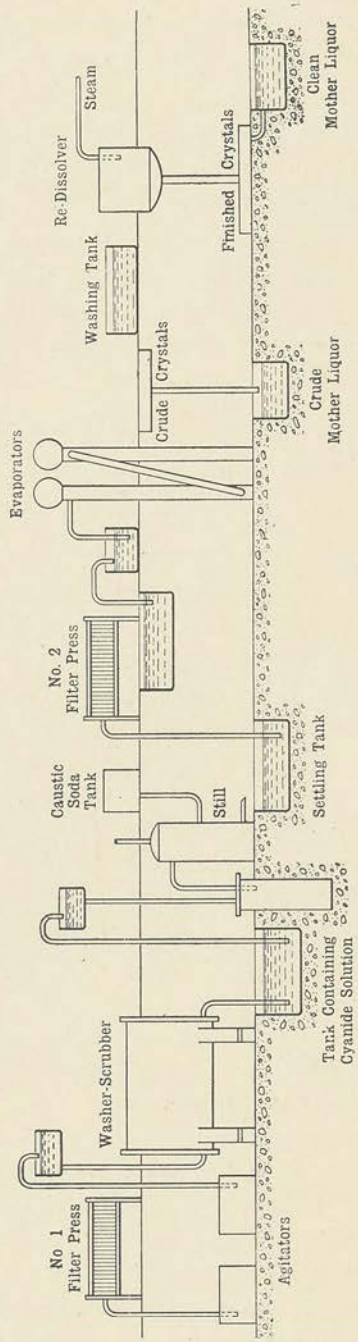


FIG. 348.—THE DAVIS-NEILL CYANIDE PROCESS.

Bueb's Process

The process of Dr. J. Bueb is one which has been used fairly widely, particularly on the Continent. The apparatus made use of is a washer-scrubber, in which a solution of ferrous sulphate dissolved in ammoniacal liquor is employed for washing the gas. The sulphate is converted into iron sulphide by the sulphuretted hydrogen in the crude gas—

$$FeSO_4 + H_2S + 2\ NH_3 = FeS + (NH_4)_2SO_4.$$

The sulphide, ammonia, and hydrocyanic acid then combine to form—

(*a*) Ammonium ferrocyanide—

$$FeS + 6\ NH_3 + 6\ HCN = (NH_4)_4Fe(CN)_6 + (NH_4)_2S.$$

(*b*) Cyanide of iron—

$$FeS + 2\ NH_3 + 2\ HCN = Fe(CN)_2 + (NH_4)_2S.$$

(*c*) Ammonium ferrous-ferrocyanide—

$$2\ FeS + 6\ NH_3 + 6\ HCN = (NH_4)_2Fe_2(CN)_6 + 2\ (NH_4)_2S.$$

By treating with lime the insoluble ferrous-ferrocyanide is converted into a soluble calcium ferrocyanide—

$$(NH_4)_2Fe_2(CN)_6 + 2\ Ca(OH)_2 = 2\ NH_4OH + Ca_2Fe(CN)_6 + Fe(OH)_2.$$

The free ammonia may then be distilled off by means of steam and recovered whilst the residual liquor is mixed with the required quantity of sodium carbonate or hydrate, when sodium ferrocyanide results—

$$Ca_2Fe(CN)_6 + 2\ Na_2CO_3 = Na_4Fe(CN)_6 + 2\ CaCO_3.$$

Ciselet and Deguide, in their process, first bring the gas into contact with ferric hydrate, which absorbs the sulphuretted hydrogen and hydrocyanic acid in the gas. The sulphur and cyanogen are precipitated in the form of iron sulphide and iron cyanide. The iron sulphide is then regenerated to the hydrate by means of an air-blast, the sulphur being precipitated in the free form. After regeneration, the ferric-hydrate solution is treated with sulphuric acid, which renders the iron soluble whilst the sulphur and cyanogen remain insoluble. The two last-named can then be separated with an alkaline solution, which dissolves the cyanogen compounds and forms alkaline ferrocyanides. Meanwhile, the free sulphur remains insoluble and can be filtered out.

South Metropolitan Gas Company's Process

The South Metropolitan Gas Company have introduced a process by means of which the cyanogen in the gas is recovered as hydrocyanic acid. The crude gas is washed with a solution of ferrous sulphate, the resulting liquor being treated with an ammonium salt and boiled with lime, so that a double cyanide—*i.e.* calcium-ammonium ferrocyanide, $Ca(NH_4)_2Fe(CN)_6$—is formed. The acid radicle, namely, the hydrocyanide acid portion of the salt, is unaffected by the action of sulphuric acid, whilst the remainder is converted into ferrous ammonium ferrocyanide and

calcium sulphate. In this way a means is provided for separating out the cyanogen as hydrocyanic acid and recovering it as such.

The Bartlett Hayward Process

This process, which has recently been introduced in America, is based on the well-known Bueb method. Explained briefly, the various stages are as follows :—

1. The crude gas, completely freed from tar, is treated in a centrifugal washer with sulphate of iron, the reactions being :—

(*a*) In upper bays of washer—

$$2\,FeSO_4, 7\,H_2O + 2\,H_2S + 4\,NH_3 = 2\,FeS + 2\,(NH_4)_2SO_4.$$

(*b*) In lower bays of washer—

$$2\,FeS + 2\,NH_3 + 6\,HCN = 2\,H_2S + (NH_4)_2Fe_2(CN)_6$$

ammonium ferrous-ferrocyanide.

$$(NH_4)_2Fe_2(CN)_6 + H_2S + 2\,NH_3 = FeS + (NH_4)_4Fe(CN)_6$$

ammonium ferrocyanide.

2. The liquor flowing from the washer is treated in a still when part of the ammonium ferrocyanide is reconverted into the ferrous-ferrocyanide :—

$$(NH_4)_4Fe(CN)_6 + FeS = (NH_4)_2S + (NH_4)_2Fe_2(CN)_6.$$

3. The ammonium sulphide is condensed and run into a precipitating tank, while the cyanide liquor—still containing some ferrocyanide—is run to a neutralizing tank where it is treated with a small quantity of sulphuric acid :—

$$(NH_4)_4Fe(CN)_6 + FeS + H_2SO_4 = (NH_4)_2Fe_2(CN)_6 + H_2S + (NH_4)_2\,SO_4.$$

Thus the end products are an insoluble double ferrocyanide and sulphate of ammonia.

4. The liquor is then filter-pressed, and the cyanide cake recovered thereby is finally washed for the removal of sulphate of ammonia. The sludge is again passed through a filter-press, while the sulphate liquor is evaporated to crystallization. The sulphate of ammonia passes from the evaporator to a centrifugal drier.

Modifications of Feld Process

Feld [1] has recently introduced a series of variations in the methods of absorbing cyanogen compounds from coal gas. In one method he fills the washer with a solution of a ferrous salt free from ferric, and adds so much milk of lime that each molecule of ferrous salt encounters three of calcium hydrate :—

$$FeSO_4 + 3\,CaO + 6\,HCN = CaSO_4 + Ca_2Fe(CN)_6 + 3\,H_2O.$$

The ferroso-calcic cyanide thus obtained remains in solution.

In another method he uses salts the oxides of which are displaceable by ammonia, of which process the following reaction is typical :—

$$MgCl_2 + 4\,NH_3 + 6\,HCN + Fe(OH)_2 = MgFe(CN)_6 + 4\,NH_4Cl + 2\,H_2O.$$

[1] *See also* Chap. XVI, p. 542.

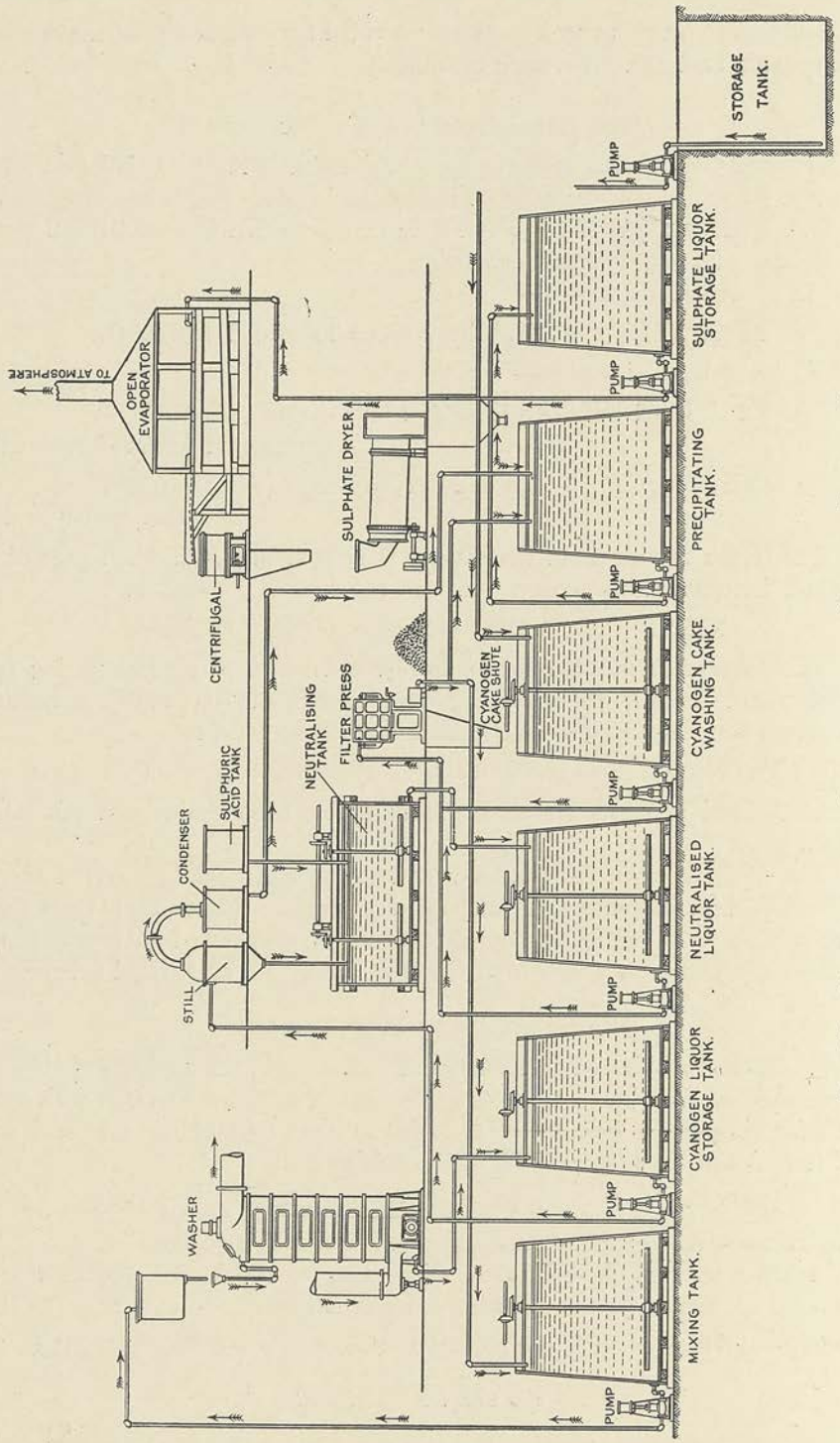


FIG. 349.—DIAGRAM SHOWING OPERATION OF THE BARTLETT HAYWARD PROCESS

In a still more recent method, he shortens the series of reactions by introducing the iron already in combination with the cyanogen. Thus :—

$$3\,Fe(CN)_2 + 6\,Ca(OH)_2 + 12\,HCN = 3\,Ca_2Fe(CN)_6 + 12\,H_2O.$$

In order to prepare pure cyanides, Feld first washes coal gas with hot magnesia solution to remove carbonic acid, then removes sulphuretted hydrogen by means of a solution of lead, iron, or manganese and then washes the gas with a cold solution of magnesia. This solution takes up all the hydrocyanic acid and gives up the whole of it when boiled. The hydrocyanic acid thus obtained is pure, and can be used for the direct preparation of cyanides. A recent process which has been commercially taken up in Germany by the firm of Otto, Dahlhausen, but which has not yet had time to prove its practical results, is that of von der Horst. He uses an alkali or, preferably, ammonia to which a suitable small quantity of a solution of copper is added. Complex compounds, such as $(NH_4)_3CuCy_4$, are then formed; and these, on being treated with dilute acids, give off pure hydrocyanic acid. A precipitate of sulphur and sulphocyanide of copper is also formed on boiling with dilute acid.

EXTRACTION FROM SPENT OXIDE

It has already been pointed out that when no special means is provided for the recovery of cyanogen from the gas a large proportion of it is arrested by the oxide of iron in the dry purifiers. Owing to the possibility of revivifying the iron sulphide, and, accordingly, the utilization of the mass over and over again, considerable quantities of cyanogen may have been collected by the time the material is finally spent. There are numerous processes for the recovery of cyanogen from oxide, but, in general, they may be classified into two distinct groups, namely—

(*a*) Those in which the free sulphur is first extracted by means of some solvent such as carbon disulphide.

(*b*) Those in which the spent material is straightway treated for the recovery of the cyanogen.

The processes in the latter group are those chiefly in use, and consist, in the main, of the lixiviation of the material for the removal of the soluble salts, such as ammonia and the sulphocyanides. The insoluble cyanide salts then undergo treatment to convert them into soluble compounds, and finally the whole of the cyanogen is recovered as potassium ferrocyanide.

Lixiviation of the material is carried out in tanks in which, by any suitable arrangement, the oxide is thoroughly washed with water. The liquor thus obtained is treated in the ordinary manner with lime for the recovery of ammonia, a certain amount of calcium sulphocyanide being formed by the action of the lime. The next stage is the recovery of the insoluble ferrocyanides by treating them with lime or other alkali. This process is now frequently carried out in a mechanical stirring apparatus. The material is led, together with the dilute liquid obtained in the first stage of the process, into a boiler, and the mass is heated with steam and thoroughly intermixed by means of the stirring apparatus. The sludge obtained is then caused to flow to a filter-press in which the cyanide solution is separated.

The cakes from the press are afterwards thoroughly pulverized and sifted, mixed with lime, and finally treated again in a stirring tank. The resultant liquor contains chiefly calcium ferrocyanide and some calcium sulphocyanide. The next step is to precipitate the ferrocyanides from the solution, so that they may be recovered. This may be carried out in several ways, that is by iron, ammonia, or potassium salts. When utilizing ammonia the cyanide solution is treated with hydrochloric acid, the acid being added until the mixture is acid. In this way a double salt, calcium-ammonium ferrocyanide, is obtained—

$$Ca_2Fe(CN)_6 + 2\,NH_4Cl = Ca(NH_4)_2Fe(CN)_6 + CaCl_2.$$

The double cyanide may then be admixed with a further quantity of lime, when a pure calcium ferrocyanide results—

$$Ca(NH_4)_2Fe(CN)_6 + Ca(OH)_2 = Ca_2Fe(CN)_6 + 2\,NH_3 + 2\,H_2O.$$

Finally, the calcium ferrocyanide may be converted into potassium ferrocyanide.

When potassium chloride is used for precipitation a double salt is again formed, in the first instance—

$$Ca_2Fe(CN)_6 + 2\ KCl = CaK_2Fe(CN)_6 + CaCl_2.$$

This salt is then separated by filtration, washed, and treated with potassium carbonate, when potassium ferrocyanide results—

$$CaK_2Fe(CN)_6 + K_2CO_3 = CaCO_3 + K_4Fe(CN)_6.$$

CONVERSION OF CYANIDES INTO AMMONIA

Although the hydrocyanic acid in coal gas may now be recovered by comparatively simple means, universal extraction is not altogether possible, owing to the limited demand for the product. For this reason renewed attempts have been made to overcome the market difficulty by converting the cyanogen into ammonia, for which there is always a steady demand. The idea is by no means novel, for mention is made of the process in scientific literature published some seventy-five years ago, whilst a patent specification for another means was filed in 1882.

As regards more recent investigation into the possibility of converting cyanides into ammonia, mention must first be made of the work of Henri Burgevin and Burkheiser. The former conducted his experiments with the cyanide compounds present in spent purifying material. Ammonia can be extracted from these by dry distillation, or by treatment with steam under pressure, followed by the use of alkalies, or by employing a mixture of soda and lime. Such processes are, however, unsatisfactory on a manufacturing scale, and Burgevin has overcome the drawbacks of using a costly reagent, soda; whilst by his method the incomplete nature of the reaction is avoided. The employment of lime alone is sufficient, while a recovery of practically the whole of the nitrogen is claimed. According to the patent specification, when cyanide compounds are recovered by means of raw purifying material, the latter must first be treated with some suitable solvent (such as carbon disulphide) in order to ensure complete absence of free sulphur. The residue is then thoroughly intermixed with slaked lime in the correct proportions, and the two

compounds are caused to react at red heat. The reaction is entirely completed at this temperature, and the gaseous mixture liberated will consist chiefly of free ammonia. If care is taken to see that the mixture is homogeneous, it is said that at least 95 per cent. of the original nitrogen in the cyanide compounds can be recovered in the form of ammonia. The approximate quantity of lime required for effecting the transformation is ten times (by weight) of the amount of nitrogen contained in the original material to be treated; and it is suggested that the ammonia should be converted into ammonium sulphate by passing the gas through a seal of sulphuric acid. The method also allows for the partial conversion into ammonia of the small proportion of nitrogen compounds, other than cyanides, which is to be found in purifying materials.

It is well known that the action of sulphuric acid upon potassium sulphocyanide gives thiocyanic acid—

$$KCNS + H_2SO_4 = HCNS + KHSO_4,$$

the latter then being decomposed by water, in the presence of an excess of sulphuric acid, into carbon oxysulphide and ammonia—

$$HCNS + H_2O = NH_3 + COS,$$

the ammonia, at the same time, combining with the sulphuric acid.

So far as the hydrolysis of ammonium sulphocyanide is concerned the South Metropolitan Gas Company and E. V. Evans [1] have introduced a process which consists essentially of treating the sulphocyanide solution with sulphuric acid of definite strength and volume at an elevated temperature. The reactions involved are as follows:—

(*a*) $2\ NH_4SCN + H_2SO_4 = 2\ HSCN + (NH_4)_2SO_4$.
(*b*) $2\ HSCN + 2\ H_2O = 2\ COS + 2\ NH_3$.

The ammonia produced combines with the sulphuric acid, which is in large excess, and the acid liquor obtained may be taken to a sulphate of ammonia saturator. The carbon oxysulphide evolved is dealt with in a Claus kiln, and the sulphur from it is thus recovered.

The process would appear to be somewhat delicate, owing to the fact that, if the working temperature is carried too high, the cyanogen is likely to be volatilized, and lost in the form of thiocyanic acid. Accordingly, temperature regulation plays an important part; but, working under good conditions, a conversion into ammonia of 98 per cent. of the total nitrogen should be possible. In addition to carbon oxysulphide being evolved, it seems probable that some sulphuretted hydrogen results from the reaction. This is most likely, owing to the fact that carbon oxysulphide is freely absorbed by ammonia, and, on evaporation, yields sulphuretted hydrogen, or possibly urea. It is feasible, too, that a portion of the carbon oxysulphide may split up in the presence of water and steam, and yield carbon dioxide and sulphuretted hydrogen, according to the equation—

$$COS + H_2O = CO_2 + H_2S.$$

[1] Eng. Pat. 29047, 1913.

THE LIME METHOD

A second successful method [1] is based on lines somewhat similar to those of Burgevin, and is particularly applicable in cases where hydrocyanic acid is recovered as ammonium sulphocyanide, and finally as calcium sulphocyanide, as is the case in the polysulphide cyanide process. The calcium sulphocyanide produced is first evaporated to dryness, and is then mixed with an excess of slaked lime, and subjected to a moderate heat of not less than 540° C. Under the influence of this temperature the cyanides are broken up in the presence of steam, and yield ammonia and carbon oxysulphide. The ammonia may be drawn off to an absorption vessel containing sulphuric acid, while the carbon oxysulphide will be mostly removed by the excess of lime. The manner in which the lime and cyanide are admixed is of no little importance for the effective working of the process. With regard to the actual reactions taking place, these appear to be on lines such as the following :—

$$(a)\ Ca(SCN)_2 + Ca(OH)_2 + 2\,H_2O = 2\,NH_3 + COS + CaCO_3 + CaS.$$

The precaution is taken of removing the carbon oxysulphide evolved by arranging for a layer of lime 2 or 3 inches deep to be placed over the mixture in the heating chamber. The carbon oxysulphide is then removed as follows :—

$$(b)\ COS + 2\,Ca(OH)_2 = CaS + CaCO_3 + 2\,H_2O.$$

The removal of the carbon oxysulphide in this way is essential ; for ammonia and this compound may combine, with the possible formation of urea, according to the following equation :—

$$COS + 2\ NH_3 = H_2S + CO(NH_2)_2.$$

So far as the respective merits of the two more modern processes are concerned, there is little to choose between them on the ground of efficiency—both giving a conversion of about 98 per cent. For a works having its own sulphuric acid plant, however, or in cases where supplies of acid can be readily obtained, the sulphuric acid method is undoubtedly to be preferred. In the lime method, use might conceivably be made of the waste heat from the retort benches, or one or two retorts could be set apart for the special cyanide purpose. Furthermore, if it was not desired to recover the evolved ammonia there and then, it could be passed into the foul main along with the gas, when, by absorption of sulphuretted hydrogen and carbonic acid, it would lighten the work of the ordinary purifying vessels.

From the financial standpoint there is nothing particularly alluring about the conversion of cyanides into ammonia. It must be remembered, however, that the indirect advantages accruing from the employment of a cyanogen plant are the chief recommendation of the process. As before stated, the universal extraction of cyanogen is scarcely feasible at the present time, owing to the restricted market for this residual and the growing tendency to produce it by other means.

[1] Williams, Eng. Pat. 2841, 1914.

If a coal yields 5 lb. of calcium sulphocyanide per ton, this quantity of sulphocyanide would give about 4¼ lb. of sulphate of ammonia, thus increasing the total yield of sulphate of ammonia from an average of 27 lb. per ton of coal to 31¼ lb., or by about 15 per cent.

Attention may be drawn here to a process in connection with cyanides which has been introduced by Devaucelle.[1] Briefly, it consists in heating a mixture of carbon and a cyanized mass in a retort through which a gas rich in nitrogen is passed, while at a later period steam is blown through the retort for the purpose of producing ammonia.

H. Baker [2] is responsible for a process whereby the sulphocyanides extracted from coal gas are worked up into insoluble sulphocyanides by the addition of metallic compounds. The insoluble cyanides are roasted with or without air, when—without the presence of air—ammonia is obtained. The sulphide of the metallic compounds remains in the retort, and this is again roasted in a current of air or oxygen so as to decompose the sulphide into oxide, with the evolution of sulphur dioxide. On the other hand, if the sulphocyanides are roasted in the first place in the presence of air, ammonia and sulphur dioxide are obtained direct, and the oxide remaining may be used again for precipitating the cyanides. Baker states that on decomposing the cyanides in the presence of air the ammonia is evolved first and the sulphur dioxide at a later stage. Therefore, it is possible to recover the two gases separately. The process refers principally to the recovery of cyanides from spent oxide of iron and the effluent liquor from sulphate of ammonia plants. After the ammonia has been evolved from the liquor soda ash is added to it, and it is boiled to concentration. The liquid is then of a blood-red colour owing to the presence of undecomposed sulphocyanides, and precipitation of the latter is effected by the addition of metallic compounds as stated above.

TESTING COAL GAS FOR CYANOGEN

The gas to be tested for cyanogen is passed through two wash-bottles of about 250 to 300 c.c. capacity, each containing 100 c.c. of ammonium polysulphide solution (made by shaking up a 10 per cent. solution of ammonium sulphide with powdered sulphur). A little (say 10 grains) of powdered sulphur is also put into each wash-bottle, to ensure the presence of an excess. The gas should be passed through the wash-bottles at the rate of about 2 cubic feet per hour, and the test should, preferably, be continued for sixteen hours or more. The amount of gas passed should be determined by a small meter. At the conclusion of the test, the contents of the wash-bottles are transferred to a litre flask, and, with the washings made up to 1,000 c.c., 50 c.c. (or such aliquot portion as represents from 1 to 2 cubic feet of gas) are transferred to a small porcelain basin, and evaporated on the water-bath down to about 10 c.c. Some hot water and a little moist carbonate of lead are added (to remove all sulphides), and the whole filtered. The filtrate is slightly acidified with dilute sulphuric acid, a solution of sulphurous acid added until the liquor smells strongly of

[1] Eng. Pat. 12946, 1915.

[2] Eng. Pat. 16879, 1917.

SO_2, and then a weak solution of pure sulphate of copper in slight excess, the whole heated a short time on the water-bath, filtered hot, and washed.

The filter containing the cuprous sulphocyanide is transferred to a beaker (preferably the one in which the precipitation took place, as small portions of the precipitate may be adhering to the glass). From 25 to 50 c.c. of normal caustic soda free from chlorides are added, and about 100 c.c. of boiling water, and the whole heated on the water-bath, with frequent stirring, until the cuprous oxide becomes sufficiently granular to filter. Filter while still hot, wash well with hot water, and allow the combined filtrate and washings to cool. Acidify slightly with pure dilute nitric acid, add a few drops of ferric sulphate solution, and titrate with decinormal silver nitrate until the colour disappears. Towards the end of the titration add a few more drops of ferric sulphate to increase the distinctness of the end reaction.

Example.—23·5 cubic feet of gas were passed through the wash-bottles in twenty-four hours, and the contents were made up to 1,000 c.c., of which 50 c.c. (representing 1·175 cubic feet of gas) were taken. After proceeding as above, 32·7 c.c. of decinormal silver nitrate were required for titration—

1 c.c. of silver nitrate = 0·0076 gramme of ammonium sulphocyanide.

∴ 32·7 ,, ,, = 0·2485 ,, ,, ,, ,,

i.e. 1·175 cubic feet of gas contain 0·2485 gramme of ammonium sulphocyanide,

or 100 cubic feet of gas contain 21·1 grammes of ammonium sulphocyanide.

There are 15·43 grains in 1 gramme, therefore $21{\cdot}1 \times 15{\cdot}43 = 325{\cdot}5$ grains of ammonium sulphocyanide per 100 cubic feet.

The molecular weight of ammonium sulphocyanide is 76, and that of hydrocyanic acid 27, so that $325{\cdot}5 \times \frac{27}{76} = 115{\cdot}6$ grains HCN per 100 cubic feet.

The above test is usually made use of only when sulphocyanide processes are in operation. When ferrocyanide plants are employed the following method is preferable :—

A 30 per cent. solution of caustic soda or caustic potash is mixed with a 12 per cent. solution of ferrous sulphate in the proportion of 5 to 1. The mixture is poured into three Woulffe's bottles, and gas is passed through at the rate of 1 cubic foot per hour. After about 10 cubic feet of gas have been passed the mixture (collected from the three Woulffe's bottles) is washed into a graduated flask, and a portion is taken for analysis. The mixture is boiled until free from ammonia, and is then filtered. The filter paper is washed with hot water until a few c.c. on being acidified with hydrochloric acid give no blue colouration on the addition of ferric chloride. The filtrate and washings are acidified with hydrochloric acid and the cyanogen is precipitated with ferric chloride, as Prussian blue. The whole is then poured into a tared filter paper and well washed with hot water until the filtrate is free from iron salts. The filter paper and contents are then dried and weighed.

Example.—10 cubic feet of gas were passed through the caustic soda and ferrous sulphate mixture. The mixture washings were then made up to 500 c.c., of which

100 c.c. were taken for analysis, *i.e.* equal to 2 cubic feet of gas. After treatment the amount of Prussian blue obtained was 4 grains.

860 parts of Prussian blue contain 468 parts of cyanogen (CN); therefore,

4 grains will contain $4 \times \frac{468}{860} = 2{\cdot}18$ grains of cyanogen from 2 cubic feet of gas,

or $2{\cdot}18 \times 50$ grains $= 109$ grains per 100 cubic feet of gas.

CHAPTER XVIII

THE DRY PURIFICATION OF COAL GAS

THE theory and practice of the dry purification of coal gas, the chemical changes involved, and the construction and working of the necessary apparatus are subjects which, if dealt with in their entirety, would justly claim a complete volume to themselves. For this reason it is impossible, within the limits of a single chapter, to touch upon more than the salient features of the process and upon those sections of it which are of direct interest to the gas engineer.

In some instances, nowadays, purification is carried to extreme lengths, in order that a gas of exceptional purity may be supplied to the consumer. In the majority of cases, however, the gas is treated in such a manner that it may satisfy the usual statutory requirements, whilst no attempt is made to produce a super-quality.[1]

At this stage of the manufacturing process the impurities present in the gas may be set down as follows :—

Ammonia	nil to 1·5 grains per 100 cubic feet.
Sulphuretted hydrogen	500 to 800 „ „ „ „
Sulphur compounds (other than H_2S)	35 to 50 „ „ „ „
Hydrocyanic acid	50 to 70 „ „ „ „
Carbon dioxide	750 to 1,150 „ „ „ „

Of these, sulphuretted hydrogen must, in accordance with the requirements of the law, be removed completely. This, however, is not the case with the remaining four compounds.

Until the year 1905 a certain limit was placed (in London and many provincial towns) on the quantity of sulphur compounds present, with the result that special treatment was accorded the gas for the removal of these compounds before it left for the distribution area. The limits imposed at that time precluded, during the winter months, a greater quantity of sulphur compounds than 22 grains per 100 cubic feet of gas, whilst during the summer months the limit was reduced to 17 grains. The greater portion of the cyanogen is extracted during the passage of the gas through the oxide purifiers, unless, of course, a special plant for its recovery has been previously interposed. Carbon dioxide, as previously explained, is not an impurity but a diluent. There are no statutory restrictions as to its presence in the finished gas, and its effect is chiefly felt as a result of the reduction it causes in calorific value and illuminating power.

[1] *Vide* S. Metropolitan Gas Co.'s Bill (1920), Chap. I., p. 7.

Of the impurities named, the gas in normal instances contains, when distributed, the following quantities :—

Sulphuretted hydrogen	nil. .
Ammonia	nil.
Sulphur compounds (other than H_2S) . .	35 to 50 grains per 100 cubic feet.
Hydrocyanic acid	nil to 10 „ „ „ „
Carbon dioxide	750 to 1,150 „ „ „ „

Where a proportion of carburetted or blue water gas is added to the coal gas the mixture (owing to the lower sulphur content of water gas) contains a smaller percentage of sulphur impurities than does a neat coal gas. Purified carburetted water gas contains on an average from 10 to 15 grains of sulphur compounds per 100 cubic feet.

The abolition of the sulphur clauses in 1905 did much to simplify the process of gas purification, in that lime as a purifying medium is now largely dispensed with. The somewhat erratic operation of this material and the uncertainty of its working were such as to prove a constant anxiety to the works manager. In addition, considerable expense was incurred in order to effect the removal of an impurity present in quantities so small as to render it practically innocuous. To-day oxide purification for the removal of sulphuretted hydrogen is of primary interest to the gas engineer, although the use of lime has been by no means universally discarded, particularly in so far as some of the smaller undertakings are concerned.

REMOVAL OF SULPHURETTED HYDROGEN

The elimination from the gas of this impurity presents no great difficulties, but the manner in which the necessary plant is operated varies considerably with the taste of the engineer. Of the original quantity of sulphuretted hydrogen the bulk remains in the gas after the latter has passed the washers and scrubbers, and is invariably removed by causing the gas to pass in contact with layers of special material in a moist condition. The chief materials employed for sulphuretted hydrogen removal have, in the past, been hydrated lime, hydrated oxide of iron, and manganese dioxide in the form of Weldon mud. Natural ferric oxide (bog-ore) is still largely made use of, but in recent years there has been a tendency to turn to various artificial preparations, which may be obtained more cheaply and which, in many cases, have increased activity as compared with bog-ore.

Natural Oxide of Iron

Natural oxide of iron, or bog-ore, occurs in peaty deposits in large quantities in Ireland, Holland, and Belgium, also to a limited extent in England, chiefly in the neighbourhood of Westbury (Wiltshire). In its natural form the ore contains from 50 to 60 per cent. of water, and between 30 to 35 per cent. of ferric oxide (Fe_2O_3). In addition to iron compounds the virgin material contains about 15 to 25 per cent. of inert matter, consisting chiefly of vegetable substances and silica. In the dried state the analysis of an oxide of good quality will vary between the following limits :—

Hydrated ferric oxide (Fe_2O_3,H_2O)	60 to 65 per cent.
Organic matter	15 to 25 „
Silica	3 to 6 „
Alumina	1 „

The silica content of a natural oxide varies very much, in accordance with the district from which it is taken. Best Dutch material seldom contains more than 4 to 5 per cent. Belgian oxide may contain from 10 to 12 per cent., whilst oxide occurring in this country has been known to contain so much as 20 per cent. of silica and alumina. The proportion of silica present has some considerable effect on the relative density of the various oxides. In general the following figures may be taken as representing the volume equivalent to 1 ton :—

Dutch oxide	45 cubic feet per ton.
Belgian oxide	40 „ „ „
Wiltshire oxide	35 „ „ „

The active material in bog-ore is not the actual oxide, but the oxide plus a certain amount of water of combination, *i.e.* a hydrated ferric oxide, Fe_2O_3,H_2O. In addition to this moisture the material as used should contain a further quantity of water, usually from 20 to 30 per cent. For effective working the moisture should never be less than the lower limit given. In practice it is generally realized that the material should be in such a state as regards moisture that it will, when pressed in the hand, bind like snow. In common with natural oxides the artificial varieties are employed with a similar degree of moisture. The made-up material is usually more active than the natural product, owing to a rather higher content of iron (which may reach so much as 75 per cent.), and on account of the elimination of vegetable matter. At the same time it is a fallacy to suppose that a material containing a high proportion of iron is better necessarily than one containing a lower proportion. The quality and condition of the iron is the main factor of efficiency. It is, as a matter of fact, possible to obtain natural bog-ore containing 90 per cent. of ferric hydrate, but a good variety containing 70 to 75 per cent. is better suited for gas-works purposes.

When foul gas containing sulphuretted hydrogen is passed through a vessel filled with oxide of iron the sulphuretted hydrogen alone is extracted, the oxide having no affinity for carbon disulphide or carbon dioxide. The absorption of the sulphuretted hydrogen occurs in two distinct ways, which may be simply shown as follows :—

(1) $Fe_2O_3,H_2O + 3\,H_2S = Fe_2S_3 + 4H_2O$ (ferric sulphide).
(2) $Fe_2O_3,H_2O + 3\,H_2S = 2\,Fe\,S + S + 4\,H_2O$ (ferrous sulphide).

It will be noted that in the first instance ferric sulphide is formed, whilst in the alternative equation ferrous sulphide and free sulphur result.

After a time the material ceases to absorb sulphuretted hydrogen, but can be returned to a state of activity by the process known as " revivification." For this purpose it is removed from the purifying boxes, spread out in a thin layer, turned

over, and exposed to the action of the oxygen in the atmosphere. By this means the iron sulphides are oxidized and assume their original character with the deposition of free sulphur :—

$$(a)\ 2\,Fe_2S_3 + 3\,O_2 + 2\,H_2O = 2\,Fe_2O_3,H_2O + 3\,S_2.$$
$$(b)\ 4\ FeS\ + 3\,O_2 + 2\,H_2O = 2\,Fe_2O_3,H_2O + 2\,S_2.$$

The material, together with the free sulphur, is then returned to the purifier, when precisely the same reactions recur. Revivification may then be carried out again, the oxide being returned some three or four times to the purifiers until it contains upwards of 55 to 60 per cent. of sulphur, beyond which figure it will not be found economical to work.

The dry purification of gas in this way may really be considered as a delayed catalytic action, the oxide of iron assuming the rôle of a catalyst. For instance, the final result of the process may be represented as follows :—

$$2\,H_2S + O_2 = 2\,H_2O + S_2.$$

As regards the generally accepted reactions quoted above, it has been pointed out by G. Weyman [1] that ferric sulphide Fe_2S_3 is the primary product, but the ferric hydrate reformed by oxidation is certainly not the compound $Fe_2O_3,3\,H_2O$, and probably contains less water than is represented by the formula Fe_2O_3,H_2O. Water, therefore, is liberated which is not going to be recombined, and unless removed will accumulate until the efficiency of the material is impaired. Weyman also draws attention to the fact that sulphur is slightly volatile in the presence of water vapour, and in this case can decompose steam, with the eventual formation of sulphur dioxide and sulphuretted hydrogen—

$$3\,S + 2\,H_2O = 2\,H_2S + SO_2.$$

Such liberation of sulphur dioxide enormously increases the complexity of the process, for it is capable of giving rise to compounds by reacting with a large number of other substances present. Sulphur acids are formed, and under the acid conditions thus set up, the ferric sulphide passes into ferrous sulphide.

Artificial and Other Materials

So far as the other mediums employed for the removal of sulphuretted hydrogen are concerned, Weldon mud, a by-product of the bleaching industry, owes its activity to the presence of manganese dioxide. The reactions occurring are very similar to those appertaining to oxide of iron, a manganese sulphide capable of regeneration resulting. In many respects Weldon mud is superior to oxide of iron for purification purposes. It cannot, however, be obtained now owing to the abandonment of the old Weldon chlorine process. The chief advantages which may be claimed for the material are increased absorptive activity as compared with oxide, whilst owing to the possibility of revivifying it *in situ* it is possible to work up the spent material to a high sulphur percentage before removing it from the purifier. Owing to its sensitive nature Weldon mud was, in the days of universal lime purification, particularly suited for use in "catch boxes."

[1] North of England Gas Managers' Assocn., May, 1920. See *Gas World*, LXXII, p. 458.

Another sensitive material is "Lux." This material is prepared from the residues left after the extraction of alumina from bauxite (ferric aluminate), these residues containing a high proportion of iron. The material is powdered, mixed with a definite proportion of sodium carbonate, and raised to a red heat, resulting in the formation of sodium aluminate and sodium ferrate. The mass consisting of these two compounds is then treated with water, when the sodium aluminate dissolves out, and the ferrate is decomposed with the formation of a colloidal ferric hydrate. The English caustic soda process of extraction leaves the iron oxide in its original condition in the bauxite ore.

In the condition as delivered for use "Lux" contains about 55 per cent. of ferric oxide and 20 per cent. of alkaline salts. In many cases it is desirable to mix a certain proportion of sawdust with the material as it is received, the usual ratio being 3 parts of "Lux" to 1 part of sawdust. It is said by some that with "Lux" the absorption of H_2S takes place more rapidly than with bog-ore, owing to the fact that the ferric hydrate is separated out in a finely divided state during the manufacture of the material. In addition, it is claimed that a greater percentage of sulphur may be obtained before the material is finally spent; but some trouble may be experienced from firing.

The Chemical Waste Products Committee of the Munitions Inventions Department [1] has studied various processes for the conversion of residues containing oxide of iron into material suitable for gas purification. Among the substances examined and found effective was a residue resulting from the manufacture of cyanide. This contained a high percentage of ferric hydrate, and was prepared for use by a special drying process which produced the correct physical texture. Iron was also recovered from the waste hydrochloric acid liquors, obtained in the pickling of iron, by the addition of lime, a suitable purification material being yielded.

The artificial preparations made up from burnt spent oxide are sold under a number of trade names (*e.g.* "Ferrox," "Brownox," "Metroxide," etc.), and contain in general a higher proportion of ferric hydrate than is the case with natural bog-ore. This accounts for their somewhat vigorous action, although in their preparation the addition of other ingredients adds to their efficiency. Broadly speaking, they may be said to result from burnt spent oxide, which is obtained from sulphuric acid works, rendered active by special treatment. This treatment varies with the type of material, but in one instance it consists almost solely of grinding the burnt product in a disintegrator with the addition of a definite proportion of soda ash and sawdust. A product known as Laming's mass was at one time a great favourite in France, Spain, Italy and the East. This consists of sawdust mixed with lime and wetted with a solution of sulphate of iron.

A. H. Scott,[2] dealing with the sources and methods of production of some of the better known forms of gas purification oxides, says that, so far as the mineral bauxite is concerned, European methods are more efficient than American, and leave less than 6 per cent. of alumina in the residue. In America as much as 11 per cent.

[1] Special Report, Ministry of Munitions, 1919.
[2] New England Assocn. Gas Eng. Ann. Meeting, 1917.

is found, and anything approaching this proportion impairs the value of the material for purification. Apparently American bauxites are prejudiced by the presence of considerable quantities of silica. As regards other sources, Scott speaks of a high quality oxide being procured as a by-product in the reduction of aniline, and mentions the fact that waste water from the West Pennsylvanian coal-mines yielded a very efficient natural oxide. Called upon to abate the nuisance caused by running it into the rivers, the owners collected it in large settling basins for treatment; and the sediment thus obtained had been found to be an excellent purification material. Metallic paint oxide showed results fairly comparable with good manufactured oxide, and would come into more general use. Finely ground pyritic cinder had met with favour as yielding good working, although somewhat crystalline and vitreous in structure. Many of these newer forms of oxide would be much improved for the purpose by experience, as manufacturers and gasworks chemists were feeling their way towards a material that would take up several times its own weight of sulphur, and not be liable to cake and cause back-pressure in the purifiers.

In absorption tests conducted on a number of oxides under similar circumstances (four foulings to each test), the percentage of sulphur taken up was as follows :—

Residue from aniline reduction	62
Sediment from mine water	61
Pennsylvania bog-ore	61
Ground pyritic cinder	53
Hematite ore	49
Hydrated iron ore	46
Residue from American bauxite	35
„ „ French „	42
„ „ English „	15
Cuban bog-ore	31
Metallic paint	49

Becquevort and Deguide[1] have introduced a process for the recovery of a gas-purifying material as a by-product from the manufacture of Glauber's salts. The process consists in treating scrap iron with a solution of sodium bisulphate at a temperature of about 90° C. The following reaction results :—

$$2\,NaHSO_4 + Fe = Na_2SO_4 + FeSO_4 + H_2.$$

An excess of powdered lime is then added, so that sulphate of lime and insoluble ferrous hydrate are produced, together with neutral sodium sulphate—

$$Na_2SO_4 + FeSO_4 + H_2O + CaO = Na_2SO_4 + CaSO_4 + FeH_2O_2.$$

The mass is then aerated and shaken until the ferrous hydrate is transformed to ferric hydrate—

$$2\,FeH_2O_2 + H_2O + O = Fe_2O_3,3\,H_2O.$$

After filtration the mass left in the filter-press is a mixture of sulphate of lime

[1] Eng. Pat. 9747/16.

and ferric hydrate to which wood dust is added in order to lighten it. It is then used for the purification of gas from sulphuretted hydrogen and hydrocyanic acid.

The Extent of Hydration

The extent to which oxide of iron should be hydrated is a point of considerable importance, the gas engineer generally preferring to work with a moisture content varying between 40 and 60 per cent. It would seem, however, that such high proportions of water are liable to have a harmful influence on activity, particularly if the active particles are so surrounded with water that the gas has to pass through the latter before any reaction can occur. The result is that excess water impedes rather than promotes reaction, and the same applies in the process of revivification. Weyman speaks of the fact that, since the solubility of oxygen in water is very much smaller than that of sulphuretted hydrogen, excessive moisture will practically bring oxidation of the sulphides to a standstill. The slower rate of oxidation as compared with sulphidation can be observed in practice, for whereas revivification may occupy the whole time during which the gas passes through, say, four boxes, sulphiding takes place in the first two. In the operation of the semi-direct process [1] for the recovery of sulphate of ammonia it has been found that periods of purifier disorganization have been most frequent with a very moist material, and less frequent when the material has been dry. Very much must depend, however, on the manner in which the process of purification is carried out, for the different conditions prevailing (*e.g.* upward or downward flow of gas, temperature, etc.) give rise to entirely different effects, so that it is extremely difficult to lay down any definite rule for moisture content. Moreover, comparison between normal purification methods and purification following the semi-direct ammonia process is likely to be misleading owing to the fact that much more moisture is in general condensed from the gas when it reaches the oxide after passing the acid bubbler employed in the latter process. A factor of importance is that of the admission of air for revivification purposes, since where any considerable amount of air is passed in with the gas there is a tendency for moisture to be extracted.

W. S. Curphey [2] speaks of the fact that the higher temperature of the gas which has to be dealt with when the semi-direct process is in use accounts for the evaporation of the moisture in the leading vessels, which moisture is eventually deposited in the later vessels of the series, thus accounting for excessive water content in the material in the final boxes. It is recommended, therefore, that instead of the usual 40 per cent. or so of water, the hydration of the material should be no more than 5 to 10 per cent., and that the quantity of water used should be gauged from the ferric hydrate content of the oxide rather than from its total bulk.

For purification as carried out when the normal process of preliminary wet purification is employed it may be said that, so far as our knowledge of prevailing conditions goes at present, it is preferable to strike a balance between excessive water content and abnormally dry material, and to regulate the moisture to something approaching, but not exceeding, 30 per cent.

[1] *See* Chap. XVI, p. 546. [2] *Alkali Report*, 1917.

The Influence of Temperature

In oxide purification the temperature of the material plays an important part, and there can be little doubt that more consistent results would be obtained from the process if fluctuations in temperature were avoided. In many gasworks the purifiers are not housed, with the result that they are readily influenced by the vagaries of atmospheric conditions. In general, the working temperature should lie between 21° and 27° C. (70° and 80° F.). Where air is being admitted with the gas the outlet temperature will be some 6° to 10° F. higher than the inlet temperature. A rise of this kind in temperature is desirable in that oxidation of the sulphides is more pronounced at the higher temperature. W. S. Curphey [1] states that (following the semi-direct process) temperatures much exceeding the limits mentioned above are found, and that such temperatures are consistent with efficiency. It should be borne in mind, however, that, if the temperature is permitted to exceed the limits named, the material will tend to become caked (thus giving rise to heavy back-pressure) owing to the moisture being carried forward to succeeding boxes. The backward rotation system is undoubtedly beneficial in the direction of distributing the moisture equally throughout the system, for each box is in its turn brought into the reaction zone, this assisting in the maintenance of a uniform temperature throughout and the equalization of moisture conditions.

At the present day it is common to find a supply of live steam arranged for in the oxide purifiers. Some precaution is necessary in the use of steam in this way, as excessive moisture may give rise to abnormal back-pressure, resulting in the remaking of the box. The chief advantage of the steam is the fact that it accounts for some rise in temperature of the gas, whereby the oxide is maintained in a warm condition, which is conducive to its effective working. For this reason it is found that the efficiency of a purifier may be enhanced by arranging for a steam coil in the gas inlet or in the base of the box—no live steam coming actually in contact with the gas. Raising the temperature of the inlet gas by 10° to 20° F. will frequently be found to get over any difficulty arising from sluggish material. In this respect it will be noticed that when purifiers are partly buried the average temperature of the gas will be somewhat higher than when the vessels are above ground in open sheds and exposed to the weather.

Live steam, however, when used in moderation, will frequently overcome inactivity or back-pressure resulting from caking. G. W. Anderson [2] suggests that for such purposes the quantity of steam employed should be 0·25 lb. per 1,000 cubic feet of gas.

It is a common works experience to find that a series of purifiers will absorb all but the merest trace of sulphuretted hydrogen, the lead papers being practically, but not perfectly clean. The condition may prevail for some time, but without any tendency to become more aggravated. Weyman suggests that the remnant of sulphuretted hydrogen left is the result of the secondary reaction.

$$3\,S + 2\,H_2O = 2\,H_2S + SO_2.$$

[1] *Alkali Report*, 1916.

[2] *Gas J.*, CXLVIII, p. 688.

Thus the whole of the original sulphuretted hydrogen is being removed, but prevailing conditions are favourable for secondary formation of this impurity as shown above. The trouble can probably be traced in most instances to temperature, and when it occurs the temperature of the final boxes should be lowered.

The Admission of Ammonia

It is now generally accepted that the operation of dry purification is facilitated by the admission of a small proportion of ammonia to the purifying vessels. It is customary, therefore, to permit from 0·5 to 1 grain of ammonia per 100 cubic feet of gas to travel forward with the gas issuing from the clean water scrubber of the wet purification plant. Experience shows that while purifiers will undoubtedly work effectively under conditions which result in the formation of soluble salts of iron (ferrous sulphate), the activity of the material is distinctly higher when sufficient ammonia is present in the crude gas to maintain the oxide in a neutral or slightly alkaline condition. The effect of ammonia so far as cyanogen compounds are concerned has already been discussed,[1] but the actual part it plays in gas purification is not as yet perfectly clear.

W. S. Curphey[2] has directed attention to the determination of the minimum amount of ammonia which is necessary, in his opinion, to maintain the purifiers at maximum efficiency. Results as yet are difficult to interpret, but there is reason to believe that the amount of ammonia required bears a direct relationship to the quantity of ferrous sulphate formed, and that the formation of ferrous sulphate is favoured by excessive moisture and possibly by low temperature. Ferrous sulphate is an objectionable constituent in that it will not undergo revivification, or at least only in the presence of alkalis or carbonates in the mass, and then only slowly. Moreover it reduces the rate of revivification of the whole material, and may give rise to the well-known effect of " souring " of the oxide. The quantity of ferrous sulphate actually present at any given moment appears to be small, probably only a fraction of 1 per cent. in normal working, but in relation to the actual reacting weights of sulphuretted hydrogen and ferric hydrate the amount cannot be regarded as negligible. This is owing to the fact that it is the surface of the oxide particles which react, and if the particles are coated with a skin of ferrous sulphate the activity of the mass may be immensely reduced. Curphey makes a suggestion with regard to the point of admission of the ammonia to the purifiers which merits the attention of gas engineers in general. In ordinary practice it is customary to admit all the ammonia with the crude gas entering the first purifying vessel. It is suggested, however, that a certain proportion of the ammonia should be admitted to the second vessel as well, instead of supplying an excess to the first box in the hope that some of it may escape absorption and travel farther along the series.

The Admission of Air

Oxide of iron is generally used in the purifiers in layers varying from 8 inches to 10 inches in depth, although in some cases it is still customary to adhere to deeper

[1] See previous chapter.

[2] *Alkali Report*, 1917.

tiers of about 30 inches. The last named, however, frequently give rise to excessive back-pressure, and are not to be advised in the ordinary way. A space of not less than 2 inches should always be allowed between the top surface of one layer and the underneath surface of the grid above it. Oxide as it becomes fouled increases in bulk—hence this precaution.

Partial revivification *in situ* is almost always arranged for nowadays, the small quantity of air admitted during the process considerably adding to the working life of the material. Care has, of course, to be exercised with regard to the quantity of air introduced. The usual allowance is $2\frac{1}{2}$ per cent. for every 1 per cent. of sulphuretted hydrogen present; and, as the H_2S amounts in normal cases to about $\frac{1}{2}$ per cent., the theoretical quantity of air required is about 1 per cent. Some engineers arrange for 15 cubic feet of air per 1,000 cubic feet of gas. The admission of air may be arranged for in two ways. It may be sucked in from the atmosphere through a pipe on the inlet or vacuum side of the exhauster (in which case the air should be drawn through a meter so that its volume may be measured), or it may be injected direct into the mains leading to the purifiers by means of an ordinary steam injector. An effective means of arranging an injector system is shown in Fig. 350. On the larger works an injector may be fitted to the inlet of each purifier, whilst in small works a run of two or three hours' duration every day should answer the purpose. When air is sucked through from the inlet side of the exhauster it is advisable to introduce some safeguard in case sudden pressure might arise from any cause. The safety seal shown in Fig. 351 is simple and convenient. It consists of a cast-iron box about 12 inches square by 4 inches deep, with a flat cover securely jointed.

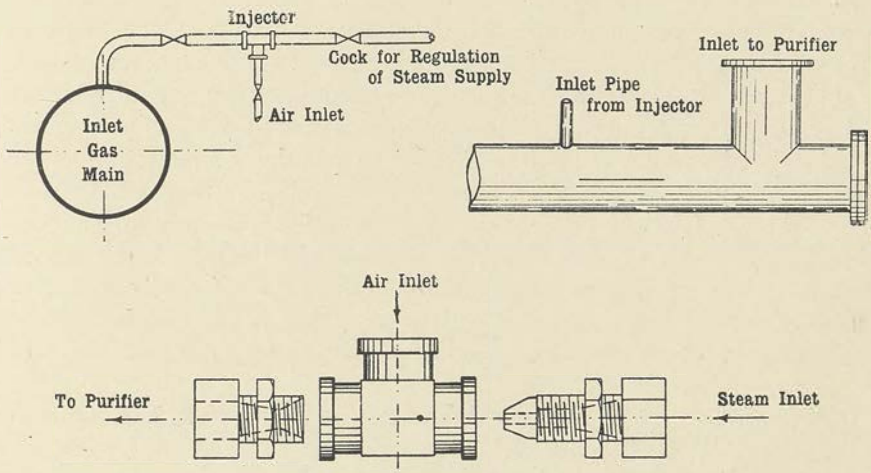


FIG. 350.—AIR INJECTOR FOR DRY PURIFIERS, SHOWING METHOD OF CONNECTING UP.

Water should be poured in at B until it overflows from the bib-cock C. The outlet of the meter is connected to A, and the service D leads to the gas main. The base of the seal-pipe A, which is screwed, is so adjusted that it dips below the surface of the water to the depth of about an inch. In the event of back-pressure the water

will be depressed and rise in the pipe A, which should not be less than 24 inches to 30 inches in height.

It should be borne in mind that most coal gas will contain a certain amount of oxygen, and the quantity varies to some considerable extent. It is important, therefore, to test the gas for oxygen before blindly admitting air, otherwise the recognized limit may be considerably exceeded. In exceptional cases the gas itself contains sufficient oxygen without the introduction of a further quantity from the atmosphere. It is interesting to note here the remarks of one authority who, as a result of a great number of experiments, found that an amount of oxygen in excess of 0·3 per cent. was never absorbed from the gas in the purifiers. In view of this, it is contended that as from 0·2 to 0·4 per cent. of oxygen is almost sure to gain admittance during the period for which the retort doors are open, there is no necessity to add a further amount to the purifiers.

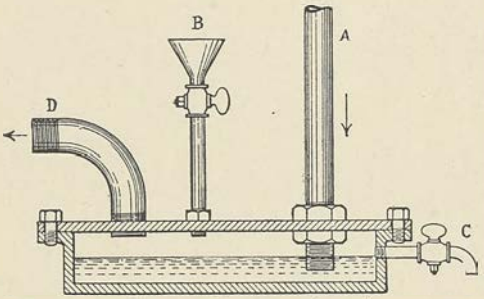


Fig. 351.—Safety Seal for Air Admission.

When air is admitted at some point prior to the purifiers it must not be overlooked that there is always the possibility of its encouraging undesirable reactions in the wet purification plant. It is, however, an excellent plan to arrange for the air to be introduced on the inlet of the clean water scrubber.

The merits of the " backward rotation " system are chiefly dependent upon the part played by the admitted air. For some time it was generally believed that the material in a purifier could not simultaneously extract sulphuretted hydrogen from the gas and undergo revivification. The assumption was not entirely accurate, as the process of sulphiding invariably takes place at a very much more rapid rate than does the absorption of air. In the case of " backward rotation," however, a purifier gradually passes from the position of first " taker," where sulphiding mainly occurs, to the end of the series where the oxygen is permitted to carry out revivification undisturbed. In this way each purifier is accorded a period of rest in which to prepare for taking its place once more at the head of the series. Accordingly, with alternate periods of sulphiding and revivification, the boxes may be operated for a lengthened time before requiring remaking, and the material may be worked up to a higher sulphur content.

Dealing with the point as to whether or not sulphiding and oxidation can occur simultaneously, W. S. Curphey says that oxidation changes are no doubt solely responsible for the slight rise in temperature noticeable in the third and fourth boxes, where sulphuretted hydrogen must be considered absent, but it is a matter of uncertainty how far the oxygen is active in the first and second boxes. Experience certainly indicates that the conditions existing in the preliminary vessels must in general be extremely favourable to concurrent revivification, and the notable variations of temperature which are not infrequently recorded in the first two boxes

may probably be attributed to varying oxygen content of the gases rather than to a varying content of sulphuretted hydrogen.

When air is admitted to the system it will usually be necessary to throw out the material only three or four times before it is finally spent (containing about 55 per cent. of free sulphur), which contrasts very favourably with the old method, of which Lewis T. Wright wrote in 1895, " Oxide can be economically sulphided and oxidized sixteen times," this meaning that before the material was economically spent it could be thrown in and out of the purifier sixteen times.

For most efficient results, so far as revivification *in situ* is concerned, a slight excess of air above the theoretical quantity indicated by the amount of sulphuretted hydrogen present should be employed. Furthermore, the capacity of the plant should be ample, otherwise the air will not produce its due effect.

It should be borne in mind that while during the sulphiding reactions a small amount of heat is generated, the oxidation process accounts for the evolution of a much greater quantity of heat. These considerations mainly affect the question of moisture, for during the sulphiding process water (corresponding to the sulphuretted hydrogen formed) is set free ; and, whereas a portion of this is required for rehydration of the oxide during the oxidation stage, the excess is removed from the system. It is, therefore, important to maintain the working temperature of the system at 70° to 80° F. (21° to 27° C.) so that the moisture thrown out during sulphiding is carried forward to the oxidation zone by the warm gas.

As regards the point of admission of air, opinion is divided as to whether it is preferable to admit the whole at the inlet of the system, to admit it at a later period (such as the inlet of the second vessel), or to split it amongst the various boxes. The author has always preferred to permit the small amount of oxidation which may occur in the first vessel to be provided for by the oxygen actually in the gas ; admitting, approximately, two-thirds of the added air to the second vessel, and one-third to the third box. G. W. Anderson [1] says that it is immaterial whether the air is admitted at the inlet of the first box or at the inlet of the second or third so long as the quantity added is below the theoretical figure. The nearer the latter figure is approached, however, the earlier should be the point of addition (*i.e.* if the full theoretical amount is used, admission should be at the first box), otherwise a certain amount of oxygen may be found in the gas leaving the last purifier.

The Effect of Adding Air

When revivification, owing to admitted air, is taking place in a purifier, a rise in temperature, usually amounting to about 5° F., will be noticed between the inlet and outlet. It is unnecessary to add that no little precaution is necessary in the regulation of the quantity of air used, chiefly owing to its diluent effect as regards the final illuminating and calorific power of the gas, and also with regard to curtailing any abnormal rise in temperature. It is necessary to bear in mind that should any excessive local heating of the oxide take place, instead of a sulphide or a normal sesquisulphide being obtained, disulphide of iron is formed, or iron sulphate.

[1] *Gas J.*, CXLVIII, p. 689.

This is due to too vigorous oxidation. In the case of the disulphide or sulphate of iron, revivification is impossible, and a portion of the material loses its activity in consequence. There is, however, a remedy, for if an alkali is added it will, on account of its basic properties, release the iron from its undesirable combination with the sulphur. The alkali may be added in the form of ammonia from the scrubber, which may be by-passed for a short period; but preferably a small proportion of powdered slaked lime should be admixed to the oxide when it is removed from the box.

So far as the diluent properties of air are concerned, mention may first be made of the oft-quoted work of Audouin and Bérard, carried out in 1862. These investigators found that—

1	per cent.	of air	reduces	illuminating	power	by 6	per cent.
2	,,	,,	,,	,,	,,	11	,,
3	,,	,,	,,	,,	,,	18	,,
4	,,	,,	,,	,,	,,	26	,,

and if 45 per cent. of air is added the loss of candle-power amounts to 100 per cent.

Later results have been given by Wurtz, who states that—

3	per cent.	of air	causes	15·69	per cent.	loss in light.
5	,,	,,	,,	24·0	,,	,, ,,

More recent experiments in this direction have been carried out by W. B. Davidson. The figures he gives are the following:—

1 per cent. of oxygen added decreases candle-power by 3 per cent. and calorific power by 1 per cent.

1 per cent. of nitrogen added decreases candle-power by 2·6 per cent. and calorific power by 1 per cent.

So far as carbon dioxide is concerned, Davidson states that 1 per cent. added to an average sample of coal gas will reduce the illuminating power by $3\frac{1}{2}$ per cent.

Reverse Action

In the ordinary way, the gas enters at the base of the purifiers and passes upwards through the material. Recently, however, it has been pointed out that reverse flow (*i.e.* gas entering above the material and passing downwards) possesses a number of advantages, so that the system is growing in popularity. Foremost, perhaps, is the back-pressure consideration; and when a purifier gives trouble in this direction an effectual remedy will be found in the reverse flow. This is largely on account of the increased area of oxide exposed to the gas, which (owing to the grids) is nearly halved when the flow is in the usual upward direction. When excessive pressure is thrown by a box, it is usually attributable to the first (*i.e.* the bottom) tier, whilst a common remedy is to draw a slide, and so by-pass the one layer. In this respect the downward travel certainly makes matters easier, for the lid may be lifted and the top material lightened (or exchanged for new) with little delay. Thus the efficiency of the box is increased and not reduced materially, as is the case when a layer is slipped.

It occasionally happens that a purifier suffers as regards activity owing to the material becoming too dry. The reverse system in such cases will usually provide

a remedy; and if the box is made first "taker," the saturated gas coming away from the scrubbing plant will deposit its moisture on the material and the purifier cover, this in time percolating through the layers, with the desired results. On the other hand, when gas is admitted to the bottom of the vessel, the water is merely deposited in the box, and runs away through the seals. The top tier of oxide in a downward-current purifier is frequently found to be in a muddy condition for a depth of two or three inches when the box is working as first "taker."

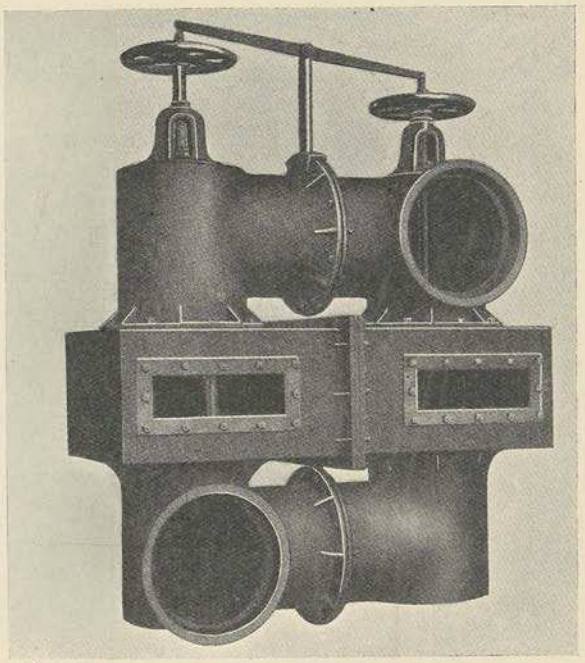


FIG. 352A.—MILBOURNE'S VALVE FOR UP OR DOWN FLOW.

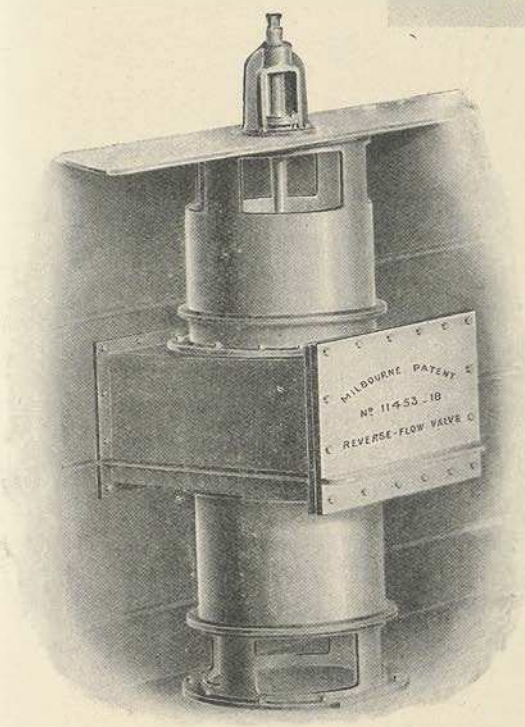


FIG. 352B.

A small point worthy of notice is that of revivification. When air is admitted to a box, it is the material at the bottom which (under the common system) derives the greatest benefit from this, and is, consequently, revivified to a somewhat greater extent than the upper tiers. If alternate flow is provided for, however, the uppermost layers are able to derive full benefit from the oxygen present.

Reversal of current is, of course, not to be recommended in the case of oil gas purification.

Purifiers which are fitted for the travel of gas in the usual upward direction may readily be modified so as to cause the gas to

take a downward path. Providing that alternating up and down travel is not desired, the easiest means is that of merely transposing the long outlet pipe, which extends above the grids in the box to the inlet main. Special valves, such as Milbourne's (Fig. 352A and B), can now be had for reversing the direction of flow at will, whilst Dempster's patent device, which is self-explanatory, is shown in Fig. 353.

The Sadler-Cockey valve (Fig. 354) is a new departure which permits of working on either the backward or forward principle of rotation, and either upwards or down-

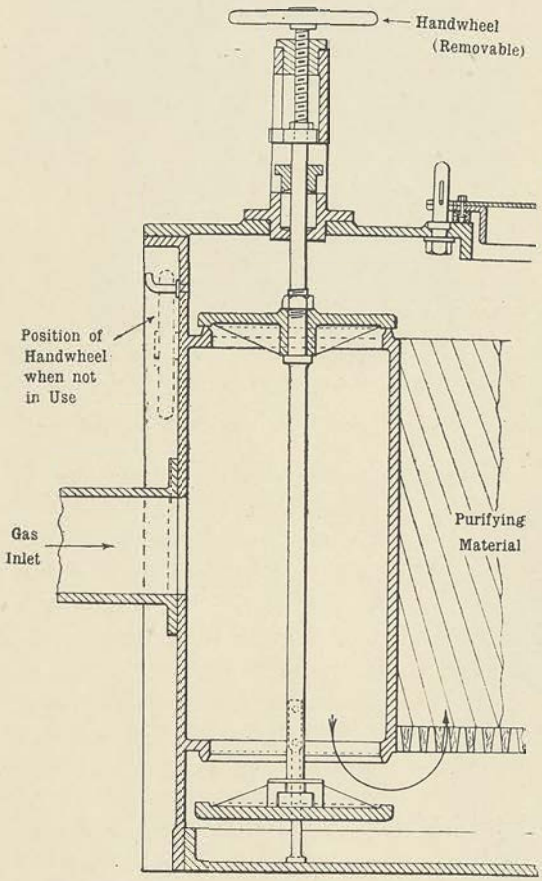


FIG. 353.—DEMPSTER'S REVERSING VALVE-BOX.

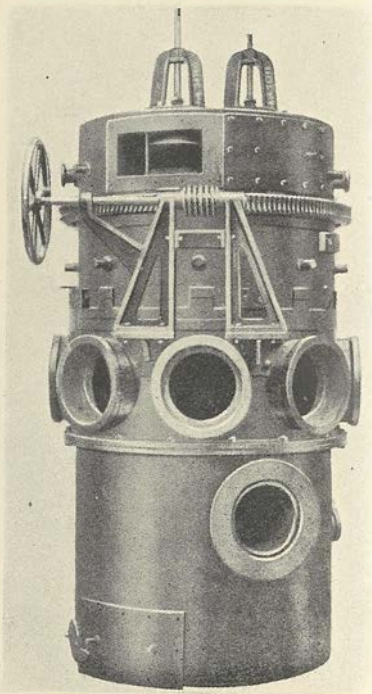


FIG. 354.—THE SADLER-COCKEY REVERSIBLE VALVE.

wards through the material. The valve certainly gives great elasticity in the operation of the purifiers ; for instance, the boxes can be worked firstly in downward direction and backward rotation, while the whole stream can be changed immediately into an upward and forward rotation. Thus, with four purifiers a variation of thirty-two changes is possible.

General Working Points

It is seldom advisable to put natural bog-ore into operation in the state in which it arrives, for some difficulty may be experienced in getting the material to commence working. When trouble is experienced in this way, the admixture of a small proportion of material which has previously been in use will generally overcome the difficulty.

It is as well to emphasize that the activity of the material is not necessarily in direct proportion to its iron content. Very much depends upon its physical condition, and it should be in as fine a state of division as possible.

When oxide is discharged from a purifier, after the preliminary foulings, it should not be returned to the box before all lumps are broken and the whole reduced to a powdery nature. Thorough pulverization will increase the efficiency of an oxide very considerably. Experiments have shown that whilst one sample of unpowdered oxide after four absorptions contained 37·3 per cent. of sulphur, the same material in the pulverized state contained 47·1 per cent., or an increase in sulphur of 27 per cent. The chief difficulty is that of ensuring that the smaller lumps, about half an inch in diameter, shall be effectively powdered. With hand labour alone the task is most laborious, and the only satisfactory result is obtained with one of the many special disintegrators now to be had.

Oxide may be prevented from caking heavily in the purifiers by adding a small proportion of coarse sawdust on each occasion that the material is changed ; whilst it should also be maintained in an alkaline condition. Even though ammonia be allowed to travel forward from the scrubber, the oxide may be found to give an acid reaction ; and, whether acid or neutral, enough finely powdered slaked lime should be added to the material to make it alkaline before it is returned to the purifier.

The importance of water content has already been referred to and, as there is, perhaps, a general tendency to employ oxide containing too much moisture rather than too little, special attention should be given to this point. Unfortunately, such questions as space-velocity and rate of travel of gas are too frequently governed by the apparatus at the engineer's disposal ; and, more often than not, the capacity of his available plant is very much below the recognized working basis. In general, however, calculations as to the quantity of material which will be required for the purpose of purification during a year's working may be based on an allowance of 25 to 30 cubic feet of oxide per million cubic feet of gas made per annum.

Whatever care may be bestowed upon the purification plant, it is occasionally the experience of every engineer to find that a perceptible trace of sulphuretted hydrogen is getting through into the finished gas. When such is the case, quick action is usually necessary, and the following three remedies are suggested :—

(1) If a small proportion of air is injected into the gas at the *outlet* of the purifiers, the trace will very frequently be temporarily cleared.

(2) If the material in the purifiers is obviously at fault, the top tier of the final box may be rendered extremely active *pro tem.* by being covered with a 2-inch layer composed of fresh oxide and chemically prepared material. The last named is

prepared by mixing together about 1 ton of ground copperas with an equal amount of lime, care being taken to ensure that the lime is present in sufficient quantity to make the mixture alkaline.

(3) The trace of sulphuretted hydrogen may be due to chemical action in the gasholder. The cause of and remedy for such derangements are discussed in the next chapter (*see* page 688).

Purifying Capacity of Material

One ton of good quality (Dutch) bog-ore may be considered capable of removing the sulphuretted hydrogen from two to two and a half million cubic feet of gas before it is finally spent. The quantity of lime required to extract carbon dioxide varies in accordance with the amount of inert matter or " core " present in the lime. In the usual way, from $3\frac{1}{2}$ to 4 yards are necessary per million cubic feet of gas. In the case of lime purification methods for complete removal of all impurities from the gas (*i.e.* when lime is used in conjunction with oxide), the quantity of lime may amount to $5\frac{1}{2}$ cubic yards per million cubic feet of gas.

Basis of Purchase

Purifying material in this country is generally purchased on the basis of analysis, *i.e.* so much per ton for a certain percentage of ferric oxide, with *pro rata* additions or reductions in accordance with the result of the test. The spent material is sold in accordance with its sulphur content, *i.e.* so many pence for each unit (or per cent.) of sulphur. For example, it may be assumed that a spent oxide contains 50 per cent. of free sulphur, *i.e.*, 50 units per ton. If the price per unit is 9*d.*, the value of the oxide is $(50 \times 9d.) = 450d.$, or 37*s.* 6*d.* per ton.

Small works frequently obtain their oxide on a loan basis, paying (say) a penny per ton of coal carbonized, and returning the spent material, when it has reached a certain sulphur content, to the supplier. As bog-ore and other purifying materials are frequently bought subject to certain conditions—particularly with regard to their content of ferric oxide or ferric hydrate—the following contract form, which may be adopted as a standard, has been included, in the belief that it may prove of some value to gas engineers having the purchase of oxide in view.

Specification and Form of Tender for Oxide of Iron

Description—The tender must state the description of material to be supplied.

Quantity—The quantity of material required is . . . tons.

Moisture—The moisture is not to exceed 50 per cent. by continued heating at 212° F.

Ferric Oxide—The quantity of ferric oxide (*i.e.* Fe_2O_3, inclusive of Fe_2O_3 as FeO) is to be not less than 25 per cent. in the material (in the natural state).

Price—The tender is to be at a rate per unit of ferric oxide (Fe_2O_3, inclusive of Fe_2O_3 as FeO) per ton in the condition as supplied.

Delivery—(As required).

Notice of Arrival—A week's notice of probable time of delivery should be given by seller to buyer.

Analysis—Within ten days of each delivery the seller and buyer shall exchange results of their respective analyses of sample. Should these results differ in the percentage of ferric oxide by not more than 2 per cent. the mean shall be taken, but if the difference exceeds 2 per cent. then a remaining sealed portion of the sample shall be submitted to an independent analyst (nominated by the buyer and agreed to by the seller), whose decision shall be final. The cost of such analysis shall be borne by the party whose result is the more divergent.

Forfeiture—Should the analysis of the sample of any delivery show that the conditions herein specified are not complied with, then it shall be at the option of the buyer to make such deductions from the account as shall compensate him for loss arising from the non-compliance.

Failure of Delivery—In the event of any failure on the part of the seller to deliver the material of stipulated quality and otherwise in accordance herewith, the buyer may procure a corresponding quantity of material from other parties, and any loss incurred by the buyer in so doing is to be borne by the seller, and to be deducted from any sum due to him, or, in the event of no such sum being due, is to be recoverable by action as if on a simple contract debt.

Payment—Payment shall be made within fourteen days of agreement as to analysis, less 2½ per cent.

Arbitration—Any dispute arising out of or in connection with this contract is to be settled by arbitration by two arbitrators (one to be named by each party) and an umpire, in manner provided by the Arbitration Act of 1889 or any statutory modification thereof.

Sampling and Testing Spent Oxide

The advance in the price of the sulphur unit in spent oxide, and, therefore, the greater accuracy necessary in both sampling and testing, has drawn attention to the want of standard methods acceptable to both buyers and sellers of spent oxide. Such standard methods exist for ascertaining the value of other sulphur raw materials. The buyers of spent oxide have therefore drawn up the following standard methods for sampling and testing spent oxide. These methods have been submitted to and approved by the National Gas Council.

Sampling—Samples sent for quotation purposes are often assumed to represent bulk deliveries. This is almost impossible to be the case, as the bulk of the oxide may subsequently dry further or become damper owing to exposure. It is also possible that portions of the heap of oxide which contain more or less sulphur may have become covered up and not included in the sample, however carefully taken. The spent oxide should, therefore, for invoicing purposes, be again sampled during loading and the greatest care taken to obtain correct proportions of lumps and fines, as these may contain different percentages of sulphur.

When deliveries are being made, daily samples are to be taken from every cart or wagon and collected in an air-tight receptacle. It cannot be too strongly emphasized that samples *must not* be allowed to lie about exposed to the risk of drying, but must be mixed, ground and bottled each day. When the delivery of the parcel

is completed all the daily samples are to be *at once* mixed and broken down, and for this purpose coning and quartering is the best method. The well-mixed oxide is poured several times on to a given centre ; this ensures an even distribution of both lumps and fines in the form of a cone. The cone is then flattened and quartered. Two opposite quarters are discarded and the remainder again mixed, coned and quartered until the quantity is reduced to a convenient amount. This is now crushed until it will *all* pass through a $\frac{1}{4}$-inch mesh sieve, and *at once* bottled.

The above operation must be carried out as quickly as possible to avoid alteration in the moisture content of the sample.

Samples should be of at least $\frac{1}{2}$ lb., and must be packed in air-tight bottles or tins ; no other receptacle may be used. In taking the necessary samples one must always be sealed and retained for reference.

Testing—Before carrying out the analysis, the *whole* of the sample is further intimately mixed and broken down and reduced to about 100 grammes, which is ground so that the whole quantity passes through a 20-mesh sieve.

Analysis

Moisture—Five grammes are dried for three hours at 100° C. in a water oven. The loss of weight found on cooling and reweighing represents the moisture.

Sulphur and Tar—The dried residue from the moisture determination is to be extracted for two hours in a Soxhlet's apparatus with freshly distilled carbon bisulphide. The carbon bisulphide is then distilled off, the flask cautiously blown out with air and dried for two hours at 100° C. in the water oven. The flask is then placed on a hot sand bath until the sulphur has just fused, care being taken that no loss by overheating and volatilization takes place. After the flask has cooled completely it is again carefully blown out with dry air and again weighed. The increase in weight multiplied by 20 gives the percentage of sulphur plus extracted tarry matter.

Estimation of the Sulphur—15 c.c. of concentrated (95 per cent.) sulphuric acid are poured on to the sulphur and tar in the flask, and the whole is heated for two hours at 100° C. in a water oven. After cooling, the contents of the flask are diluted with water, filtered, washed free from acid and dried. The dried filter paper with contents is placed in a Soxhlet's tube and again extracted with carbon bisulphide. The bisulphide is distilled off, and the residue fused exactly as described above. The weight of the residue in the flask multiplied by 20 gives the percentage of sulphur free from tarry matter in the oxide originally taken.

THE OPERATION OF DRY PURIFIERS

Present-day systems of purification may be classified under two headings, namely—

(*a*) Series purification.
(*b*) Rotation purification.
,, (1) Forward system.
,, (2) Backward system.

The difference between the two systems is in reality a constructional one, and depends merely upon whether a set of purifiers is arranged around a centre valve, as shown in Fig. 355, or in a line, with a number of single valves, as seen in Fig. 357. For the operation of the rotation system it is not necessary that the four purifiers should be set one at each corner of a square, although this arrangement is the most convenient. With oxide purification the *modus operandi* usually adopted is that of having three of the four boxes in action at a time ; that is, gas is passing first through

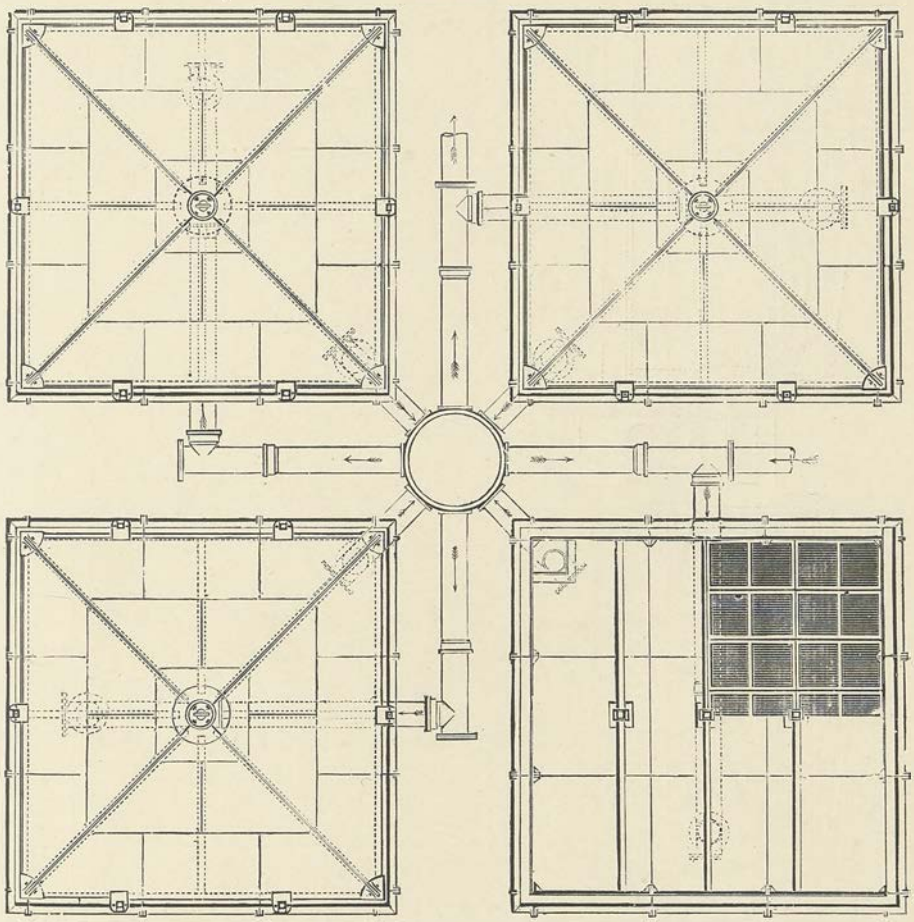


Fig. 355.—Rotation System of Purification.

the first box or "taker," then through the second, and lastly through the third, by which time it is wholly deprived of sulphuretted hydrogen. After a time the oxide in the first box becomes "fouled" and useless for the further extraction of H_2S until the material is revivified. No. 4 box is then put into action and No. 1 box is shut off, so that the original second box now becomes first "taker." In the mean-

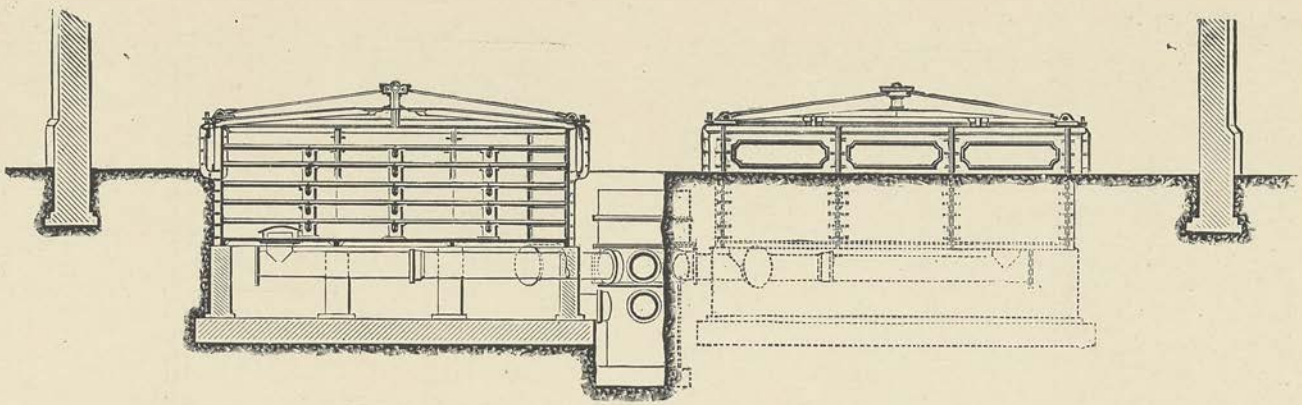


FIG. 356.—SECTION THROUGH PURIFIERS AND CENTRE VALVE.

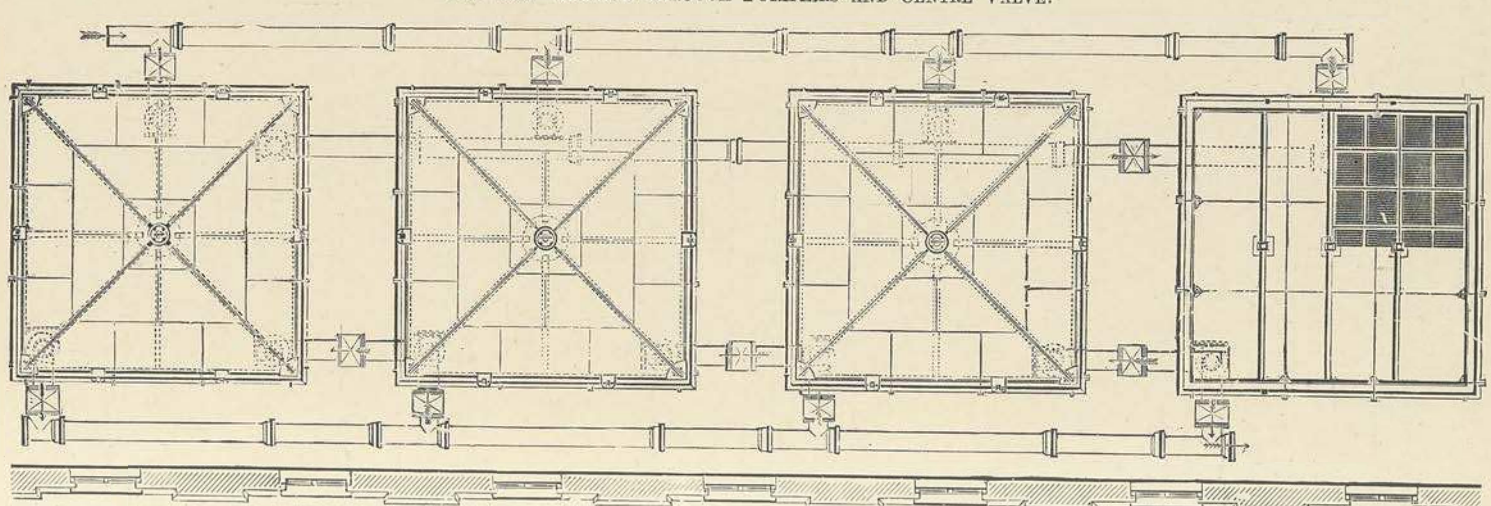


FIG. 357.—PURIFIERS ARRANGED IN SERIES.

time No. 1 box is thrown out, revivified and remade, and is then ready for action once more as the final box when required. Thus we get—

First series→ 1 → 2 → 3, 4 off.
Second „ → 2 → 3 → 4, 1 off.
Third „ → 3 → 4 → 1, 2 off.
Fourth „ → 4 → 1 → 2, 3 off.

In this way each purifier comes in for an " off " period, so that it may be dealt with when it has become " fouled." The system of working as described applies to purifiers arranged either in series or around a centre valve. It should be mentioned that in the majority of works, with the exception of those of small dimensions, a

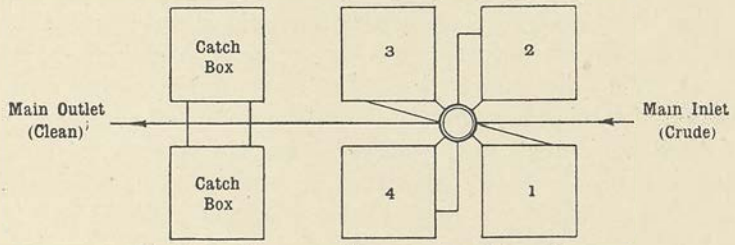


FIG. 358.—ROTATION SYSTEM WITH CATCH-BOXES.

further safeguard against the possibility of sulphuretted hydrogen getting through to the district mains is provided for by the insertion of two " catch-boxes," as shown in Fig. 358.

Within recent years a new and effective method of arranging the series of purifiers has come into operation, and is known as " backward rotation." It differs essentially from the ordinary system in that when a box operating first in the series becomes fouled the clean box is placed first in position instead of last. Thus if four purifiers are operating in series, we shall have—

First series → 1 → 2 → 3 → 4
Second „ → 4 → 1 → 2 → 3
Third „ → 3 → 4 → 1 → 2, and so on.

By the adoption of this method it is claimed that where " catch-boxes " have previously been in use they may be dispensed with, although such a procedure would seem to be attended by some risk. The author finds that where a works has outgrown its purifying capacity the method is particularly suitable, and instances are known where the cubical capacity available is so low as 0·25 cubic feet per 1,000 cubic feet of gas per diem, and yet no trouble is experienced.

Another method which has found some favour is that known as " forward rotation." That is to say, when the first " taker " becomes fouled it is placed at the end of the series, thus—

First series → 1 → 2 → 3 → 4
Second „ → 2 → 3 → 4 → 1, etc.

When working in this manner it would seem essential that "catch-boxes" should be used, owing to the tendency of the final purifier to throw off a certain amount of sulphuretted hydrogen. In fact, it may be said that in all cases the introduction of "catch-boxes," although theoretically unnecessary, is a wise precaution against sudden eventualities.

LIME PURIFICATION

Lime in the hydrated or slaked condition is an active absorbent of sulphuretted hydrogen and carbon dioxide, and—under certain conditions—is capable of removing a proportion of the remaining sulphur compounds. On the smallest of works, where the amount of sulphur recoverable would (owing to cost of carriage and other considerations) not materially affect the receipts, lime is used exclusively. On the larger works its use has been largely discontinued, owing to the general removal of statutory restrictions relating to sulphur compounds—other than sulphuretted hydrogen—in the district gas. The admixture with coal gas of water gas, which contains but a small proportion of sulphur compounds, has tended to curtail considerably the total quantity of these compounds in the mixed gases. In the case of some of those concerns where coal gas alone is manufactured, the removal of a portion of the carbon disulphide is still occasionally practised. In some instances it is effected by methods known as "hot" purification, but more generally with the aid of lime.

The sulphur compounds remaining in the gas after the sulphuretted hydrogen has been removed consist mainly of carbon disulphide (which is present to the extent of about 0·02 per cent.). Of the remainder, thiophene is the chief constituent, but so far the other compounds have not been definitely determined.

In studying purification by lime it is, primarily, necessary to bear in mind that of the three acid gases involved, carbon dioxide has the strongest acidic properties, sulphuretted hydrogen following next, with carbon disulphide last in order. Thus when the crude gas meets an active base such as slaked lime there is a tendency for the most vigorous acid to be absorbed first. The combination between lime and CO_2 takes place on simple lines, as follows—

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

Sulphuretted hydrogen reacts with lime in the following manner—

$$Ca(OH)_2 + H_2S = CaS + 2\ H_2O.$$

Thus, as before explained, the whole of the purification can, by employing a sufficiency of material, be carried out with lime. The great drawback to such methods, however, is the loss of the sulphur, which cannot be recovered in useful form, as is the case where oxide of iron is employed. As explained above, when the gas from the wet purification plant enters the first (lime) purifier, the CO_2 is absorbed to the greatest extent, although some sulphuretted hydrogen is also removed. As the process proceeds, this sulphuretted hydrogen is displaced by the stronger acidic nature of the CO_2, and the spent material consists almost wholly of the carbonate. The manner in which the sulphide is displaced is shown as follows—

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S.$$

If a small proportion of air is admitted to the purifier, a certain amount of the calcium sulphide will be converted into free sulphur, and will thus escape ultimate decomposition by CO_2.

In preparing ordinary dry lime for use in purifiers, the material should be well slaked with water, and as much as possible of the " core " (*i.e.* inert matter, such as chalk, stones, etc.) should be removed by screening. In addition to the water actually required for slaking, the lime should contain a further 30 per cent. of moisture. Excessive watering will, however, give rise to caking. Caking, and consequent loss in power of absorption, may also result from too much sulphuretted hydrogen having been passed through the lime, this occasionally occurring in those boxes which are set aside for the removal of CS_2. So far as the thickness of the layers of lime is concerned, it may be pointed out that a depth of about 8 inches is preferable to the thinner layers of 4 and 5 inches which were often employed in the past. Whatever the type of purifying material, a thin layer is likely to " blow " and thus permit a certain amount of gas to escape untreated.

When gas manufactured at the larger works is to be freed from the whole of its impurities, it is usual to instal a system in which oxide of iron and lime are used in conjunction. In this way the greater proportion of the sulphuretted hydrogen may be recovered and not wasted. Many methods of operating the purifiers for this purpose have been employed, but the whole principle may be readily grasped by a consideration of the following system. It consists in the main of four sets of purifiers operated in rotation :—

First set.	Contains lime.	These remove the whole of the CO_2 and some H_2S, which is afterwards displaced by CO_2. Some CS_2 is also absorbed.
Second set.	Contains oxide of iron.	These remove the whole of the H_2S, including any which may be displaced from the lime in the previous set.
Third set.	Contains lime.	This lime has been previously " sulphided " and removes the bulk of the CS_2. It will not remove the *whole* of the sulphur compounds.
Fourth set.	Contains oxide of iron.	These vessels act as " catch-boxes " and remove any H_2S which is disengaged from the third set.

In order to understand the method of working, it must be borne in mind that ordinary slaked lime—*per se*—has no action upon carbon disulphide. The chemical reactions involved in the elimination of this impurity are somewhat complex and are set out below. First, it will be seen that the calcium hydrate must be " sulphided " by passing through it a stream of sulphuretted hydrogen. For this purpose the crude gas, after travelling through the first set of purifiers, is led direct into the third set, the oxide vessels comprising the second series being by-passed for the time. Working in this way is continued until sulphuretted hydrogen is noticed at the outlet of the lime boxes forming the third set. At this juncture the two oxide vessels (second set) are put into action. The lime vessels forming the third set are then in a condition to absorb carbon disulphide and purification proceeds as outlined above. Of the total CS_2 present, up to 20 per cent. may be removed by the first lime vessels, 55 per cent. by the sulphided boxes, whilst about 25 per cent. will remain in the gas.

The total amount of sulphur compounds (other than H_2S) in crude coal gas varies in normal cases from 35 to 50 grains per 100 cubic feet, although in exceptional instances the figure may rise to 60 grains.

Chemical Reactions in CS_2 Removal

The exact nature of the chemical reactions occurring during the removal of carbon disulphide is still open to question. It should be stated at once, however, that although the active medium consists primarily of calcium sulphide, and although this compound in the moist state is capable of absorbing CS_2, the reaction is certainly *not* represented by the following simple equation—

$$CaS + CS_2 = CaCS_3.$$

The most enlightening work on the subject has been carried out by Veley (1885), whose theory is generally accepted as correct. This investigator concluded that the compound which absorbs the CS_2 is not calcium hydrosulphide (as has sometimes been supposed), but calcium hydroxyhydrosulphide (CaS,H_2O, or $CaOH,SH$). The hydroxyhydrosulphide, it is understood, is formed in the following manner :—

(1) Calcium hydrosulphide results in the first place—

$$Ca(OH)_2 + 2\ H_2S = Ca(SH)_2 + 2\ H_2O.$$

This compound $Ca(SH)_2$ has no action on the CS_2.

(2) By the addition of water or oxygen the hydrosulphide is then converted into the hydroxyhydrosulphide—

$$(a)\ Ca(SH)_2 + H_2O = CaOH,SH + H_2S$$

or

$$(b)\ 2\ Ca(SH)_2 + O_2 = 2\ CaOH,SH + 2S.$$

The former reaction is the one most likely to occur in practice, for oxygen may not be present at this stage.

(3) The CS_2 and calcium hydroxyhydrosulphide intereact as follows :—

$$(a)\ 2\ CaOH,SH + CS_2 = H_2S + Ca(OH)_2,CaCS_3$$

or

$$(b)\ 3\ CaOH,SH + CS_2 + H_2O = 2\ H_2S + 2\ Ca(OH)_2,CaCS_3.$$

In either case it will be seen that sulphuretted hydrogen is thrown off and is absorbed in the final oxide boxes.

Derangements with lime purification are only too common, owing to the difficulty of applying in practice a series of somewhat delicate chemical operations. Occasionally the sulphided boxes will actually throw off carbon disulphide, and thus increase instead of reduce the sulphur compounds in the gas. If adequate precautions are taken, however, this trouble should not occur. The chief necessity is that of ensuring that no CO_2 should be allowed to travel forward to the CS_2 boxes. The CO_2 will instantly displace the carbon disulphide, which must then travel forward with the gas. An important point to bear in mind is that the sulphiding action should never be carried out at a low temperature, otherwise the activity of the material may be impaired. The temperature of the lime during this operation should, if

possible, be maintained at about 10° C. (50° F.), although this will not always be possible during winter. An inactive purifier may frequently be revivified by the injection of a small quantity of air, the oxygen probably reacting with the hydrosulphide and oxidizing it to hydroxyhydrosulphide, as shown in the above equation.

THE CONSTRUCTION OF PURIFIERS

Purifiers, as used in gasworks, are generally constructed of cast iron (ferro-concrete has lately been employed), and may be classified into three distinct groups :—

(*a*) Water-lute vessels, the type originally employed and still largely made use of, the lute varying from 15 inches to 40 inches deep.

(*b*) Dry-lute purifiers, a modification of the above, in which the use of a hydraulic joint is dispensed with.

(*c*) Purifiers, such as Green's well-known type, in which small sections of the cover are alone removable. These are fitted with dry joints.

All the above groups may be erected—

(*a*) At ground level, or partially buried.

(*b*) Above ground level, *i.e.* overhead types.

So far as the arrangement of the purification plant is concerned, irrespective of the design of the actual vessels, it is essential to provide facilities for rapid and economical discharging and charging. It will be seen at once that where ground space is a consideration the overhead system should be decided upon, as in this way a floor space for mixing and revivification is provided beneath the vessels. With the ground-level system a special preparing floor must be arranged for alongside the boxes. When ground-level or sunk purifiers are employed they usually rest on a plain, flat slab of concrete. The nature of the subsoil should, however, be carefully ascertained, as piling or other methods may be necessary (*see* page 42). Overhead types are supported, usually from 8 to 12 feet above the lower floor, on cast-iron columns or steel stanchions braced together by cross girders, which provide a seating for the boxes.

In large works the purification plant is comparatively costly, but some outlay may be saved by arranging the vessels so that they butt one on to another, with one division plate, thus saving a side plate between each pair. This arrangement applies to dry-lute purifiers alone.

With overhead purifiers the gas outlets are often constructed in such a manner as to form a discharging shoot to the floor below ; in this way the spent material may be easily shot to the lower level and spread out in layers to undergo revivification. After revivification the material is carried up to the upper floor, in the smaller works by manual labour, and in larger works by some form of lift, elevator, or crane. With overhead purifiers the operation of discharging and recharging may be carried out in a half or a third of the time required with ground-level systems, where a considerable amount of wheeling to and fro has to be done. Other advantages of the overhead types are that they are very much more accessible for painting and repairs, whilst there is less capital outlay on land. The outstanding merit of the ground-level purifiers is their comparatively moderate cost, whilst maintenance

charges are lower, owing to the absence of heavy girder-work and stanchions. In cases of treacherous subsoils it may not be possible to adopt the overhead type, owing to the impossibility of concentrating the whole load on small areas (*i.e.* the bases of the standards). In spite of their good features, the overhead purifiers are comparatively rare. The explanation probably lies in the fact that the interest accruing from the additional capital expenditure involved, combined with increased maintenance costs, would probably be a greater item than the saving which would be effected in labour.

Concrete Purifiers

The recently constructed purifiers at the Tottenham gasworks provide the most notable example of the application of concrete for this purpose. The capacity of the installation is 5 million cubic feet of coal gas per diem, the number of purifiers

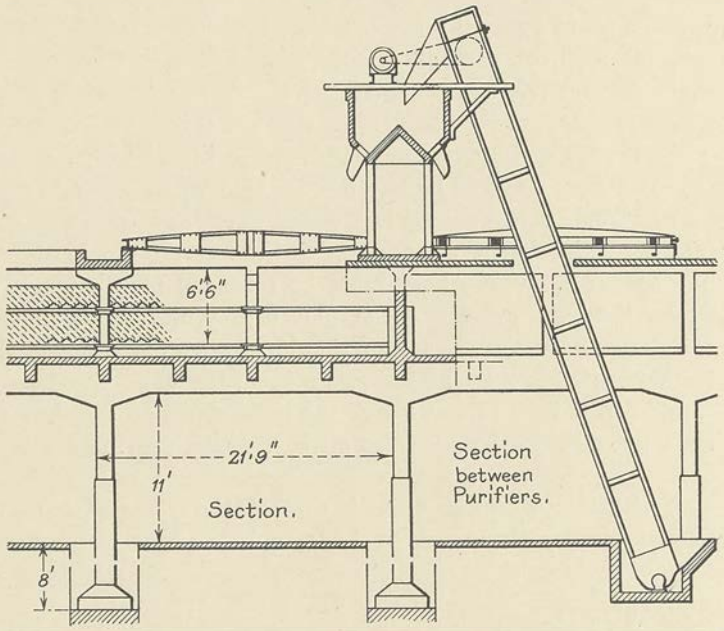


Fig. 359.

being five, each 56 ft. 1 in. by 42 ft. 6 in. inside, with an internal depth of 6 ft. The main set is formed by four of the boxes, the remaining box acting as a catch vessel. The general construction of the installation is shown in Fig. 359. To minimize the effect of temperature the main series of four boxes was divided into two pairs with an intervening space wide enough for an elevator. The catch vessel was constructed as an entirely separate structure.

The main beams, 33 inches deep, are divided into four spans and are carried on columns 15 inches square for the interior and 13 inches square for the exterior. These columns have reinforced feet resting on mass concrete foundations with a steel

mat to distribute the pressure. The secondary beams are 21 inches deep, the floor slab 5 inches thick, the sides 7 inches thick, and the decks and gangways 6 inches thick. Only five pillars, 10 inches square, are used internally to support the gangways. These pillars form ties between the floor and top when the purifiers are closed and under pressure. The mixture used was one of 4 : 2 : : 1, but for the columns a slightly richer mixture was used, as they were made horizontally and elevated into position when set. To render the concrete gas-tight the purifiers were treated on the inside with "Ironite." Special provision was made to keep the weight of the massive 24 inches diameter pipes, forming the gas mains, from coming on to the floor of the purifiers. There are also four discharge outlets provided for emptying each purifier.

THE SIZE OF PURIFIERS

It is essential that purifiers should be of ample capacity for the work they are called upon to perform. Nothing is more detrimental to working efficiency than an overloaded series of purifiers, and the cost of an additional unit can soon be expended in labour charges owing to the shorter life of the material when capacity is inadequate.

For oxide purification alone it will suffice if the following allowance is adhered to :—

Set of four purifiers : Allow, as a minimum, an area of 0·5 square foot per 1,000 cubic feet of gas to be purified per day. This is the allowance for *each* box, and not the total area of all boxes. If lime is to be used for the removal of sulphur compounds, the figure should be increased to 0·6 square foot, or 0·65 to 0·7 square foot if no "catch-boxes" are available.

So far as the *total* area of all boxes is concerned, Hunt states that for lime and oxide purification combined 20 to 30 square feet per ton of coal carbonized per day should be allowed.

As has already been pointed out in Chapter I, it is essential to make provision for future requirements, and so far as a new works is concerned it is preferable to erect only three boxes to each unit, provision being made for the easy addition of the fourth when it is required. In such cases the three boxes should be constructed with a capacity 50 to 60 per cent. larger than that necessary in a group of four ; that is, an allowance for each box of 0·8 to 0·85 square foot per 1,000 cubic feet of gas passing per day. Considering the case of a very small works with prospects, it would be advantageous to provide only two boxes at the outset. Each box, however, should be of large capacity, say 1·5 to 1·7 square feet per 1,000 cubic feet per day. In this way there will be very little increase in first cost (as compared with a system of three small purifiers), and money will be saved when extensions are carried out.

Within certain high and low limits purifiers may be constructed of almost any dimensions. They are invariably square or rectangular in shape. The minimum size is usually 4 feet square by 3 feet in depth, whilst the maximum size will not, except in abnormal cases, exceed 1,600 superficial feet, *i.e.* boxes having sides of 40

feet. A vessel of this description would be capable of dealing with about 2¾ million cubic feet per diem; consequently, in the case of those works making more than this quantity of gas, it is preferable to split the stream prior to reaching the purifiers and to treat it in two (or a number of) separate units.

An examination of the multitude of formulæ for calculating purifier capacity which have from time to time been suggested shows that in the past the variation in opinion has been remarkable. As an example, it is instructive to note the contradictory results which are obtained by working to the following selection of formulæ, all of which were more or less accepted at different periods in the history of gasmaking.

1. *Clegg.* Allow 1 square foot of purifier area per 3,600 cubic feet of gas per maximum day.
2. *Hughes.* Allow 1 square yard of sieve area per 1,000 cubic feet of gas per maximum day.
3. *Colson.* Allow 1 cubic foot internal content of purifier per 376 cubic feet of gas per day.
4. *F. Livesey.* Allow 1 square foot of area per 2,500 cubic feet of gas per diem.
5. *Wyatt.* Allow 33 cubic feet, or 50 square feet of area per ton of coal per diem.
6. *L. T Wright.* Where the Beckton method of eight vessels is employed, allow for each box an area of 0·4 square foot per 1,000 cubic feet of gas per day.
7. *Reissner.* Allow 1·17 square feet per box per 1,000 cubic feet of gas made per day.
8. *French Rule.* Bulk of oxide should be equivalent to one-twentieth of the volume of gas passed per hour.

American Rules

9. *Earnshaw.* Experiments were conducted on small purifiers with gas passed at 1,000 cubic feet per day per 0·4 square foot and 0·5 square foot of area. In the latter case the efficiency of the oxide was 57 per cent. greater than with the former allowance.
10. *E. S. Jones.* Volume of oxide required =

$$\frac{\text{Max. make of gas per hour} \times \text{grains of } H_2S \text{ in gas}}{4{,}000}.$$

A recent method of calculation which is employed in America is that known as the Steere formula, namely—

$$A = \frac{G \times S}{3{,}000\ (D + C)}.$$

Where A = cross-sectional area in square feet of the oxide bed in each box of a given set.

G = maximum make of gas per hour in cubic feet.

S = a predetermined factor which is based upon the quantity of sulphuretted hydrogen in the crude gas at inlet of purifiers.

D = depth (in feet) of oxide in the whole set of purifiers. Thus, if depth of oxide in each box is 4 feet and there are four boxes, then D = 16.

C = a factor dependent upon the number of boxes in the set. Thus for two-box series C = 4, three-box series C = 8, four-box series C = 10.

The value of S is determined from the following table :—

Grains H_2S per 100 c. ft. unpurified gas.	Factor S.
1,000 or more	720
900	700
800	675
700	640
600	600
500	560
400	525
300	500
200 or less	480

The above formula, it will be noted, gives the necessary capacity as much smaller than that commonly worked to in this country. For instance, if consideration is given to a works with a make of 1,800,000 cubic feet per maximum day, the following results are obtained :—

(*a*) By the author's formula (page 21) 900 square feet area for each box.
(*b*) By the Steere formula 600 ,, ,, ,,

General Construction

The body of a purifier is invariably constructed from cast-iron plates, bolted together, the joints being made in the usual manner from borings, or faced and red-leaded (*see* page 523). On the other hand, it is essential that the lid of the vessel should be light, to which end it is built up from steel or wrought-iron plates (usually $\frac{1}{4}$ inch thick) and suitably braced with rolled steel sections. Owing to the necessity of maintaining a clear passage for the cover in the water-lute, the flanges of purifier plates are frequently arranged in a somewhat unconventional manner. The construction of the lute, showing the way in which the flange changes over from the exterior to the interior, and the method of bolting on the separate lute plate and the base plate, will be followed from Fig. 360. It should be noted that in the case of a ground-level vessel the flanges would be internal, and not external. In this way the joints and bolts, being inaccessible from below, can be attended to from the interior. So far as the thickness of the cast-iron plates employed is concerned, the following figures may be taken as satisfying all requirements :—

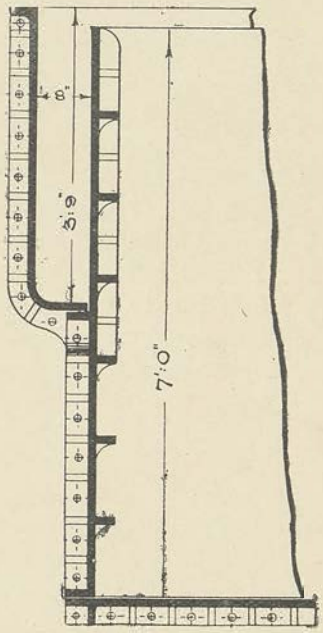


Fig. 360.—Purifier Side Plate (Cast-iron).

Purifiers up to 10 feet square	$\frac{5}{8}$ inch plates.
„ „ 20 „ „	$\frac{11}{16}$ „ „
„ above 20 „ „	$\frac{3}{4}$ „ „

Flanges are cast $\frac{1}{16}$ inch or $\frac{1}{8}$ inch thicker.

The common methods of jointing cast-iron plates together are described and illustrated on page 523. Side plates are usually cast with a width of four or five feet for standardization.

The smallest purifiers are usually three feet deep, and the largest sizes vary from six to eight feet deep. Intermediate sizes are four to six feet in depth. As a rule for ascertaining the required depth for a purifier, the author suggests the following :—

$$\text{Depth in feet} = \sqrt[4]{\text{Total superficial area}} \times 1{\cdot}1.$$

The depth may then be taken to the nearest foot—portions of a foot being neglected owing to the general practice of casting these plates in lengths divisible by a foot. For smaller purifiers, that is boxes with an area up to 300 square feet, multiply by 1·3 instead of 1·1.

Thus, considering a purifier 30 feet × 30 feet—

$$\text{Total area} = 900 \text{ square feet}$$

$$\sqrt[4]{900} = 5{\cdot}47 \text{ and } 5{\cdot}47 \times 1{\cdot}1 = 6{\cdot}017 \text{ feet.}$$

Therefore the required depth is six feet.

Again, with a smaller purifier, say 12 feet × 16 feet—

$$\text{Total area} = 192 \text{ square feet.}$$

$$\sqrt[4]{192} = 3{\cdot}725 \text{ and } 3{\cdot}725 \times 1{\cdot}3 = 4{\cdot}84 \text{ feet.}$$

Accordingly required depth is 5 feet.

PURIFIER CONNECTIONS

The size of the gas main working in connection with purifiers may be best calculated as follows :—

Diameter of pipe in inches $= \sqrt{\text{area of each box in square feet.}}$ For small purifiers (up to 60 square feet area) the result can be taken as it stands, but for medium-size boxes deduct one-sixth and for large boxes one-fourth. As an example, consider a square purifier with 40 feet sides, then—

$$\begin{aligned} \text{Diameter of pipe in inches} &= \sqrt{1{,}600} \text{ less one-fourth} \\ &= 40 - (\tfrac{1}{4} \text{ of } 40) \\ &= 40 - 10 = 30 \text{ inches} \end{aligned}$$

i.e. a 30-inch main would be used.

Another rule which may be conveniently employed is that due to Milbourne :—

Diameter of pipe in inches =

$$\frac{\text{Length and breadth of purifier (in feet)}}{2} \times 0{\cdot}7.$$

Thus, with a 40-feet square purifier we get—

$$\frac{40+40}{2} \times 0{\cdot}7 = \frac{80}{2} \times 0{\cdot}7 = 28 \text{ inches.}$$

In such a case it would be decided to put in the next largest standard size of main, *i.e.* a 30-inch pipe.

Ordinary water-lute purifiers are constructed from side plates having the lute made as portion of the plate itself, or with the lute as a distinct casting (Fig. 360). From the economical standpoint the former type is preferable, first, owing to the initial outlay being less, and secondly, on account of the greater ease with which it is erected. With both types the most costly section is the corner plate. The depth of the water lute (usually half the depth of the box) is an important consideration,

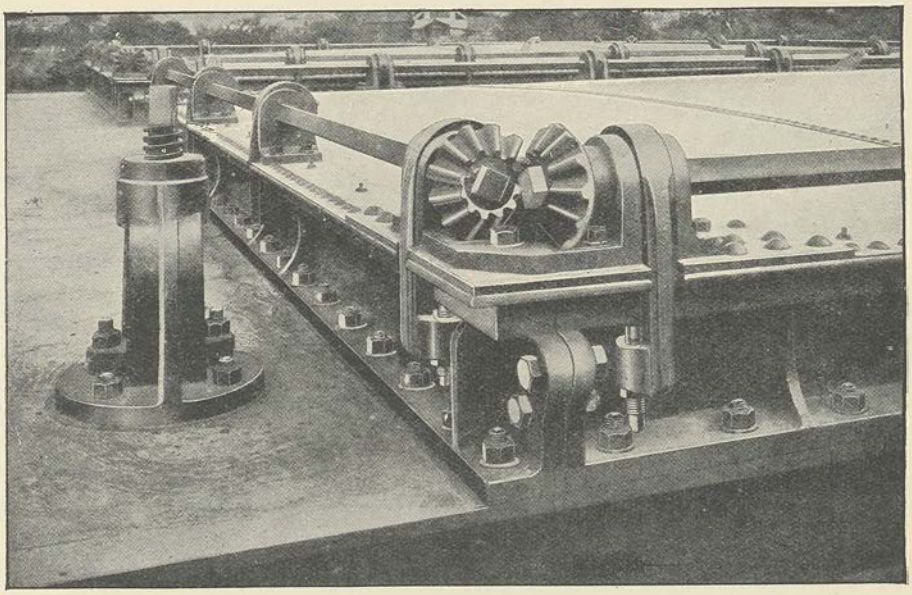
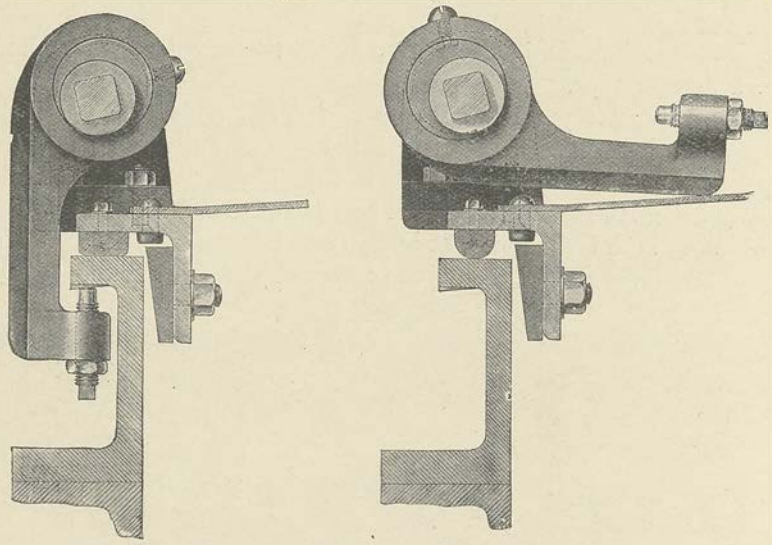


Fig. 361.—Milbourne's Cover Fastener.

and it must be ensured that the depth of water obtainable will be sufficient to withstand the heaviest pressure which is likely to prevail inside the vessel. Covers for purifiers may be either flat or curved. In either case some form of trussing or stiffening will be required, and strong curbs should be provided when the vessel is of any size. So far as lifting is concerned, the cover, when of the domed type, is usually provided with a stout lifting-eye attached to straps, which are in turn riveted to the side plates and again to the bottom curb. With the flat cover, which is invariably employed with dry lutes, the lifting is frequently carried out by means of eyes attached to the external stiffening sections or trussing. The floor plates of purifiers should, when possible, have internal flanges, thus avoiding local stress on the bottom plates. The box, moreover, when of the ground-level type, obtains a level bearing on the

concrete and the joints are readily accessible. The plates of purifiers should be designed with as few different patterns as possible, whilst an eye must be given to



a *b*

FIG. 362.—MILBOURNE'S COVER FASTENER, SHOWING (*a*) CATCHES SHUT, AND (*b*) CATCHES OPEN.

the avoidance of awkward castings. When the plates are large, they must be adequately stiffened. Some means should always be provided for by-passing the

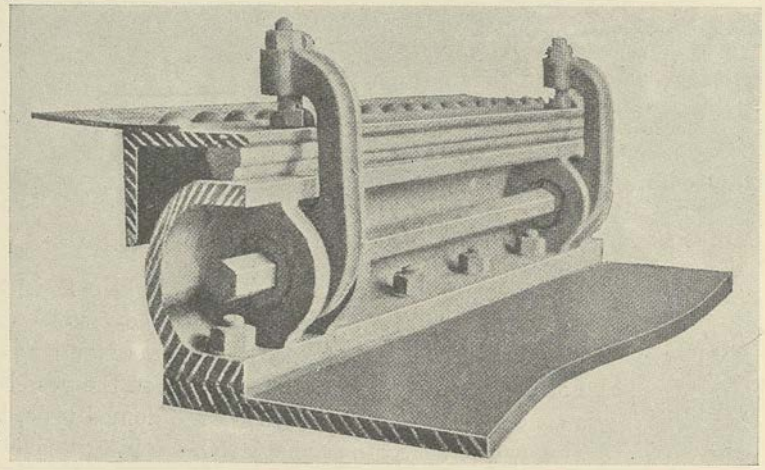


FIG. 363.—"ECLIPSE" COVER FASTENER, SHOWING RUBBER JOINT.

separate tiers of material should this be necessary owing to abnormal back-pressure. Special tier-valves are made for the purpose, although a mild-steel plate attached to a rod passing through a stuffing-box on the purifier will answer the

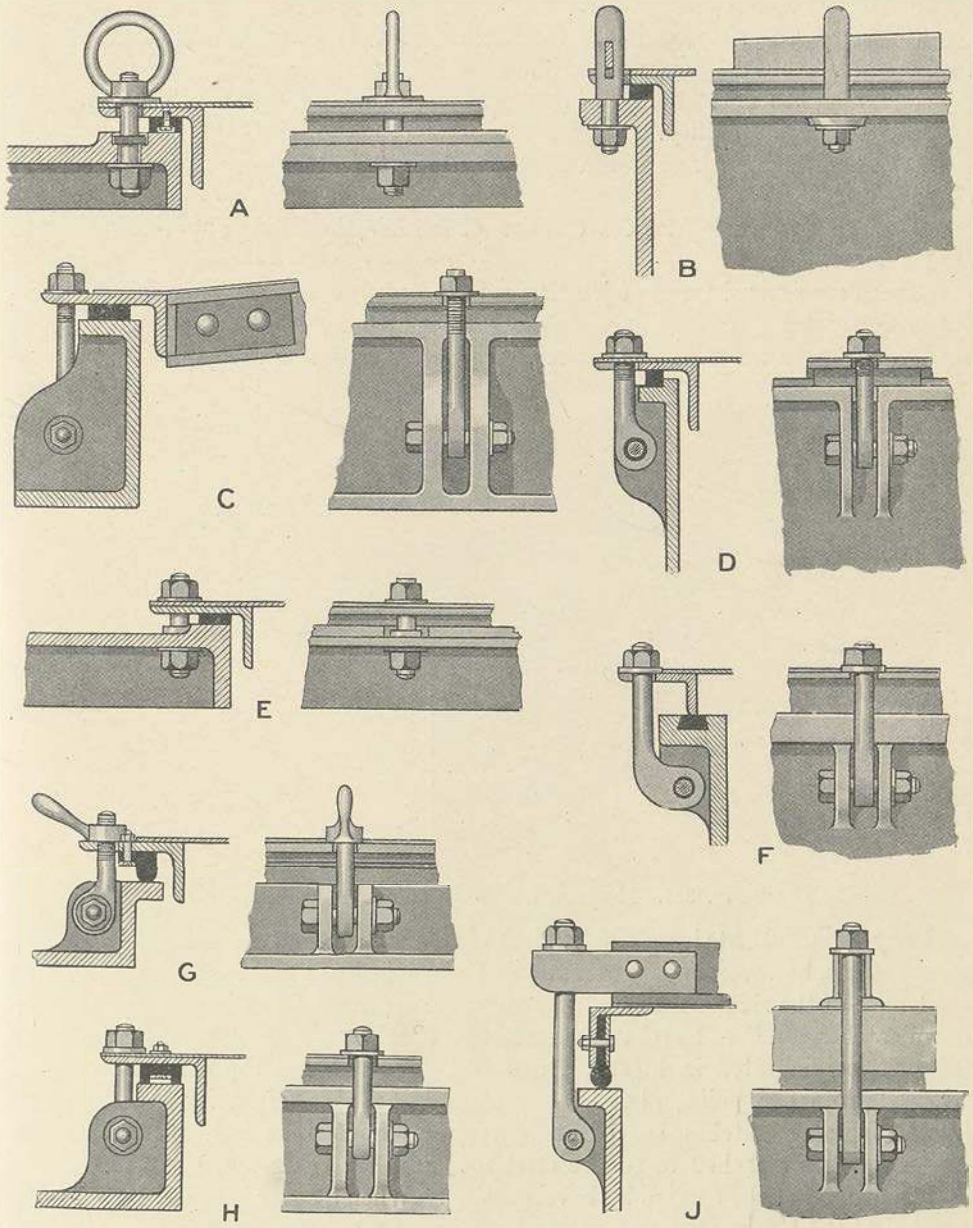


FIG. 364.—FASTENERS FOR LUTELESS COVERS.

purpose equally well. This plate lies flat on the grid, and is not covered with the purifying material. In addition, it is a good plan to have a pressure cock fitted to each layer.

The chief advantages of the dry-lute purifiers may be summarized as follows :—

(*a*) Lower initial cost.

(*b*) Increased safety, owing to the elimination of the water seal, which is liable to evaporate, thus lessening the seal.

(*c*) They will not " blow " in the event of a temporary excess of back-pressure.

(*d*) Greater durability.

(*e*) There is no risk of frozen lutes in winter, with the consequent absence of anxiety.

(*f*) Owing to the lighter construction of the lids, the lifting apparatus is not so cumbersome.

There are several types of jointing material made use of with luteless purifiers. A gas-tight joint is ensured by a strip of rubber or tallowed hemp inserted between the flanges of the cover and side plates. The two flanges are then pulled together by

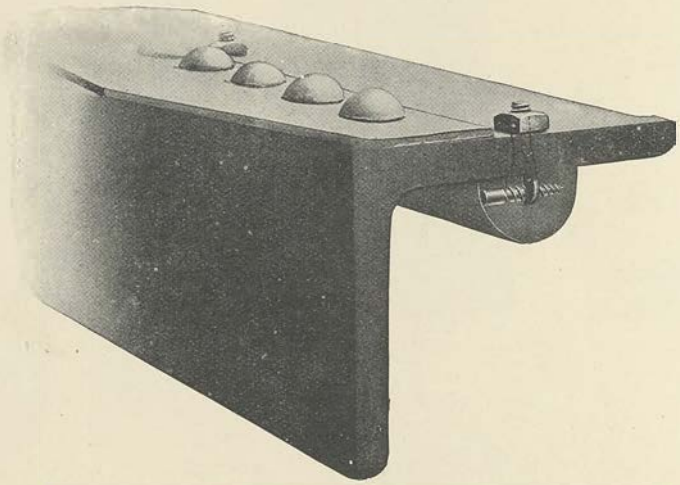


Fig. 365.—Milbourne's Jointing for Dry Lutes.

ordinary bolts and nuts inserted at a pitch of about twelve inches. The most effective arrangement, however, is an automatic catch attached to a shaft running throughout the length of the side of the box. By means of an eccentric movement the holding-down catches can then be released simultaneously along the whole side. Milbourne's fastener is illustrated in Figs. 361 and 362. In this case the complete cover is released from one point, about thirty seconds being required for the operation. Special fastener clutches, spaced at intervals of about three feet, are actuated by eccentric discs attached to square steel rods running along the edge of the cover and connected at the corners by bevel gearing. When a cover is unfastened the first portion of the stroke of the operating lever imparts a downward vertical motion to the fastener clutch, whilst the second portion of the stroke swings the clutches out of position. When a lid is tightened up the reverse occurs. The " Eclipse " fastener is shown in Fig. 363. In this case the fastener is fixed to the side of the purifier, the steel shaft running beneath a raised cast-iron flange. When the cover is released the whole of the catches fall clear, and leave the cover a free passage for lifting.

So far as the various means of jointing are concerned the main difference lies in the formation of the rubber strip and as to whether it is applied to the upper or lower curb. Common types are shown in Figs. 363, 364, and 365.

LIFTING-GEAR

In small works the cover may be lifted by means of eyebolts or hooks attached to it, with pulley blocks running on a horizontal joist overhead and supported at each end by columns of timber, cast iron or steel. In medium-sized and large works, a common lifting-gear is that composed of two " A " frames running on rails on either side of the purifiers. The apexes of the two " A " frames are then connected by a single joist or a lattice girder. Travelling can be effected by hand, a purchase being obtained by means of suitable toothed gearing. The actual lifting of the cover may be carried out by pulley blocks, or in the case of very heavy covers by means of hydraulic or other power. Where electric power is available an overhead crane of the shop or foundry pattern can be used with advantage.

THE PRESSURE ON PURIFIER COVERS

It should be borne in mind that in the case of purifiers with a water-luted cover, the internal gas pressure on the box and cover is limited by the depth of water in the seal. The pressure which the cover has to withstand, therefore, is the total pressure of the gas on its (the cover's) area, less the weight of the cover itself. Holding-down lugs have, therefore, to be constructed accordingly. The bracing of the cover must also be strong enough to avoid distortion of the members, with its consequent tendency towards leaking rivets. When abnormal pressure occurs the lute in this type of purifier forms the safety valve, and the seal " blows."

In dry-luted covers the pressure provided for must be greater, and a normal specified test would be $1\frac{1}{2}$ lb. per square inch, *i.e.* a water column of 3 feet 6 inches. As the holding-down bolts are closer together than in the water-lute purifier, no difficulty is found in designing them of sufficient area to withstand the upward tension. When domed tops are employed the pressure is less than with the flat top, and an allowance for this can accordingly be made.

PURIFIER GRIDS

The most usual form of grid employed for supporting the material within the

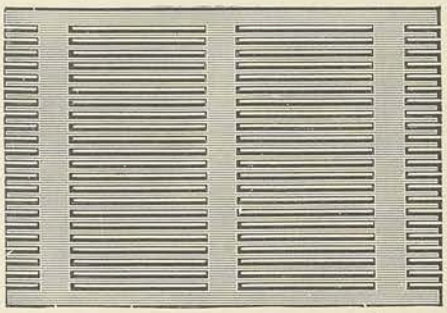


FIG. 366.—OPEN-ENDED PURIFIER GRID.

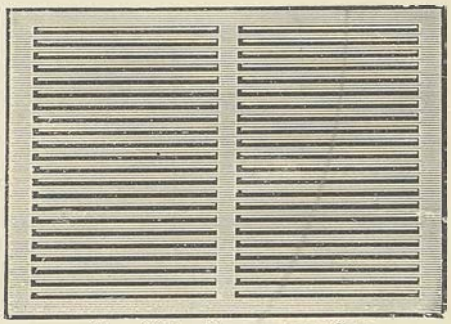


FIG. 367.—BUTT-ENDED GRID.

purifier is the flat sieve, made in wood, and built up with either open or butt-ends, as shown in Figs. 366 and 367. Within recent years there has been some tendency to employ grids of the hurdle type, either by themselves or in conjunction with the ordinary flat sieves. The chief advantage attached to such grids is that they may, in some cases, be responsible for a reduction in back-pressure, but it seems that their advantages are sometimes outweighed by their defects. Amongst the latter may be mentioned—

(*a*) The tendency of the gas to short-circuit through the material.

(*b*) The wear and tear on the grids is greater.

(*c*) A common method of overcoming back-pressure in an ordinary purifier is by drawing a slide and thus by-passing a tier of the material. With the hurdle grid this cannot be done.

(*d*) The operation of discharging is more costly, and occupies a greater length of time.

It must not be supposed, however, that the hurdle grids have not their good points, and many engineers adhere entirely to their use.

THE COST OF PURIFIERS

No definite figure for costs based on the capacity per 1,000 cubic feet of gas dealt with can be given, owing to the expenditure per unit volume undergoing considerable reduction as the capacity increases. For instance, a set of four purifiers complete with connections, lifting crane, etc., to deal with 100,000 cubic feet of gas per diem, will cost about £1,750, *i.e.* £17 10*s.* per 1,000 cubic feet ; whilst a similar set capable of taking two million cubic feet per diem will run into rather more than £15,750, *i.e.* about £8 per 1,000 cubic feet. These figures refer to dry-luted ground-level boxes, and do not include the building. If water-luted boxes are under consideration, 15 to 20 per cent. may be added. The diagram shown in Fig. 368 gives an indication of the manner in which the cost varies in accordance with the capacity. The figures include connections, lifting gear, valves and foundations. The following table shows the manner in which the outlay is distributed over the various portions of the installation in normal cases for medium-sized plant :—

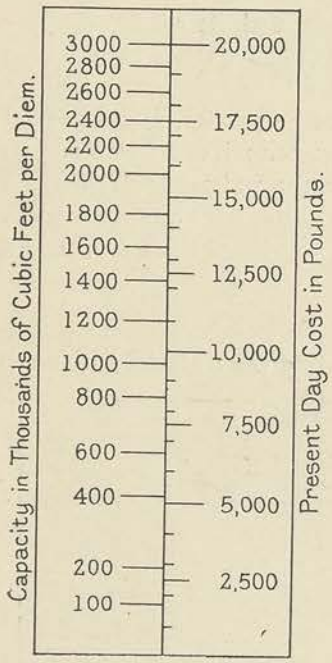


FIG. 368.—DIAGRAM SHOWING APPROXIMATE COST OF A SET OF FOUR PURIFIERS.

Purifying boxes . .	50	per cent. of total expenditure.
Covers (dry lute) . .	15	„ „ „ „
Lifting apparatus .	4 to 6	„ „ „ „
Grids (ordinary flat type)	6 to 10	„ „ „ „
Connections and valves	20 to 30	„ „ „ „

Castings for the boxes, etc., cost, to-day, from £35 to £40 per ton. The covers cost from £55 to £60 per ton, or the whole set, including connections, from £40 to £45 per ton.

So far as the cost of buildings is concerned, this has already been touched upon in Chapters I and II. If a steel-framed, brick-panelled structure is erected the cost will amount approximately to 6*d*. per cubic foot capacity, including foundations. This type of building is, however, rarely employed, and the modern tendency is to erect a light steel-framed shed carrying a roof, but open at the sides. Such a building may be estimated at 4*s*. 6*d*. per square foot of area covered.

PURIFIER VALVES

The valves made use of on purifiers are commonly of three distinct types :—

(*a*) Centre valves.

b) Separate slide valves (such as the well-known rack and pinion type).

c) Hydraulic valves.

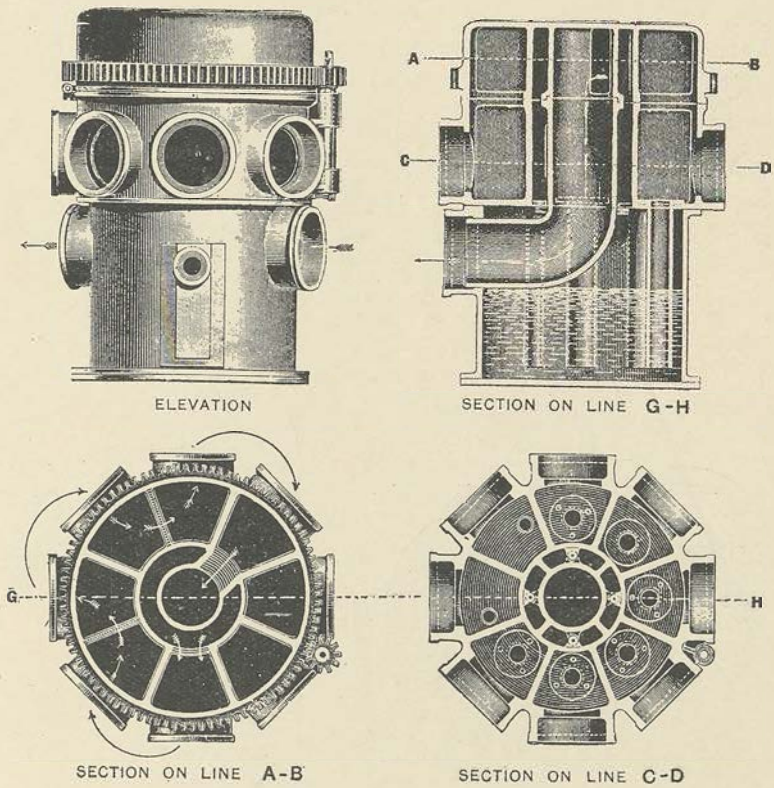


Fig. 369.—Dry-faced Centre Valve.

One type of centre valve is shown in Fig. 369. This valve is constructed with dry faces, and enables any number of the four purifiers to be in action at one time. It is claimed that with valves of this description, as the faces are always covered

when at work, no deposit of any kind can collect, thus leakage from one valve chamber to another is precluded. Hydraulic centre valves, in which water is the sealing medium, are also employed, but the ordinary type possesses the disadvantage that it will only operate the purifiers in one combination, *i.e.* any three boxes at work with one out of action. The construction of the centre valve is somewhat complex, but an idea of the principle may be obtained from the diagrammatic representation given in Fig. 370.

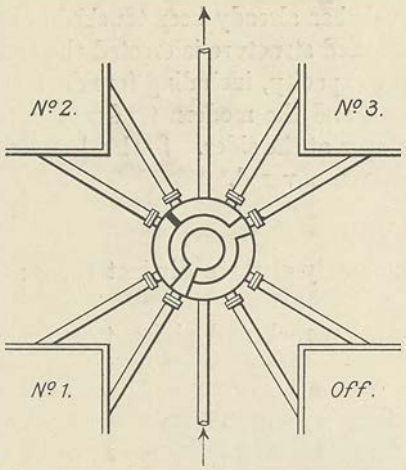


Fig. 370.—Diagram showing Principle of Operation of Centre Valve.

Common types of rack and pinion valves are shown in Figs. 371 and 372, whilst the ordinary single water valve is seen in Fig. 373. These water or hydraulic valves are of simple construction and consist of a rectangular cast-iron box with a mid-feather extending to within a short distance of the bottom. When water is admitted to the box the gas way is stopped, and in order to open the gas passage the water is merely run off from the drain pipe at the base. The depth seal employed in these valves is usually the same as that in the seal of the purifier cover.

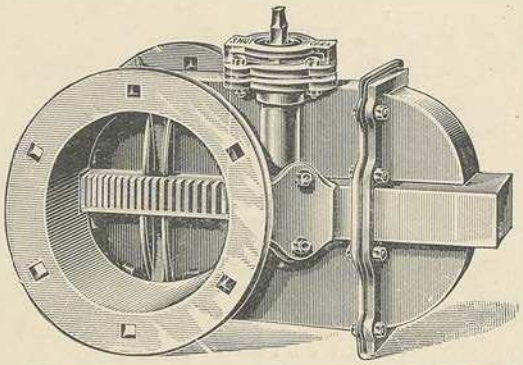


Fig. 371.—Rack and Pinion Valve.

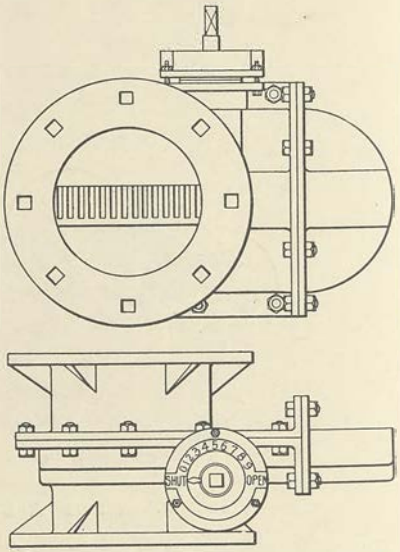


Fig. 372.—Rack and Pinion Gas Valve.

So far as the relative advantages of the various types of valves are concerned, the following points may be stated:—

(*a*) Centre valves. Are simple in operation. but may give trouble owing to gas leaking from one valve chamber to another. If this occurs a portion of the crude gas may get through to the clean gas outlet and give rise to a stain.

(*b*) Slide valves. These may be either of the rack and pinion or worm and rack type. They should be flanged so that they may be readily replaced if faulty. One spare valve should always be kept as a stand-by. If this is done, all the valves in use can be overhauled in turn.

(*c*) Water valves. These valves are probably the safest, but they are undoubtedly cumbersome, and decidedly slow in action in comparison with the other types. The latter disadvantage is, however, not of paramount importance at the present day, owing to the extended life of each purifying vessel.

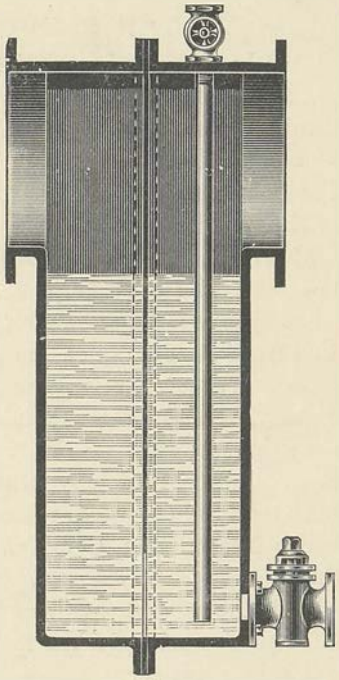
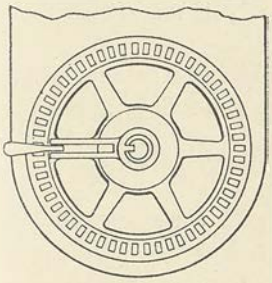


FIG. 373.—COMMON WATER VALVE.



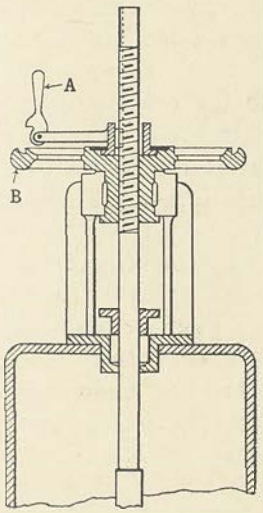


FIG. 374.—"BEARSCOT" VALVE OPERATING GEAR.

A novel device in the construction of purifier valves is the "Bearscot" patent operating gear (Fig. 374), which has for its object the revolving and grinding in of various kinds of valve discs upon their seatings. When, as often happens, valves remain either closed or open for long periods, tar, sediment, and other undesirable substances are apt to accumulate on the exposed face, thus preventing close contact between the disc and its seat. The method under notice makes the grinding in of the disc a very simple matter. When closing a valve, when the disc is coming in contact with the face of the valve, the small lever marked "A" is swung, so that the tooth gears into one of the recesses on the handwheel marked "B." This action locks the spindle and disc to the handwheel. The operator then moves the handwheel, to and fro, thus revolving the disc. The lever is then raised, releasing the spindle, and the handwheel is turned slightly, thus tightening the disc on the seat. The lever "A" is again geared with the handwheel, and the disc further revolved. When the disc is fairly bedded down, the lever is raised, and the valve closed home, thereby ensuring that the faces are in complete contact and the valve absolutely gas-tight.

THE REDUCTION OF SULPHUR COMPOUNDS

It has already been pointed out that the sulphur compounds remaining in coal gas after the extraction of sulphuretted hydrogen consist for the most part of carbon disulphide, and are present to the extent of about 0·02 per cent. by volume, or from 25 to 50 grains per 100 cubic feet of gas. The carbon disulphide represents about 75 to 80 per cent. of the impurities classed as "sulphur compounds," the constitution of the remaining 7 to 10 grains being still uncertain. No doubt, from 60 to 70 per cent. of the remainder consists of thiophen, whilst it seems probable that a portion is accounted for by ethyl and methyl sulphides and certain mercaptans.

During recent years the process of purification has received a good deal of attention from the scientific standpoint, with the result that many new processes for the reduction of sulphur compounds have been successfully developed on a semi-technical scale. From the commercial standpoint, however, it must be borne in mind that the sulphur compounds other than sulphuretted hydrogen are present in quantities so small (more especially where a mixture of coal gas and water gas is distributed) as to render them more or less innocuous. Thus, with the notable exception of the South Metropolitan Gas Company, no serious attempt has been made to remove them.

Of the modern methods for CS_2 purification those of chief importance at the moment depend upon the fact that under certain conditions the following reaction will take place—

$$CS_2 + 2\,H_2 = 2\,H_2S + C.$$

The reaction occurs readily at high temperatures and with a moderately high concentration of CS_2 in the gas mixture ; but owing to the extremely small quantities (0·02 per cent.) in which carbon disulphide is present in coal gas it is essential that the reaction, if it is to be effective, should be of extremely high velocity. The development of hot purification methods is largely due to the inventors of the Oregon process, who, after numerous experiments with plant which proved unsuitable, evolved apparatus very similar in appearance to the carburettor of a modern water-gas plant. These investigators found that when the gas was passed through a vessel containing broken firebricks at a temperature of about 870° C., the CS_2 was decomposed into sulphuretted hydrogen and free carbon. The plant employed consisted of two cylindrical vessels lined with fireclay and packed with firebricks laid chequerwise. The vessels were heated internally by the combustion of producer gas, and whilst one was being heated, the second was purifying the gas, and conversely. That is to say, when the vessel which was purifying was cooled down by the inflowing gas to a temperature at which its efficiency was low, the operations were reversed, the gas being diverted to the second vessel, which had been undergoing a spell of reheating. In a series of experiments, extending throughout 1909, it was found that the average reduction in the quantity of sulphur compounds amounted to 71 per cent. In a process of this description, where no catalyst is employed, temperature must necessarily play an important part. The inventors found that at 340° C. the percentage reduction averaged only 20·7 per cent., whereas at 700° C.

it might be so much as 76 per cent. The cost of the process, including all charges, was given at that time as 0·5*d*. per 1,000 cubic feet of gas treated.

The Carpenter-Evans Process

The Carpenter-Evans system of hot purification is in many respects similar to that described above, but differs in one very important particular, and that is the working temperature employed. The chemical reaction occurring is precisely similar to that taking place in the Oregon process, but the velocity of reaction is greatly increased by the adoption of a suitable catalyst. Consequently, extremes of temperature are not needed. The process is carried out on the following lines: The gas is first heated up to about 410° C. by passage through tubular heat-interchangers, and afterwards through tubes placed within the furnace. It then passes into chambers containing a catalysing agent, wherein the carbon disulphide is converted into sulphuretted hydrogen and free carbon—

$$CS_2 + 2\,H_2 = 2\,H_2S + C.$$

The catalytic agent employed consists of fireclay balls about 1 inch in diameter impregnated with nickel reduced from the chloride, the apparatus being maintained at a temperature of about 430° C. The heated gas, on leaving the catalyser, passes through a special heat interchanger in which it gives up part of its heat to the inflowing cool gas. The purified gas is then reduced to atmospheric temperature, and, finally, the sulphuretted hydrogen from the above reaction is removed by oxide of iron in the usual manner. The free carbon is left behind in the catalysing apparatus, and after about thirty days' run it is necessary to remove it. This is done by the process known as "aeration."

In order to regenerate the material of any distinct unit the temperature is permitted to drop, and air is pumped at a definite rate through the tubes containing the catalyst. This process usually occupies about a week, and consists in burning out the deposit of free carbon, which travels away as CO_2. During the first four days of aeration the air is deprived of the whole of its oxygen. When once oxygen makes its appearance in the effluent products the temperature of the chamber is raised to 430° C., and this temperature is maintained until carbon dioxide ceases to be evolved, when the process is complete. Some precaution is necessary when preparing for aeration, or when recommencing purifying after aeration has taken place. The tubes will contain either gas or air as the case may be, and the formation of an explosive mixture is prevented by passing in a current of inert waste gases collected from the furnace chimney. In this way the gas or air is displaced by nitrogen and carbon dioxide. The original activity of the catalyst is immediately restored by the aeration process.

E. V. Evans [1] has pointed out that in a system of this kind it is necessary, for effective working, to bear in mind the following salient points:—

1. The temperature of the gas should be raised to that of the reaction before coming in contact with the catalyst.

[1] *J. Soc. Chem. Ind.*, XXXIV, 1915.

2. There must be a sufficiency of surface area of catalytic material exposed per unit volume of gas passed.

3. The reaction is affected by the porosity, specific heat and thermal conductivity of the porous carrier of the catalyst, and also by the volume of free space allowed between the contact surfaces.

4. The presence of sulphuretted hydrogen in the gas before treatment decreases the efficiency of the process, which cannot, therefore, be advantageously applied to crude gas. It seems probable that carbon oxysulphide is produced by conducting gas containing carbon monoxide and sulphuretted hydrogen over the catalyst—

$$(1)\ H_2S = H_2 + S. \qquad (2)\ CO + S = COS.$$

It is possible, in fact it has been found in practice, that the small quantity of carbon oxysulphide formed may give trouble in the way of sulphuretted hydrogen stains. This may probably be explained by the fact that when the gas enters the station meters the carbon oxysulphide combines with the water as follows—

$$COS + H_2O = CO_2 + H_2S.$$

Ammonia is to be found at the outlet of the plant, and results from the hydrolysis of hydrocyanic acid, which occurs on the lines described in the previous chapter (*see* page 564). The inventors point out that although this ammonia is too small in quantity to represent a financial asset, it serves a useful purpose in maintaining the oxide of iron used to remove the sulphuretted hydrogen (formed by the decomposition of the CS_2) in a strongly alkaline condition. Practically the whole of the oxygen is removed by the process, but there is neither increase nor decrease in the volume of gas. So far as the effect on the general composition of the gas is concerned, Dr. Carpenter[1] has given the following figures :—

Analysis of Gas.	Before Treatment.	After Treatment.
CO_2, per cent. by volume	1·44	1·45
Unsaturated hydrocarbons	3·55	3·63
Oxygen	0·33	0·06
Carbon monoxide	8·16	8·03
Methane	26·85	27·26
Hydrogen	54·19	54·25
Nitrogen	5·48	5·32
Illuminating power	14·7	14·7
Calorific power, B.Th.U. gross	590·0	594·4

A complete view of the plant, with explanation of the working, is shown in Fig. 375. The plant illustrated is that in operation at the East Greenwich works of the South Metropolitan Gas Company and consists of five units each capable of dealing with three million cubic feet of gas per day. Each unit is provided with a producer (*A*) and a combustion chamber (*B*). On either side of the combustion chamber are the heating chambers (*C*), which contain the reaction tubes (*F*). The gas (purified

[1] *Proc. Inst. Gas Eng.*, June, 1914.

from H_2S) enters the plant by a main (*H*) and passes into the heat interchangers (*G*). The last-named vessels are constructed on the lines of a multitubular boiler, being filled with 3-inch tubes. The hot gas leaving the plant passes through the heat interchangers in the opposite direction to that of the inflowing gas, and in this way gives up a large proportion of its heat to the cold untreated gas. The gas is further raised in temperature in the heating chambers, and then flows in parallel currents through the tubes containing the catalyser, passing thence to the collector tube (*D*) and through the heat interchangers. After undergoing treatment in this manner

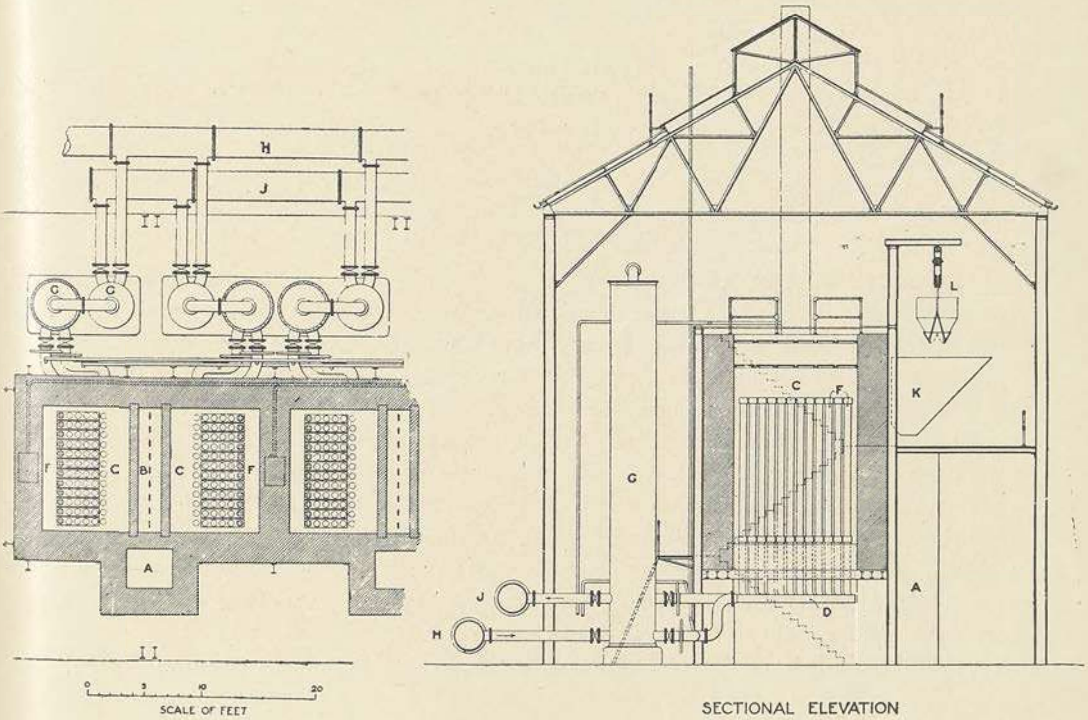


FIG. 375.—THE CARPENTER-EVANS HOT PURIFICATION PLANT.

A Furnace, *B* Combustion Chamber, *C* Heating Chamber, *D* Collector Tube, *F* Tubes containing Catalyst, *G* Heat Interchangers, *H* Gas before treatment, *J* Gas after treatment, *K* Coke Hopper, *L* Coke Handling Plant.

the gas will usually contain about 20 to 30 grains of sulphuretted hydrogen per 100 cubic feet. This is removed by a series of s econdary purification vessels containing oxide of iron.

A 15 million cubic feet plant consumes approximately 5½ tons of coke in the furnaces per day, this being fed into the producer by a hopper (*K*) receiving its supply from a telpher (*L*). The approximate cost of purifying the gas in this manner is now roughly 0·8*d*. per 1,000 cubic feet. The expenditure is accounted for as follows :—

Cost of Purification by Carpenter-Evans Process

	Pence per 1,000 cubic feet.
Fuel (coke at 42*s.* 6*d.* per ton)	0·2550
Conveying coke and cleaning producers	0·0240
Power	0·0129
Labour and chemical supervision	0·1180
Repairs and maintenance	0·1649
Capital charges	0·1967
Total	0·7715*d.*

Before the war the total capital expenditure for a large plant was in the neighbourhood of £1,500 per million cubic feet per day. As regards efficiency of extraction, the proportionate reduction is somewhat higher when a gas containing a large amount of CS_2 is dealt with. The following results illustrate the average effect obtained :—

CS_2, etc.—Grains per 100 cubic feet of gas.		Reduction, per cent.
Before	After	
63·78	10·34	83·8
19·21	5·34	72·2

Other CS_2 Processes

Prevailing opinion all goes to show that the problem of removing sulphur compounds from gas is by no means solved. These compounds consist for the most part of carbon bisulphide, with a small proportion of thiophen, ethyl and methyl sulphides, and in all probability certain mercaptans. Certainly, the first named may be removed by several known processes, but the difficulty lies in determining a method whereby the more elusive organic compounds may be eliminated. The Carpenter-Evans process marked a great step forward ; but it must be borne in mind that, while it removes some 80 per cent. of the impurities it does not completely eliminate them. Moreover, very much depends upon the efficiency of the catalytic agent ; which appears to fall off to some considerable extent between the periods of regeneration. While, therefore, the method has partly served its purpose it must not be considered as the final word in purification processes of the kind, more particularly as it is still of an intermittent nature, and requires a certain amount of care in operation. The past two years have been particularly productive of newer suggestions for effecting purification, and many of the proposals are of interest in that they indicate the possibility of evolving means which would be scientifically perfect and readily operated without practical complications.

Rideal and Taylor,[1] for instance, have carried the matter a stage further by causing the carbon bisulphide to react with water vapour instead of with hydrogen as in the Carpenter-Evans process. The desirable effect of this may best be illustrated by considering the reactions occurring. Thus,

(1) Carpenter-Evans :

$$CS_2 + 2\,H_2 = 2\,H_2S + C.$$

(2) Rideal-Taylor :

$$CS_2 + 2\,H_2O = 2\,H_2S + CO_2.$$

[1] B.P. 130054/18.

It will be noted that whereas in the former process an objectionable solid (carbon) remains as a residue and chokes the catalyst, in the newer method the residue is in gaseous form. Herein lies the advance, for it is the necessity for burning off the deposited carbon from the surface of the catalyst which demands intermittent operation in the Carpenter-Evans process, while Rideal and Taylor effect continuity of action by reason of the fact that the carbon passes out of the plant in the form of a gas. In the Carpenter-Evans process the catalyst employed is costly, namely, nickel reduced from the chloride, while in the newer process oxide of iron is used, which is activated by the addition of a small proportion of oxide of chromium. The water vapour for the reaction is provided by the admission of a small quantity of steam, passed in with the crude coal gas at the inlet of a preheater which is situated just prior to the catalyst vessel. As regards the quantity of steam admitted, it has been found that it is necessary to add only that amount which is required to prevent the reduction to the metallic state of the catalyst by the reducing action of the gas. For example, at a temperature of 350° C. over 90 per cent. of the sulphur impurities may be removed by the addition of 7 per cent. by volume of steam. As in the Carpenter-Evans process, the sulphuretted hydrogen formed by the reaction is subsequently removed in the ordinary way by means of oxide of iron. The temperature of saturation with water vapour and the temperature of the catalyst are dependent upon the composition of the gas, its sulphur content, and the nature of the catalyst employed.

W. G. Leamon[1] has introduced a process in America whereby the gas to be purified is subjected, in the presence of oxygen, to the action of heat at a temperature sufficiently high to produce effective dissociation of the contained hydrogen sulphide (about 280° to 300° C. is the optimum) by the aid of porous contact-material, which may carry a more actively catalytic substance, under conditions such that the hydrogen of the hydrogen sulphide is oxidized to water by reaction with oxygen contained in, or added to, the gas, while the sulphur passes on through the purifying system to be mechanically removed as elemental sulphur by some suitable method such as washing. Alternatively, it is also oxidized to a greater or less extent and removed by absorption in a suitable absorbing medium.

F. W. Berk & Co.[2] have patented a process which is on somewhat similar lines to the Carpenter-Evans method. Coal gas is brought into contact with granulated alumina, preferably prepared from the trihydrate of alumina. In place of pure alumina, however, high-grade bauxite may be employed, or ignited magnesite. The material is raised to a temperature varying between 200° and 600° C. and the gas is then passed through it. In this way the carbon disulphide is dissociated with the formation of sulphuretted hydrogen. As in the Carpenter-Evans process the deposited carbon eventually impairs the activity of the material, and the procedure of burning-off is then resorted to.

[1] B.P. 15568/18.
[2] B.P. 5079/19.

The Development of Catalysis

There can be no question that the development of catalysis is likely to have a profound influence on the future of gas production. So far as actual carbonization in the retort is concerned, it is difficult for the moment to foresee how the forces of catalysis can be applied with such discrimination that the production of any particular products may be facilitated and cultivated. With the purification of gas, however, the way is perhaps easier. At the present time the operation of removing the main impurity, sulphuretted hydrogen, is necessarily intermittent owing to the fact that oxidation of the iron sulphides formed cannot be carried out with sufficient rapidity. As it stands, the process is essentially one of delayed catalysis, for after the completion of sulphidation and oxidation the oxide of iron remains in its original condition. It can, however, be only a matter of time before a practical process is developed by means of which both sulphuretted hydrogen and sulphur compounds are oxidized at high velocity to sulphur or, carrying the process a stage further, to sulphur dioxide. Rideal and Taylor have already gone some way towards the attainment of this ideal. Three main points stand out, namely, the choice of a suitably activated catalyst which is unaffected by poisoning influences such as cyanides, the provision of an absolutely tar-free gas, and the provision of an economical source of heat, *i.e.* waste heat if possible, for carrying on the reaction. The high-speed oxidation of sulphur to sulphur dioxide would provide the solution of that will-o'-the-wisp of the gas engineer—complete purification. With sulphur dioxide available it would be a comparatively easy matter to take the process a stage further and to arrange for the production of ammonium sulphate or at least sulphite, as a matter of course.

Absorption Processes

The primary objection to hot purification processes is that fuel has to be consumed for the purpose of the reaction. For this reason many favour absorptive methods which may be conducted at ordinary temperatures. On the other hand, the objection to the latter processes is that they are comparatively slow in action, the space-velocity ratio being enormous when compared with the high velocity obtained by introducing a catalyst. One of the most promising of absorptive methods is that introduced recently by Gordon Adam,[1] who has taken advantage of the relative absorptive power of charcoal for various gases. For instance, if the constituents of coal gas are considered it will be seen that some are more readily absorbed than others. Thus, 1 volume of charcoal absorbs approximately 65 volumes of sulphur compounds at normal temperature and pressure, while the same volume of charcoal only retains 1·75 volumes of hydrogen and 9·5 of carbon monoxide. In Adam's process the coal gas (subsequent to the usual treatment in wet and dry purification plant, and, therefore, with sulphuretted hydrogen and ammonia removed) is passed through animal or wood charcoal in a granulated form. The selective action of the charcoal is employed to ensure that only the sulphur constituents and naphthalene are absorbed. This is of importance owing to the fact that ethylene and other unsaturated hydrocarbons would otherwise be removed. The quantity

[1] B.P. 127431/19.

of charcoal utilized, therefore, is limited to that amount which would just be saturated with sulphur compounds and naphthalene. In practice it has been found that the sulphur compounds and naphthalene may be removed by employing 70 lb. of charcoal per ton of coal carbonized. Once the initial outlay has been met the process should certainly prove economical, for the saturated charcoal by being heated to about 300° C., throws off the absorbed vapours, and is thus regenerated for use again as a purifying medium.

The process possesses some of the characteristics of that introduced by Soddy [1] for the purpose of stripping and recovering the illuminants from coal gas, and for the isolation of ethylene. Soddy found that at ordinary temperatures 1 ton of charcoal serves to remove the ethylene from 10,000 cubic feet of average coal gas, or 1 ton will absorb approximately 300 cubic feet of ethylene. The process, of course, differs from that of Adam, in that the latter necessarily has in mind the retention in the gas of the hydrocarbons, while Soddy seeks to recover them for other industrial purposes. It is interesting, however, to follow up Soddy's process from the fact that it might have proved a reasonable alternative to the oil-stripping treatment of coal gas which was so largely adopted to meet the exigencies of war.[2]

In carrying out the process coal gas, preferably purified, is passed through charcoal at ordinary temperature, and the charcoal is subsequently heated to expel the absorbed constituents. The invention also includes a method by which the process may be made continuous, and which depends in part on the known principle underlying methods of scrubbing generally—namely, that continued passage of the gas causes displacement of the more volatile constituents first absorbed by the less volatile constituents as these accumulate in the absorptive agent. The process also depends on the well-known fact that the expulsion of a dissolved or absorbed gas by heat is aided by diminishing the partial pressure of the gas in the atmosphere surrounding the solvent or absorbent.

Whatever the mode of treating the coal gas with charcoal to absorb the illuminants, carbon bisulphide and sulphuretted hydrogen should first be removed. The sulphur compounds are absorbed by the charcoal effectively; but the charcoal deteriorates in absorbing power when unpurified gas is used. It is also of advantage that carbon dioxide and water vapour should be removed, as representing useless diluents subtracting from the efficiency of the charcoal as an absorbent of illuminants. Hence the process is best applied to gas which has undergone the usual purification process for the removal of these impurities. But still further purification is desirable when the separation of the more volatile illuminants—particularly ethylene—is the main object of the treatment. As already explained, the ethylene is displaced from the charcoal as benzene accumulates; and the charcoal is so efficient in removing benzene that, even though the gas has already been subjected to a process for stripping the benzene from it, there should be a further treatment with charcoal for completing this purpose.

Carbon disulphide may be removed by utilizing certain compounds such as aniline, when sulphuretted hydrogen is evolved and a somewhat complex organic

[1] B.P. 7698/18.

[2] *See* Chapter XII, page 423.

residue remains. It has been stated that the reaction takes place on lines such as the following—

$$2\ C_6H_5NH_2 + CS_2 = (C_6H_5NH)_2CS + H_2S.$$

The carbon disulphide is thus precipitated in the form of a solid, namely, thiocarbanilide. The outstanding difficulty would appear to be the loss of the amino compounds by volatilization. This loss may, however, be curtailed by washing the gas with weak acids, but the cost of the process renders it prohibitive for use on a working scale.

The Liming of Coal

The treatment of coal by adding lime to it in the retort is by no means novel, for it was attempted in the earliest days of gas lighting. The use of lime for this purpose did not, however, become anything like general, and any advantages which may result from the process seem to have been lost sight of for a long time, until, in 1882, W. J. Cooper was granted a patent relating to the treatment of coal in this way. Cooper claimed substantial advantages for his system, amongst others an enhanced illuminating power, a better coke, less impurities, and more ammonia.

Present-day interest in coal-liming is chiefly attached to the method as carried on at Cheltenham Gas Works, and with which the names of R. O. and J. Paterson are particularly associated. Liming at Cheltenham was first practised in the early 'eighties, and in spite of the repeal of the sulphur restrictions in 1906, the process, though dropped for a time, was reintroduced in 1910. In its modern form the system consists in admitting to the coal, just prior to its entering the breaker, a small proportion of caustic lime. In order that the liming effect may be uniform a small steam jet is allowed to play on the coal as it falls from the breaker. In this way the lime is fixed to the surface of the coal, giving each small particle of coal a regular coating. A further quantity of steam, introduced at the overhead retort-house hoppers, completes the fixing process.

So far as results are concerned, it is of interest to note that at Cheltenham the sulphur compounds were reduced to a steady average of about 21½ grains per 100 cubic feet of gas. The yield of gas per ton of coal advanced by over 800 cubic feet, whilst the sulphate of ammonia showed an increase of 1·88 lb. per ton of coal. The quantity of lime employed varies from 1·5 to 2 per cent. of the weight of coal carbonized, and it is estimated that of the total quantity 75 per cent. remains behind in the coke.

The intermixture of lime with coal is adopted on gasworks, not with a view to increasing the make of gas and other products, but primarily for the purpose of curtailing the sulphur compounds in the finished gas. The manner in which this object is attained is not wholly understood, the reaction, both chemically and physically, taking place on extremely complex lines. It has been suggested that the addition of lime is followed by a decrease of sulphur compounds in the gas, but a corresponding increase may be noted in the sulphur contents of the other products, chiefly the coke. Possibly the presence of the lime merely curtails the formation of CS_2, the gaseous sulphur being evolved almost wholly as sulphuretted hydrogen.

Moreover, if CS_2 were evolved, the lime, acting as a catalytic agent, might account for its partial decomposition into H_2S.

Experiments have been conducted in connection with the effect of lime when admixed with coal slack employed in the production of low-grade gases.

At an installation gasifying 100 tons of coal per day, using varying classes of slack from Staffordshire, Nottinghamshire, and Lancashire, an increase of 15 to 20 per cent. of sulphate of ammonia was consistently obtained over a period of two or more years. Similar experiments carried out on coal carbonized in a retort house stoked by Fiddes-Aldridge machinery gave the following results :—

Period of test	Two weeks
Coals carbonized	1,864 tons
Slaked lime used	2 per cent.

No increase in the yield of gas per ton was noticeable. Cyanogen content (sodium ferrocyanide) increased from 7·1 lb. to 10·1 lb. per 10,000 cubic feet.

Ammonia increase, 3·94 gallons per ton (10 oz.).

Sulphur compounds reduced from 34·6 grains to 12·99 grains per 100 cubic feet.

Sulphuretted hydrogen increased from 2·08 to 2·66 per cent.

The "Athion" Process

The "Athion" process has been used to some extent on the Continent, but it has never gained favour in this country. The gas (Fig. 376), after being deprived

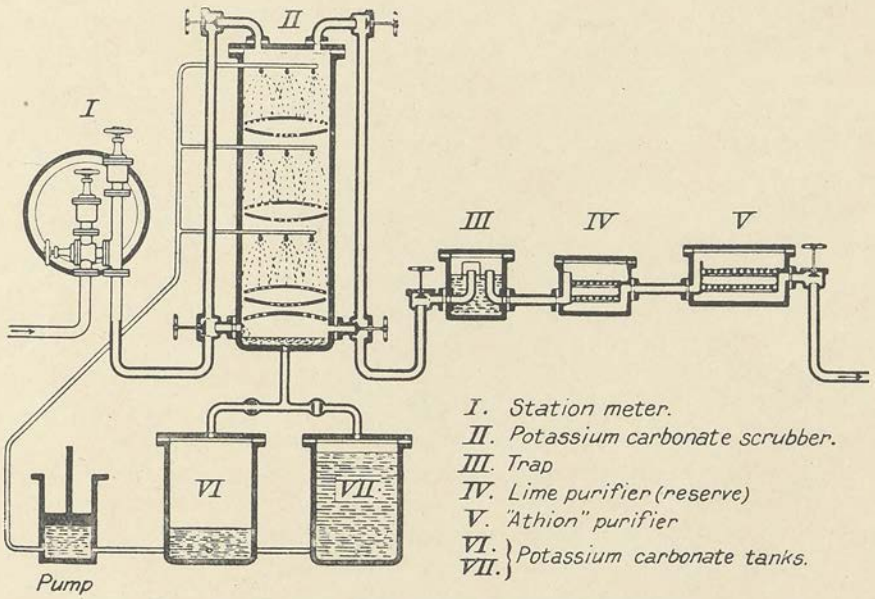


Fig. 376.—Diagram illustrating the "Athion" Process.

of tar, ammonia, and sulphuretted hydrogen, is washed with a solution of potassium carbonate, in order to effect the complete removal of carbon dioxide. The potassium

carbonate, by the absorption of carbon dioxide, is converted into the bicarbonate, and when the solution of the latter is boiled, the salt is reconverted into the simple carbonate, carbon dioxide being expelled. The potassium carbonate solution acts, therefore, in a continuous cycle. After being saturated with carbon dioxide in the washers, it is deprived of it again by boiling, cooled, and sent back to the washers. The removal of CO_2 in this way is necessary, otherwise the remainder of the process for the extraction of the sulphur compounds is rendered ineffective. The carbon disulphide is taken up by the " Athion " material, which is an alkalinated cellulose —that is, a compound of alkali and cellulose, obtained by treating cellulose sulphite with soda lye. The material thus produced is subjected to rolling and crumbling, afterwards being spread on purifier grids in the ordinary manner. The carbon disulphide, on combining with the material, then converts it into xanthogenate of cellulose (viscose), the latter product being of use in the manufacture of non-inflammable celluloid. The inventors claim that with English coal the sulphur compounds are reduced from 30·75 to 7·87 grains per 100 cubic feet, or a reduction of 75 per cent. Ten tons of the special material absorb $1\frac{1}{4}$ tons of carbon disulphide, and it is thus calculated that 10 tons would purify 35,000,000 cubic feet of gas.

CHAPTER XIX

THE STORAGE OF GAS

Of the various portions of apparatus commonly found on gasworks, that made use of for storing the finished gas prior to its delivery to the supply area accounts for the greatest individual outlay. In normal instances, from one-quarter to one-third of the total capital expenditure on the works will be absorbed by the storage plant, whilst the ground area covered by this plant will amount roughly to some 20 per cent. more than that required for retort houses and coal stores combined.

Since the introduction of gas as an illuminant the same principle, that of a floating vessel rising and falling in a seal of water, has been embodied in all storage apparatus ; and although suggestions for replacing the gasholder by some less cumbersome contrivance have, from time to time, been brought forward, they have not as yet materialized in practice.

The quantity of gas which it is desirable to hold in reserve at the works is chiefly dependent upon the fluctuation of the daily load curve. During recent years the hourly consumption has tended to become more and more regular, with a consequent levelling out of the curve. For this reason, the necessary holder capacity has undergone reduction ; and it has been suggested that, in the future, storage will be practically unnecessary, once the daily curve of consumption has been straightened out altogether. It must be remembered, however, that one of the most important functions of the gasholder is the provision it affords against breakdown, and it would seem that the day of gasworks without this familiar apparatus is still far distant. With present-time conditions it may be assumed that the maximum hourly consumption is approximately arrived at by dividing the maximum daily output by 22. The amount of storage provided will not only be influenced by the nature of the supply, that is, whether chiefly lighting, power or cooking, but by the facilities at the works for meeting fluctuating demands with a similar variation in the quantity of gas produced.

It is in the latter respect that a water-gas plant, capable of being started up or dropped at short notice, proves of value. Accordingly, in instances where the daily load curve is moderately constant, and where the peak of the load may occur during the daytime, the storage provided may be safely reduced to 16 or 18 hours' maximum production. On works in which no surplus water-gas plant (or no water-gas plant at all) is available the capacity of the holders should be increased to from 21 to 24

hours' maximum "make." As has already been pointed out in Chapter I, storage capacity on the daily "make" basis is decidedly elastic; for when an extra holder is erected on a works, it is invariably the largest. Consequently, before the new holder is put into operation the storage is deficient; whilst, once it is at work, the storage may be excessive, provision being made for the future.

When building a new works, or when adding to the capacity of an older works,

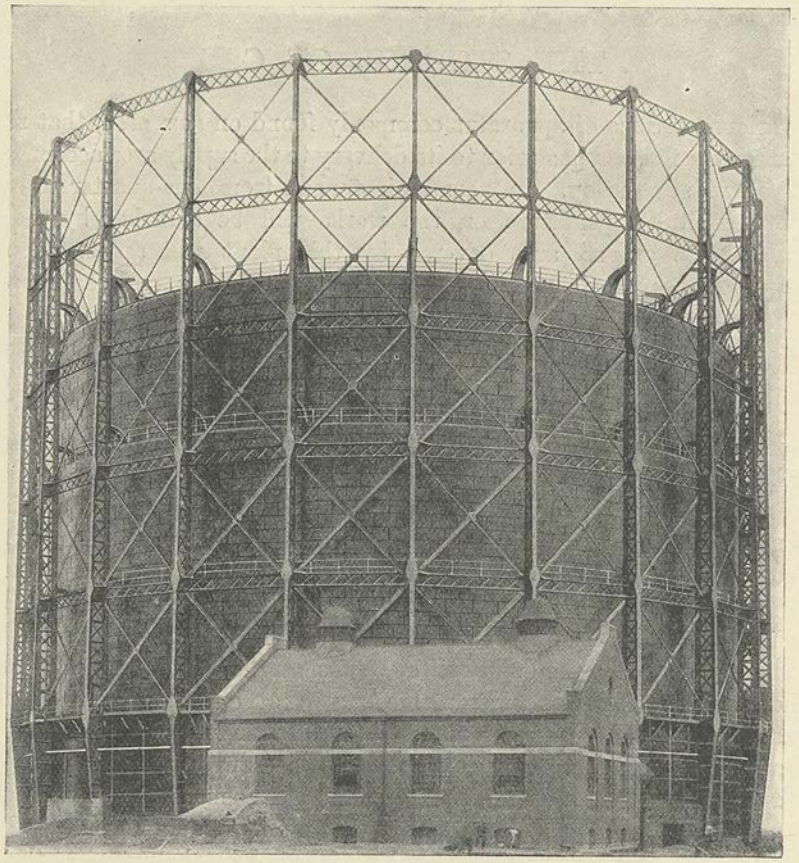


Fig. 377.—Telescopic Holder with Braced Guide-Framing.

it should be borne in mind that future development must be expected, and that the most ready and economical way of meeting this is to make arrangements for the addition of a further (outer) lift in the future. The holder tank in such cases is constructed of sufficient size to contain the extra lift, and in this way capacity may be increased by from 50 to 100 per cent. for a comparatively small outlay. If the holder is of the ordinary guided type the top section may be converted into a "flying-lift" when the new bottom lift is added, or, alternatively, the guide-framing may

be carried up to suit. For this reason the spirally guided holder, having no distinct guide-framing, lends itself more readily to extension, although prior to the insertion of the extra lift the tank will be subjected to additional stressing owing to the increased "overhang" of the guide roller carriages. Needless to say, the effect

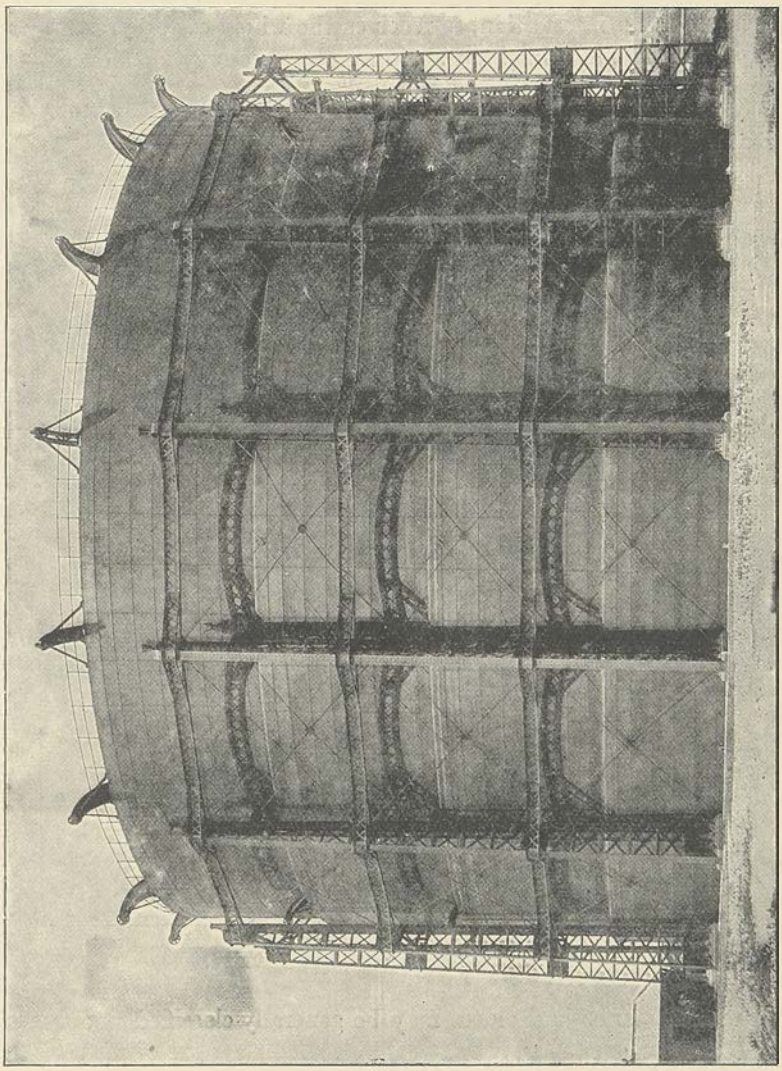


Fig. 378.—Telescopic Holder with Flying Lift.

of this loading should be carefully considered when the tank is being designed. The addition of an extra lift cannot be contemplated if the holder represents the principal storage unit, for the time required to complete the alteration would be at least from five to six weeks, and might amount to three or four months.

THE VARIOUS TYPES OF GASHOLDERS

The chief distinction between the various forms of holders is to be found, not so much in the formation of the floating bell but in the manner adopted for guiding the bell, and in the construction of the tank containing the water. The function of the water is primarily that of providing an elastic gas-tight seal in which the bell may rise or fall; in addition, it receives the whole of the pressure thrown by the weight of the bell, and in this way forms the necessary resistance by means of which the bell is raised or the gas expelled.

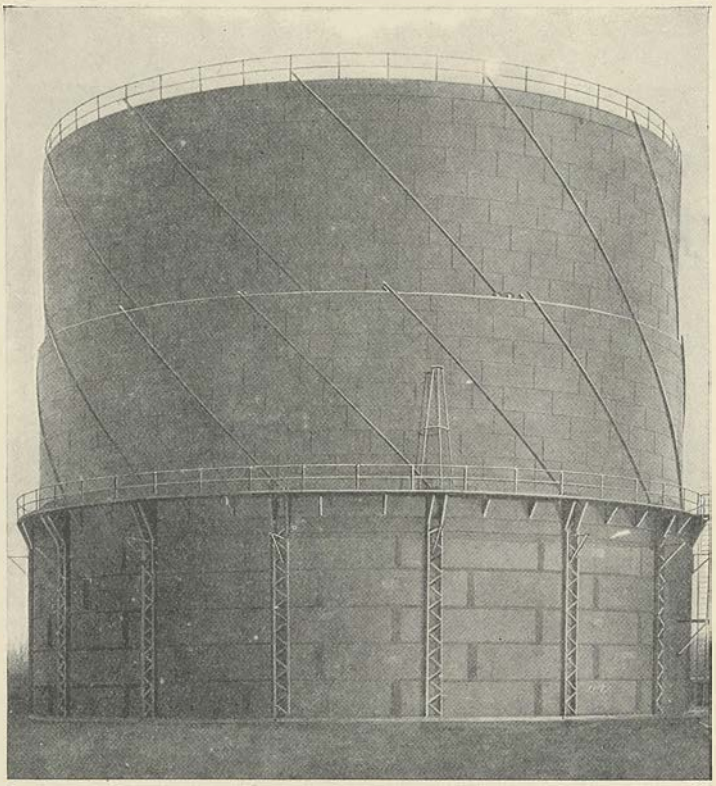


FIG. 379.—SPIRALLY GUIDED HOLDER.

In the first instance gasholders may be generally classified under two distinct headings :—

1. Simple holders, in which the bell consists of one section or "lift" only.

2. Compound holders, in which the bell is composed of two, or a number of "lifts," arranged to telescope one into another when the holder is empty, or partly so.

More broadly classified, the various descriptions of holders may be set down as follows :—

1. Holders guided by wire cables. (Now obsolete.)

2. Holders guided by ordinary distinct vertical guide-framing, with or without "flying lifts."

A typical holder with braced guide-framing is shown in Fig. 377. A telescopic holder with "flying" lift is seen in Fig. 378.

3. Spirally guided holders (left or right hand, or a combination of both). The guides, so far as the bell is concerned, may be either internal or external. Fig. 379 shows a spirally guided gasholder.

4. Holders with a floating roof, generally known as the Nuremberg type.

The cable-guided holder, though of historical interest, can scarcely be considered under the heading of modern structures. Holders of this type are still in use, the largest of the kind being in operation at Middlesbrough.

This holder has three lifts (the outer of which is 185 feet in diameter) and a total capacity of $2\frac{1}{4}$ million cubic feet. Theoretically, at least three cables are necessary for a single-lift holder. One extremity of each is attached to the upper edge of the tank, the cable is then led round a pulley fixed to the top curb of the gasholder and afterwards passes over the top of the bell to a second pulley attached to the top curb at a distance of about one-third of the circumference from the first pulley. The cable is then led downwards and around a third pulley fitted to the bottom curb of the holder, its other extremity being fastened to the top of the tank. Thus, as the bell rises or falls each cable is maintained in a taut condition.

THE DESIGN OF GASHOLDERS

By far the most common type of gasholder is the single or multiple "lift" vessel guided by a number of columns spaced circumferentially around the top of the tank at distances of from 15 to 30 feet apart. The columns are adequately braced together by horizontal girders and diagonal ties, the girders for large holders being built up from steel sections, whilst the ties (which are in tension only) may be made from plain round or flat steel bars. In the past, it was customary to erect massive cast-iron columns which carried a guide rail and ensured the rigid guiding of the holder. A heavy cast-iron or wrought-iron trellis cross girder extended from apex to apex of the columns, whilst tie-rods of unusual length completed the framework. To-day, the cast-iron frame has been entirely superseded by that composed of comparatively light columns constructed from rolled mild-steel sections. For the smaller holders (say up to 750,000 cubic feet capacity) the standards may advantageously be plain rolled steel joists at centres of from 15 to 18 feet, stayed up by a smaller size of the same section for the horizontal cross struts. Each panel would then be tied together by circular rods arranged diagonally, and meeting in the centre of the panel. At the junction of the ties a centre ring, permitting of adjustment, may be used, but modern practice tends towards adjustment at the standards. Centre rings, moreover, are inclined to spring, and are often absurdly weak in comparison with the bars. Particulars of the guide-framing for a holder of this kind are given in Fig. 388.

For larger holders the necessary size of a single rolled section for the upright stanchion would not conduce towards economy or comeliness; accordingly, it is customary to build up the columns on the principle of the lattice girder, the horizontal cross girders being designed on the same lines. As a general rule, it may be said that single rolled steel joists may be used for the vertical columns so long as their depth is not found (after the necessary calculations for stability have been made) to exceed 18 inches. When joists are employed their total height from tank level should not be greater than 65 times their cross-sectional depth.

THE PROPORTIONS OF GASHOLDERS

The preliminary operations in designing a gasholder are to ascertain the required capacity; and, this being done, to determine upon the diameter and height of the bell, the number of lifts, etc. In calculating the capacity of holders the space enclosed by the domed top is neglected, owing to the fact that the gas in this portion is ineffective from the point of view of storage. For preliminary calculations the size of the holder may be arrived at by applying the simple formula—

$$\text{Capacity in cubic feet} = \cdot 7854 \times (\text{diameter})^2 \times \text{height}.$$

For a single-lift holder this calculation will suffice, but when a multiple-lift holder is under consideration the capacity of the separate lifts should be distinctly estimated by applying the above rule to each section, due allowance being made for the cups.

CONSIDERATIONS AFFECTING THE PROPORTIONS OF GASHOLDERS

There are many factors by which the general proportions of gasholders are influenced. Chief amongst these are:—

(*a*) The nature of the sub-soil, and, therefore, the design of the tank.

(*b*) The ground space available for construction.

(*c*) The pressure required to be thrown by the holder if "boosting" is not to be resorted to.

If the ground space available is unlimited the constructor is not hampered in having to curtail diameter, with a consequent increase in height, although deep lifts may be necessary in order to obtain the desired pressure. Deep lifts give rise to more costly tanks, although a saving may be effected by arranging for one lift less than the number which might ordinarily be inserted, thus economizing on the total number of cups and grips, these accounting for a considerable item in the outlay. When the erection of a holder is contemplated, it is an excellent plan to consider two suitable propositions entailing different proportions, with a view to taking out quantities for both. The following figures, which show, very approximately, the weight of metal employed in the construction of two types of gasholders of identical capacity (1$\frac{3}{4}$ million cubic feet), will serve to illustrate the point:—

	Four-lift Holder.	Three-lift Holder.
Ratio $\frac{\text{Depth of top lift}}{\text{Diameter}}$	0·18	0·21
„ $\frac{\text{Total height}}{\text{Diameter}}$	0·64	0·50
Weight of steel tank	336 tons	405 tons
„ crown rest framing	52 „	63 „
„ guide-framing	230 „	223 „
Total, tank and framing	618 tons	691 tons
Top lift	128 tons	146 tons
Second lift	68 „	80 „
Third lift	68 „	74 „
Fourth lift	60 „	—
Weight of bell	324 tons	300 tons
Total weight	942 „	991 „

It will be seen that the four-lift holder shows some considerable saving, chiefly in the construction of the tank, in weight of metal, and therefore in expenditure.

The depth and diameter of the various lifts of gasholders are readily arrived at by any one of experience, the following being the usual proportions adhered to :—

Ratio of Height to Diameter of Holder

For single-lift holders the height varies from 0·3 to 0·4 of the diameter. With telescopic holders the normal proportion varies between 0·6 to 1·0 of the mean diameter. In both cases the figure given refers to the height of the bell only, and does not include the depth of the tank.

Depth of Lifts

Each lift will be *approximately* of similar depth ; *i.e.* the depth of each is equal to the total height of the bell divided by the proposed number of lifts, due allowance being made for the depth of cups and grips.

Diameter of Lifts and Size of Cups

For the smaller holders the width of the cups should be 8 inches. Medium-sized and larger holders are preferably provided with a 10-inch cup, although in the case of the largest sizes 12 inches is occasionally found. It will be understood that the diameter of the second lift is greater than the diameter of the top lift by an amount equal to three times the width of the cup ; the diameter of each succeeding lift increasing by the same amount. The depth of the cups must be such as to carry a water seal sufficient to withstand the maximum pressure thrown by the holder. In general, it may be said that no telescopic holder would be provided with cups less than 16 inches deep, whilst for the largest holders the figure would not exceed 24 inches.

Rise of Crown

The rise given to the domed crown of a holder varies in accordance with the stresses induced ; the greater the rise, the stronger the crown. The dome should

in all cases conform to a segment of a sphere. Normally, the rise will lie between $\frac{1}{15}$ to $\frac{1}{20}$ of the diameter (though seldom $\frac{1}{15}$), a greater pitch being given when no trussing is employed. The cubic capacity of the crown space may be found as follows :—

$$\text{Volume (in cubic feet)} = 0{\cdot}5236\ R\left(R^2+\frac{3\,D^2}{4}\right)$$

Where R = Rise of crown in feet,
and D = Diameter of holder in feet (top lift).

Proportions of Lifts

The ratio of the depth of a lift to its diameter varies to some considerable extent, but it has been laid down by Cripps as a working principle that the depth of the lift must never be less than one-seventh of its diameter, otherwise tilting is extremely likely to occur. In ordinary practice the proportion varies from one-fourth to one-fifth of the diameter.

THE GUIDE-FRAMING OF GASHOLDERS

The author takes this opportunity of pointing out that the knowledge we have of the stresses and strains in gasholder structures at the present day is almost solely built up from the theories expounded by the late Sir Benjamin Baker and by Mr. F. Southwell Cripps. The latter has published an eminently practical and scientific treatise—now unhappily out of print—which has for long been and still remains the standard work of reference on the subject. The treatment adopted by the author in the following pages—so far as the stresses in the guide-framing and top curb are concerned—is, for the most part, a reiteration of the deductions and methods of Mr. Cripps, as set forth in his work entitled, "The Guide-framing of Gasholders, and other papers chiefly relating to the strains in structures connected with Gas-Works."

The stresses occurring in the guide-framing of a gasholder are occasioned by pres-

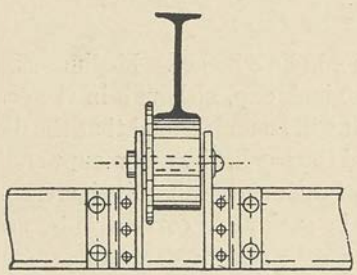


Fig. 380.—Radial Guide Roller.

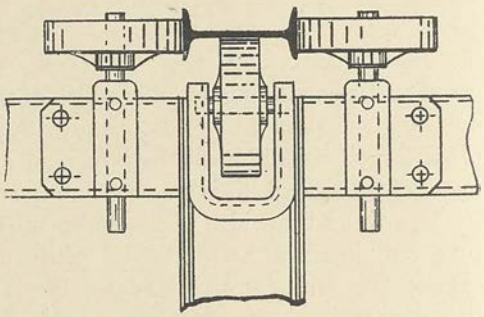


Fig. 381.—Tangential Guide Rollers.

sure of wind and snow. The weight of the members themselves will, however, give rise to certain loading, and this effect must not altogether be neglected. In calculations of the kind it is customary to assume a wind pressure equal to a maximum of 32 lb. per square foot, but owing to the surface on which the pressure is received

being rounded, the usual 50 per cent. reduction may be assumed—thus giving an effective pressure of 16 lb. per square foot on the diametrical projection. Primarily

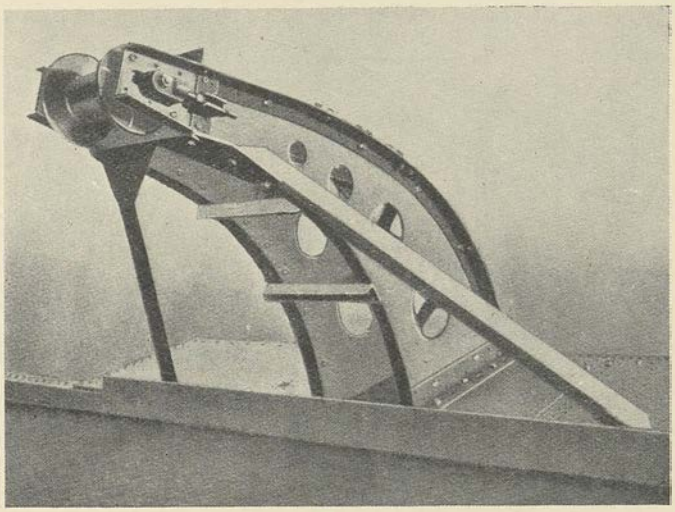


FIG. 382.—RADIAL ROLLER AND CARRIAGE, SHOWING METHOD OF ADJUSTMENT.

it must be understood that the wind and snow pressure is received by the holder bell, and, by means of the guide rollers, it is transmitted to the upright standards, which are braced together in such a manner as to withstand distortion and any tendency to capsize. The manner in which the stresses are transmitted to the framing is chiefly dependent upon the system of guide rollers adopted; *i.e.* whether the rollers are radial, tangential, or a combination of both. The ordinary radial roller is shown in Fig. 380. Fig. 381 shows a combination of the radial and tangential methods.

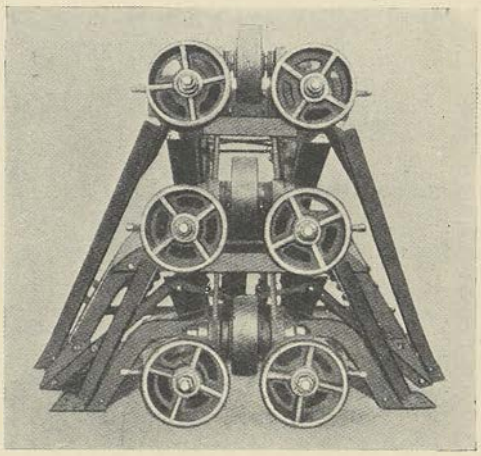


FIG. 383.—COMBINED RADIAL AND TANGENTIAL GUIDE ROLLERS AND CARRIAGES FOR 3-LIFT GASHOLDER.

The arrangement of guide rollers adopted on the large holder at East Greenwich is shown in Fig. 384. With the 10 million cubic feet holder at Manchester the design shown in Fig. 385 was employed.

For the purposes of calculation, the whole of the guide-framing may be regarded as an immense cylinder, receiving partial stiffening from a light internal ring (the bell itself). If we consider a simple holder with radial guide rollers subjected to

wind pressure in one direction it is plain that there is a tendency for the bell to press hard up against those columns on the leeward side. Owing to the provision of horizontal struts and diagonal ties between the columns this stress is, in the modern form of holder, transmitted throughout the whole framework, and not merely to a

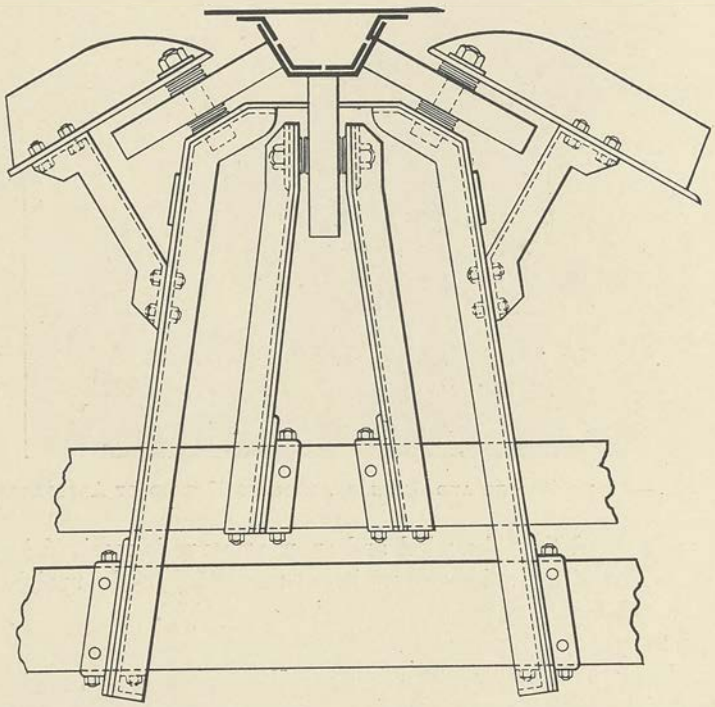


FIG. 384.—ARRANGEMENT OF GUIDE ROLLERS ON LARGE HOLDER AT EAST GREENWICH.

portion of it. If tangential rollers are employed in addition to radial guides the pressure will come directly on to about one-half of the total number of columns; but

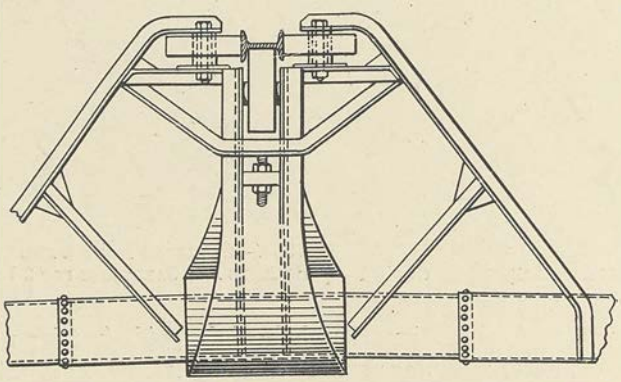


FIG. 385.—MANCHESTER TEN MILLION CUBIC FEET HOLDER.

when radial rollers alone are used, one-quarter of the columns must be considered as directly loaded. As stated above, however, the remainder of the framework will, indirectly, be taking its share of the load.

As the vertical columns are fixed at one end only (*i.e.* to the top of the tank) the whole framing may be looked upon as a girder acting in the capacity of a huge cantilever. A simple cantilever when loaded tends—

1. To shear off at the point of support.

2. To undergo distortion due to the bending moment. Hence, the vertical columns have a tendency—

1. To shear off at the base and overturn.

2. To bend and become distorted, thus causing some deformation of the true cylindrical form of the guide-framing.

The first condition applies to the frame structure as a whole, whilst the second affects each column individually in accordance with the wind pressure on any particular section.

The general proportions and scheme of design (such as height, diameter, and probable number of standards) of the holder being known, the first step in the calculations is that of determining the maximum stress likely to be met with in each standard.

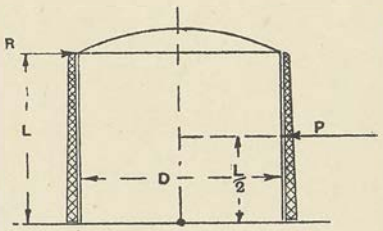


FIG. 386.

WIND PRESSURE

Consider a common form of gasholder having guide-framing extending to the full height of the bell.

Let L = total length of columns, which in this case is the same as the height of the bell (in feet).

Let D = mean diameter of bell (in feet).

,, P = Wind pressure (total force) in lbs.

The wind pressure P acts at the centre of pressure of the bell, *i.e.* at a distance half-way up from the base. Therefore, the overturning moment

$$= P \times \frac{L}{2},$$

but P = total wind pressure,

i.e. 16 lb. per sq. foot on an area of L × D sq. feet,

$$\therefore P = 16\,LD,$$

or, the overturning moment $= 16\,LD \times \frac{L}{2} = 8\,L^2D.$

This moment is resisted by the reactionary force R at the top of the guide-framing, and the moment of the reaction

$$= R \times L$$

$$\therefore R \times L = 8\,L^2D,$$

$$\text{or } R = \frac{8\ L^2D}{L} = 8\ LD,$$

i.e. the overturning force due to the wind amounts to 8 LD.

Snow Pressure

Snow pressure may be considered equal to 5 lb. per square foot on one-fourth of the area of the dome, and acting at a point of one-sixth the diameter from the top curb.

Then if Ws = the total weight of snow, this acts at a distance of $\frac{D}{6}$ from the edge, or $\frac{D}{3}$ from the centre of the bell.

To find total weight of snow :—

Total area of dome = ·7854 D^2.

$$\therefore \text{ Portion covered by snow} = \frac{\cdot 7854\ D^2}{4},$$

$$\text{or, weight of snow} = \frac{\cdot 7854\ D^2}{4} \times 5$$

$$= \cdot 981\ D^2 \text{ lb.}$$

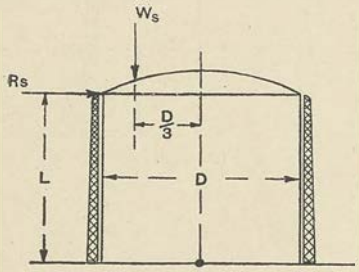


Fig. 387.

(0·981 is very nearly 1, and for the purposes of calculation Cripps considers that it may be assumed equal to 1.)

Therefore, total weight of snow = D^2 lb.

Now the snow gives rise to a tilting moment.

$$Ws \times \frac{D}{3} = D^2 \times \frac{D}{3},$$

$$\text{or } \frac{D^3}{3}.$$

This moment is resisted by the reaction Rs at the top of the columns, and the moment of the reaction = $Rs \times L$.

$$\therefore Rs \times L = \frac{D^3}{3},$$

$$\text{or } Rs = \frac{D^3}{3\ L}.$$

Considering the results of wind and snow together, we see that the total reaction in the structure, that is the total force it has to resist, is—

$$8\ LD + \frac{D^3}{3\ L}.$$

Accordingly, the bending moment on the structure will amount to

$$L\left(8\ LD + \frac{D^3}{3L}\right) = 8\ L^2D + \frac{D^3}{3},$$

and the section modulus must be made of such dimensions as to withstand this bending moment.

The sectional dimensions of the columns are calculated from the well-known formula—

$$\text{Bending moment} = f_{\max.} Z,$$

where $f_{\max.}$ is the maximum allowable stress in the steel, *i.e.* 6 tons per square inch for ordinary steelwork,

and Z = the section modulus, or $= \frac{I}{Y}$.

Where I = the total moment of inertia of the structure,
and Y = half the depth of the section.

It must here be borne in mind that we are dealing with a cantilever composed of the structure as a whole, and not with an isolated column. Therefore, in arriving at the value for Z,

$$Y = \text{half the total diameter of the holder} = \frac{D}{2}.$$

The moment of inertia I can be found by the summation of the elements, using the ordinary formula—

$$Ix = Io + AD^2.$$

Where Ix = the moment of inertia of each element about the true neutral axis of the section.
Io = the moment of inertia of each element about its own neutral axis.
A = the area of the element.
D = the distance of its neutral axis from the true neutral axis.

This formula is, however, somewhat tedious ; and, although not strictly accurate, Rankine's formula is very much more easily handled.

The formula says—

$$Z = 0{\cdot}25 \text{ NAD}.$$

Where N = number of the columns.
A = cross-sectional area of each column in square inches.
D = diameter of holder in feet.

Then, having found the value of Z, it is possible to equate this to the bending moment in the ordinary way :—

$$\text{Bending moment} = f_{\max.} Z.$$

(It must be noticed that the wind pressure P was taken in lbs., and the allowable stress $f_{\max.}$ is in tons. The two must therefore be reduced to equivalent units.)

From above—

$$8 L^2 D + \frac{D^3}{3} = 6 \times 2240 \times 0{\cdot}25 \text{ NAD},$$

$$\text{or } A = \frac{8 L^2 D + \frac{D^3}{3}}{6 \times 2240 \times 0{\cdot}25 \text{ ND}}$$

$$= \frac{24 L^2 + D^2}{10{,}080 \text{ N}},$$

$$\text{or (very nearly)} = \frac{24\,L^2 + D^2}{10{,}000\ N}.$$

The area A given by this formula is the cross-section of each column necessary to prevent failure of the structure as a whole.

Bending moment on one bay only.

Consider the standard as a beam supported at both ends and uniformly loaded. Then if—

B = the pitch of the columns in feet,
L = the total length of each column,

The bending moment $= \frac{wl^2}{8}$, where w = the load per foot run. Working on the assumptions of Cripps, it is customary to consider the wind pressure equal to 10 lb. per square foot, which is assumed as acting upon a length of standard equal to three-quarters of the depth of the holder. In the above formula, therefore, we have—

$$w = 10 \text{ lb. per sq. foot, and } l = \frac{3}{4}\,L.$$

$\therefore$ Bending moment (B_b)

$$= \frac{10 \times B \times (\frac{3}{4}L)^2}{8 \times 2240} \text{ tons-feet}$$

$$= \text{(approximately) } \frac{BL^2}{270}.$$

The bending moment (B_b) on a single bay is, therefore, equal to—

$$\frac{BL^2}{270} \text{ inch-tons,}$$

where B = the width in feet of one bay, *i.e.* distance from column to column,
and L = height of standard as before.

(This conclusion appertains only to those holders in which the guide-framing is carried the whole way up.)

Then $B_b = f_{max.}\,Z$,

$$\text{or Z (the section modulus)} = \frac{B_b}{f_{max.}}.$$

Knowing Z, the required area of the section of the column can be found from the following approximate formula :—

$$Z = 2Ay.$$

Where A = the area of *each* flange of the column.
y = half the depth of the cross-section of the column.

$$\text{or, } A = \frac{Z}{2y}.$$

(It will be noticed that this gives the cross-sectional area at the base, *i.e.* where the greatest stresses have to be withstood. The cross-sectional area may, of course, be reduced towards the top.)

In designing a column the total area required must be taken (*i.e.* formulæ A +B).

$$\text{The total area} = \left(\frac{24\,L^2 + D^2}{10{,}000\,N} + \frac{BL^2}{3240y}\right).$$

(*Note.*—The value for *f* has been taken as 6 tons per square inch. Cripps, in order to allow a margin owing to the fact that the standard is acting as a column, takes a value of 4 tons per square inch.)

The method of calculation will be readily understood by the consideration of a simple example.

Take a holder of such design as that seen in Fig. 388, having a capacity of about 750,000 cubic feet. Let the diameter of the bottom lift be 110 feet, and the total height of the bell (which is the same as the effective height of the standards) 80 feet. The standards will be conveniently spaced at a pitch of about 16 feet; or, as the tank circle will measure approximately 352 feet, it can be assumed that the standards will be 22 in number.

The total area required for each flange at the base of the standards

$$= \frac{24\,L^2 + D^2}{10{,}000\,N} + \frac{BL^2}{3240y}.$$

In the example under consideration—

$L = 80$ feet
$D = 110$,,
$N = 22$
$B = 16$ feet
y = half depth of cross-section in inches.

$$\text{Therefore area} = \left(\frac{(24 \times 80 \times 80) + (110 \times 110)}{10{,}000 \times 22} + \frac{16 \times 80 \times 80}{3240 \times y}\right)$$

$$\text{,, ,,} = 0{\cdot}75 + \frac{31{\cdot}60}{y}.$$

Assuming a depth of 18 inches for the cross-section, $y = \frac{18}{2} = 9$, therefore area of each flange $= 0{\cdot}75 + \frac{31{\cdot}60}{9} = 4{\cdot}26$ sq. inches,

or, total area of flanges = 8·52 sq. inches.

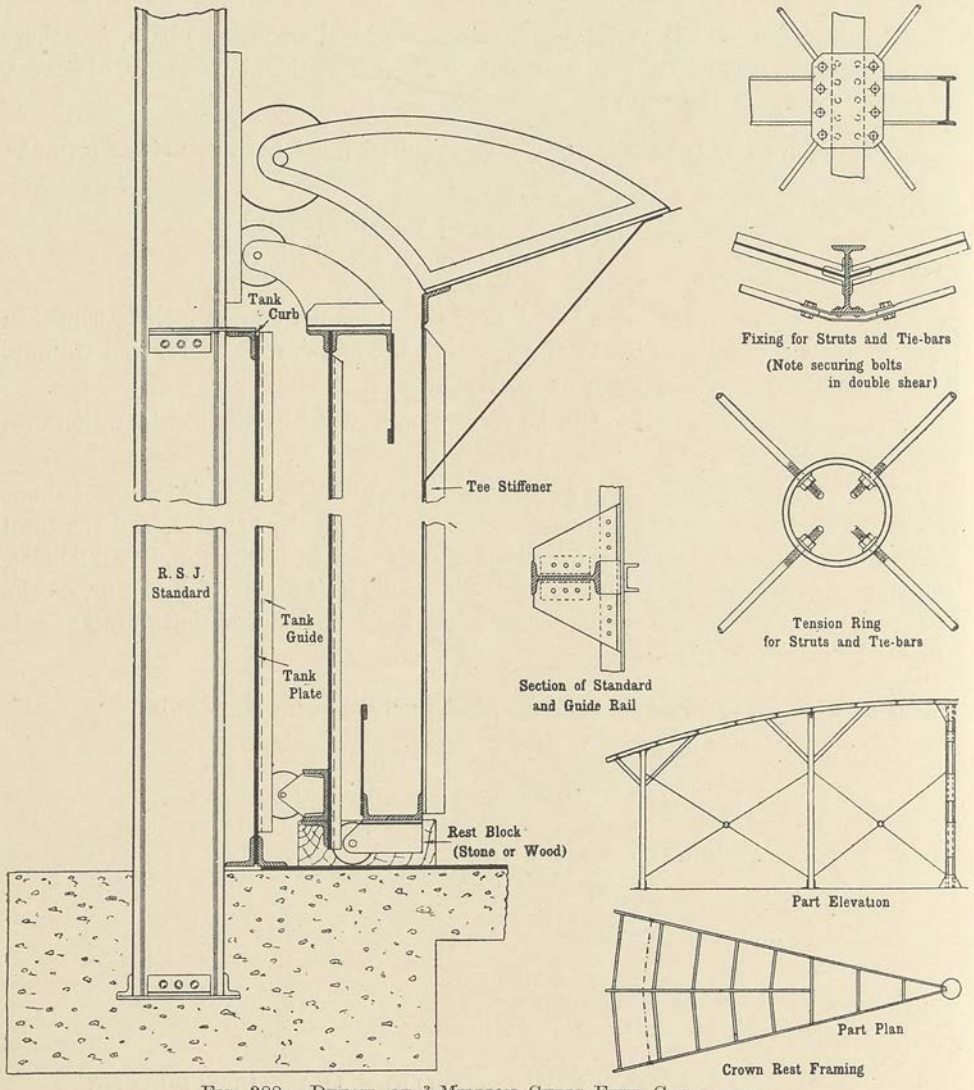


FIG. 388.—DETAIL OF ¾-MILLION CUBIC FEET GASHOLDER.

Considering a number of possible standard sizes of R.S.J. the following comparison may be made :—

	Size of Joist.	Weight lbs. per Foot.	Theoretical Area Registered (Both flanges).	Area Given.	
	Inches.		Square inches.	Square inches.	
A	18 by 6	55	8·52	8·44	1 per cent. deficient
B	18 „ 7	75	8·52	13·5	excessive
C	16 „ 6	62	9·4	10·36	slight excess
D	15 „ 6	59	9·92	10·73	slight excess
E	15 „ 5	42	9·92	6·60	deficient

Choice should fall on the lightest section which fulfils the required condition as to stability. Section A would, therefore, be decided upon, for the very slight deficiency would be more than compensated for by the metal in the web. Some designers might not care about a section so deep as 18 inches for a holder of this size, and if such is the case, that under heading D, though slightly heavier, might be conveniently employed.

It should be mentioned that with a rolled standard of this description some engineers base the required flange area on the figure given by the formula relating to the bending moment on the single bay only, delegating the remainder (*i.e.* the area required to resist the capsizing of the holder as a whole) to the web of the section. It is necessary to emphasize, however, that when a composite section of the lattice-braced type is adopted, no reliance must be placed in the web. For this reason, and also owing to the fact that a maximum stress of 6 tons per square inch has been taken, the author prefers to deal with all sections in the manner indicated above, so that when the web is of assistance a small increase is obtained in the gross factor of safety.

TYPES OF STANDARDS

The ultimate design of the standards must primarily be influenced by the calculation for area as shown above. Keeping this figure in view and bearing in mind generally accepted working precedents, it is possible to evolve a section combining a minimum of metal with a maximum of stability. For instance, the metal composing the flanges may (within certain limits) be reduced in proportion to the increase in depth of the section ; in other words, the weight per foot run may be decreased as the depth becomes greater. So far as the plain rolled steel joist is concerned, this possesses the disadvantage that it cannot be reduced in cross-section towards the top of the columns, thus considerable wastage of metal occurs. In spite of this, however, a joist will be found the most economical section for holders up to about ¾ million cubic feet capacity, owing to the comparatively small amount of labour involved, and in contrast to the expenditure under this item in connection with standards of the built-up description. Also the plain girder will weather better and offers less chance of deterioration.

So far as the old-fashioned cast-iron columns are concerned, it may be noted that gasholders designed on these lines cannot be treated as a braced cantilever, as is the case with the modern structure. In the old pattern each standard forms a cantilever in itself, and although horizontal girders, and in some instances, light diagonal ties, connect the columns together, it cannot be assumed that the framework is of such elasticity as to distribute the loading throughout the whole. Being of the rigid type each column takes the loading in accordance with the direction in which this may be imposed, and rigidity is obtained by employing a superabundance of dead weight. Fig. 389 shows the elevation of a number of forms of gasholder columns, both steel and cast iron. The cast-iron designs with pulleys for the chains of counterbalance weights are now obsolete, except in special circumstances.

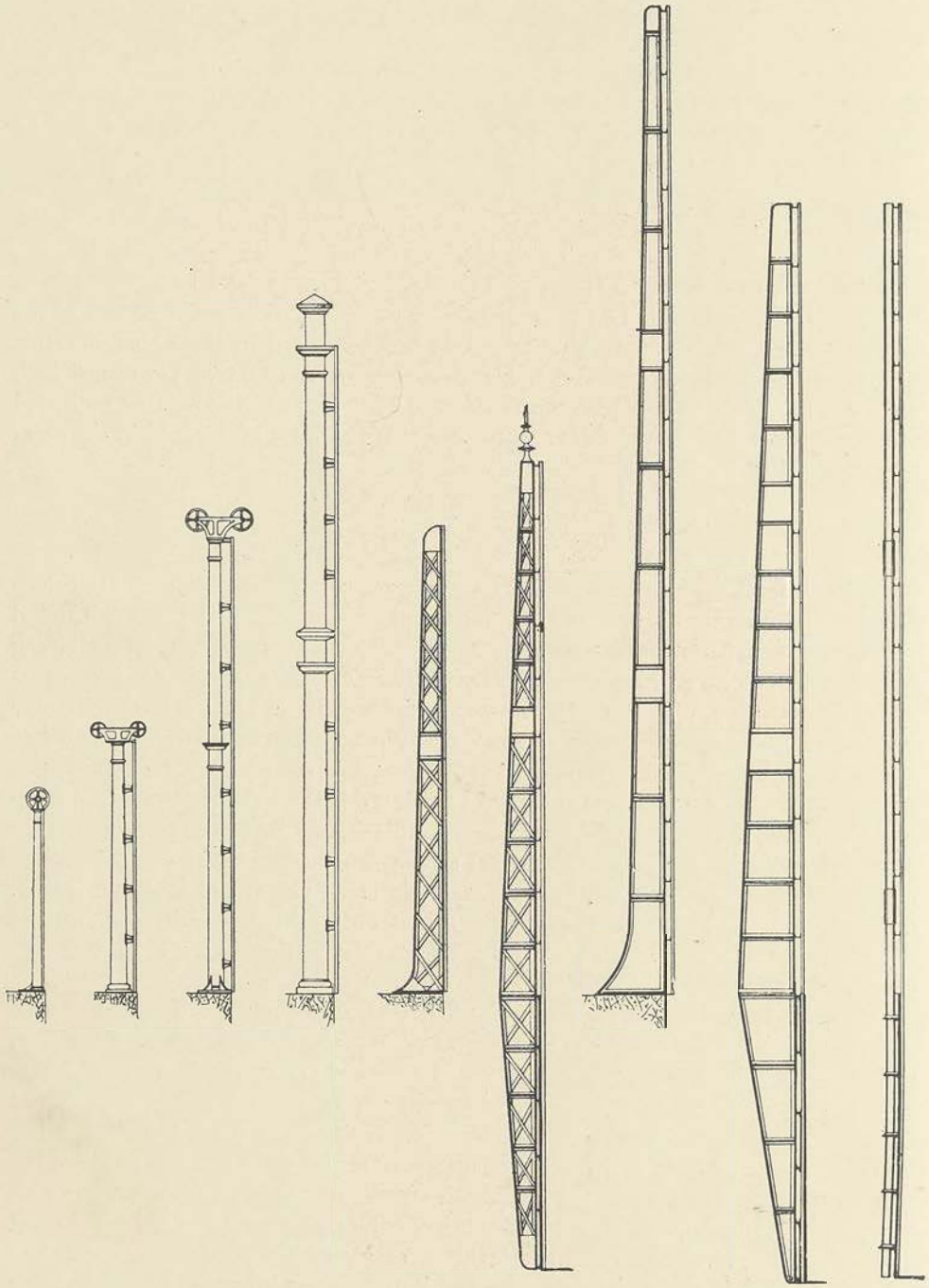


FIG. 389.—VARIOUS FORMS OF GASHOLDER STANDARDS.

DETERMINATION OF MAXIMUM SHEAR

Consider a braced cantilever as in Fig. 390.

Bending moment = WL, and this is resisted by Rd.

(taking moments about support)

$$\therefore \text{WL} = \text{R}d,$$

or, R (which is horizontal shearing force at flange) $= \dfrac{\text{WL}}{d}$,

or, horizontal shearing force $= \dfrac{\text{Bending moment}}{\text{Depth of girder}}$.

The section we have to consider is a braced cantilever of cylindrical form, *i.e.* with no actual top and bottom flanges. Now the radius of gyration of a hollow cylinder about a pole passing through its centre is 0·707 D. Sir Benjamin Baker assumed, therefore, that if the guide-framing was considered as an ordinary two-flanged girder the two imaginary flanges might be taken as occurring at the radius of gyration. F. S. Crippps, however, whose conclusions on matters relating to holders are accepted as final, states that, taking all things into consideration, the depth of the imaginary girder may be considered as ¾ of the diameter of the cylinder, *i.e.* 0·75 of the diameter of the holder, *i.e.* ¾ D. Then we have an assumption such as that shown in Fig. 390, the depth of our girder being ¾ D.

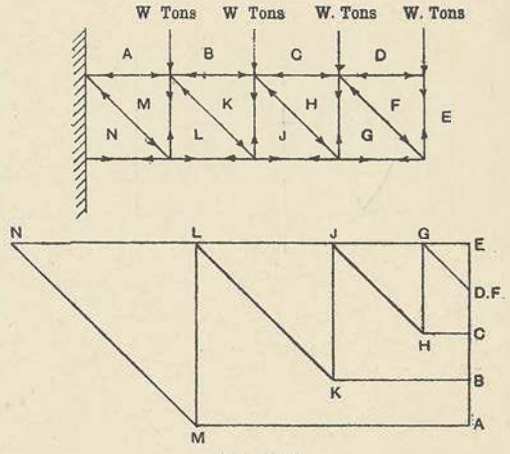


FIG. 390.

It has been shown above that horizontal shear $= \dfrac{\text{Bending moment}}{\text{Depth of girder}}$.

But it has already been shown that in the case of the holder framing (*see* page 633) the total bending moment is equal to—

$$\left(8\,\text{L}^2\text{D} + \frac{\text{D}^3}{3}\right) \div 2240 \text{ ton-inches},$$

and the depth of the girder = ¾ D.

$\therefore$ Total horizontal shearing force

$$= \frac{\left(8\,\text{L}^2\text{D} + \dfrac{\text{D}^3}{3}\right) \div 2240}{\frac{3}{4}\,\text{D}}.$$

It will be noticed that the plane of the shearing force cuts the framing in two points (such as O and P, Fig. 391), consequently the shear on each of the horizontal planes will be half the total shear, or—

$$= \tfrac{1}{2}\left(\frac{\left(8\,L^2D + \frac{D^2}{3}\right) \div 2240}{\tfrac{3}{4}\,D}\right) = \frac{24\,L^2 + D^2}{10{,}080}.$$

Cripps points out that sufficient accuracy will be obtained by taking this formula as—

$$\text{Horizontal shear} = \frac{24\,L^2 + D^2}{10{,}000} \text{ tons.}$$

(It will be noticed that the shear is spoken of as *horizontal*, for the reason that we are now considering a horizontal cantilever as shown in Fig. 390. In the case of the gasholder the cantilever is in a vertical position, therefore the shear is *vertical* shear.)

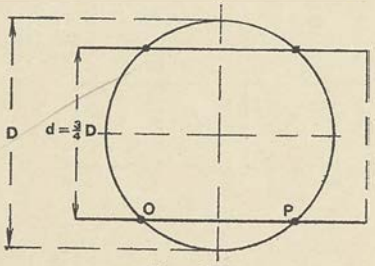


FIG. 391.

So far as computing the effect of the shearing-stress is concerned, Cripps has shown that although the loading on the standards is in reality concentrated at each roller contact, it may be considered as a distributed load, for the stiffness of the standards converts the forces given out opposite the rollers into a distributed load so far as the struts and ties are concerned.

THE STRESSES IN A BRACED CANTILEVER

The method of computing the stresses in the struts and ties of the guide-framing will readily be followed by considering an ordinary braced cantilever (Fig. 390) and the reciprocal stress diagram for the same. The equally distributed load will be apportioned amongst each of the nodes, the loads AB, BC and CD, being equal (W tons) whilst the end node carries $\frac{W}{2}$. If, however, we assume that each node carries an equal weight (not a strictly accurate assumption, but nevertheless approved by Cripps) it is easily seen from the reciprocal diagram that the stress in the diagonal ties and vertical struts increases from the end towards the abutment in the proportion 1, 2, 3, 4. Therefore, if we have the total horizontal shear it is possible to compute the stress in the struts and ties. For instance, if S, is the total shear resolved in the direction of the ties, and S_s is the total

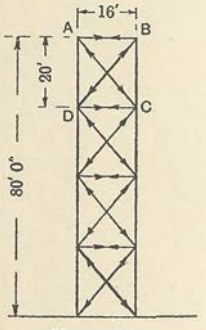


FIG. 392.

shear resolved in the direction of the struts—then, if we have four panels—

$$1 + 2 + 3 + 4 = 10,$$

$$\therefore \text{ Tension in tie nearest abutment} = \frac{4}{10} \text{ of } S_t$$

$$\text{,, ,, tie in 2nd panel} = \frac{3}{10} \text{ ,, ,,}$$

$$\text{,, ,, tie in 3rd ,,} = \frac{2}{10} \text{ ,, ,,}$$

$$\text{,, ,, tie in 4th ,,} = \frac{1}{10} \text{ ,, ,,}$$

Similarly (*see* reciprocal diagram, Fig. 390),

$$\text{Compression in strut nearest abutment} = \frac{4}{10} \text{ of } S_s$$

$$\text{,, ,, ,, in 2nd panel} = \frac{3}{10} \text{ ,, ,,}$$

$$\text{,, ,, ,, ,, 3rd ,,} = \frac{2}{10} \text{ ,, ,,}$$

$$\text{,, ,, ,, ,, 4th ,,} = \frac{1}{10} \text{ ,, ,,}$$

In the example already considered the height of the columns was 80 feet, the distance apart 16 feet, and it may be assumed that there would be four equal panels as in Fig. 392.

The length of diagonals AC and BD is readily calculated. Then—

$$\text{Maximum vertical shear} = \frac{24\,L^2 + D^2}{10{,}000} \text{ tons} = 16{\cdot}57 \text{ tons.}$$

Resolving this in direction of struts, we get—

$$\text{Total compression in struts} = 16{\cdot}57 \times \frac{16}{20} = 13{\cdot}24 \text{ tons.}$$

$$\text{Compression in bottom strut} = \frac{4}{10} \times 13{\cdot}24 = 5{\cdot}29 \text{ tons.}$$

Resolving 16·57 tons in direction of ties, we get—

$$\text{Total tension in ties} = 16{\cdot}57 \times \frac{25{\cdot}6}{20} = 21{\cdot}2 \text{ tons.}$$

$$\text{Tension in bottom ties} = \frac{4}{10} \times 21{\cdot}2 = 8{\cdot}5 \text{ tons.}$$

The above calculations give the maximum compressive and tensile stresses occurring in struts and ties, the members in the lowest panel being subjected to this loading. From previous statements it will be seen that the stresses in the individual struts and ties decrease towards the top of the framework ; hence, theoretically, the section of these members may be reduced in proportion. In practice, however, it

is frequently the custom to allow for all struts to be of similar section, although in the case of the larger holders some reduction is admissible and conducive to economy. This particularly applies to holders having built up struts such as the lattice or open-box type. It must be borne in mind, however, that there is some tendency to deformation due to torsion, and this torsional force is a maximum at the top of the framing. Hence, too liberal a reduction in the section of the upper struts should not be permitted.

THE DESIGN OF STRUTS

Struts are best designed by trial and effect methods. That is to say, an engineer acquainted with the practical construction of holders will decide upon what he considers to be a reasonable section, and will then prove the stability of his section by ordinary theoretical methods. For this purpose the safe load which the strut is capable of withstanding may be calculated from the following modification of the "straight line" formula which the author suggests as being the most adaptable for the purpose :—

$$\text{Safe load} = 6\left(1 - \cdot0053\frac{L}{K}\right) \times \text{area of section.}$$

Where L= length of strut in inches,
K= *least* radius of gyration.

Then, the section must be such that the safe load given is not less than the compressive stress in the member calculated as shown above.

To return to the example in question, the maximum stress in the bottom strut is 5·29 tons. For a holder of this size the struts would be most economically composed of ordinary R.S.J. The probable section required would be 10″ by 5″ by 30 lb. per foot. Applying the test formula to this, we get—

$$\begin{aligned}\text{Safe load} &= 6\left(1 - \cdot0053\frac{L}{K}\right) \times \text{area} \\ &= 6\left(1 - \cdot0053 \times \frac{16 \times 12}{1{\cdot}05}\right) \times 8{\cdot}82 \\ &= 6\ (1 - \cdot9699) \times 8{\cdot}82 \\ &= 52{\cdot}92 \times \cdot0301 \\ &= 6{\cdot}76 \text{ tons.}\end{aligned}$$

The section is therefore amply strong for the purpose.

(*Note.*—The value of K for above may be readily obtained from one of the many sections tables published by the steel manufacturers, or it may be calculated from the principle that $K = \sqrt{\frac{I}{A}}$, where I is the *least* moment of inertia of the section.)

THE DESIGN OF TIES

The design of the tie-bars which, with few exceptions, consist of plain round mild steel rods is simple. If the load on the tie is known then the following formula gives the required diameter :—

$$\text{Diameter in inches} = \sqrt{\frac{\text{Load in tons}}{4{\cdot}71}}.$$

In the example in question the maximum tension was found to be 8·5 tons, therefore—

$$\text{Diameter of tie bar} = \sqrt{\frac{8{\cdot}5}{4{\cdot}71}}$$

$$= \sqrt{1{\cdot}8} = 1{\cdot}34 \text{ inches},$$

or, say, a $1\frac{3}{8}$ inch or $1\frac{1}{2}$ inch bar.

Round bars are to be preferred to other sections, such as flats, tees or channels, in that they are more simply connected to the standards and are more adaptable for tension gear. Care should be taken, however, to ensure that the rods are thickened at the screwed end, so that there is no loss in strength when the screw is cut. When connecting eyes are employed they must be of such design as to be of equal strength to the bar. The attachment of the eye to the standard should be such that the connecting pin is in double shear.

It will, of course, be understood that of the two diagonal ties in each panel only one is under stress at a time.

THE HOLDER BELL

In the design of the holder bell, particular consideration must be given to the top curb (where side sheets and top sheets meet), the ring curb at the base of the top lift, and the curbs at the upper and lower edges of succeeding lifts.

The top curb, owing to the gas pressure on the dome, is by far the most highly stressed. The forces acting on it are shown in Fig. 393. They produce, as is seen, a compound stressing which tends either—

(*a*) To tear the top bodily away at the junction of side and dome plates.

(*b*) To buckle the curb, side plates or dome plates.

The function of the top curb is, therefore, to resist these tendencies, whilst an additional safeguard is provided against the blowing-in of the side sheets by interposing vertical stiffeners at intervals around the cylinder. The resultant pressure of the gas on the interior of the dome, and the weight of the plates composing the dome, will be such as to produce a pull in the plates, the direction of which pull will be at a tangent to the point under consideration. So far as the plates forming the sides are concerned, the effect of the internal gas pressure is to produce a slight ring tension, but the plates are of necessity more than strong enough to cope with this. The ring stress is transmitted to the curbs by the vertical

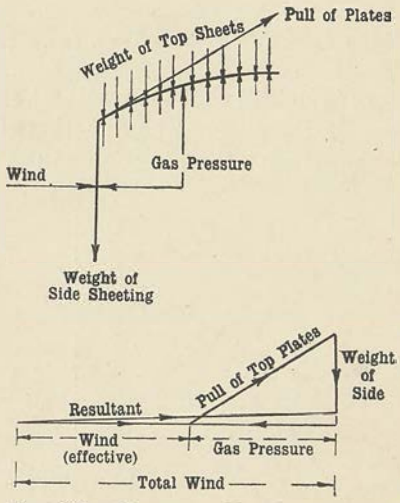


FIG. 393.—FORCES ON TOP CURB. NOTE.—RESULTANT IS ALWAYS HORIZONTAL, BUT HAS BEEN SHOWN SLIGHTLY OUT OF HORIZONTAL TO EXPLAIN DIAGRAM.

stiffeners, and in this way assists in counteracting the compression in the curbs. If buckling or distortion of the curb took place the ring tension would have a tendency to right the whole to its circular form, but the effect would be almost inappreciable.

By a consideration of the main forces, it may be shown from the polygon of

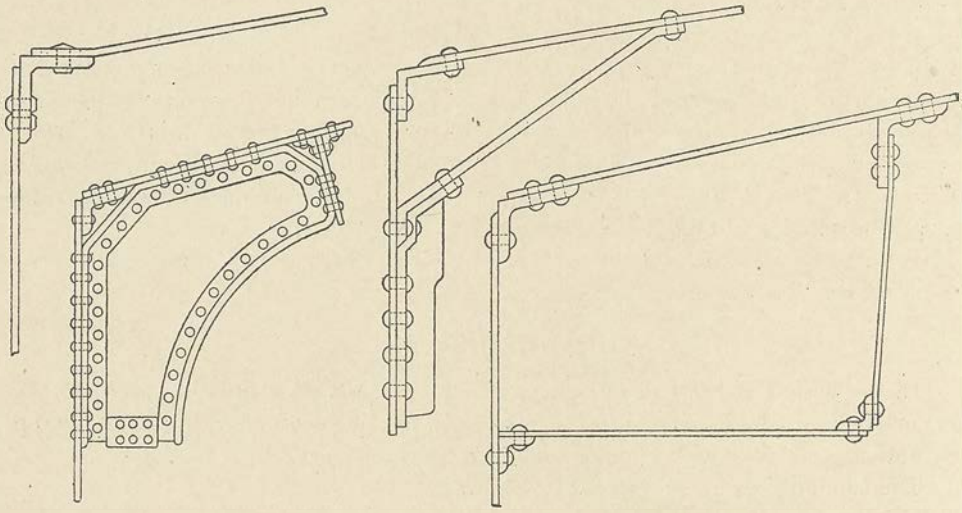


Fig. 394.—Top Curbs for Gasholders.

forces (Fig. 393) that the resultant acts in such a direction as to induce a compressive stress in the curb. The direction of the resultant will, in fact, be horizontal and in alignment with the direction of the wind. In the diagram of forces (Fig. 393) the

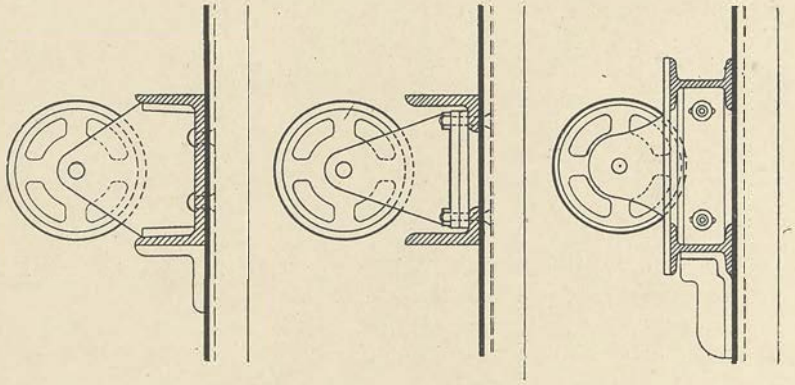


Fig. 395.—Common Designs for Bottom Curbs.

resultant has been slightly tilted in order to show the conditions more clearly. Failure of the curb will be due, as may be seen, to an excessive compressive ring stress. In

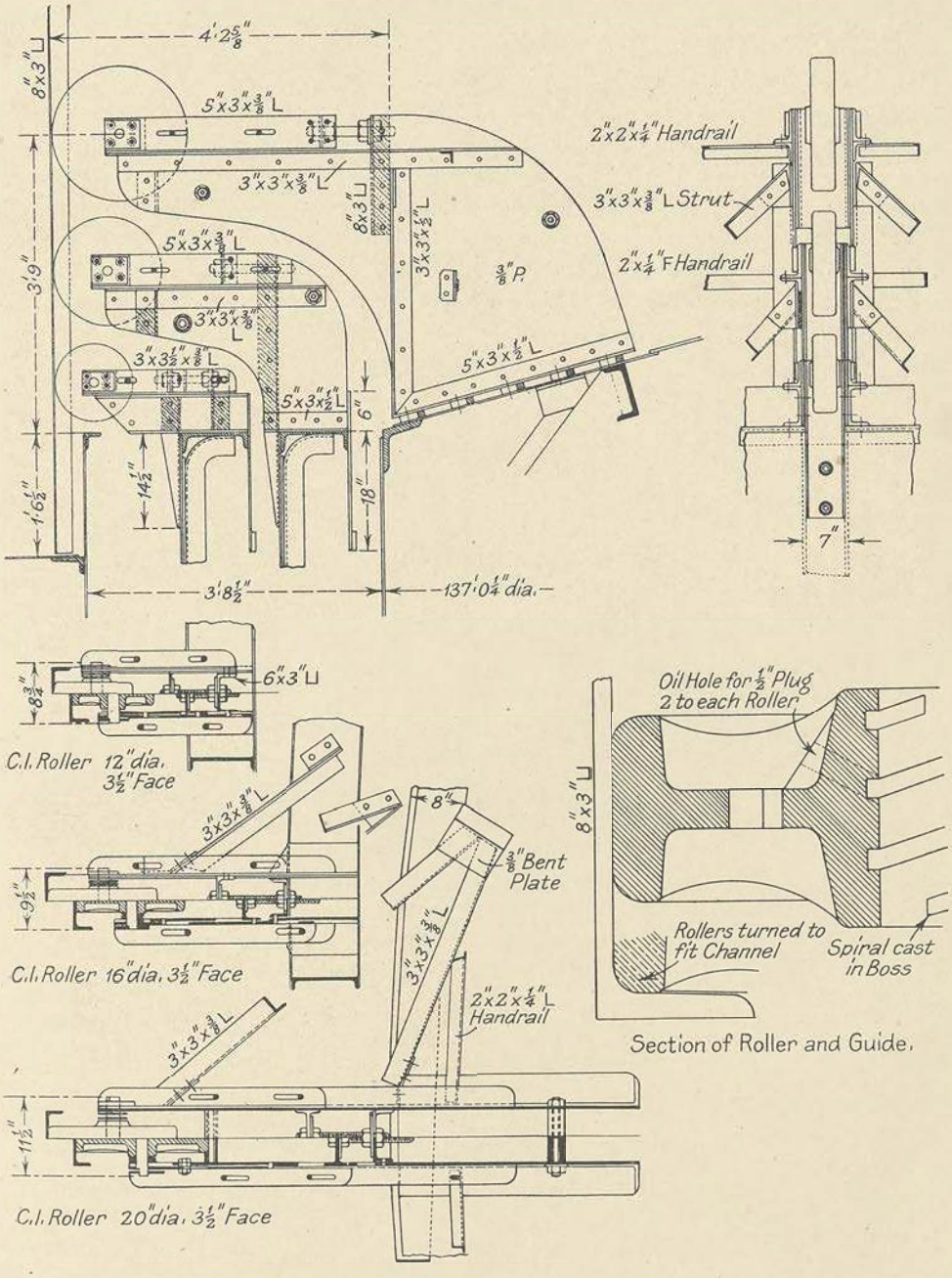


FIG. 396.—TOP CURB AND ROLLERS OF 3-LIFT HOLDER.

practice, however, the chief danger of buckling lies, not so much in the stresses produced by wind and top pull, but from the possibility of the bell tilting during its movement on the guide stanchions. In this direction a heavy drift of snow might give rise to danger.

For the purpose of withstanding any buckling effort which might occur, the dome curb in holders of any size should preferably be designed on the girder principle, or be provided with suitable gussets. Various forms of top curbs, which have been adopted in practice, and some of which are not to be recommended, are shown in Fig. 394. Cripps has pointed out that if these curbs are of sufficient strength to resist the compressive stress, then there will be little likelihood of buckling. Common designs for bottom curbs, that is the lower curb of the bottom lift, are shown in Fig. 395, while Fig. 397 illustrates the rollers and bottom curbs on the three lifts of a telescopic holder.

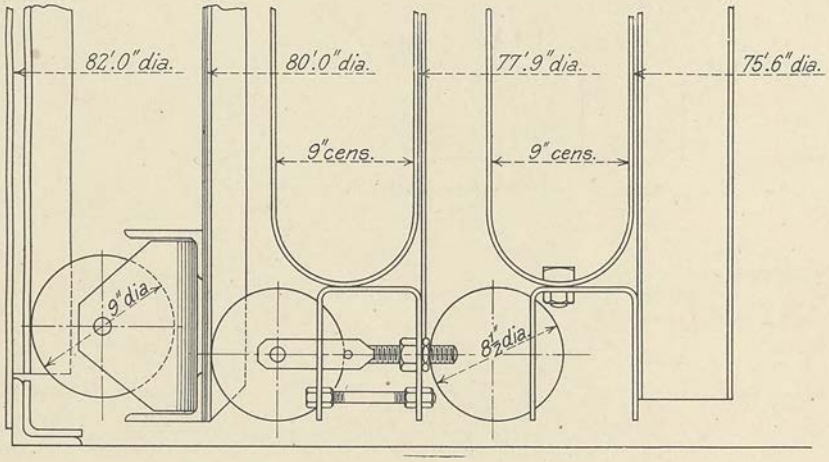


Fig. 397.—Bottom Curbs and Rollers, 3-Lift Holder.

COMPRESSION IN THE TOP CURB

The compressive stress in the top curb and hence its necessary dimensions may be calculated as follows :—

Let D be the diameter of the top lift, in feet.
,, R ,, ,, rise ,, ,, dome, in feet.
,, P ,, ,, effective pressure thrown by the holder in lb. per square foot.

As regards pressure it will be seen that if the total weight of the holder bell is W lb., then the nominal pressure thrown would be $\frac{\text{W lb.}}{\text{area of bell}}$. It is necessary to consider, however, the upward pressure of the gas on the dome sheeting, which actually detracts from the total weight of the dome.

Thus, if w = the weight of the top sheeting in lb. per square foot,

and h = the gross pressure thrown by the holder in lb. per square foot,

then the effective pressure will be—

$$(h - w) \times \text{area of bell} = \cdot 7854\ D^2\ (h - w) = P.$$

The net upward thrust on the dome due to the gas will then be equal to $\cdot 7854\ D^2\ (h - w)$, that is the effective pressure P. Then, referring to Fig. 398, it will be seen that the resultant vertical thrust is kept in equilibrium by the tangential pull at the circumference acting at an inclination DF or EF. In the triangle of forces FDO, if OF represents the net upward thrust of the gas, then DF represents in magnitude and direction the tangential pull in the plates.

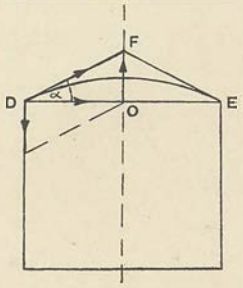


Fig. 398.

$$OF = P,$$

$$\text{and } DF = \frac{FO}{\sin.FDO} = \frac{FO}{\sin.\ a}.$$

$$\text{Therefore, tangential pull, } T = \frac{P}{\sin.\ a} = \frac{\cdot 7854\ D^2(h - w)}{\sin.a}.$$

$$\text{Or, T, per foot length of circumference} = \frac{\cdot 7854\ D^2(h - w)}{\sin.a} \times \frac{1}{\pi D},$$

$$i.e.,\ T = \frac{D(h - w)}{4\ \sin.a} \text{ per foot of circumference.}$$

$$\text{But } (h - w) = \text{effective pressure} = P \quad \therefore\ T = \frac{DP}{4\ \sin.a}.$$

This result is approximate, but any error is on the safe side. If the above expression gives the pull per foot of circumference, then the total pull over the whole diameter

$$= \frac{DP}{4\ \sin.\ a} \times D,$$

and this thrust is taken by the two sections of the curb diametrically opposite. Therefore, thrust on each section

$$= \tfrac{1}{2} \left(\frac{DP}{4\ \sin.\ a} \times D \right) = \frac{D^2P}{8\ \sin.\ a}.$$

Weight of the Side Sheets

This may be calculated by taking out the weight of the side sheeting, curbs, guide rollers, etc., from the specification or, more readily, from a consideration of the above formula. The *effective* pressure thrown by the holder must necessarily be derived from the weight of the side sheeting, for owing to the upward thrust of the gas upon the dome the weight of this portion is ineffective. Considering Fig. 398, it will be seen, then, that the weight of the side sheets is represented by the vertical component of the tangential pull T; moreover, the resultant of the two forces T

and W must be horizontal, otherwise the holder bell would not be in equilibrium, but would tend to be always moving upwards or downwards in its framing.

The resultant of T and W is, therefore, represented by the line DO (Fig. 398).

$\therefore$ Resultant = T cos. a

$$= \frac{D^2P}{8 \text{ sin. } a} \times \text{cos. } a = \frac{D^2P}{8} \times \text{cotan. } a.$$

The angle a may be readily found as follows :—

$$\text{cos. } a = \frac{D^2 - 4R^2}{D^2 + 4R^2}.$$

where D = diameter of holder in feet,
and R = rise of dome in feet.

Internal Pressure of Gas on Sides

Cripps' method of calculating the effects of this force is to consider the ring tension in the side sheets, and to allow a definite proportion of this as transmitted to the curbs. Thus ring tension

$$= \frac{h \times D \times d}{2}, \text{ where } d = \text{depth of lift in feet.}$$

Then $\frac{1}{10}$ of the above is taken for holders having vertical stays attached throughout their length, and $\frac{1}{16}$ for stays attached at top and bottom only. The effect of the internal gas pressure is to counteract in some degree the external wind pressure and buckling effect. The extent to which this effect is felt is, at all events, an uncertain factor; and, in the light of practical observations, the author considers that it is quite reasonable to allow for it by deducting 55 per cent. from the usual figure taken for maximum wind pressure on a cylindrical surface; that is to say, to assume external effective wind pressure at 12 lb. instead of 26 lb. per square foot. This, of course, applies to those cases in which the vertical stays are attached throughout their length. Such an allowance would be representative of the effect in the majority of holders now erected, and in the case of the very large holders any slight error would be on the right side.

Objection might be raised to this method owing to the fact that the gas pressure, the magnitude of which is easily computed, is taken as constant in all holders. But as the whole treatment must necessarily be one of some conjecture, the author considers that his assumption, owing to its simplification of formulæ, is perfectly justifiable.

Effective wind pressure, therefore,

$$= D \times d \times 12 \text{ lb. per square foot.}$$

But this is distributed to both upper and lower curbs of the lift and is also withstood by the two diametrically opposite sections of the curb. Accordingly, the total force on any section of the curb

$$= \frac{1}{4} \times D \times d \times 12 = 3Dd.$$

By a summation of the above force and the resultant of the tangential and

vertical pulls, which act parallel with the wind, the total compressive force on the curb may be readily calculated.

COMPRESSIVE FORCE IN TOP CURB

$$= \frac{D^2 P \text{ cotan. } \alpha}{8} + 3\ Dd.$$

Where D = Diameter of holder in feet.

P = Effective pressure in lb. per square foot.

α = Angle made by tangent with chord at base of the dome, or the angle α may be found from the following. (Note the formulæ gives cos. α and not cotan. α direct.)

$$\text{cos. } \alpha = \frac{D^2 - 4R^2}{D^2 + 4R^2}, \text{ where R = rise of dome in feet.}$$

d = Depth of top lift in feet.

In the event of the holder being designed with vertical stays attached at top and bottom only, substitute 5 Dd for the expression 3 Dd above.

Having obtained the total compressive force it is merely necessary to design a curb of sufficient cross-sectional area to withstand this safely. A stress of 6 tons per square inch should not be exceeded. In calculating the cross-sectional area it should be remembered that the two outer crown rows and the two top side rows of the sheeting may be included in the effective area. These plates should be butted, when the full cross-sectional area may be considered effective, but if lapped the shearing strength of the rivets only should be considered.

CUPS AND GRIPS

The proportions of cups and grips for telescopic holders have already been dealt with (page 627). There are two standard types, namely, the semi-circular cup and grip, and that composed of the square channel section. The channel type is strongly to be preferred. It is simply constructed, while it obviates the objectionable initial stressing which is set up in the semi-circular grip when the plate is bent to shape. Moreover, if one portion is not in perfect alignment with its counterpart, a grinding action will be set up when the two come together. This will be particularly severe when

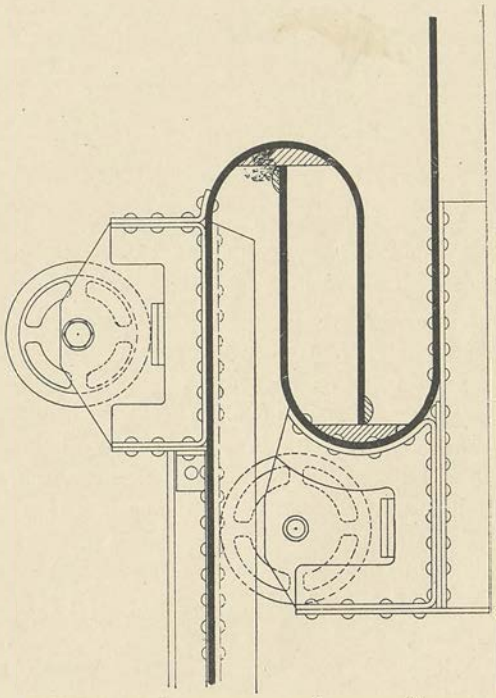


FIG. 399.—SEMI-CIRCULAR CUP AND GRIP. BENT-PLATE TYPE.

there is some slight constructional defect, such as the grip being slightly larger than the cup, or if the two are not set to an exact circle. If the grip is slightly large the cup will not engage centrally, with the result that the grip is slightly tilted and the guide rollers are, in turn, thrust hard over against the columns. The effect will be noticed by a consideration of Fig. 401. The tendency can, of course, be minimized by additional guide rollers on the grip running on guides attached to the inner lift. When properly constructed, the grip with the weight it carries should act as a support to the inner lift, and counteract any tendency towards tilting.

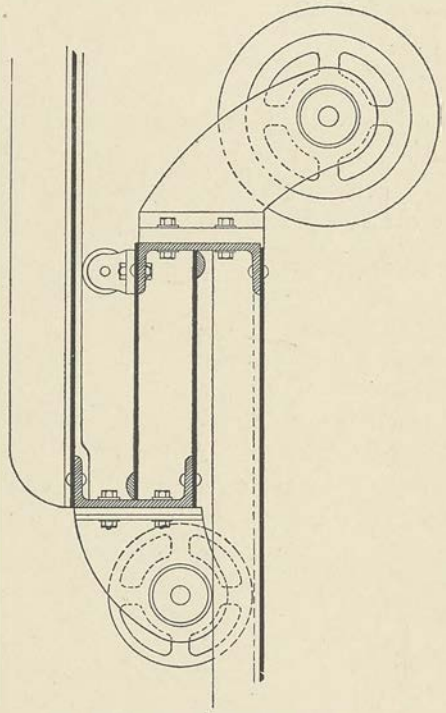


FIG. 400.—SQUARE CUP AND GRIP. EARLY DESIGN.

When designing the cup and grip, sufficient width should be allowed so that riveting may be carried out with ease. The minimum width should be 8 inches. The cup sides and cup rows on the bell must be stouter than the normal side sheeting, and a beading, to increase rigidity, should be run all round at the base of the cup side. The stouter cup sheets will prove effective in meeting any corrosion due to the changing level of the water in the lute. In addition, they avoid the undesirable practice of riveting very thin sheets to the thick section of the cup or curb. The thickening up of these plates enables the reduction to be effected in two steps. For the cup rows and cup sides $\frac{1}{4}$ inch sheeting is common, while the beading, which may be either moulded or flat, varies from $\frac{5}{8}$ inch to $\frac{3}{4}$ inch thick; but everything, of course, depends upon the size of the holder.

The crown sheeting of gasholders varies from 14 gauge to 10 gauge in thickness (*i.e.* $\frac{5}{64}$ inch to $\frac{1}{8}$ inch), depending entirely upon the size of the holder; curb rows being, of course, thicker ($\frac{1}{4}$ inch to $\frac{3}{8}$ inch in medium-sized holders, and so much as $\frac{7}{8}$ inch in large holders). As regards side sheeting, this varies from 12 gauge to 10 gauge in thickness; curb, or cup and grip rows again being heavier. The side sheets of the top lift are occasionally thicker (say 8 gauge) than those of succeeding lifts; and it should be remembered that where joints between rolled sections and plates occur it is always advisable to use heavier plates, so as to avoid attaching a very thin section to a thick one, a practice generally followed by imperfect and leaky joints. The sheets employed should be as large as practicable,



FIG. 401.

for the jointing is then reduced to a minimum and the labour of riveting is lessened. On the other hand, smaller plates and, therefore, more liberal riveting have a tendency to stiffen up the whole shell.

The most modern forms of the cup and grip are seen in Figs. 402, 403, and 404, the last-named being of the bent-plate type and showing the method of using the riveting tool at inaccessible

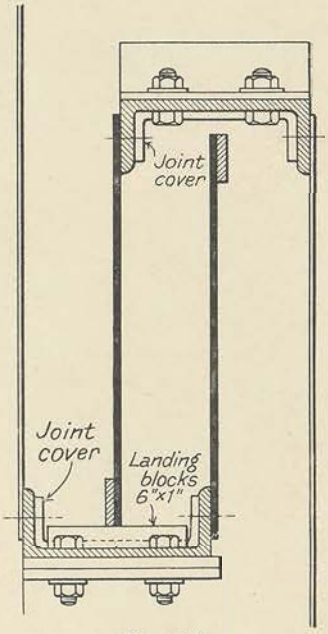


FIG 402.

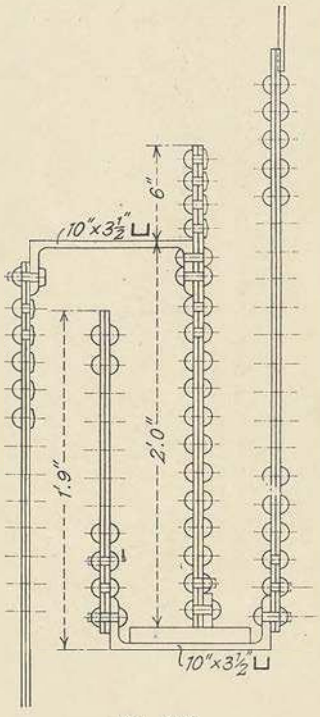


FIG. 403.

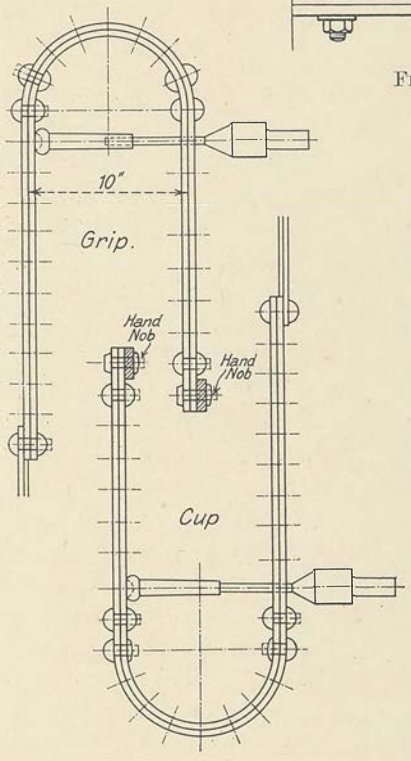


FIG. 404.

places. The extension of the upper portion of the grip plate shown in Fig. 403 ensures greater safety against the possibility of blowing. In connection with the design shown in Fig. 400, it should be mentioned that trouble is frequently experienced with the dip plates landing on top of the bolt heads which fix the bottom roller carriages to the horizontal channel, and also on the joint covers. The difficulty is avoided by placing landing blocks round the cups about every two feet (*see* Fig. 403). These blocks are of iron, being usually 6 inches by 1 inch for an 8-inch channel.

The thinner sheets of the gasholder bell are usually riveted up cold with $\frac{1}{4}$ inch rivets at a pitch of 1 inch, or $\frac{5}{16}$ inch rivets at $1\frac{1}{8}$ inch pitch. Curb and such rows have stiffer rivets at a slightly greater pitch, but all rivets

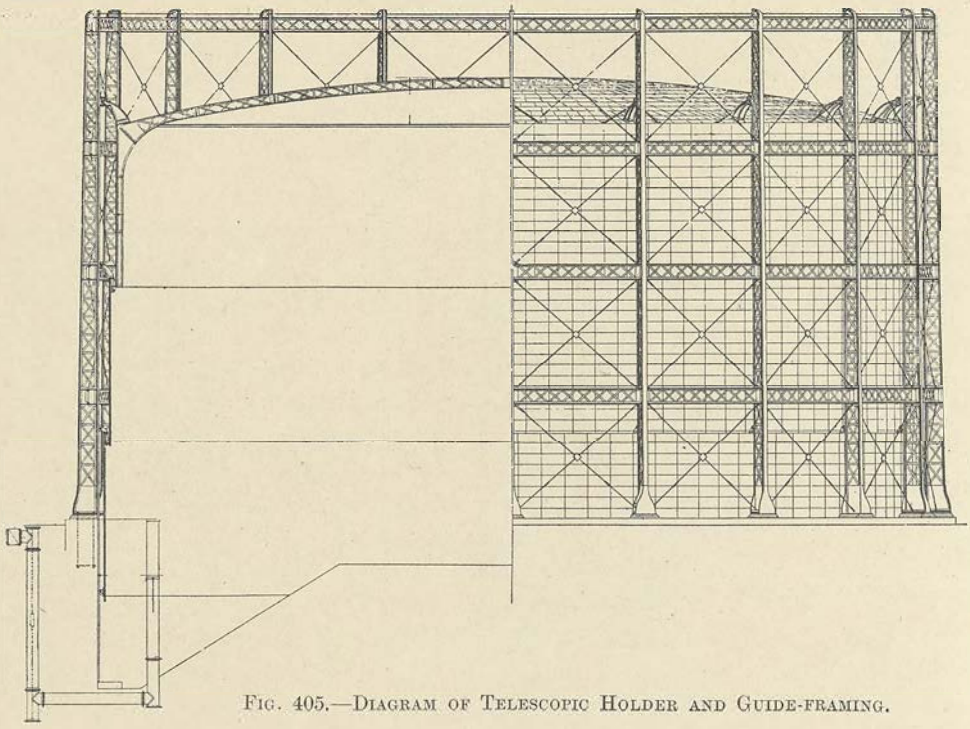


FIG. 405.—DIAGRAM OF TELESCOPIC HOLDER AND GUIDE-FRAMING.

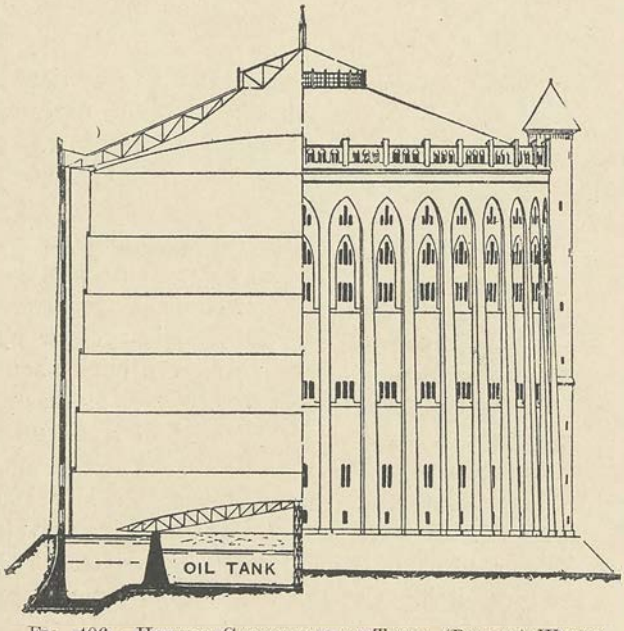


FIG. 406.—HOUSED GASHOLDER AT TEGEL (BERLIN) WORKS.

above ½-inch diameter must be driven hot. For the purpose of making the joints between the plates gas-tight, it is essential to insert at the lap strips of tape soaked in red lead.

SUPPORT FOR THE CROWN

The dome of a gasholder, owing to its frail construction, requires some form of support when the holder is grounded and is receiving no support from the internal pressure of the gas. There are two common methods of preventing the crown from buckling inwards, namely :—

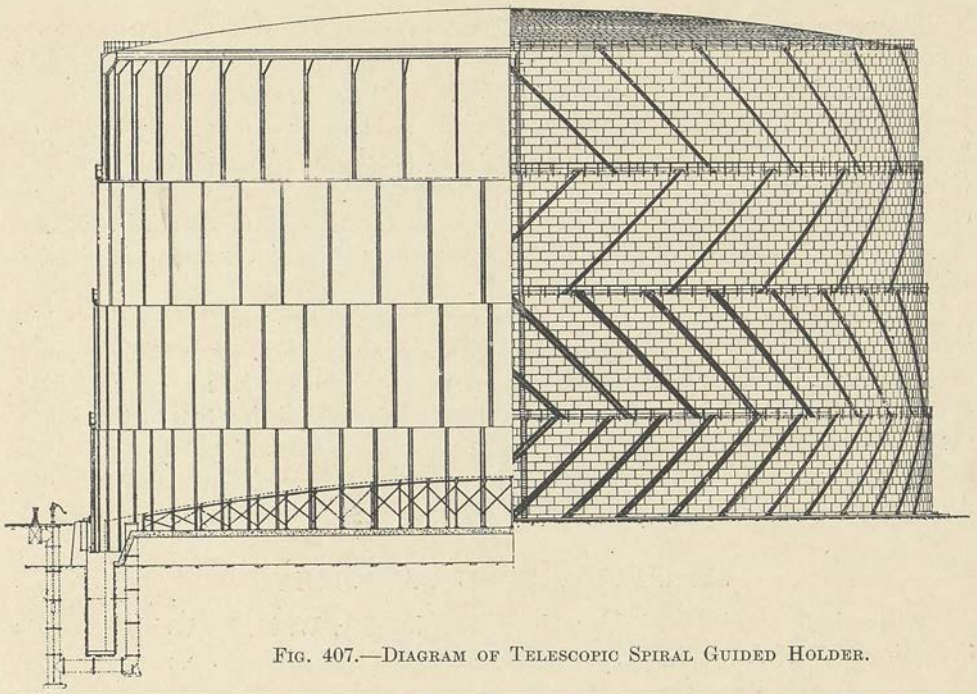


FIG. 407.—DIAGRAM OF TELESCOPIC SPIRAL GUIDED HOLDER.

(*a*) The provision of an internal trussing to the crown, on the lines of the framing of an umbrella.

(*b*) The erection of a crown rest in the tank.

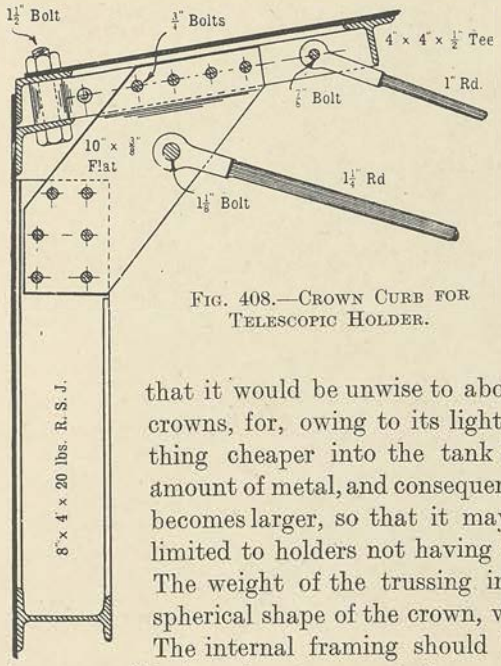


FIG. 408.—CROWN CURB FOR TELESCOPIC HOLDER.

In the former method the framing is affixed to a series of rafters radiating from the centre and attached to the crown curb. A strong centre column is also provided, and when the holder is grounded this rests on a bed-plate or pier in the centre of the tank. For smaller holders the crown trussing is generally employed, and Cripps says that it would be unwise to abolish the system in the case of the smaller crowns, for, owing to its lightness, it would be impossible to put anything cheaper into the tank in the form of separate frames. The amount of metal, and consequently the cost, increases rapidly as the holder becomes larger, so that it may be said that the trussed crown must be limited to holders not having a greater diameter than about 170 feet. The weight of the trussing in large holders would tend to distort the spherical shape of the crown, which the upward gas pressure is assisting. The internal framing should be as independent of the crown sheeting as possible in order to prevent the possibility of straining the seams.

As regards the crown rest, this consists of a series of radiating rafters carried on columns erected in the tank and connected together by purlins to form a skeleton framework of the same camber as the dome. The frame is frequently constructed from timber, although light sections of rolled steel may be economically employed. The design is simple and may be seen in Figs. 388 and 407. An important consideration is that of arranging for the bracing of the columns, which are usually of some considerable height, particularly in the cases of the flat-bottomed steel tanks.

A complete diagram of a telescopic gasholder with guide-framing is given in Fig. 405.

An interesting feature of some of the earlier gasholders was the housing which was erected over and around them as a means of protection. A notable example of the covered gasholder is that at the Tegel works of the Berlin municipality (Fig. 406). The building is an architectural work of brilliance, being 300 feet in height and overlooking the whole of the northern part of the city. The capacity of the holder is nearly 8 million cubic feet, and the cost complete with house was £107,000. An unusual feature is the lead-covered oil storage reservoir in the middle of the tank.

SPIRALLY GUIDED GASHOLDERS

The spirally guided gasholder, the proposal of Mr. W. H. Y. Webber and the invention of Mr. W. Gadd (Fig. 379) with which an external guide-framing is wholly

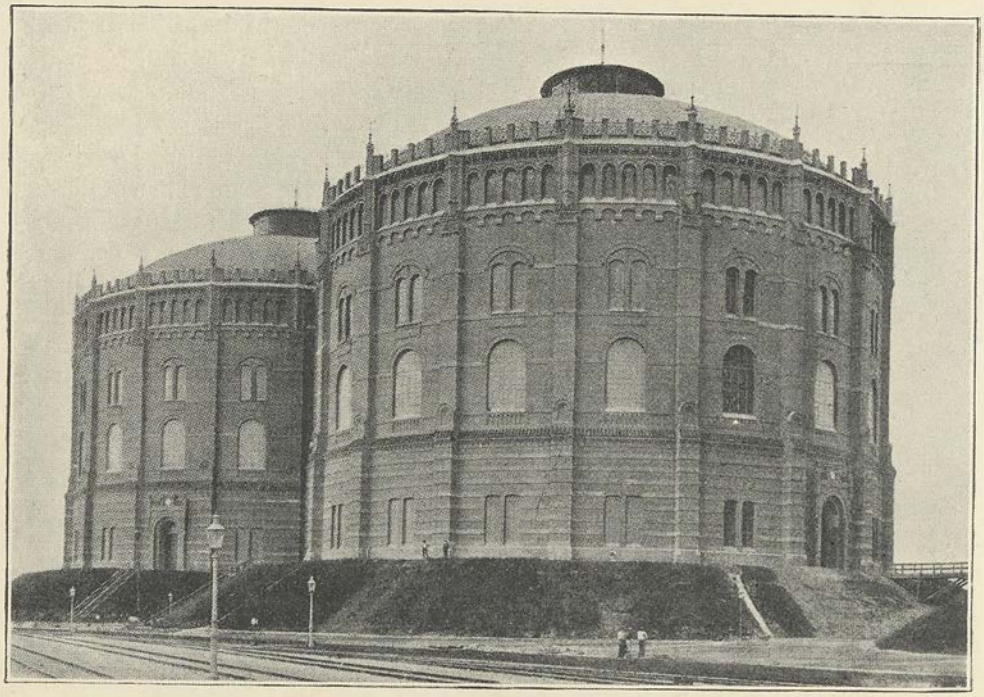


Fig. 409.—Housed Gasholders, Vienna Gasworks.

TABLE GIVING PRINCIPAL DETAILS OF CONSTRUCTION OF VARIOUS EXISTING GASHOLDERS

SINGLE-LIFT GASHOLDERS

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . . .	30′ 0″	30′ 0″	14′ 0″	30′ 0″	28′ 0″	35′ 0″	70′ 0″	27′ 0″	35′ 0″
Depth	14′ 6″	14′ 6″	8′ 0″	12′ 0″	12′ 0″	12′ 0″	20′ 0″	10′ 3″	16′ 0″
Vertical Stays . .	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{3}{8}''$ T	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{3}{8}''$ T	None	None	None	$3''\times3''\times\frac{3}{8}''\llcorner$	5″×3″×11 lb I	$3''\times3''\times\frac{1}{2}''$T	$3''\times3''\times\frac{3}{8}''\llcorner$
No. do. . . .	8	8	—	—	—	5	16	4	6
Plates : Top Row .	13 Gauge	13 Gauge	14 Gauge	13 Gauge	14 Gauge	12 Gauge	10 Gauge	12 Gauge	13 Gauge
„ Bottom Row	13 Gauge	13 Gauge	14 Gauge	13 Gauge	14 Gauge	12 Gauge	10 Gauge	12 Gauge	13 Gauge
„ Intermediate Rows .	14 Gauge	14 Gauge	14 Gauge	14 Gauge	15 Gauge	14 Gauge	14 Gauge	13 Gauge	—
Top Curb . . .	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{3}{8}''\llcorner$	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{5}{16}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$4''\times4''\times\frac{1}{2}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$
Bottom Curb . .	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{3}{8}''\llcorner$	$2\frac{1}{2}''\times2\frac{1}{2}''\times\frac{5}{16}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$	$10''\times3\frac{1}{2}''\times\frac{7}{16}''\sqsubset$	$3''\times3''\times\frac{3}{8}''\llcorner$	$3''\times3''\times\frac{3}{8}''\llcorner$
Inlet and Outlet size	5″	8″	3″	5″	—	6″	—	6″	8″
Tank	Steel	Steel	Steel	Steel	Brick	Brick	Brick	Existing	Steel
Do., diam. & depth	31′ 0″×14′ 9″	31′ 0″×14′ 9″	15′ 0″×8′ 1″	31′ 0″×12′ 4″	—	36′ 0″×12′ 6″	—	—	—

TWO-LIFT GASHOLDERS (OUTER LIFTS)

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . .	65′ 0″	65′ 0″	30′ 0″	30′ 0″	68′ 0″	74′ 3″	99′ 9″	60′ 0″	47′ 0″
Depth . . .	17′ 0″	17′ 0″	12′ 0″	12′ 0″	22′ 0″	20′ 6″	25′ 0″	16′ 0″	16′ 0″
Bottom Curb .	2@4″×3″×⅜″ ∟	2@4″×3″×⅜″ ∟	3″×3″×⅜″ ∟	3″×3″×⅜″ ∟	2@5″×3″×⅜″ ∟	2@4″×4″×⅝″ ∟	See Note.	2@3½″×3½″×½″ ∟	3½″ × 3½″ × ½″ ∟
Distance apart .	9½″	9½″	—	—	18″	17¼″	—	12″	—
Vertical Stays .	6″×2½″ ⊏	6″×2½″ ⊏	4″×2″ ⊏	4″×2″ ⊏	7″×2½″ ⊏	6″×2½″ ⊏	6″×3″ ⊏	6″×2½″ ⊏	4½″×2″ ⊏
No. of „ .	16	16	4	4	14	20	18	16	24
Grip . . .	8″×16″	8″×16″	6″×14″	6″×14″	8″×16″	8″×15″	9″×20″	8″×18″	8″×18″
„ how formed	8″×3½″ ⊏	8″×3½″ ⊏	6″×3″ ⊏	6″ ⊏	Bent P.	Bent P.	Bent P.	8″×3½″ ⊏	Bent P.
„ Dip Plate	3/16″	3/16″	10 S.W.G.	10 S.W.G.	5/16″	¼″	5/16″	Note: 6″ Wind Screen 9 G.×2′ 0″	3/16″
„ Bead . .	2″×⅜″	2″×⅜″	2″×¼″	2″×¼″	2″×⅜″	2″×⅜″	2″×⅜″	2½″×⅜″	2½″×⅜″
Side Sheets and Centres . .	29 @ 5′ 1″ 11 @ 5′ 2″	29 @ 5′ 1″ 11 @ 5′ 2″	11 @ 5′ 11″ 5 @ 5′ 10″	11 @ 5′ 11″ 5 @ 5′ 10″	41 @ 5′ 1″ 1 @ 5′ 2″	40 @ 5′ 10″ —	49 @ 5′ 9¾″ 5 @ 5′ 8⅝″	22 @ 5′ 11″ 10 @ 5′ 10″	24 @ 11′ 6″ 24 strips 9⅝″ cens.
Bott. Row . .	2′ 6″×12 S.G.	2′ 6″×12 S.W.G.	—	—	2′ 0″×11 G.	2′ 6″×¼″	2′ 0″×5/16″	2′ 8″×12 G.	2′ 4″×12″
Next Row . .	—	—	—	—	—	—	3′ 6¾″×11 G.	—	—
Top Row . .	2′ 6″×12 S.G.	2′ 6″×12 S.G.	—	—	2′ 0″×5/16″	2′ 0″×¼″	2′ 0″×5/16″	2′ 8″×12 G.	2′ 0″×3/16″
Next Row . .	—	—	—	—	—	—	3′ 6¾″×11 G.	—	2′ 4″×12 G.
Interm. Rows .	4@3′ 0″×14 S.G.	4@3′ 0″×14 S.G.	4@3′ 0″×13½ G.	4@3′ 0″×13½ G.	6@3′ 0″×13 G.	5 { 2@3′3″×12 G 3@3′2″	5@3′ 5⅝″×12 G.	4@2′ 8″×14 G.	4@2′ 4″×14 G.

TWO-LIFT GASHOLDERS (INNER LIFTS)

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . .	63′ 0″	63′ 0″	28′ 6″	28′ 6″	66′ 0″	72′ 3″	97′ 6″	58′ 0″	45′ 0″
Depth . . .	17′ 0″	17′ 0″	12′ 0″	12′ 0″	22′ 0″	20′ 6″	25′ 0″	16′ 0″	16′ 0″
Vert. Stays . .	5″×3″ I	5″×3″ I	3″×4″×$\frac{3}{8}$″ T	3″×4″×$\frac{3}{8}$″ T	5″×3″ I	$6\frac{1}{4}$″×$3\frac{1}{8}$″ I	10″×6″ I	4″×3″×$\frac{3}{8}$″ T	4″×3″×$\frac{3}{8}$″ T
No. of Do. . .	8	8	4	4	14	20	18	16	24
Stiffeners . .	—	—	—	—	—	—	—	King Truss Strut 1″ dia. Ties $\frac{3}{4}$″ dia.	King Truss Strut $1\frac{1}{8}$″ dia. Ties $\frac{3}{4}$″ dia.
Cup	16″×8″	16″×8″	14″×6″	14″×6″	16″×8″	15″×8″	20″×9″	18″×8″	18″×8″
„ how formed	8″×$3\frac{1}{2}$″ ⊏	8″×$3\frac{1}{2}$″ ⊏	6″ ⊏	6″⊏	Bent P.	Bent P.	Bent P.	8″×$3\frac{1}{2}$″ ⊏	Bent P.
„ Dip Plate .	$\frac{3}{16}$″	$\frac{3}{16}$″	10 S.W.G.	10 S.W.G.	$\frac{5}{16}$″	$\frac{1}{4}$″	$\frac{3}{8}$″	9 G.	$\frac{3}{16}$″
„ Bead . .	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″	2″×$\frac{1}{4}$″	2″×$\frac{1}{4}$″	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″	$2\frac{1}{2}$″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″
Side Sheets and	15 @ 5′ 0″	15 @ 5′ 0″	14 @ 5′ 7″	14 @ 5′ 7″	32 @ 4′ 11″	36 @ 5′ 8″	27 @ 5′ 8$\frac{5}{8}$″	22 @ 5′ 8″	24 @ 11′ 6″
Centres . .	25 @ 4′ 11″	25 @ 4′ 11″	2 @ 5′ 8″	2 @ 5′ 8″	10 @ 5′ 0″	4 @ 5′ 9″	27 @ 5′ $7\frac{1}{2}$″	10 @ 5′ 9″	24strips $9\frac{3}{8}$″cens.
Cup Row . .	2′ 6″×12 S.W.G.	2′ 6″×12 S.G.	—	—	2′ 0″×$\frac{5}{16}$″	2′ 0″×$\frac{1}{4}$″	2′ 0″×$\frac{3}{8}$″	2′ 8″×12 G.	2′ 0″×$\frac{3}{16}$″
Next Row . .	—	—	—	—	3′ 0″×11 G.	—	3′ 5$\frac{5}{8}$″×$\frac{3}{16}$″	—	2′ 4″×12 G.
Top Row . .	2′ 6″×12 G.	2′ 6″×12 G.	—	—	2′ 0″×11 G.	2′ 6″×$\frac{3}{16}$″	2′ $2\frac{1}{4}$″×$\frac{5}{16}$″	2′ 8″×12 G.	2′ 4″×12 G.
Next Row . .	—	—	—	—	—	—	3′ 5$\frac{5}{8}$″×$\frac{3}{16}$″	—	—
Interm. Rows .	4@3′ 0″×14 G.	4@3′ 0″×14 G.	4@3′ 0″×13$\frac{1}{2}$G.	4@3′ 0″×13$\frac{1}{2}$G.	5@3′ 0″×13 G.	3 at 3′ 2″ / 2 @ 3′ 3″ ×12 G.	4@3′ 5$\frac{5}{8}$″×9G.	4@2′ 8″×14G.	4@2′ 4″×14 G.
Top Curb . .	4″×4″×$\frac{3}{8}$″ ∟	4″×4″×$\frac{3}{8}$″ ∟	3″×3″×$\frac{3}{8}$″∟	3″×3″×$\frac{3}{8}$″ ∟	$4\frac{1}{2}$″×$4\frac{1}{2}$″×$\frac{1}{2}$″∟	5″×5″×$\frac{1}{2}$″ ∟	6″×6″×$\frac{1}{2}$″ ∟	5″×5″×$\frac{1}{2}$″	$3\frac{1}{2}$″×$3\frac{1}{2}$″×$\frac{1}{2}$″∟

TWO-LIFT GASHOLDERS (OUTER LIFTS)

	K.	L.	M.	N.	O.	P.	R.	S.
Diameter . .	47′ 0″	34′ 9″	49′ 9″	48′ 6″	60′ 0″	78′ 0″	60′ 0″	78′ 0″
Depth . . .	17′ 0″	14′ 0″	20′ 6″	18′ 9″	20′ 0″	22′ 0″	20′ 0″	22′ 0″
Bottom Curb .	$5\frac{3}{4}''\times2\frac{3}{8}''$ ⊏	$3''\times3''\times\frac{3}{8}''$ ∟	$5''\times3''\times\frac{3}{8}''$ ∟	$2'\,3\frac{1}{2}''\times3\frac{1}{2}''\times\frac{3}{8}''$	$2'3\frac{1}{2}''\times3\frac{1}{2}''\times\frac{3}{8}''$ ∟	$2'\,4''\times4''\times\frac{1}{2}''$ ∟	$2'\,4''\times3''\times\frac{3}{8}''$ ∟	$2'\,5''\times3''\times\frac{1}{2}''$ ∟
Distance apart .	—	—	—	10″	10″	12″	10″	12″
Vertical Stays .	$9''\times\frac{3}{8}''$ F.	$4''\times2''$ ⊏	$6''\times2\frac{1}{2}''$ ⊏	$5\frac{11}{16}''\times2\frac{1}{8}''$ ⊏	$6''\times2\frac{1}{2}''$ ⊏	$6''\times2\frac{1}{2}''$ ⊏	$6''\times3''$ ⊏	$6''\times2\frac{1}{2}''$ ⊏
No. of Do. . .	16	5	12	12	18	20	15	14
Grip	$18''\times18''$	$14''\times6''$	$16''\times8''$	$16''\times7''$	$16''\times8''$	$18''\times8''$	$18''\times9''$	$18''\times8''$
„ how formed	$8''\times3\frac{1}{2}''$ ⊏	$6''\times2\frac{1}{2}''$ ⊏	Bent P.	$7''\times2\frac{3}{4}''$ ⊏	Bent P.	$8''\times3''$ ⊏	Bent P.	Bent P.
„ Dip Plate .	8 G.	10 G.	$\frac{5}{16}''$	8 G.	$\frac{5}{16}''$	7 G.	$\frac{11}{32}''$	$\frac{5}{16}''$
„ Bead . .	$2''\times\frac{1}{2}''$	$2''\times\frac{1}{4}''$	$2''\times\frac{3}{8}''$	$2''\times\frac{3}{8}''$	$2''\times\frac{3}{8}''$	$2''\times\frac{1}{2}''$	$2''\times\frac{3}{8}''$	$2''\times\frac{3}{8}''$
Side Sheets and Centres	16 @ 8′ 7″	10 @ 5′ $7\frac{1}{2}''$	19 @ 4′ 11″	28 @ 4′ 9″	30 @ 5′ 3″	20 @ 6′ 2″	18 @ 6′ 3″	42 @ 5′ 10″
	16 strips $7\frac{3}{4}''$ w.	10 @ 5′ $6\frac{1}{2}''$	13 @ 4′ 10″	4 @ 4′ 10″	6 @ 5′ 2″	20 @ 6′ 1″	12 @ 6′ 4″	—
Bott. Row . .	$3'\,3\frac{1}{4}''\times8$ G.	$1'\,9''\times14$ G.	$3'\,9''\times12$ G.	$2'\,0''\times10$ G.	$2'\,1''\times10$ G.	$2'\,0''\times8$ G.	$2'\,1''\times10$ G.	$2'\,10''\times11$ G.
Top Row . .	$3'\,5''\times8$ G.	$1'\,9''\times14$ G.	$1'\,6''\times\frac{5}{16}''$	$2'\,0''\times12$ G.	$2'\,1''\times\frac{5}{16}''$	$2'\,0''\times8$ G.	$2'\,1''\times\frac{11}{32}''$	$1'\,9''\times\frac{5}{16}''$
Next Row . .	—	—	$3'\,9''\times12$ G.	$3/2'\,11''\times14$ G.	$3'\,2''\times12$ G.	—	$3'\,2''\times10$ G.	$2'\,10''\times11$ G.
Interm. Rows .	$3@3'\,5\frac{1}{4}''\times12$ G.	$3@3'\,6''\times14$ G.	$3@3'\,10''\times14$ G.	$2@3'\,0''\times14$ G.	$4@3'\,2''\times14$ G.	$6@3'\,0''\times12$ G.	$4@3'\,2''\times12$ G.	$5@2'\,11''\times12$ G.
Inlet and Outlet	8″	—	10″ and 12″	12″ and 10″	12″	12″	10″	14″

TWO-LIFT GASHOLDERS (INNER LIFTS)

	K.	L.	M.	N.	O.	P.	R.	S.
Diameter . .	45′ 0″	33′ 3″	47′ 9″	46′ 9″	58′ 0″	76′ 0″	57′ 9″	76′ 0″
Depth . . .	17′ 3″	14′ 0″	20′ 0″	18′ 3″	20′ 0″	22′ 0″	20′ 0″	22′ 0″
Vert. Stays . .	4″×3″×$\frac{3}{8}$″ T	3″×4″×$\frac{3}{8}$″ T	5″×3″×11″ I	4″×3″ I	5″×3″ I	3$\frac{1}{2}$″×3$\frac{1}{2}$″×$\frac{1}{2}$″ T	6″×3″ I	5″×3″ I
Stiffeners . .	—	—	—	—	—	Queen Truss Struts $\frac{7}{8}$″ dia. Ties $\frac{3}{4}$″ dia.	—	—
No. Stays . .	16	5	12	16	18	20	20	14
Cup	18″×8″	14″×6″	16″×8″	16″×7″	16″×8″	18″×8″	18″×9″	18″×8″
„ how formed	8″×3$\frac{1}{2}$″ ⊏	6″×2$\frac{1}{2}$″ ⊏	Bent P.	7″×2$\frac{3}{4}$″ ⊏	Bent P.	8″×3″ ⊏	Bent P.	Bent P.
„ Dip Plate .	8 G.	10 G.	$\frac{5}{16}$″	8 G.	$\frac{5}{16}$″	7 G.	$\frac{11}{32}$″	$\frac{5}{16}$″
„ Bead . .	2″×$\frac{1}{2}$″	2″×$\frac{1}{4}$″	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″	2″×$\frac{1}{2}$″	2″×$\frac{3}{8}$″	2″×$\frac{3}{8}$″
Side Sheets and	12 @ 8′ 9$\frac{3}{4}$″	14 @ 5′ 3″	24 @ 4′ 8″	30 @ 4′ 7″	26 @ 5′ 1″	25 @ 6′ 0″	17 @ 6′ 1″	23 @ 5′ 8″
Centres	4 @ 8′ 10$\frac{7}{8}$″	6 @ 5′ 2″	8 @ 4′ 9″	2 @ 4′ 8″	10 @ 5′ 0″	15 @ 5′ 11″	13 @ 6′ 0″	9 @ 5′ 9″
Cup Row . .	3′ 5″×8 G.	3′ 6″×14 G.	1′ 6″×$\frac{5}{16}$″	2′ 0″×10 G.	2′ 1″×$\frac{5}{16}$″	2′ 0″×7 S.G.	2′ 1″×$\frac{11}{32}$″	1′ 9″×$\frac{5}{16}$″
Next Row Do. .	—	—	3′ 9″×12 G.	—	3′ 2″×12 G.	—	3′ 2″×10 G.	2′ 10″×11 G.
Top Row . .	3′ 5$\frac{1}{8}$″×8 G.	3′ 6″×14 G.	3′ 9″×12 G.	2′ 0″×12 G.	2′ 1″×10 G.	2′ 0″×7 G.	2′ 1″×$\frac{3}{16}$″	2′ 10″×11 G.
Next Row Do. .	—	—	—	2′ 11″×14 G.	—	—	3′ 2″×10 G.	—
Interm. Rows .	3@3′ 5$\frac{5}{8}$″×12 G.	2@3′ 6″×14 G.	3@3′ 8″×14 G.	4@2′ 10″×14 G.	4@3′ 2″×14 G.	6@3′ 0″×11 G.	3@3′ 2″×12 G	5@2′ 11″×12 G.
Top Curb . .	4″×4″×$\frac{1}{2}$″ ∟	3″×3″×$\frac{5}{16}$″ ∟	3$\frac{1}{2}$″×3$\frac{1}{2}$″×$\frac{3}{8}$″	3″×3″×$\frac{3}{8}$″	3$\frac{1}{2}$″×3$\frac{1}{2}$″×$\frac{3}{8}$″ ∟	4″×4″×$\frac{1}{2}$″ ∟	4″×4″×$\frac{7}{16}$″ ∟	4″×4″×$\frac{1}{2}$″

THREE-LIFT GASHOLDERS (OUTER LIFTS)

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . .	60′ 0″	117′ 6″	133′ 6″	96′ 6″	117′ 6″	133′ 6″	99′ 0″	117′ 6″	60′ 5″
Depth . . .	16′ 0″	30′ 0″	26′ 0″	27′ 3″	30′ 0″	32′ 6″	25′ 0″	30′ 0″	20′ 0″
Bottom Curb .	2′ 3″×3″×⅜″ ∟	2′ 8″×3½″ ⊏	2′ 8″×3″ ⊏	2′ 5″×3″×½″ ∟	2′ 8″×3½″ ⊏	2′ 8″×3″ ⊏	2′ 5″×3″×½″ S.∟	2′5″×3″×½″S. ∟	2′4″×3″×⅜″S. ∟
Dist. apart Do. .	10″	1′ 6″	1′ 6″	1′ 7″	1′ 6″	1′ 6″	1′ 5″	1′ 7″	1′ 0″
Vert. Stays . .	6″×2½″ S. ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16lb S.⊏	6″×3″×16lbS.⊏	6″×2½″×22lb S.⊏
Stiffeners . .	—	2/3″×3″×⅜″∟	2/3″×3″×⅜″∟	2/3″×3″×⅜″∟	2/3″×3″×⅜″∟	2/3″×3″×⅜″S∟	—	—	—
No. Stays . .	16	18	22	16	18	20	18	18	18
Grip	21″×8″	24″×10″	21″×10″	20″×10″	24″×10″	20″×10″	21″×10″	21″×10″	20″×8″
„ how formed	8″×3½″ S. ⊏	Bent Plate	Bent Plate	Bent Plate	Bent Plate	Bent Plate	10″×3½″×23½ lb	Bent Plate	8″×3½″ S.⊏
„ Dip Plate .	3/16″	10 m/m	⅜″	10 m/m	10 m/m	10 m/m	5/16″ 25″ deep	⅜″	¼″×20″
„ Bead . .	2″×⅜″	2½″×½″	2½″×½″	2″×½″	2″×½″	2″×½″	2½″×½″	2½″×½″	2″×⅜″
Side Sheets and	16 @ 5′ 10″	49 @ 6′ 10⅛″	52 @ 6′ 4½″	30 @ 6′ 13⅜″	49 @ 6′ 10⅛″	34 @ 7′ 0⅜″	24 @ 5′ 9¾″	49 @ 6′ 10⅛″	27 @ 5′ 3″
Centres . .	16 @ 5′ 11″	5 @ 6′ 9″	14 @ 6′ 3⅜″	18 @ 6′ 4½″	5 @ 6′ 9″	26 @ 6′ 11¼″	30 @ 5′ 8⅝″	5 @ 6′ 9″	9 @ 5′ 4″
Bott. Row . .	2′ 8″×12 B.G.	2′ 10½″×8 m/m	2′ 10½″× 5/16″	2′ 4½″×8 m/m	2′ 10½″×8m/m	2′ 10½″×8 m/m	2′ 5⅝″×¼″ thk.	2′ 10½″×10lb	2′ 1″×10 S.W.G.
Row next Bott..	—	3′ 0¾″×4 m/m	2′ 9 15/16″× 3/16″	3′ 0″×4 m/ n	3′ 0¾″×4 m/m	2′ 11 13/16″×4m/m	3′ 3⅜″×5.22 lb	3′ 2¼″×5.22lb	—
Top Row . .	2′ 8″×12 B.G.	2′ 3″×10 m/m	2′ 0″×⅜″	2′ 0″×10 m/m	2′ 3″×10 m/m	2′ 0″×10 m/m	2′ 5⅝″×¼″ thk.	Bent 2′0″×15lb	2′ 1″×10 S.W.G.
Row next Top .	—	3′ 0¾″×4 m/m	2′ 9 15/16″× 3/16″	3′ 0″×4 m/m	3′ 0¾″×4 m/m	2′ 11 13/16″×4m/m	3′ 3⅜″×5.22 lb	3′ 2¼″×5.22 lb	—
Interm. Rows .	4@2′ 8″×14B.G.	5@3′ 9″×3m/m	5@3′1⅛″×11 G.	5@3′4½″×3m/m	5@3′9″×3m/m	7@3′1⅛″×3 m/m	4@3′ 4½″×12 S.W.G	5@3′ 9″×12 G.	5@3′ 2″×10 S.G.
Inlet and Outlet	—	24″	20″	27½″	30″	23½″ & 39⅜″	18″	18″	14″

THREE-LIFT GASHOLDERS (MIDDLE LIFT)

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . .	58′ 0″	115′ 0″	131′ 0″	94′ 0″	115′ 0″	131′ 0″	96′ 6″	115′ 0″	58′ 5″
Depth . .	16′ 0″	30′ 0″	26′ 0″	27′ 3″	30′ 0″	32′ 6″	25′ 0″	30′ 0″	20′ 0″
Vert. Stays . .	6″×2½″ ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16lb ⊏	6″×3″×16 lb ⊏	6″×3″×16 lb ⊏	6″×3″×16 lb ⊏	6″×3″×16 lb ⊏	6″×2½″ ⊏
Stiffeners . .	—	2′ 3″×3″×⅜″ ∟	2′ 3″×3″×⅜″ ∟	2′ 3″×3″×⅜″ ∟	2′ 3″×3″×⅜″ ∟	2′ 3″×3″×⅜″ ∟	—	—	—
No. Stays . .	16	18	22	16	18	20	18	18	18
Cup	21″×8″	24″×10″	21″×10″	20″×10″	24″×10″	20″×10″	21″×10″	21″×10″	20″×8″
„ how formed	8″×3½″ ⊏	Bent Plate	Bent P.	Bent P.	Bent P.	Bent P.	10″×3½″×23½lb	Bent P.	8″×3½″ ⊏
„ Dip Plate .	3/16″	10 m/m	⅜″	10 m/m	10 m/m	10 m/m	5/16″	15 lb per ft.	¼″
„ Bead . .	2″×⅜″	2½″×½″	2½″×½″	2″×½″	2″×½″	2″×½″	2½″×½″	2½″×½″	2″×⅜″
Grip	21″×8″	24″×10″	21″×10″	20″×10″	24″×10″	20″×10″	21″×″ wind screen ×10″	21″×10″	20″×8″
„ how formed	8″×3½″ ⊏	Bent Plate	Bent P.	Bent P.	Bent P.	Bent P.	10″×3½″×23½lb	Bent P.	8″×3½″ ⊏
„ Dip Plate .	3/16″	12 m/m	7/16″	10 m/m	11 m/m	11 m/m	5/16″	16.5 lb per ft.	¼″
„ Bead . .	2″×⅜″	2½″×½″	2½″×½″	2″×½″	2″×½″	2″×½″	2½″×½″	2½″×½″	2″×⅜″
Side Sheets and Centres . .	16 @ 5′ 9″ 16 @ 5′ 8″	20 @ 6′ 9″ 34 @ 6′ 7⅞″	34 @ 6′ 3⅜″ 32 @ 6′ 2¼″	30 @ 6′ 2¼″ 18 @ 6′ 1⅛″	20 @ 6′ 9″ 34 @ 6′ 7⅞″	10 @ 6′ 11¼″ 50 @ 6′ 10⅛″	48 @ 5′ 7½″ 6 @ 5′ 6⅜″	20 @ 6′ 9″ 34 @ 6′ 7⅞″	6 @ 5′ 2″ 30 @ 5′ 1″
Cup Row . .	2′ 8″×12 G.	2′ 3″×10 m/m	2′ 0″×⅜″	2′ 0″×10 m/m	2′ 3″×10 m/m	2′ 0″×10 m/m	2′ 5⅝″×¼″	2′ 0″×15 lb/ft.	2′ 1″×3/16″
Row next Do. .	—	3′ 1 11/16″ ×4 m/m	2′ 9 9/16″×3/16″	2′ 11 7/16″×4 m/m	3′ 1 11/16″×4 m/m	3′ 1⅛″×4 m/m	3′ 3⅜″×⅛″	3′ 4 11/16″×5.22lb/ft.	—
Top Row at Grip	2′ 8″×12 B.G.	2′ 3″×12 m/m	2′ 0″×7/16″	2′ 0″×10 m/m	2′ 3″×11 m/m	2′ 0″×11 m/m	2′ 5⅝″×¼″	2′ 0″×16.5lb/ft.	2′ 1″×10 S.G.
Row next Do. .	—	3′ 1 11/16″×4 m/m	2′ 9 9/16″×3/16″	2′ 11 7/16″×4 m/m	3′ 1 11/16″×4 m/m	3′ 1⅛″×4 m/m	3′ 3⅜″×⅛″	3′ 4 11/16″×5.22lb/ft.	—
Interm. Rows .	4@2′8″×14G	5@3′10⅛″×3m/m	5@3′ 3⅜″×11 S.G.	5@3′ 5⅝″×3 m/m	5@3′10⅛″×3m/m	7@3′ 2¼″×3 m/m	4@3′ 4½″×12 G.	5@3′ 10⅛″×4.24 per ft.	5@3′2″×13S.G.

THREE-LIFT GASHOLDERS (INNER LIFT)

	A.	B.	C.	D.	E.	F.	G.	H.	J.
Diameter . .	56′ 0″	112′ 6″	128′ 6″	91′ 6″	112′ 6″	128′ 6″	94′ 0″	112′ 6″	56′ 5″
Depth . . .	16′ 0″	30′ 0″	26′ 0″	27′ 3″	30′ 0″	32′ 6″	25′ 0″	30′ 0″	20′ 0″
Vert. Stays . .	3″×3″×$\frac{7}{16}$ T	12″×6″×41lb I	12″×6″×54 I	12″×6″×54lb I	12″×6″×41″ I	10″×6″×42 I	8″×5″×28 I	8″×5″ I	5″×3″ I
Stiffeners . .	$\frac{3}{4}$″ Rod 1$\frac{1}{8}$″ dia. strut	—	—	—	—	—	—	—	—
No. Stays . .	16	18	22	16	18	20	18	18	18
Cup	21″×8″	24″×10″	21″×10″	20″×10″	24″×10″	20″×10″	21″×10″	21″×10″	20″×8″
,, how formed	8″×3$\frac{1}{2}$″ ⊏	Bent Plate	Bent P.	Bent P.	Bent P.	Bent P.	10″ ⊏	Bent P.	8″×3$\frac{1}{2}$″ ⊏
,, Dip Plate .	$\frac{3}{16}$″	13 m/m	$\frac{7}{16}$″	10 m/m	11 m/m	11 m/m	$\frac{5}{16}$″	16.5 lb	$\frac{1}{4}$″
,, Bead . .	2″×$\frac{3}{8}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2″×$\frac{1}{2}$″	2″×$\frac{1}{2}$″	2″×$\frac{1}{2}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2″×$\frac{3}{8}$″
Side Sheets and Centres .	32 @ 5′ 6″	44 @ 6′ 6$\frac{3}{4}$″	50 @ 6′ 1$\frac{1}{8}$″	42 @ 6′ 0″	44 @ 6′ 6$\frac{3}{4}$″	46 @ 6′ 9″	36 @ 5′ 5$\frac{1}{4}$″	44 @ 6′ 6$\frac{3}{4}$″	34 @ 4′ 11″
	—	10 @ 6′ 5$\frac{5}{8}$″	16 @ 6′ 2$\frac{1}{4}$″	6 @ 5′ 10$\frac{7}{8}$″	10 @ 6′ 5$\frac{5}{8}$″	14 @ 6′ 7$\frac{7}{8}$″	18 @ 5′ 6$\frac{3}{8}$″	10 @ 6′ 5$\frac{5}{8}$″	2 @ 5′ 0″
Cup Row . .	2′ 8″×12 B.G.	2′ 3″×13 m/m	2′ 0″×$\frac{7}{16}$″	2′ 0″×10 m/m	2′ 3″×11 m/m	2′ 0″×11 m/m	2′ 5$\frac{5}{8}$″×$\frac{1}{4}$″	2′ 0″×16.5 lb.	2′ 1″×$\frac{3}{16}$″
Row next Do. .	—	3′ 1$\frac{1}{4}$″×4 m/m	2′ 9$\frac{15}{16}$″×$\frac{5}{16}$″	3′ 0$\frac{1}{4}$″×4 m/m	3′ 1$\frac{1}{4}$″×5 m/m	2′ 11$\frac{13}{16}$″×4 m/m	3′ 3$\frac{3}{8}$″×5.22 lb	3′ 2$\frac{5}{8}$″×10 G.	—
Top Row . .	2′ 8″×12 B.G.	3′ 6″×13 m/m	2′ 10$\frac{1}{2}$″×$\frac{5}{16}$″	2′ 9$\frac{5}{8}$″×6 m/m	3′ 6″×8 m/m	2′ 10$\frac{1}{2}$″×8 m/m	2′ 5$\frac{5}{8}$″×$\frac{1}{4}$″	3′ 6″×$\frac{1}{4}$″	2′ 1″×10 G.
Row next Top R.	—	3′ 4″×4 m/m	2′ 9$\frac{15}{16}$″×$\frac{3}{16}$″	3′ 0$\frac{1}{4}$″×4 m/m	3′ 4″×4 m/m	2′ 11$\frac{13}{16}$″×4 m/m	3′ 3$\frac{3}{8}$″×5.22 lb	3′ 5$\frac{5}{8}$″×10 G.	—
Interm. Rows .	4@2′ 8″×14B.G.	5@3′ 6$\frac{3}{4}$″×3m/m	5@3′1$\frac{1}{8}$″×11S.G.	5@3′3$\frac{3}{8}$″×3 m/m	5@3′6$\frac{3}{4}$″×4 m/m	7@3′1$\frac{1}{8}$″×3 m/m	4@3′4$\frac{1}{2}$″×4.24 lb	5@3′ 6$\frac{3}{4}$″×12 G.	5@3′ 2″×13G.
Top Curb . .	3$\frac{1}{2}$″×3$\frac{1}{2}$″×$\frac{1}{2}$″ ⌊	6″×6″×$\frac{5}{8}$″ ⌊	6″×6″×$\frac{1}{2}$″ ⌊	5″×5″×$\frac{5}{8}$″ ⌊	6″×6″×$\frac{5}{8}$″ ⌊	6″×6″×$\frac{5}{8}$″ ⌊	4″×4″×$\frac{1}{2}$″ ⌊	5″×5″×$\frac{1}{2}$″ ⌊	4″×4″×$\frac{3}{8}$″ ⌊
Secondary Do. .	—	6″×4″×$\frac{1}{2}$″ ⌊	—	—	—	—	—	—	—
Distance apart .	—	3′ 0″	—	—	—	—	—	—	—

FOUR-LIFT GASHOLDERS (OUTER LIFTS)

	A.	B.	C	D.	E.
Diameter	150′ 0″	180′ 6″	247′ 0″	190′ 0″	157′ 6″
Depth	34′ 0″	33′ 0″	43″ 0″	28′ 0″	30′ 0″
Bottom Curb	2′ 5″×4″×$\frac{5}{8}$″ ⌐	2′ 6″×6″×$\frac{3}{4}$″ ⌊s	2′ 7″×3$\frac{1}{2}$″×$\frac{1}{2}$″ ⌊	2′ 9″×3$\frac{1}{2}$″ ⌊⌋	2′ 9″×3$\frac{1}{2}$″ ⌊⌋
Distance apart	12″	1′ 0$\frac{1}{2}$″	18″	18″	18″
Vert. Stays	6″×3″×$\frac{1}{2}$″ ⊏	7$\frac{3}{32}$″×2$\frac{7}{8}$″ ⊏	6″×3″×$\frac{1}{2}$″ ⊏	6″×3″×16 lb ⊏	6″×3″×16 lb ⊏
Stiffeners	—	—	2′ 3″×3″×$\frac{3}{8}$″ ⌊'s inside sheets 2′ 4″×3″×$\frac{1}{2}$″ ⊏ outside sheets	2/3″×3″×$\frac{3}{8}$″ ⌐	2/3″×3″×$\frac{3}{8}$″ ⌊
No. Stays	26	40	56	28	24
Grip	20″×9″	18$\frac{3}{4}$″×9″	21″×10$\frac{1}{2}$″	24″×10″	24″×10″
,, how formed	Bent P.	Bent P.	Bent P.	Bent P.	Bent Plate
,, Dip Plate	$\frac{3}{8}$″	$\frac{7}{16}$″	$\frac{3}{8}$″	$\frac{3}{8}$″	$\frac{3}{8}$″
,, Bead	2$\frac{1}{2}$″×$\frac{1}{2}$″	3″×$\frac{1}{2}$″	3″×$\frac{5}{8}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″
Side Sheets and	42 @ 6′ 0″	49 @ 7′ 1$\frac{1}{2}$″	56 Plates 12′ 5″	67 @ 7′ 1$\frac{1}{2}$″	50 @ 6′ 10$\frac{1}{8}$″
Centres	36 @ 6′ 1″	31 @ 7′ 0$\frac{3}{8}$″	56 Strips 1′ 5$\frac{1}{4}$″ wide cens.	17 @ 7′ 0$\frac{3}{8}$″	22 × 6′ 11$\frac{1}{4}$″
Bott. Row	2′ 6″×$\frac{1}{4}$″	3′ 6$\frac{3}{4}$″×$\frac{1}{4}$″	2′ 3″×$\frac{3}{8}$″	2′ 10$\frac{1}{2}$″×$\frac{5}{16}$″	2′ 10$\frac{1}{2}$″×$\frac{5}{16}$″
Row next Do.	4 rows 3′ 5″×11 G.	3′ 11$\frac{1}{4}$″×10 G.	3′ 2$\frac{3}{4}$″×9 G.	3′ 0″×$\frac{3}{16}$″	3′ 0$\frac{3}{4}$″×$\frac{3}{16}$″
Top Row	2′ 0″×$\frac{3}{8}$″	1′ 11″×$\frac{7}{16}$″	2′ 0″×$\frac{3}{8}$″	2′ 3″×$\frac{3}{8}$″	2′ 3″×$\frac{3}{8}$″
Row next Do.	2′ 6″×$\frac{1}{4}$″	3′ 6$\frac{1}{4}$″×$\frac{1}{4}$″	3′ 2$\frac{3}{8}$″×9 N.S.W.G.	3′ 0″×$\frac{3}{16}$″	3′ 0$\frac{3}{4}$″×$\frac{3}{16}$″
Interm. Row	4 rows 3′ 4″×11 G.	3′ 11$\frac{1}{4}$″×10 G.	10 @ 3′ 2$\frac{3}{4}$″×11 do.	5 @ 3′ 4$\frac{1}{2}$″×10 S.G.	5 @ 3′ 9″×10 S.W.G.

FOUR-LIFT GASHOLDERS (THIRD LIFT)

	A.	B.	C.	D.	E.
Diameter	147′ 9″	178′ 3″	244′ 4″	187′ 6″	155′ 0″
Depth	34′ 2″	33′ 0″	43′ 3″	28′ 0″	30′ 0″
Vert. Stays	6″×3″×½″ ⊏	7 3/32″×2 7/8″ ⊏	6 1/8″×3″ ⊏ 3″×3″×⅜″ ⌞'s inside	6″×3″×16lb ⊏	6″×3″ ⊏
Stiffeners	—	—	4″×3″×½″ ⊏ outside	2/3″×3″×⅜″ ⌞'s	2/3″×3″×⅜″ ⌞'s
No. of Stays	20	40	56	28	24
Cup	20″×9″	18¾″×9″	21″	24″×10″	24″×10″
„ how formed	Bent P.	Bent P.	Bent Plate	Bent P.	Bent P.
„ Dip Plate	⅜″	7/16″	7/16″	⅜″	⅜″
„ Bead	2½″×½″	3″×½″	3″×⅝″	2½″×½″	2½″×½″
Grip	20″×9″	18¾″×9″	21″×10″	24″×10″	24″×10″
„ how formed	Bent P.	Bent P.	Bent Plate	Bent Plate	Bent P.
„ Dip Plate	⅜″	7/16″	7/16″	⅜″	⅜″
„ Bead	2½″×½″	3″×½″	3″×⅝″	2½″×½″	2½″×½″
Side Sheets and Centres	49 @ 5′ 11″ 29 @ 6′ 0″	53 @ 7′ 0⅜″ 27 @ 6′ 11¼″	56 @ 12′ 3 7/8″ 56 strips 1′ 4⅝″ cens.	67 @ 7′ 0⅜″ 17 @ 6′ 11¼″	62 @ 6′ 9″ 10 @ 6′ 10⅛″
Cup Row	2′ 0″×⅜″	2′ 0½″×7/16″	2′ 3″×7/16″	2′ 3″×⅜″	2′ 3″×⅜″
Row next Do.	2′ 6″×¼″ 3′ 1″×11 G.	2′ 6¼″×¼″ 3′ 11¼″×10 G.	3′ 3″×9 G 3′ 4″×11 G. (N.S.W.)	3′ 10 15/16″×3/16″	3′ 1 11/16″×3/16″
Top Row (Grip)	2′ 0″×⅜″	1′ 11″×7/16″	2′ 0″×7/16″	2′ 3″×7/16″	2′ 3″×7/16″
Row next Do.	2′×6″×¼″ 3′×1″×11 G.	2′ 6¼″×¼″ 3′ 11¼″×10 G.	3′ 3″×9 N.S.W.G. 3′ 4″×11 „	3′ 10 15/16″×3/16″	3′ 1 11/16″×3/16″
Interm. Rows	6 @ 3′ 2″×11 G.	4 @ 4′ 0⅜″×10 G.	8 @ 3′ 2¾″×11 G.	5/3′ 5⅝″×10 S.W.G.	5/3′ 10⅛″×10 S.W.G.

FOUR-LIFT GASHOLDERS (SECOND LIFT)

	A.	B.	C.	D.	E.
Diameter	145′ 6″	176′ 0″	241′ 8″	185′ 0″	152′ 6″
Depth	34′ 4″	33′ 0″	43′ 6″	28′ 0″	30′ 0″
Vert. Stays . . .	6″×3″×½″ ⊏	7 3/32′×2 7/8″ ⊏	7″×3″×½″ ⊏	6″×3″×16 lb ⊏	6″×3″×16″ lb ⊏
Stiffeners	—	—	2/3½″×3″×⅜″ ⌊ s. inside 2/3″ ×3″×½″ ⊏ outside	2/3″×3″×⅜″ ⌊'s	2/3″×3″×⅜″ ⌊
No. of Stays . . .	26	40	56	28	24
Cup	20″×9″	18¾″×9″	21″×10¼″	24″×10″	24″×10″
„ how formed . .	Bent P.	Bent P.	Bent P.	Bent P.	Bent P.
„ Dip Plate . .	⅜″	7/16″	7/16″	7/16″	7/16″
„ Bead	2½″×½″	3″×½″	3″×⅝″	2½″×½″	2½″×½″
Grip	20″×9″	18¾″×9″	21″×10¼″	24″×10″	24″×10″
„ how formed . .	Bent P.	Bent P.	Bent P.	Bent P.	Bent P.
„ Dip Plate . .	⅜″	7/16″	½″	½″	½″
„ Bead	2½″×½″	3″×½″	3″×⅝″	2½″×½″	2½″×½″
Side Sheets and Centres . . .	56 @ 5′ 10″ 22 @ 5′ 11″	58 @ 6′ 11¼″ 22 @ 6′ 10⅛″	56 @ 12′ 1⅝″ 56 strips @ 1′ 5 1/16″ cens.	67 @ 6′ 11¼″ 17 @ 6′ 10⅛″	70 @ 6′ 7⅞″ 2 at 6′ 6¾″
Cup Row	2′ 0″×⅜″	2′ 0½″×7/16″	2′ 3″×7/16″	2′ 3″×7/16″	2′ 3″×7/16″
Row next Do. . . .	2′ 6″×¼″	2′ 6¼″×¼″ 3′ 11¼″×10 G.	3′ 3¼″×9 N. S.W.G.	3′ 0 15/16″×3/16″	3′ 1 11/16″×3/16″
Top Row (Grip) . .	2′ 0″×⅜″	1′ 11″×7/16″	2′0″×½″	2′ 3″×½″	2′ 3″×½″
Row next Do. . . .	2′ 6″×¼″	2′ 6¼″×¼″ 3′ 11¼″×10 G.	3′ 3¼″×9 N.S.W.G. 2. 3′ 4″ ×11 do.	3′ 0 15/16″×3/16″	3′1 11/16″×3/16″
Interm. Rows . . .	8/3′ 2″×11 G.	4/4′ 0⅜″×10 G.	6. 3′ 2¾″×11 do. 2. 3′ 4″ ×11 do.	5/3′ 5⅝″×10 S.W.G.	5/3′ 10⅛″×10 S.W.G.

FOUR-LIFT GASHOLDERS (INNER LIFTS)

	A.	B.	C.	D.	E.
Diameter . . .	143′ 3″	173′ 9″	239′ 0″	182′ 6″	150′ 0″
Depth	32′ 6″×2′ 0″ bend	34′ 0″	42′ 6″	28′ 0″	30′ 0″
Vert. Stays . . .	4/3″×3″×$\frac{3}{8}$″ ⌞'s 2$\frac{1}{2}$″×$\frac{5}{16}$″ Lattices	6″×5″ R.S.J.	⊃ Boom 15$\frac{1}{4}$″×9$\frac{1}{2}$″ $\frac{3}{16}$″ and $\frac{1}{4}$″ thk.	15″×6″×59 lb I	15″×6″×59 lb I
Stiffeners	—	—	2/3″×2$\frac{1}{2}$″×$\frac{3}{8}$″ L At top Angle Lattices 2$\frac{1}{2}$″×$\frac{3}{8}$″	—	—
No. of Stays . . .	26	40	56	28	24
Cup	20″×9″	18$\frac{3}{4}$″×9″	21$\frac{1}{2}$″×10$\frac{1}{4}$″	24″×10″	24″×10″
„ how formed .	B. Plate	B. Plate	B. Plate	B. Plate	B. Plate
„ Dip Plate . .	$\frac{3}{8}$″	$\frac{7}{16}$″	$\frac{1}{2}$″	$\frac{1}{2}$″	$\frac{1}{2}$″
„ Bead	2$\frac{1}{2}$″×$\frac{1}{2}$″	3″×$\frac{1}{2}$″	3″×$\frac{5}{8}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″	2$\frac{1}{2}$″×$\frac{1}{2}$″
Side Sheets and Centres . . .	63 @ 5′ 9″ 15 @ 5′ 10″	62 @ 6′ 10$\frac{1}{8}$″ 18 @ 6′ 9″	56 @ 12′ 0$\frac{1}{2}$″ 56 strips @ 16$\frac{3}{8}$″	68 @ 6′ 10$\frac{1}{8}$″ 16 @ 6′ 9″	58 @ 6′ 6$\frac{3}{4}$″ 14 @ 6″ 5$\frac{5}{8}$″
Cup Row	2′ 0″×$\frac{3}{8}$″	2′ 0$\frac{1}{2}$″×$\frac{7}{16}$″	2′ 3″×$\frac{1}{2}$″	2′ 3″×$\frac{1}{2}$″	2′ 3″×$\frac{1}{2}$″
Next Row . . .	2′ 6″×$\frac{1}{4}$″	2′ 6$\frac{1}{4}$″×$\frac{1}{4}$″ 4′ 1$\frac{1}{2}$″×10 G.	3′ 0$\frac{1}{2}$″×9 G.	3′ 0″×$\frac{3}{16}$″	3′ 1$\frac{1}{4}$″×$\frac{3}{16}$″
Top Row	2′ 0″×$\frac{1}{2}$″ Curved to 2′ 6″ rad.	2′ 7$\frac{5}{8}$″×$\frac{7}{16}$″	1′ 5$\frac{1}{4}$″×$\frac{7}{8}$″ 1′ 5$\frac{3}{4}$″×$\frac{1}{2}$″	3′ 6″×$\frac{1}{2}$″	3′ 6″×$\frac{1}{2}$″
Next Row . . .	2′ 6″×$\frac{1}{4}$″	2′ 6$\frac{1}{4}$″×$\frac{1}{4}$″	3′ 0$\frac{1}{2}$″×9 N.S.W.G.	3′ 3$\frac{3}{4}$″×$\frac{3}{16}$″	3′ 4″×$\frac{3}{16}$″
Interm. Rows . .	2. 3′ 3″×11 G. 6. 3′ 2″×11 G.	5/4′ 0$\frac{3}{8}$″×10 G.	10/3′ 1$\frac{1}{2}$″×10 do.	5/3′ 2$\frac{1}{4}$″×10 S.W.G.	5/3′ 6$\frac{3}{4}$″×10 G.
Top Curb	6″×6″×$\frac{3}{4}$″ ⌞	6″×6″×$\frac{3}{4}$″ ⌞	6″×6″×$\frac{7}{8}$″ ⌞	6″×6″×$\frac{3}{4}$″ ⌞	6″×6″×$\frac{3}{8}$″ ⌞
Secondary Do. . .	—	6″×6″×$\frac{3}{4}$″ ⌞	6″×4″×$\frac{7}{8}$″ on top shift	6″×4″×$\frac{1}{2}$″ ⌞	6″×4″×$\frac{1}{2}$″ ⌞
Distance apart . .	—	4′ 8$\frac{1}{2}$″ on the st.	2′ 10″	3′ 0″	3′ 0″

unnecessary, was first installed in this country in 1888. At the time of its introduction there was much discussion as to the stability of the design, and many engineers pronounced the system as dangerous. As holders of the kind have now been in operation for upwards of twenty-five years, there can be little doubt that with proper precaution in design and supervision during working they are no more likely to fail than the guided types, whilst with modern improvements there is practically no limit, within reason, to the dimensions to which they may be constructed. Briefly, the principle of their operation is dependent upon the introduction of spiral guide rails affixed to the holder side, these acting in lieu of the vertical standards and bracing of the more common type of holder. The spiral rails engage with rollers on the edge of the tank in such a manner that the bell screws itself up and down. The direction of the spiral may be either left-handed or right-handed, or successive

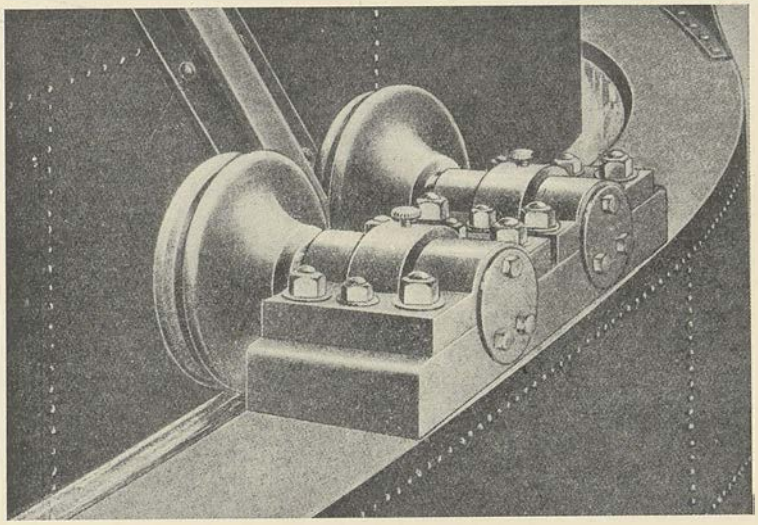


Fig. 410.—Dual Guide Rollers for Spiral Holder.

lifts may operate in reverse directions as shown in Fig. 408. The rails on the outer lift must be affixed to the exterior of the bell, but those on succeeding lifts may be either interior or exterior, although the latter are invariably employed. The holder seen in Fig. 408 is of the four-lift spiral type, operating in an annular brick tank. The crown is untrussed, being supported, when the bell is grounded, by a timber framing. It will be noticed that to the two lower lifts are attached twin spiral rails, which are desirable in all spiral holders of 250 feet diameter and upwards. (As the effect of frost might be attended by serious results, it is frequently the custom to instal an anti-freezing apparatus in connection with the water-lutes of modern holders.) It will be seen that it is the guide rollers which have to withstand the ordinary forces acting on the bell, and, through them, the forces are transmitted to the upper tank curb. The curb has, accordingly, to be of particularly stout construction, the more so if provision is made in the original structure for the insertion of

an additional (outer) lift at some later date, in which case the tank rollers will have a considerable overhang.

Per unit of capacity the spiral holder is considerably cheaper than the guide-framed type. It requires, however, great accuracy of fitting; and, when composed of a number of lifts, an element of danger from "jamming" or breakage is introduced by the numerous sliding brackets and rollers. Trouble might chiefly be expected in countries in which marked variations of temperature are met with, for the bell is subject to a certain amount of radial contraction and expansion. This difficulty has been overcome by the introduction of special compensating carriages. The bell of the spiral holder is of much stiffer construction than that of the ordinary holder, and some form of trussing is usually employed in the crown. A suitable form of crown curb for a holder of about 125 feet diameter working on this principle is seen in Fig. 409.

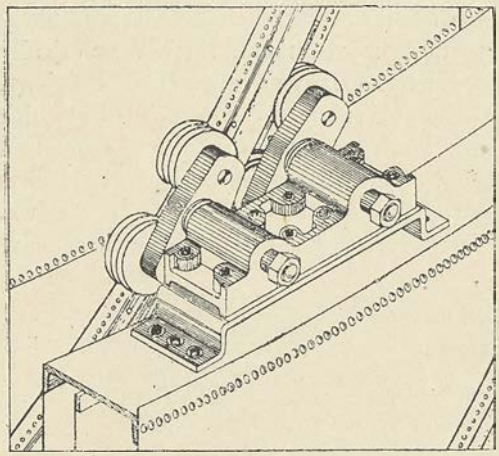


FIG. 411.—MULTIPLE ROLLER CARRIAGE FOR SPIRAL HOLDER.

The guide rollers are either of the dual or multiple type. The dual type illustrated in Fig. 410 are provided with continuous automatic lubrication, being so designed that the axle runs in a bath of oil formed in the bed-plate of the carriage. The multiple roller carriage, in which four instead of two rollers are employed, is shown in Figs. 411 and 412. It will be observed that the bolts securing the carriage are brought as near as possible to their work, thus reducing the strain from leverage upon the tank and the carriage. As regards provision for any radial contraction or expansion of the bell, this is usually arranged for by fitting a sliding axle as in Fig. 413. The oil grooves in the axle, and the special packing rings at front and back to prevent the lubrication from being lost, will also be noticed. The roller is not free to revolve on the axle, but fixed to it. The space for expansion is shown between the back of the roller and the front of the carriage. A recent feature is the "run down stop" which is affixed at the upper

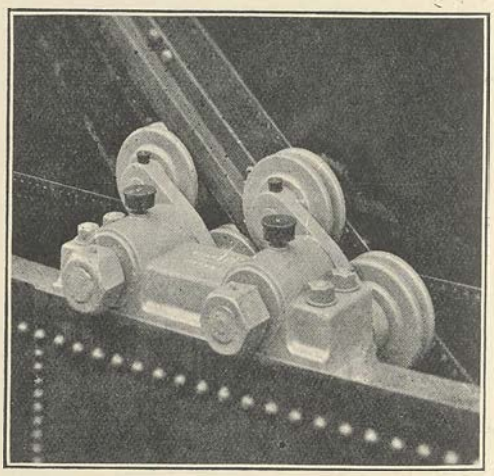


FIG. 412.—MULTIPLE ROLLER CARRIAGE.

ends of the guide rails. At the inquiry held in connection with the gasholder accident at Ilkeston it was suggested that the outer lift "jammed" and the inner lift ran through and fell into the tank, the concussion thereby causing fracture of the latter. The "run down stop" prevents such an occurrence, and may be readily fitted to existing gasholders. In Fig. 414 is shown the method of holding down the roller carriage to the upper edge of a brick tank. The method shown is particularly applicable when a tank formerly constructed to take a bell guided by standards is adapted for the use of a spiral holder.

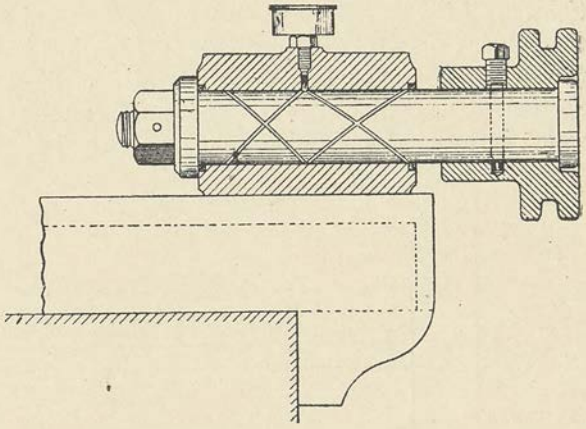


FIG. 413.—SLIDING AXLE FOR ROLLER.

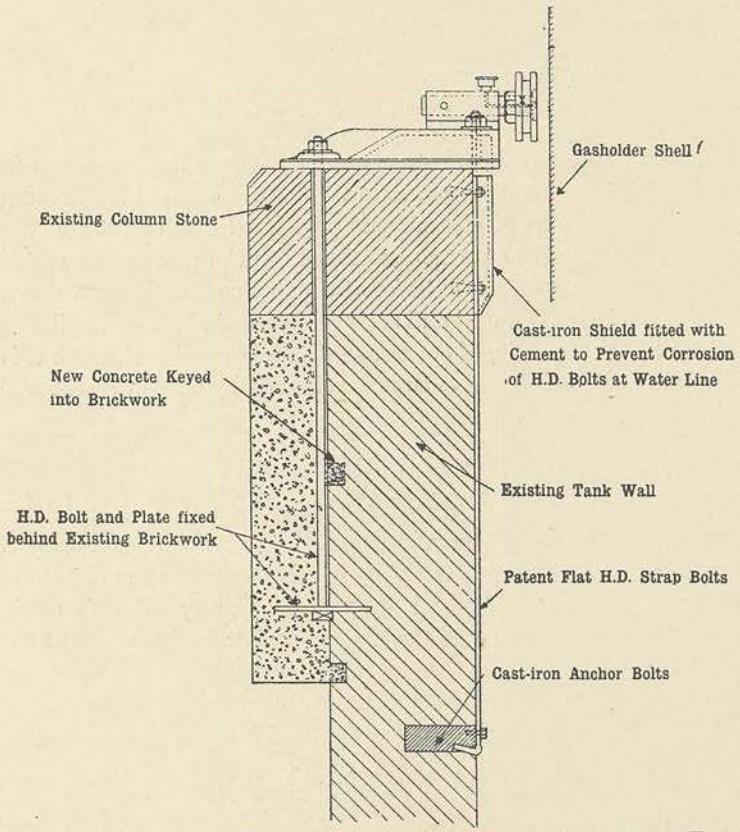


FIG. 414.—SHOWING METHOD OF ATTACHING ROLLER CARRIAGE TO BRICK TANK.

THE NUREMBERG HOLDER

So far as originality is concerned, the new "floating roof" holder (hailing from Nuremberg) demands a certain amount of attention. The principle employed permits of the expensive water tank being dispensed with altogether, although "gas-

tightness " is ensured by the use of a water seal as heretofore. Simply explained, the holder (Fig. 415) consists of an outer cylindrical shell very similar in appearance to the present holder bell, but with the exception that the roof is the only moving portion. The contrivance is, in fact, little more than a cylindrical tank, the roof of which is, by means of guide rollers, permitted to rise or fall within the tank. Gas

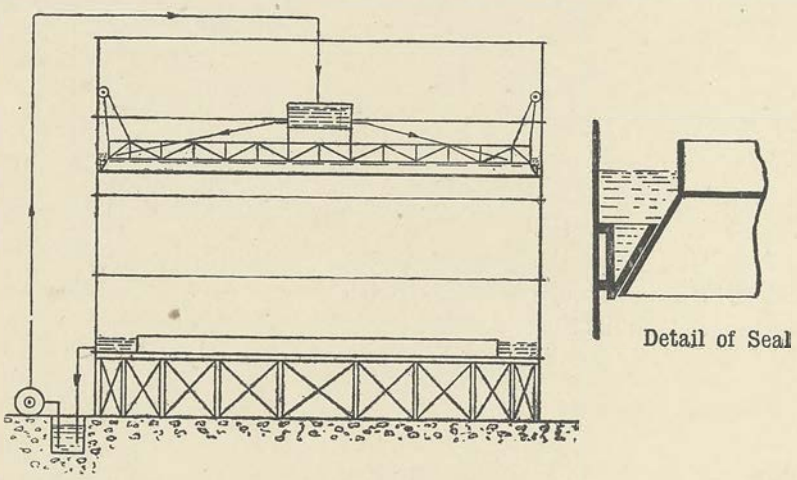


FIG. 415.—THE NUREMBERG HOLDER.

in the ordinary way is admitted beneath the roof, which ascends and descends in accordance with the prevailing pressure in the interior. The guidance of the floating roof is such that the smallest amount of clearance is permitted between it and the internal periphery of the cylinder. The means employed for the prevention of gas leakage consists in pumping water upon the exterior of the roof so that it runs down to the portions above the guide rollers, and seals up the clearance between cylinder and dome. Some portion of the water is, of course, continually passing through this clearance into the interior of the holder, whence it is removed by way of a seal and returned to the suction of the pump.

THE LEERDAM " DRY " GASHOLDER

A novel form of gasholder, designed on somewhat similar lines as the Nuremberg type, has recently been erected at Leerdam in Holland. The gasholder is merely a tank or reservoir of polygonal cross-section, consisting of a bottom, sides, and travelling roof. It is 52 feet in diameter and 45 feet high, with a capacity of 70,000 cubic feet. The joint between the moving roof and the shell is maintained gas-tight by a tar seal, the bottom of the tank containing an annular trough which acts as a collector for any tar which leaks through the seal. This tar is returned again to the roof seal by a pump. The travelling roof is guided by rollers acting in conjunction with the shell, and around its periphery there is an annulus for the reception of the sealing tar, the bottom of the annulus being formed of wooden wedges with springs, making a loose sliding fit with the shell. The annulus is divided into sections, so that should

a leak develop in one it can be repaired without interfering with the working of the holder. There has been no trouble with excess of tar passing through the seal: but the quantity passing in summer is larger than in winter. Gauges are provided for showing the level of the tar in the seal and in the bottom of the holder.

The weight of this new gasholder is considerably less than that of the old design, in view of the absence of the large quantity of water. This is a consideration particularly important in Holland, where the ground is generally not capable of carrying heavy weights, as it involves a large saving in foundations.

NOTABLE GASHOLDERS

The largest gasholder in the world is that at New York, having a capacity of 14 million cubic feet. The next largest is that which was recently erected for the Australian Gas Company at Sydney, the capacity being 12¾ million cubic feet. The largest holder in this country, the bell of which was almost completely destroyed by the Silvertown explosion in 1916, is that at the East Greenwich works of the South Metropolitan Gas Company. It has a capacity of 12 million cubic feet.

THE LIVESEY MAN-LID

The man-lid introduced by the late Sir George Livesey is a convenient device commonly fitted to holders for facilitating inspection of the gas inlet and outlet pipes. In the ordinary way, if a simple manhole cover was employed the gas between the water-level and the crown would be lost. The man-lid, however, prevents this. It consists (Fig. 416) of a circular hood bolted to the underside of the gasholder crown. To the side of the hood is attached a seal tank with a feather plate projecting halfway down into it. There is an aperture in the hood, near the crown, to allow the gas in the hood to escape when the holder is coming down on to the rest stones. When the bell is at rest the seal tank is filled with water until the seal on the hanging plate is greater than the pressure in the holder. The man-lid may then be removed.

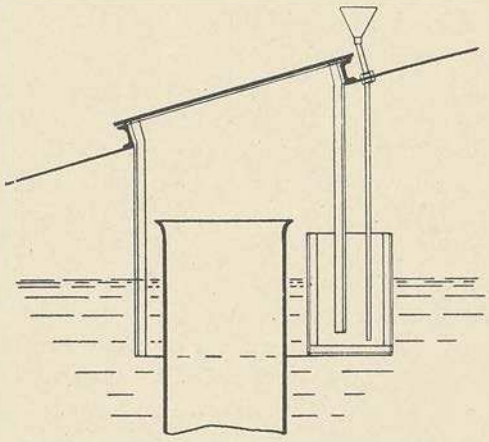


Fig. 416.—The Livesey Man-lid.

THE CARE OF GASHOLDERS

It may be said without fear of contradiction that the gasholder receives in general less attention than any other portion of gasworks apparatus. Once the holder has been erected and put into commission it is more often than not permitted to look after its own welfare, with the result that imperfections develop which might readily be avoided. The following points in particular should be watched, periodical in-

spections should be made, and slight imperfections should be dealt with in the incipient stage.

(*a*) Worn pins in the carriages should be replaced. As the wear develops the lifts will be thrown out of level, with the result that additional stresses will be set up.

(*b*) The guide rails should be examined, and should be greased periodically. According to some designers the best preparation to use for the purpose is a mixture of blacklead, oil and tallow.

(*c*) The bottom row of plates and the cup plates should be carefully examined at the level of the normal water-line. Corrosion occurs most actively at these points, and it is as well to paint or tar these portions of the holder every year. In order to reach the seat of the trouble effectively a few inches of water should be syphoned out of the cups.

(*d*) Roller carriages require oil or grease, and should be attended to every two months. The majority of carriages are fitted with some arrangement for adjustment of the rollers against the guide rail. Therefore, when a roller is running free it should be brought back again on to its rail.

(*e*) The overflow pipe for tank water must be kept clear. If the water level (through rain) is allowed to exceed the normal depth the gas inlet and outlet may become flooded.

(*f*) Leaking cups are a continual source of trouble as, if the leak is serious, it may necessitate a constant supply of water to the cup in order to make good the water lost through leakage. Such leaks are not easy to deal with during working, and one of the chief difficulties is that of locating them. One successful method of determining the exact spot is to ground the lower lifts of the holder, and to maintain the top lift in such a position that it is sealed in the tank water to a depth just sufficient to ensure that the gas will not blow. The water is then pumped out of the cup, when it will be possible to see where the tank water is coming in through the leak. A similar procedure may be followed with intermediate cups which may be leaking.

(*g*) Leaks in crown and side plates and seams. There are several methods of dealing with these, and as a temporary expedient the author has found that brown paper and tar may be employed with considerable success while preparing for a more permanent remedy. A patch is tarred extending about 8 inches around the hole and a sheet of brown paper is pressed over this. The paper is then tarred and another sheet pressed over it, the outer surface of the second sheet also being tarred over.

A comparatively permanent treatment is to clean and scrape the plate around the leak, apply a coat of red-lead paint, and then press red-lead putty into the leaking seam or hole, afterwards painting over with a good coat of red-lead paint.

It is interesting to note that in Germany the practice of oiling gasholders in lieu of painting them is becoming popular. The treatment is said to be just as effective, while the saving in expenditure is considerable. Any light oil, so long as it is free from acid, may be employed, the oil being poured on to the water in the tank and into the cups. In this way, as the bell rises and falls, the oil automatically forms a thin protecting film on the plates, but the crown must be treated by hand. In 1910 eight large holders in Vienna were treated in this way, and nothing has been done

to them since. It is estimated that treatment of this kind costs only one-fiftieth of the outlay demanded for painting.

GASHOLDER TANKS

Gasholder tanks as now erected may primarily be classified under three headings :—

(*a*) Buried tanks, the top of which is approximately level with the prevailing ground line.

(*b*) Tanks entirely aboveground, in which the top of the concrete foundation is on a level with the ground line.

(*c*) Semi-buried tanks which are constructed partly below ground and which are "banked up" level with their upper edge with the material taken from the excavation.

There is, in addition, a fourth, but uncommon, type, in which the floor of the tank is constructed upon piers or arches above ground-level, the space below being employed as a storehouse or for some similar purpose. With one or two possible exceptions, it may be stated that types (*a*) and (*c*) are almost solely constructed from brick, concrete, or reinforced concrete, while steel, reinforced concrete, or cast iron are employed in all tanks aboveground. From the point of view of modern practice, cast iron may be dismissed from consideration forthwith. It was employed largely some three or four decades ago at a time when rolled steel plates were in comparison extremely costly and could not be obtained of sufficient thickness for large tanks. The number of brick tanks which are to be found to-day, particularly in connection with the older gasholders, is chiefly the outcome of the fact that in years past it was not deemed advisable to construct cast-iron tanks above a certain capacity ; and, as the cost of steel was still prohibitive, the only alternative was that of excavating a hole and lining it with a shell capable of retaining water and of sufficient stability to withstand the forces acting against it.

Brickwork and Concrete Tanks

Tanks composed of brickwork are, in general, of two descriptions :—

(*a*) Puddled tanks.
(*b*) Rendered tanks.

The main difference between the two types is in the means introduced for ensuring that the tank shall be water-tight. Brickwork, *per se*, is not impervious to water, hence recourse must be had to some means of making it so. Water-tightness is ensured either by jacketing the tank on its exterior surface with a layer of puddled clay (hence the expression "puddled tank"), or by coating the interior of the tank with a thin rendering (about $\frac{1}{2}$ inch to 1 inch thick) of neat cement or rich mortar, in which case it will be a "rendered tank." A half-section of a typical puddled tank, showing how the work of excavation is lessened by leaving a "dumpling," is shown in Fig. 417. In constructing a tank of this description, it is usual to build

up the brickwork in short lifts and then to fill in with puddle between the wall and the ground. The puddle may consist of pure clay, but some engineers at one time preferred to introduce a small proportion of sand or mould in order to prevent cracking when the material dries off. As each layer of puddle is filled in it must be well moistened and thoroughly "punned." It will be noticed from the accompanying figure that the puddle is spread entirely over the "dumpling."

An elementary consideration of the static pressure of water is sufficient to show that the bursting pressure at any section due to the contained water varies in direct

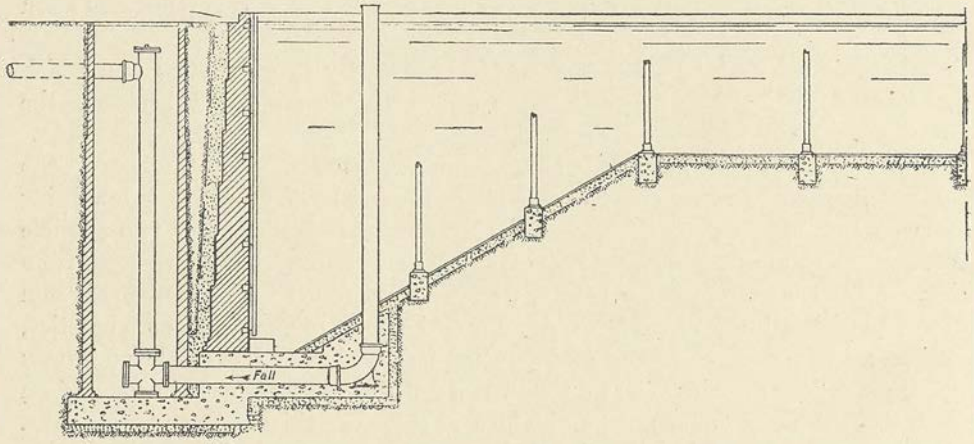


FIG. 417.—PART SECTION OF MASONRY TANK SHOWING "DUMPLING."

ratio to the depth of the section below the surface. Thus for determining the pressure due to water at any point the following simple formula may be used :—

$$P = w\ d$$

where P = pressure in lb. per square foot
w = weight of a cubic foot of water
d = depth below surface in feet.

In a circular tank the radial thrust will, therefore, gradually increase from the surface of the water to the bottom of the tank ; in other words, the magnitude of the pressure is shown by the line AB (Fig. 418), and the thickness of the tank wall may theoretically be graduated in accordance with this line. Theoretically, no thickness at all is required at the surface of the water, but for reasons too obvious to need explanation such a condition is impossible in practice.

From a consideration of the simple formula previously given, it might be presumed that the calculation of the stresses in a masonry tank, and hence its design, would be a comparatively easy operation. Such, however, is by no means the case, for many factors of an uncertain nature (such as the cohesive resistance of the brickwork) are introduced, with the result that a purely theoretical method of design is extremely difficult of application. There is no doubt that in the design of a masonry tank some sound theoretical treatment would prove of immense value, but at present

there is no such treatment at our disposal, with the result that practical experience and the lesson of precedents chiefly influence the designer. Herein lies one of the paramount advantages of the steel tank, our knowledge of which permits of a reasonably accurate computation of the stresses to which it will be subjected. Occasionally one may come across the most elaborate calculations for arriving at the factor of safety obtaining in a masonry tank worked out to two decimal places. The inconsistency of such procedure should be self-evident when it is remembered that the theories so far laid down for the treatment of these tanks are merely the result of surmise, and are built up from a series of pure structural considerations, which probably have no relation to actual conditions.

Some forty years ago a series of formulæ were deduced wherewith it was proposed to calculate the stability of masonry tanks. These formulæ are still occasionally used at the present day, and may be found quoted in textbooks. A cursory examination of the formulæ, however, would appear to show that they contain such elementary errors as that of assuming the horizontal pressure of earth constant for all depths and independent of the distance below the surface. Any one acquainted with the theories of Rankine and others will perceive the absurdity of such an assumption. It must be realized that the brick tank of a gasholder is not subjected to a simple bending moment as in the case of an ordinary retaining wall, but stresses are set up on the lines of those occurring in the plates of a cylindrical boiler ; and, instead of the wall tending to tilt over from the base, the whole undergoes, in almost all cases, slight circumferential stretching, whilst there is also a strain in the vertical direction. As in the case of the steel tank, which receives support from the bottom curb and floor space, so is the brick wall restrained to a certain extent by its adhesion to the foundations.

H. W. Alrich, in a communication to the American Gas Institute, has shown that the restraint exercised by the foundation will be effective, approximately, a distance up from the bottom of the tank equal to $\frac{1}{5}$ to $\frac{1}{4}$ of the total depth of the tank. Accordingly, if in the diagram (Fig. 418) the dotted line represents the tank as constructed, the position and shape it will take up when filled with water will be of the nature of that shown by the full line. As before explained, the theoretical thickness at the top is nil, but the thickness allowed in practice is such as to prevent a certain amount of stretching in the upper portion ; thus there is in reality a restraining influence at both top and bottom.

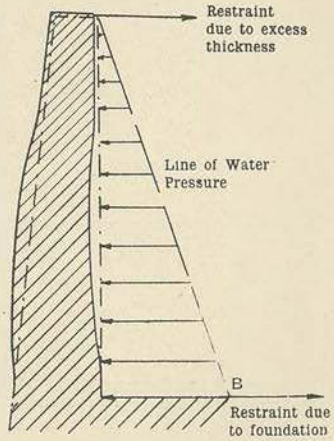


FIG. 418.—SHOWING EFFECT OF WATER PRESSURE ON MASONRY TANK.

The author has made a particular study of the various mathematical treatments which have been suggested for the computation of the stresses induced in masonry tanks, but finds that on examination they are more likely to be misleading rather

than of any service in design. It is believed that hitherto the vertical strain in the tank, an extremely important factor in the evolution of a theoretical treatment, has never been considered, and there is no doubt that the difficulty of ascertaining this with accuracy is not encouraging.

The nature of the assistance of the earth backing has given rise to a good deal

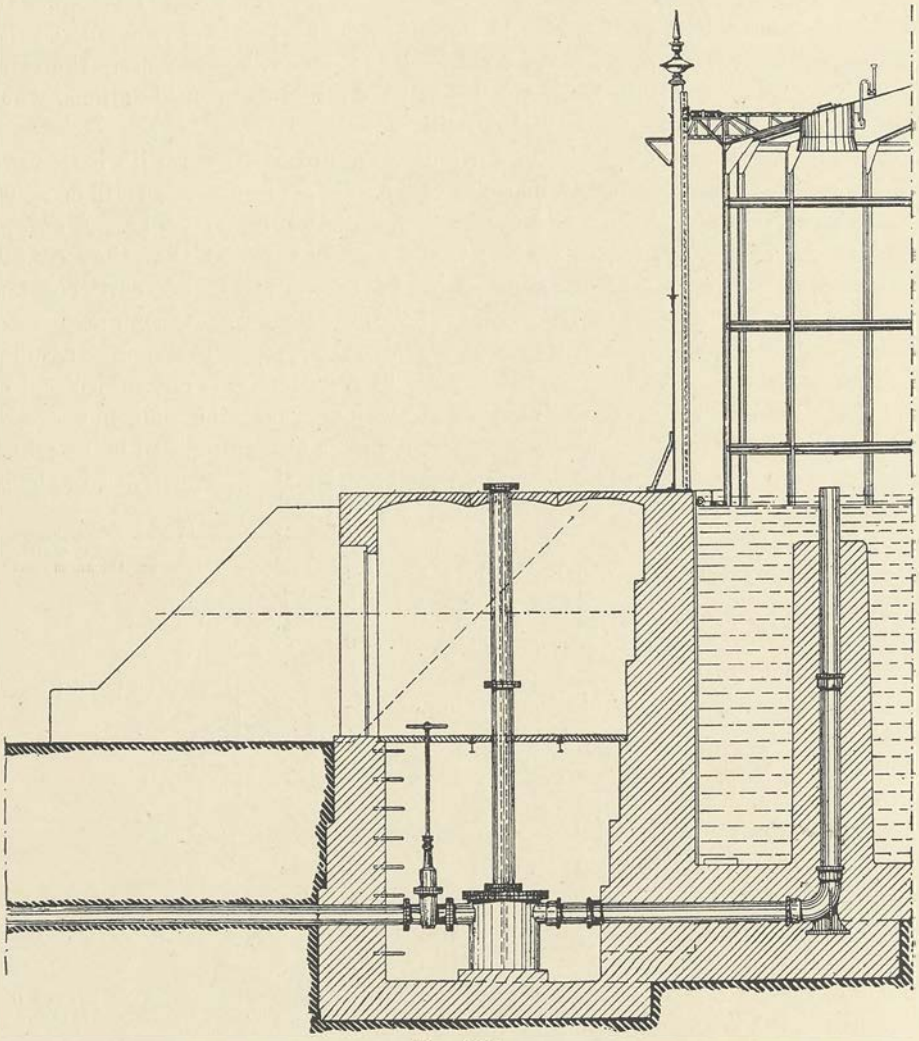


Fig. 419.

of controversy, some authorities believing it to be active, and some passive. There can be little doubt, however, that once the tank has been put under stress the ring tension and circumferential stretching induced are followed by a passive resistance in the earth. The earth, moreover, is a somewhat uncertain quantity. To emphasize this it is only necessary to refer to the well-known work of Sir Benjamin Baker.

In the course of his examination of dams and river walls, Baker found that in some cases it was possible to thrust down an iron bar some considerable distance between the earth and the brickwork, showing that the latter was receiving practically no assistance from the earth backing. Such conditions might well be found in the case of semi-buried tanks having the earth mounded up against the upper portion. In such instances there may be some tendency for the earth to slide backwards and so relieve the pressure against the wall.

An old-fashioned rule, due to Wyatt, for the proportion of brick tanks, is as follows :—

Thickness of concrete walls = $\frac{1}{10}$ the depth of tank
,, ,, piers = $\frac{1}{5}$,, ,, ,, ,,
Width ,, piers = $\frac{1}{7}$,, ,, ,, ,,

This refers to tanks up to 150 feet diameter and 36 feet deep.

For very large holders, a brick or concrete tank is most suitable, so long as a firm foundation, free from water, can be obtained. Concrete tanks, with cement and ballast at reasonable prices, are cheaper than the brick variety, and they are in almost all cases rendered on the interior. The brick tank possesses advantages over the concrete tank in that less skill is required in its construction, there is less initial stress due to shrinkage, and less liability towards cracking caused by any variation in the temperature of the water. The method of connecting up inlet and outlet pipe to a gasholder with masonry tank and the construction of the "dry well" is shown in Fig. 417. In Fig. 419 is shown a method sometimes adopted on the Continent. It will be noted that the inlet and outlet pipes, instead of being supported with iron stays, are jacketed with brickwork or concrete. An enlarged view of a common form of dry well is shown in Fig. 420.

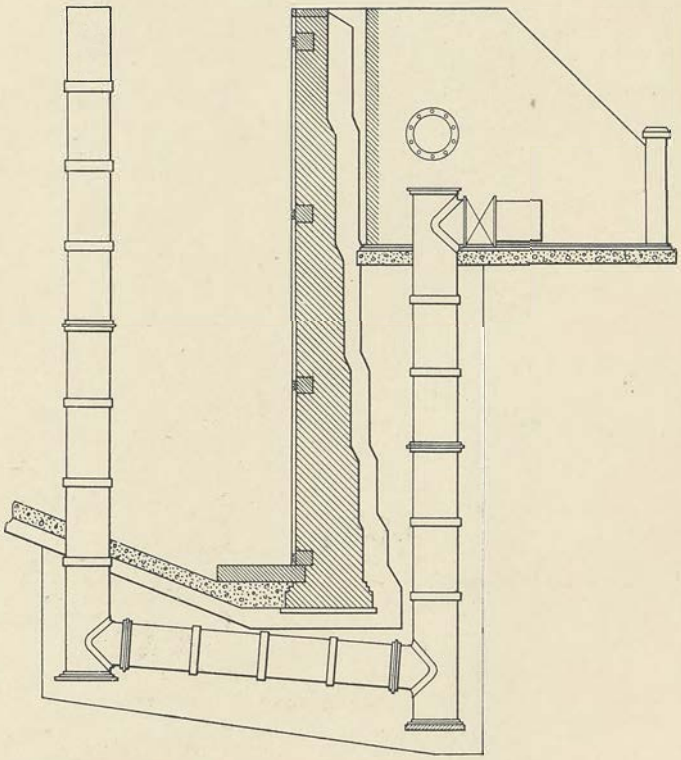


FIG. 420.—COMMON FORM OF DRY WELL.

An interesting example of extending the depth of a gasholder tank was that carried out in reinforced concrete for the Metropolitan Gas Company of Melbourne.

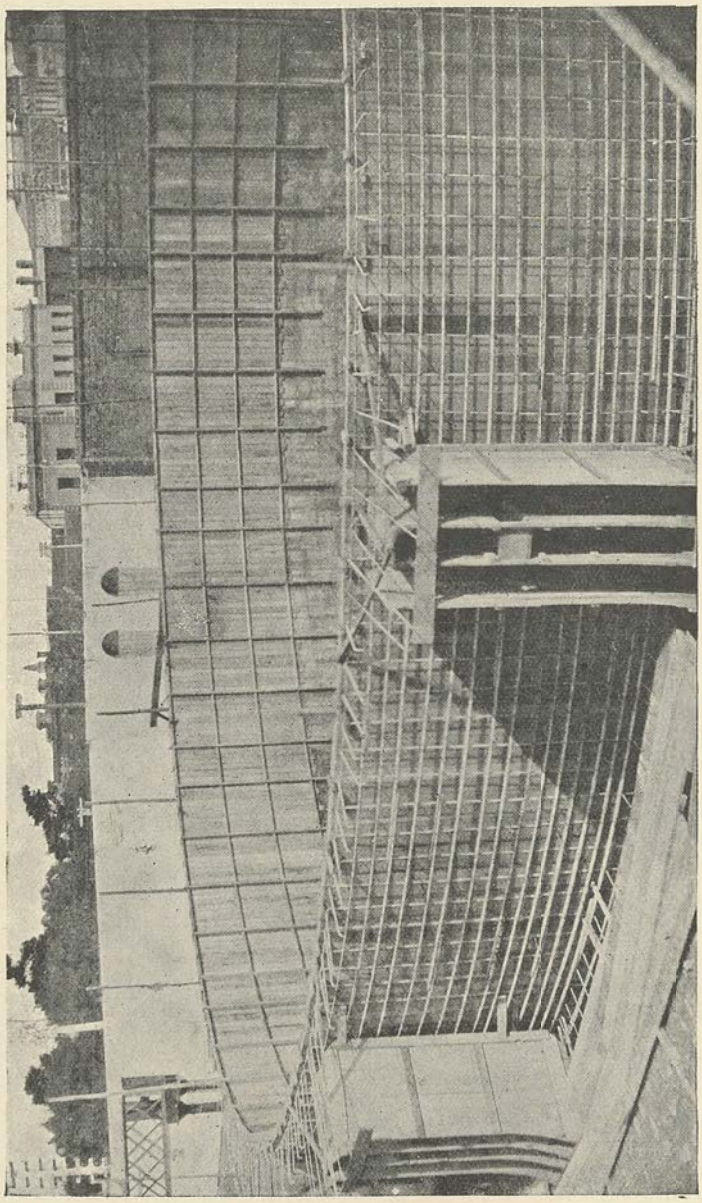


FIG. 421.—MELBOURNE GASHOLDER TANK DURING CONSTRUCTION, SHOWING REINFORCEMENT.

The original tank was of brick and cement, 83 feet 3 inches in diameter, the depth being increased by 10 feet. The reinforced concrete extension was constructed on the top of the old brickwork, which was below ground-level. To make the joint

between old and new work water-tight, a reinforced concrete apron, 17 inches thick and 6 feet 6 inches deep, was placed round the outside of the old tank and connected monolithically with the ring of reinforced concrete, 15 inches thick, which was built directly on top of the stone coping of the old tank. The walls of the tank were then carried up monolithically to a height of 10 feet. The reinforced concrete is 9 inches thick at the bottom and 6 inches thick at the top, the reinforcement (*see* Fig. 421) consisting of rib bars varying from 1 inch diameter at 6 inches centres at the bottom to $\frac{1}{2}$-inch bars at 7 inches centres at the top. On the top of the tank a reinforced concrete platform, 2 feet 6 inches wide and 3 inches thick, was cantilevered off the wall. To carry the gasholder guide-framing standards twelve reinforced concrete piers were built monolithically with the tank ; and, owing to the treacherous nature of the ground, the piers were supported on heavily reinforced concrete cantilevers, bearing on the old brick wall and tailed down by the entire weight of the reinforced concrete tank. When finished the interior of the tank was rendered with a $\frac{1}{2}$-inch layer of 2 to 1 cement rendering.

Steel Tanks

It may be laid down as a general rule that unless a gasholder is upwards of two million cubic feet capacity a steel tank is undoubtedly the most economical. In modern practice the steel tank finds considerable favour in all cases except where the holder is of any great size, although steel was employed for a ten million holder tank at New York, which has a diameter of 250 feet and a depth of 46 feet.

Steel tanks may be said to possess the following advantages :—

(*a*) They are usually less expensive than masonry tanks.

(*b*) A foundation which might be classed as unsuitable for a sunk tank may be sufficiently stable for a steel tank.

(*c*) Quickness and ease of construction.

(*d*) Owing to the ease of determining the working stresses with reasonable accuracy there is no difficulty in designing the tank with a known factor of safety.

(*e*) Steel is reliable under stress. The properties of brickwork and concrete in this direction are uncertain.

(*f*) The tank can be readily tested and made water-tight, for the whole is accessible for inspection. As regards the floor plating, it is usual to put the sections together on bearers which raise it a short distance above the foundation. When the floor, bottom curb and bottom row are riveted up, the tank is filled with water to a depth of about one foot. Any joint " weeps " are then attended to and the whole is afterwards let down on to its foundation.

(*g*) Masonry tanks must be allowed to stand for some time after completion before they are filled with water. The steel tank may be filled immediately it is finished.

(*h*) With the steel tank there is no initial stressing caused by shrinkage or change of temperature.

(*i*) The failure of a steel tank is extremely rare.

On the other hand, the advocates of the masonry tank point out that :—

(*a*) The life of a steel tank is short in comparison with that of the masonry tank.

(*b*) The exterior of a steel tank is affected by corrosion, thus fairly frequent painting is essential. This periodical expense is not incurred with the buried tank. (It should be noted, in this connection, that the inside surface of the plates, being always under water, is not affected by corrosion, except to a certain extent at and above the surface of the water.)

(*c*) The crown-rest framing for the holder bell will be more costly, owing to the impracticability of employing a dumpling.

(*d*) The guide standards of the holder will be longer.

The Design of Tanks

When the erection of a gasholder is contemplated, trial holes must be bored down on the site in order to determine the suitability of the ground for foundations. A good foundation is absolutely essential, not only to provide for the satisfactory working of the holder, but to ensure economy in construction. Where brick tanks have been already built, care should be taken that the ground in their vicinity is not violently disturbed. Instances can be pointed to where such tanks have been cracked by the driving of piles near by. Good ballast may occasionally be obtained from the subsoil, and in this case it may prove more economical to provide a concrete tank, even though the holder be comparatively small.

As regards the foundations for steel tanks, the circular slab is usually levelled off flush all over, but some designers prefer that the concrete should slope up to a height at the centre of 4 or 5 inches above the level at the periphery. It is said that in this manner, if there is any sinking of the ground underneath, the bottom will assume a level bedding. It would seem, however, that if any rise is to be given this should be allowed at the periphery (where the whole of the weight of side sheets and standards is concentrated) rather than at the centre. As in the case of the masonry tank, the gas inlet and outlet pipes are led up through the floor of the steel tank, but they should be constructed from wrought iron and with the open ends bell-mouthed. The floor plates themselves are comparatively thin and should be rectangular, except for those in the outer row, which are made to the circular shape of the tank and are usually slightly thicker. Outside floor plates are usually $\frac{5}{16}$ inch to $\frac{3}{8}$ inch, with the curb row $\frac{1}{2}$ inch thick.

The bottom row of the side sheeting is composed of the heaviest plates in the structure, the thickness of the plate depending upon the depth of the tank, but in exceptional cases being as much as $2\frac{1}{4}$ inches. These plates are connected to the tank floor by means of a bottom curb which usually consists of a single angle placed internally (as shown in Fig. 422) or externally, or a double angle may be employed. By far the most common practice, however, is to provide the internal angle alone. In the treatment of gasholder tanks it is generally assumed that a certain amount of restraint is exercised by the bottom curb and floor plates in preventing the circumferential stretching of the bottom row when the tank is under load. This, no doubt,

is the case, but a series of experiments carried out with scale models has shown that the magnitude of this restraint is actually very small.

In designing tanks for gasholders it is usual to calculate the required thickness of the side plate by considering the head of water as equal to the depth above the centre of gravity of the plate, and not the depth to the base of the plate. The author is of the opinion that such a practice is inadvisable and that the depth to the base of each row should be taken when the stability of that row is being calculated.

When arriving at the thickness of the bottom row of side plates, some allowance, as before mentioned, is often made by designers for the restraint due to the floor plating. The most ready means of doing this is to make a deduction from the total depth of the tank. This deduction usually amounts to about 3 per cent. of the depth. It should be borne in mind, however, that owing to the restraining influence of the bottom curb, however slight this may be, the bottom row plates will be prevented to a certain extent from joining in the expansion of the remainder of the ring. Accordingly, bending stresses will be set up in the lowest ring plates, for which due allowance should be made.

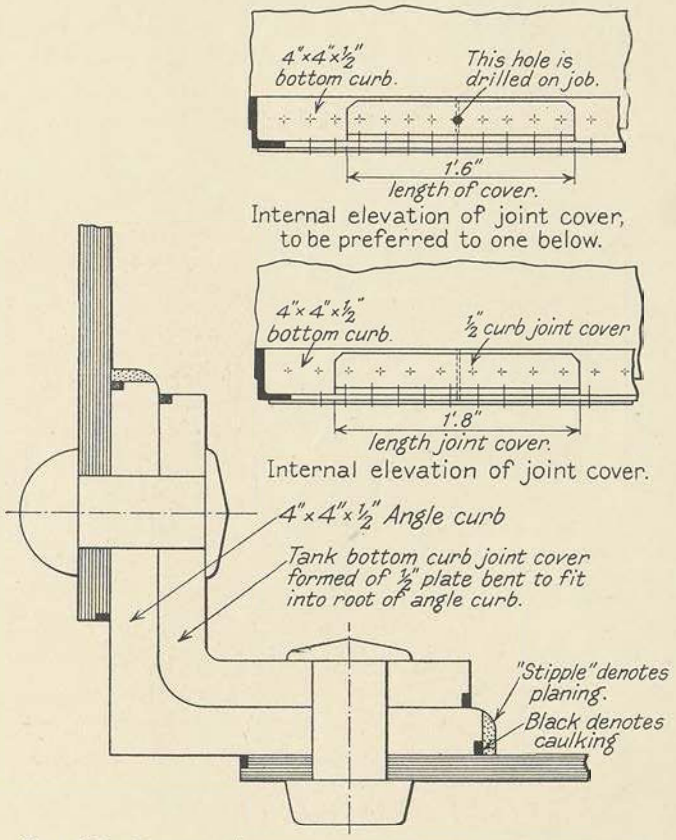


FIG. 422.—SHOWING CONSTRUCTION OF BOTTOM CURB OF STEEL GASHOLDER TANK.

So far as the author is aware, the largest steel tank erected is that at the Kingsbridge works of the New York Consolidated Gas Company. The holder has a capacity of 10 million cubic feet, whilst the diameter of the tank is 251 feet 3 inches, with a depth of 46 feet 4 inches. The tank shell is composed of nine rows of plates, the lowest row of which is $2\frac{5}{16}$ inches thick, the plates being 4 feet in height. The topmost ring consists of $\frac{1}{2}$ inch plates, 6 feet in height. All the vertical seams—and

here it should be pointed out that in the riveting of tanks it is the vertical seams which require particular forethought, the horizontal joints give little trouble—are double butt-joints designed so that a portion of the rivets are acting in single shear and some in double shear, and so arranged that the efficiency of the joint is 93 per cent. All the horizontal seams are lap joints single-riveted with rivets varying in size from $1\frac{3}{4}$ inch at the base to 1 inch for the top row. Both plates and butt-straps are bevelled-edged, this or ordinary planing being commonly carried out to facilitate caulking. The tank bottom is formed of $\frac{3}{8}$ inch plates, 20 feet long, and 7 feet 6 inches wide, connected together by $\frac{5}{8}$ inch rivets. The curb row of plates is $\frac{5}{8}$ inch thick. The bottom curb consists of an external angle, 8 inches by 8 inches by $1\frac{1}{8}$ inch thick, put together in twenty-six sections joined by angle connection plates. The upper curb of the tank consists of a horizontal plate $\frac{1}{2}$ inch thick attached to the tank

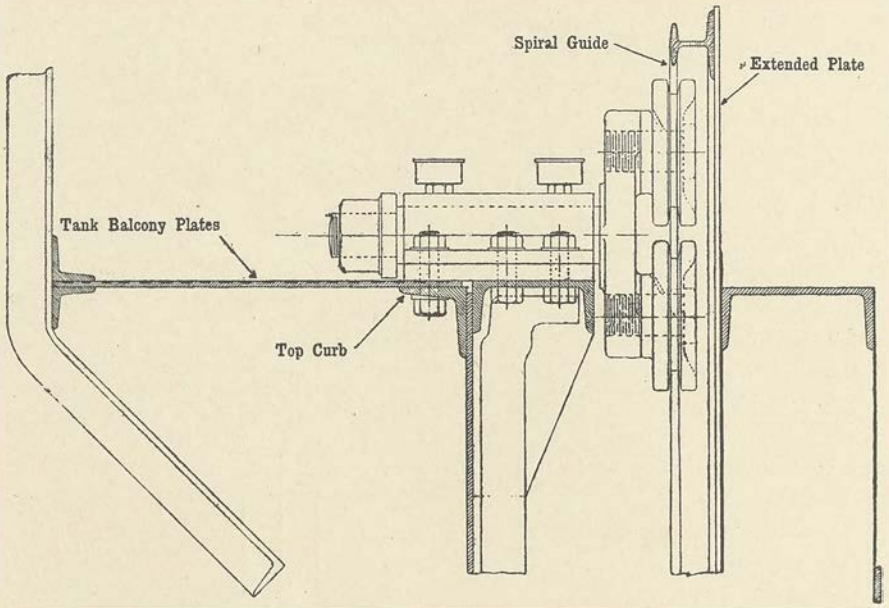


Fig. 423.—Top Curb for Steel Tank (Spiral Holder).

shell by a 5 inch by 5 inch by $\frac{1}{2}$ inch angle, and is stiffened round its outer edge by a 12 inch channel.

A point of importance in the design of holders with steel tanks is that of ensuring that the tank structure shall itself be as independent as possible of the stresses set up in the guide-framing. Any such stresses should be carried down, not to the top curb of the tank, but to the foundation. This precept is often overlooked, with the result that the tank plates are subjected to stresses for which they were not designed. A frequent error in design is that of carrying the diagonal cross-bracing of the panel down to the top curb of the tank, thus leaving the tank-panels unbraced. As regards the guiding of the bell in the tank it is customary to provide intermediate rails

between those fixed at the main upright stanchions. The construction of the top curb for a steel tank to take a spirally guided bell is shown in Fig. 423.

Thickness of Side Plates

The necessary thickness for side plates is readily calculated by considering the pressure on the ring at a certain depth due to the head of water, and by treating the tank as an ordinary thin cylinder subjected to internal pressure.

The following is the formula employed, which may easily be deduced from first principles :—

$$P \times D = 2fte$$

$$\text{or } t = \frac{P.D}{2fe}$$

Where P = pressure due to water in lb. per square inch.
D = diameter of tank in inches.
f = allowable working stress (usually 7 to 7½ tons per square inch).
t = thickness of plate in inches.
e = the efficiency of the vertical riveted joints. Up to 90 per cent. for large holders. For small holders it ranges from 75 to 85 per cent.

The pressure P is found as before explained, namely—

$P = wd$ lb. per square foot, where

w = weight of a cubic foot of water = 62·4 lb.
d = depth below surface of the *bottom* of the plate.

Thus, to calculate the required thickness of the bottom row for a tank 30 feet deep and 150 feet diameter we have—

$P = wd = 62{\cdot}4 \times 30 = 1872$ lb. per square foot = 13 lb. per square inch

$$\text{then } t = \frac{13 \times (150 \times 12)}{2 \times 7 \times 2240} \times \frac{100}{90} = 0{\cdot}83 \text{ inch.}$$

As regards the calculation of the efficiency of riveted joints, this is a simple procedure which may be found described in full in many books on structural design. The rivets should be checked for their stability in the way of resisting shearing and bearing stresses, whilst the plate at the joints must be sufficiently strong to preclude tearing, shearing or bursting through the edge. The efficiency of the joint

$$= \frac{\text{Least strength of joint}}{\text{Strength of solid plate}}.$$

It has been shown by experiment that in many instances the ultimate resistance of tank plates is less than the stress that would be necessary to overcome the friction at the joints, and that the friction is so great that within the limits of working stress there is neither shear in the rivet nor bearing stress against the shank. Such a

condition applies, of course, to those cases where the rivet exactly fits the hole, and the work and design is of a first-class character. An example of a typical vertical seam butt-joint is shown in Fig. 424.

Tanks with Bulging Sides

One of the chief objections to the steel tank, when its depth becomes appreciable, is the necessity for providing plates of abnormal thickness, which are often difficult to obtain and cumbersome to handle. For this reason it has been suggested that the tank should be designed in such a manner as to permit of the side plates being of uniform thickness throughout, whilst the very thick plates common to the cylindrical tank could be dispensed with. The principle involved is that of curving or bulging the sides of the tank in such a manner that the horizontal stresses due to the head of water are transmitted to the top curb (which must, accordingly, be of stout construction) and to the tank floor. A tank of this description, designed on Bonnet's system, is seen in Fig. 425. It will be noticed that vertical posts are placed at intervals round the tank ring. The static pressure of the water is then transformed into—

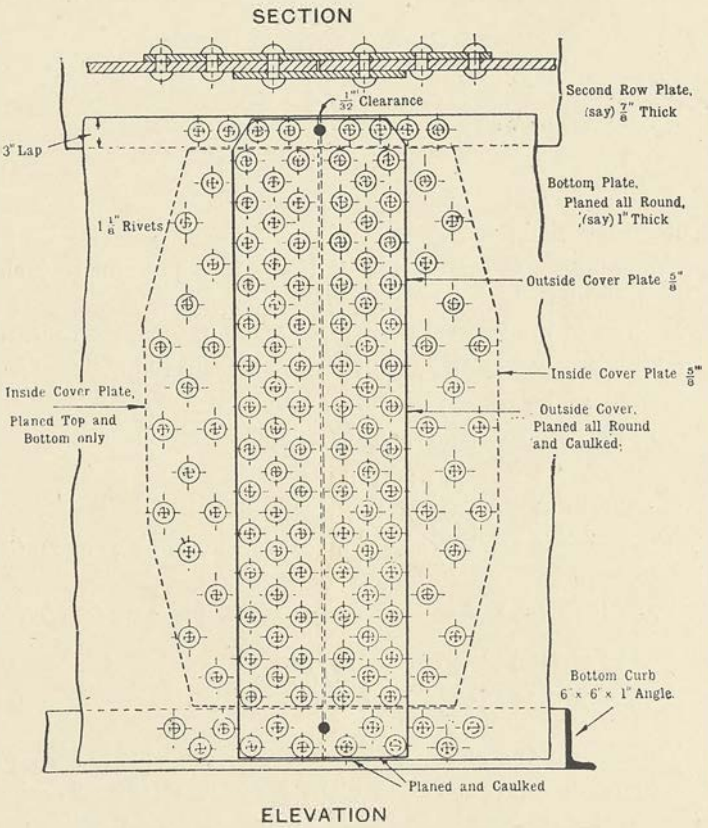


Fig. 424.—Vertical Seam Butt-joint for Steel Tank.

(*a*) A horizontal pull at the base, this being balanced by the tension in the floor plates (*see* Fig. 426).

(*b*) A pull at the upper surface of the tank acting at a tangent to the curve at that point. This tangential pull will be distributed as a vertical downward thrust in

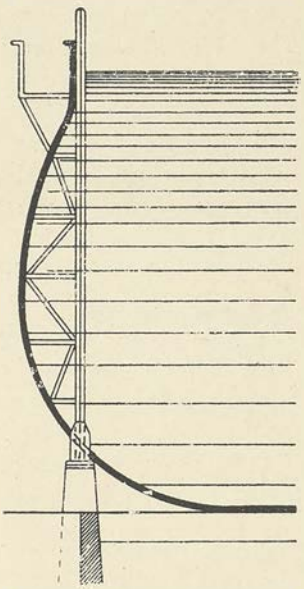


FIG. 425.—BONNET'S TANK WITH BULGING SIDES.

the columns, and by a horizontal outward radial thrust in the top ring curb.

The principle of the method is undoubtedly interesting, but it has made little headway in practice. The most interesting example of a tank constructed on these lines is that at Simmering, in connection with a holder having a capacity of nearly 5½ million cubic feet.

F. S. Cripps has designed a tank for attaining the same object in which the sheets, instead of being bulged, are fluted. The sides are split up into a series of circular arcs of much smaller radius than that of the tank, with vertical posts at the intersections, the whole being united by a ring girder at the top. As pointed out by Cripps, however, the greatest objection to this type of construction is the enormous stress on the top girder (*see* Fig. 427).

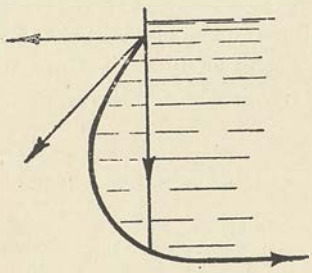


FIG. 426.

REINFORCED CONCRETE TANKS

Reinforced concrete as a material of construction for gasholder tanks is now beginning to make some headway. The inherent principle of reinforced structures is that whilst the compressive stresses may be apportioned to the concrete the tensional forces must be provided for by the insertion of steel. In the gasholder tank the stresses are almost wholly tensional, with the result that the amount of steel required for reinforcement is no less than that required for the construction of a complete steel tank. This statement must be qualified by the fact that the efficiency of the riveted joint must be taken into account, but in large steel tanks the heavier plates may have a joint efficiency of 90 per cent. It is agreed that even though this be the case the steel work is merely inserted in place in the concrete and, consequently, there is no riveting to be done. It is clear, however, that the cost of the concrete itself might be greater than the expense incurred for riveting.

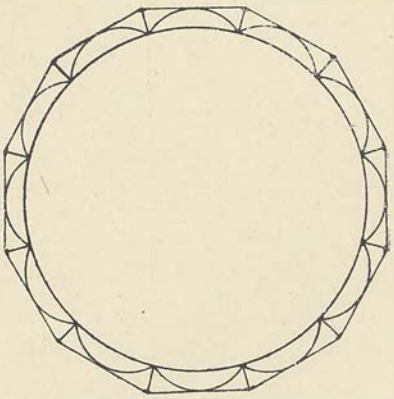


FIG. 427.—CRIPPS' FLUTED TANK.

When under construction there is no little difficulty in getting the reinforcing

bars into position, also in ensuring that the concrete forms a homogeneous mass round bars which must of necessity be closely pitched. The factor of safety must depend largely on these two conditions, for if the tank is carelessly constructed the tensional stresses will be falling upon the concrete instead of on the steelwork. The result is that cracks and leaks will make their appearance. One of the great drawbacks to this type of tank is the time taken in construction, this being—from the time of commencement until the tank is ready for service—nearly twice that required with a similar tank made from steel. Probably the largest reinforced tank in existence is that erected at New York. This tank is 300 feet in diameter and 48 feet 3 inches deep.

It should be mentioned that reinforced concrete tanks develop minute hair cracks when the stress in the tensile members becomes excessive, in fact when the stress in the steel reaches 6,000 lb. per square inch. The New York City Board, as a result of investigations with reinforced concrete cylinders, have limited the unit stress in the reinforcement of water-retaining structures to 8,000 lb. per square inch.

THE COST OF GASHOLDERS

A large holder is much cheaper per unit of volume than is one of smaller dimensions. So far as the actual weight of metal is concerned, the holder of light construction is not necessarily the cheapest, for there will in all probability be additional labour expenditure which will more than absorb any saving in material. Increasing the number of lifts, moreover, actually renders the holder bell more costly ; but, in this case, there would be a reduced expenditure on tank and guide-framing, so that a three-lift holder will usually be cheaper than a two-lift holder of equal capacity. For very small holders a single lift is, as a general rule, the cheapest form of construction.

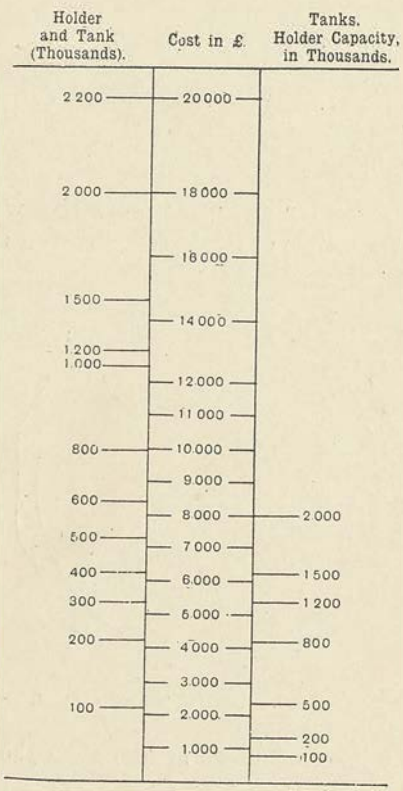


FIG. 428.—CHART SHOWING PRE-WAR COSTS OF ERECTING GASHOLDERS AND TANKS.

Per ton of metal the average cost of a gasholder in pre-war times varied between £19 and £22, this figure including the whole structure and steel tank. To-day the cost is so much as £60 to £70. As regards the individual items, much, of course, depends on size and design, but the total outlay will be accounted for somewhat as follows :—

Bell, complete	. 35 to 45	per cent. of total
Guide-framing	. 18 to 23	„ „
Tank (steel)	. 35 to 45	„ „

Some interesting examples of the cost of existing holders are given here; but it must be remembered that as these holders were erected at a time when materials and labour were in comparison extremely cheap, the costs cannot be taken as anywhere approaching present-day figures:—

	Approximate capacity.	Cost per 1,000 cubic feet contents.
East Greenwich	12 million cubic feet	£5 5 0
Manchester	10½ „ „	£5 0 0
Berlin	8 „ „	£13 9 0
Vienna	8¾ „ „	£7 13 0

Single-lift gasholders, with guide-framing, of small dimensions (say up to 50,000 cubic feet capacity) now cost from £80 to £90 per 1,000 cubic feet, but if of the spiral type the cost would be about 25 per cent. less.

Two-lift holders of about a quarter of a million cubic feet capacity range now from £50 to £70; or if spirally guided about £35 per 1,000 cubic feet. Holders of the most usual size as found in provincial works, those of 2 to 3 million capacity, would now cost from £30 to £40 per 1,000 cubic feet, as against £9 to £12 in pre-war days.

The following are typical instances of costs as they stood in pre-war days:—

	Brick and Puddle.	Concrete Rendered.	Steel.
For 2 million cubic feet holder—			
Cost per 1,000 cubic feet holder capacity	£5 10*s.* to £7	£5 to £6 5*s.*	£4 to £4 5*s.*[1]
Cost per cubic foot tank capacity	4½*d.* to 6*d.*	4·2*d.* to 5·3*d.*	3·3*d.*
For 1 million cubic feet holder—			
Cost per 1,000 cubic feet	—	—	£4 10*s.*[1]
Do. for ½ million cubic feet holder	—	—	£5 5*s.*[1]
Average cost of tank for 1 million cubic feet holder			
Per 1,000 cubic feet capacity	£6 5*s.*	£5 15*s.*	£4 10*s.* + 17*s.* 6*d.* foundations = £5 7*s.* 6*d.*
Per cubic foot tank capacity	6·3*d.*	5·7*d.*	3 4*d.*

[1] Add foundations 17*s.* 6*d.* to 35*s.* in each case.

The cost of the tanks varies in accordance with their size and design, and with the prevailing costs of steel, brick and cement.

The diagram (Fig. 428) shows the relation between the pre-war cost of gasholders and their capacity, also the cost of steel tanks.

Although from the point of view of present-day erection pre-war costs for gasholders are of little assistance, the author feels that they should be included for the reason that they represent the expenditure which has been incurred in connection with the majority of holders now in service. Since 1914 practically no holders of any size have been erected.

THE PRESSURE THROWN BY A GASHOLDER

The pressure thrown by a gasholder is dependent upon the weight of the floating portion and its diameter. Thus, if the total weight of the bell, including the weight of the water in the lutes, is W tons and the diameter of the holder is D feet the pressure may be calculated as follows —

$$\text{Maximum pressure in inches of water} = \frac{549\ W}{D^2}$$

A single-lift holder usually throws from 3 to 4 inches of water pressure, while in the case of a telescopic holder the top lift will throw about the same amount, with each succeeding lift throwing about 2 inches. When dealing with multiple-lift holders a figure comparing very closely with the actual pressure thrown in practice may be obtained by considering the total weight and the mean diameter of the holder, although this is not strictly accurate. Theoretically, the weight of the bell, when the holder is fully inflated, acts on the greatest area, *ie.* the area obtained by considering the diameter of the lowest lift. In practice, the pressure thrown by the inner lift alone is the chief consideration, owing to the fact that this governs the minimum pressure which the holder throws; and, therefore, bears a distinct relation to the pressure on the district.

THE CONTAMINATION OF GAS IN HOLDERS

It occasionally happens that coal gas, although found to be perfectly clean at the outlet of the purifiers, shows decided traces of sulphuretted hydrogen at the holder outlet. Fortunately, such an occurrence is comparatively rare in this country, but one London company experienced considerable annoyance in this respect some few years ago. The pollution of gas in this way is the result of the spontaneous production of sulphuretted hydrogen in the gasholders, or, less commonly, in station meters. Although no positive reason can be ascribed for the formation of the impurity, it seems extremely probable that it may be due to the presence of certain micro-organisms, or to an electrolytic action set up by the iron plates. It is, of course, a recognized fact that certain bacilli characteristic of ordinary water possess the property of decomposing definite salts (such as calcium sulphate, present in the water), with the evolution of sulphuretted hydrogen. A series of experiments conducted on water taken from a gasholder tank seemed to corroborate the organic theory, the bacteria deriving their necessary food supply from dead iron organisms. In the case of the London company, complete immunity from the trouble was obtained after the bacilli had been destroyed by means of a germicide, such as sulphate of copper. The French investigator, M. Guillet, has concluded that contamination is also caused by exposure of the gas to a clean iron surface resulting from the detachment of rust. He has shown that in the presence of the bare metal the carbon disulphide in the gas reacts with carbon dioxide and water, with the liberation of sulphuretted hydrogen. The remedy suggested in this case, however, is somewhat inconvenient, as the holder must temporarily be put out of action. It entails the soldering of zinc sheets to the iron plates at definite places, when galvanic action checks the formation of the sulphuretted hydrogen.

CHAPTER XX

WATER GAS : MANUFACTURE, ENRICHMENT AND USE

WATER gas is the term applied to the impure mixture of hydrogen and oxides of carbon which is formed when steam is passed through incandescent carbon. The basis of the process was probably discovered by Fontana in 1780, and was quickly followed up by Cavendish, Lavosier, Meusnier and others. The first attempt to utilize water gas on a commercial scale was made in 1824 by Ibbotson, who experimented with a process of steaming the coke remaining in horizontal retorts at the end of the period of carbonization. Many of the earlier attempts, however, met with failure, but a great advance was made by Gillard at Narbonne in 1856, when that town was lighted by means of blue water gas in conjunction with platinum wire mantles. In America Dr. J. M. Sanders erected a plant in 1858 which consisted of L-shaped cast-iron retorts placed in an ordinary coal-gas setting. The retorts were filled with charcoal and were externally heated, superheated steam together with melted rosin being admitted to the top of the retorts. Published results show that the gas was not stable, while the excessive deterioration of the retorts precluded the general adoption of the process.

The intermittent system as commonly operated to-day did not make its appearance until 1873 when two processes, based on alternate periods of " run " and " blow," were introduced in the United States. One of these—the Strong process—employed a high generator made from firebrick and two secondary chambers packed with firebrick. These latter chambers, heated up during the blow, were employed as superheaters for the steam. Strong aimed purely at making a heating gas ; and his system, though neglected in this country, was energetically followed up in Germany. Lowe, on the other hand, set out to make an illuminating gas. His plant was designed on lines very similar to those employed in present-day apparatus. That is to say, he employed for his generator a brick-lined cylindrical shell made from wrought iron, the fuel resting on grate bars above a closed ash-pit. Steam and air were introduced alternately, the blue gas passing on to a large superheater packed with firebricks. Anthracite was the fuel commonly used, while the enriching oil was sprayed on to the top of the fuel, the gas mixture being fixed by passage through the superheater. The Lowe system was introduced into this country in 1889.

Water gas must be looked upon as essentially an auxiliary to coal gas, and in this capacity it is employed by a large number of gas undertakings as a means of providing for increase of business and fluctuations in demand. At the outset it

was adopted on account of its comparative cheapness as an enriching medium as compared with the methods then in vogue. To-day, however, the position has been completely changed by the world shortage of oil and, consequently, the prohibitive cost of the latter. Enrichment, moreover, has lost much of its significance owing to the introduction of calorific power standards. Accordingly, the pre-war quality of high illuminating power water gas has given way largely to the unenriched or "blue" water gas. In some cases, where the diluent effect of the blue gas is too severe, a semi-carburetted water gas is manufactured. Enriched water gas to-day, owing to the high price of oil, costs more to produce than does coal gas, while with coke standing at high values it is open to question as to whether even the manufacture of unenriched gas provides, from the commercial standpoint, the most profitable outlet for coke.

The extent of the water-gas industry in this country may be gathered from the fact that approximately 24,000 million cubic feet are generated annually, while the world's output is in the neighbourhood of 130,000 million cubic feet per annum. The latest figures available show that the number of gasworks in the United Kingdom producing water gas is 148, of which 101 are owned by companies, while 48 are attached to local authorities.

The benefits derived from the use of water gas as an auxiliary to coal gas may be summarized as follows:—

1. Low capital outlay per unit of capacity. Including relief holder the outlay on a carburetted water-gas plant of large capacity would amount to about one-third that entailed by a coal-gas plant of similar capacity.

2. The ground space occupied by the plant is considerably smaller than the area covered by equivalent coal-gas plant. The ratio of the areas required may, in fact, be so great as 9 to 1.

As regards ground area required, Shelton gives the following figures:—

Capacity of Plant.	Ground Area Required.
100,000 cubic feet per diem	4 square feet per 1,000 cubic feet.
200,000 „ „	3·5 „ „ „
400,000 „ „	2·75 „ „ „
600,000 „ „	2 to 2·5 „ „ „
7 to 10 million „	1·25 to 1·5 „ „ „

These figures include scrubbers and condensers, but not boiler house, engine room, or relief holder.

3. Sudden demands, such as those due to fog and other unforeseen contingencies, may be easily and quickly coped with. A water-gas plant may be picked up from cold in rather more than three hours. Retort benches require three days to bring them up to working heats.

4. The expense of retort benches constantly under slow firing is obviated.

5. The quality of the gas made is easily regulated to the requirements of the moment.

6. The proportion of water gas intermixed with the coal gas may be varied in accordance with the demand for coke. Thus, a water-gas plant possesses a con-

trolling influence over the coke market, and large stocks of this by-product may to some extent be avoided.

7. The fact that a considerable proportion of the gas may be manufactured from coke in lieu of coal places the works in a position of rather greater independence so far as coal supplies are concerned.

8. In these days of labour upheavals the small amount of manual work required with a water-gas plant is a prominent consideration. The item of wear and tear, both in the direction of labour and materials, is low in comparison with the ordinary machine-charged horizontal retorts.

9. The sulphur impurities in the gas are low in comparison with the same impurities in crude coal gas. As regards sulphuretted hydrogen, crude coal gas contains on an average 500 to 800 grains per 100 cubic feet, and crude water gas 120 grains. Of carbon disulphide and other sulphur compounds coal gas contains from 35 to 50 grains, and carburetted water gas 10 to 15 grains per 100 cubic feet.

10. In many instances carburetted water gas has proved itself effective in diminishing trouble from naphthalene deposits. It is said that the carburetted gas acts as a solvent vehicle for naphthalene and, accordingly, prevents its precipitation from the coal gas. Much, however, would appear to depend upon the temperature at which the carburettor and superheater are operated, for if the light oil vapours are submitted to too great a temperature, over-cracking will occur and the virtue of the gas as a naphthalene sedative is likely to be lost. Again, of course, much will depend upon the proportion in which the carburetted gas is present. At any rate, water gas as a naphthalene eradicator must not by any means be looked upon as infallible. Moreover, as blue gas is most commonly made to-day the effect is more likely to aggravate rather than diminish trouble in this direction.

As regards the inherent disadvantages of water gas, it is not possible to compile a very formidable list; but, first, mention must be made of the very high percentage of noxious gas, carbon monoxide, which it contains, the proportion amounting to three or four times as much as that to be found in coal gas. The objection is, no doubt, one which is largely discounted in the present day, for the many years' experience of water gas shows no tendency towards any increase in the number of deaths from asphyxiation. A further disadvantage lies in the fact that, at the time of writing, the expense of manufacture of carburetted gas is greater than that of coal gas owing to the very considerable increase in the cost of oil.

The smooth operation of a water-gas plant may be quickly upset by the introduction of an inferior coke, and its somewhat sensitive nature in this respect is liable to give trouble in those works where a high-class coal, with a low ash-content, is not always procurable. In some works it is customary to set aside the coke from the higher quality coals for the exclusive use of the water-gas plant. It is frequently urged as a merit of carburetted water gas that its permanence is a great recommendation in preventing any deterioration of or deposition from the district gas as it passes through the street mains. On the other hand, the author's experience goes to show that any slight imperfection in the fixing chambers, or any insufficiency of condensation, may be followed by a very appreciable drop in quality during the passage of

the gas through the district mains. Deterioration of the kind may, however, be guarded against by operating both carburettor and superheater at their correct temperatures, and by attending to the periodical cleaning and rechequering of these vessels. The condensers, too, must operate on efficient lines, so that the temperature of the gas is reduced as near as possible to that of the atmosphere before entering the oxide purifiers.

S. Carter has pointed out that 21° C. may be looked upon as a critical temperature in the process, and that with gas leaving the purifiers at this temperature oil will be precipitated in the holders.

THEORY OF MANUFACTURE

The generation of water gas depends upon the action of steam upon red-hot carbon, the latter being present in the form of coke (containing about 90 per cent. of carbon). As is well known, water, or steam, cannot be decomposed by the action of heat alone ; but if subjected to heat in the presence of a reducing agent the oxygen will combine with this agent, with the evolution of hydrogen in the free state. Heated carbon possesses a greater affinity for oxygen than does the hydrogen with which the oxygen is combined in the form of steam. Hence the sequence of reactions which result. The oxygen of the steam combines in the first place with the carbon to form carbon dioxide, and some carbon monoxide. Thus, in the lower portions of the fuel-bed we have the following reactions :—

$$\begin{cases} (a)\ C + 2\,H_2O = CO_2 + 2\,H_2. \\ (b)\ C + \ H_2O = CO \ + H_2. \end{cases}$$

According to the generally accepted theory the carbon dioxide is subsequently "reduced," by combination with another carbon atom, during its travel through the remainder of the fuel-bed :—

$$(c)\ CO_2 + C = 2\,CO.$$

The manner of the combustion of carbon has already been discussed from the point of view of retort-bench producers in Chapter III. The main problem requiring definite elucidation is as to whether the carbon burns first to carbon dioxide or to carbon monoxide. Rhead and Wheeler [1] have concluded that the two oxides of carbon are formed simultaneously. They assume that in the first instance a physico-chemical complex C_xO_y is formed, and that this subsequently breaks up into CO and CO_2. In all probability the reactions take place concurrently, so that the result amounts practically to the following :—

$$2\,C + 3\,O = CO + CO_2.$$

It should be borne in mind that during the blowing period in a water-gas plant the replenishment of heat is the main requirement. Therefore, the carbon must be burnt as completely as possible to CO_2. This is all the more important when blue water gas is manufactured, in that, as no heat is required in auxiliary vessels for carburetting, any CO escaping from the generator performs no useful function.

[1] *Trans. Chem. Soc.*, CI, p. 846.

Decrease in pressure and increase in temperature favour the formation of carbon monoxide. On the other hand, decrease in temperature and increase in pressure promote the formation of carbon dioxide. For all practical purposes it must be remembered that CO_2 will be at a maximum when oxygen is in excess of carbon. The importance of ensuring adequate air will be appreciated from a consideration of the following thermochemical equations :—

(*a*) $C + O_2 = CO_2 + 14{,}600$ B.Th.U. per lb. of carbon.
(*b*) $2\,C + O_2 = 2\,CO + 4{,}400$ B.Th.U. ,, ,, ,,

The quantities of carbon monoxide and dioxide formed are to an extent determined by the equilibrium obtaining in the reversible system given below, but in technical chemical processes reaction velocity is nearly always a more important factor than chemical equilibrium :—

$$C + CO_2 \gtrless 2\,CO.$$

In the above reaction equilibrium is reached with some rapidity from either side at temperatures above 930° C., but at temperatures below 800° C. the rate of reaction is extremely low.

Temperature.	Carbon monoxide.	Carbon dioxide.
800° C.	86·4 per cent.	13·6 per cent.
850° C.	93·2 ,, ,,	6·8 ,, ,,
900° C.	96·6 ,, ,,	3·4 ,, ,,
925° C.	97·5 ,, ,,	2·5 ,, ,,
1,000° C.	99·4 ,, ,,	0·6 ,, ,,
1,100° C.	99·8 ,, ,,	0·2 ,, ,,

By the continuance of the "blow" for a definite period, usually rather more than half that of the gasmaking "run," the temperature of the bed and of the surrounding brickwork is restored. The part played by the substantial firebrick lining must not be overlooked. These walls, once they are heated through, form a reserve of heat which is available to be drawn upon during the gasmaking period.

The main reactions which occur during the interaction between steam and coke have already been considered, but it is important to study their thermal nature as the principle upon which water-gas plant is operated is dependent upon this. All three reactions are endothermic, as is shown by the following :—

(*a*) $C + 2H_2O = CO_2 + 2\,H_2 - 2{,}850$ B.Th.U. per lb. of carbon consumed.
(*b*) $C + H_2O = CO + H_2 - 4{,}350$,, ,, ,, ,, ,,
(*c*) $CO_2 + C = 2\,CO - 5{,}850$,, ,, ,, ,, ,,

The energy changes shown above, however, are based on the assumption that the substances are reacting at zero temperature and finish with the products at that temperature. In the production of water gas, however, the reactions occur at high temperatures.

It will be appreciated that the principle of water-gas production depends upon the heat which is available in the fuel-bed and generator for raising the reacting substances to a temperature sufficient to complete those reactions which yield combustible gases.

In reality the blow reaction is as follows :—

$$C + O_2 + 4\,N_2 = CO_2 + 4\,N_2 + 14{,}600 \text{ B.Th.U. per lb. of carbon.}$$

It has been shown by experiment that in the water-gas process the reaction mainly predominating at 600° C. is

$$C + 2\,H_2O = CO_2 + 2\,H_2.$$

At such temperatures only a small proportion of the water vapour is decomposed, but as the temperature is raised carbon dioxide gives way almost entirely to carbon monoxide. An indication of the effect of temperature is given by the following table :—[1]

Effect of Temperature on Water-Gas Reactions

Temp. Cent.	Per cent. of steam decomposed.	Per cent. by Volume.		
		Hydrogen.	CO.	CO_2.
674	8·8	65·2	4·9	29·8
758	25·3	65·2	7·8	27·0
838	41·0	61·9	15·1	22·9
954	70·2	53·3	39·3	6·8
1,010	94·0	48·8	49·7	1·5
1,060	93·0	50·7	48·0	1·3
1,125	99·4	50·9	48·5	0·6

As a matter of fact, at the lower temperatures the proportion of undecomposed steam would, in practice, be considerably greater than the percentages given in the above table.

Other figures [2] show the variation of the products to be as follows :—

Temp. of Carbon. Cent.	Per cent. by Volume.		
	Hydrogen.	CO.	CO''.
600	66	4	30
700	65	6	29
800	62	15	23
900	54	39	7
1,000	50	48	2

Clearly, therefore, the temperature of the fuel-bed should be maintained as far as possible above 1,000° C., even towards the end of the run.

[1] Bunte. [2] Thorpe's *Dict. Applied Chem.*

The water-gas process is affected adversely in practice owing to the fact that considerable quantities of undecomposed steam are frequently permitted to pass through the fuel-bed, particularly in the later minutes of the gasmaking period. This introduces the question of the reversible reaction :—

$$CO + H_2O \gtrless CO_2 + H_2 + 1{,}500 \text{ B.Th.U. per lb. of carbon.}$$

This reaction plays an important part in establishing the relative concentration of carbon dioxide and carbon monoxide. The following ratio in the equilibrium of the reaction has been found by Hahn :—

$$K = \frac{\text{Per cent. of } CO \times \text{per cent. of } H_2O}{\text{Per cent. of } CO_2 \times \text{per cent. of } H_2}.$$

K varies with the temperature as follows :—

Temp. Cent.	686	786	688	986	1,086	1,205
K . .	0·53	0·84	1·20	1·57	1·986	2·13

From this it will be clearly seen that increase in temperature favours the production of carbon monoxide. On the other hand, excess of steam tends to promote an increase in the equilibrium concentration of carbon dioxide and hydrogen.

Catalysis in the Water-Gas Process

The synthetic production of methane from carbon monoxide or carbon dioxide and hydrogen in water gas has assumed a new importance at the present time in view of the fact that if synthesis can be carried out with success on a practical scale a means is provided for producing a comparatively high-grade straight water gas without the use of enriching agents. A method for the synthesis of methane is afforded by the reduction of carbon monoxide by hydrogen in the presence of nickel. Thus—

$$CO + 3\,H_2 = CH_4 + H_2O.$$

With an active catalyst the reaction occurs at 180°–200° C., and at 250° C. the reaction is practically complete. When carbon dioxide is substituted for carbon monoxide the reaction becomes—

$$CO_2 + 4\,H_2 = CH_4 + 2\,H_2O.$$

The reaction temperature in this case is rather higher, commencing at about 230° C. and becoming rapid over 300° C. At temperatures above 250° C. in the case of carbon monoxide a secondary reaction occurs, namely, the conversion of carbon monoxide into carbon dioxide and free carbon—

$$2\ CO \gtrless CO_2 + C.$$

This reaction complicates the process owing to the deposition of the free carbon on the catalyst, thus rendering the latter inactive.

Ordinary straight water gas contains approximately equal quantities of hydrogen and carbon monoxide, and if passed over a nickel catalyst at about 450° C. the

carbon monoxide disappears, being converted into methane and carbon dioxide, a certain amount of free carbon being deposited on the catalyst. When the catalyst becomes choked with carbon it is maintained at a temperature of about 450° C. and a current of steam is blown through it with the formation of carbon dioxide and hydrogen. The former gas in turn interacts to form methane, so that the final mixture consists of hydrogen, methane and CO_2. The last named may be removed, when a gas of moderately high calorific power is obtained. The two stages of the process may be combined by employing simultaneously suitable proportions of water gas and superheated steam.

In practice, more particularly so far as gasworks are concerned, the production in this way of a gas containing methane presents considerable difficulty owing to the fact (as seen from the above equations) that theoretically three volumes of hydrogen are required for one volume of carbon monoxide, while on a working scale the necessary proportion is found to be very much greater. With straight water gas as produced in the ordinary manner the proportions of the two gases are nearly equal. Moreover, water gas in the crude state contains a considerable quantity of sulphuretted hydrogen and some sulphur compounds. All sulphur bodies quickly poison the catalyst, and even if gas purified in the ordinary manner from sulphuretted hydrogen were treated, there would still remain the problem of the other sulphur compounds. The author has experimented with the process on a semi-technical scale, but concluded that from the gasworks point of view it was impracticable for many reasons. Primarily the question of relative concentration of CO and hydrogen rendered the evolution of a simple process almost impossible, while it was found extremely difficult to obviate entirely the formation of nickel carbonyl. Again, from the point of view of gas production, it must be borne in mind that four volumes (at the lowest) of carbon monoxide and hydrogen yield only one volume of methane. Accordingly, on a volume basis the output of a water-gas plant would be very seriously reduced ; although this consideration is not of so great importance now that the therm basis of selling gas has been introduced. It will be appreciated that, although the volume output of a given plant would suffer, the thermal output would not be affected to so great an extent.

Sabatier [1] endeavoured to overcome the difficulty of adjusting volume differences by making a low temperature water gas having a high content of carbon dioxide and a low proportion of carbon monoxide. In this way the necessary excess of hydrogen was obtained, the carbon dioxide being removed before the mixture was passed over the nickel catalyst. Before reaching the catalyst vessel the gas was passed over heated copper for the removal of impurities. The objection to this method lies in the fact that large quantities of generator fuel in the form of carbon dioxide must necessarily be wasted. As an alternative to this Elworthy [2] proposed to add hydrogen to the water gas so as to adjust the relative volume requirements, but such a method is as yet rendered prohibitive owing to the cost of producing hydrogen.

[1] French Patent 400656/1908. [2] B.P. 12461/1902 and 14333/1904.

The possibilities of the process are well illustrated by the following results obtained from laboratory experiments :—

CONVERSION OF CO INTO METHANE

	H_2	CO	CH_4	CO_2	N_2	B.Th.U per cu. ft.
Mixture used for reduction . .	80·9	16·3	—	—	2·8	298
Mixtures after reduction : (*a*) .	64·8	—	28·3	—	6·9	466
(*b*) .	60·6	0·2	31·8	1·4	5·8	488
(*c*) .	61·4	—	31·8	0·6	6·2	490

Ash Constituents as a Catalyst

Considerable study has been given to the effect of catalysts in the reversible reaction known as the water-gas equilibrium—

$$CO + H_2O \gtrless CO_2 + H_2.$$

In connection with hydrogen manufacture a number of processes are based on the fact that in the presence of suitable catalysts steam and carbon monoxide react to give hydrogen and carbon dioxide as shown above, and at temperatures above 600° C. equilibrium is quickly established. It has been shown that iron and lime (constituents of ash) tend to promote the attainment of equilibrium, and for this reason it has been suggested that the ash content of coke is operative in facilitating equilibrium. Gwosdz [1] has pointed out that over a range of 560°–855° C. a considerable proportion of carbon dioxide (up to 29 per cent.) is always formed with coke containing 8·5 per cent. of ash ; whereas with pure carbon (lampblack with 0·1 per cent. of ash) even at 600° C. the water gas contained only 8·6 per cent. of carbon dioxide. The opinion of this investigator is that, in the primary reaction between coke and steam, carbon dioxide is not formed, but only carbon monoxide and hydrogen. This is followed by the establishment of the water-gas equilibrium in the upper layers of the fuel-bed, followed by catalysis promoted by the ash in the fuel.

Further experiments show that if steam is passed through coke the gas resulting contains a comparatively high proportion of carbon dioxide. On the other hand when, under the same conditions, retort carbon is substituted for coke the carbon dioxide content of the gas is extremely small, in fact under 1 per cent. Both theory and practice, therefore, point to the fact that the final gas mixture obtained and the proportion of incombustible gas present are affected by the proportion of ash present in the fuel. As, therefore, equilibrium in the above-quoted reaction is most probably established in the upper layer of the fuel, there is every need to ensure that the steam flow to the generator is so regulated (particularly during the later minutes of the "run") that the least possible excess shall pass through to the top portions of the fuel-bed.

[1] *Z. Angew. Chem.*, 1918, p. 137.

It has been suggested that the small proportion of methane (0·5 to 1 per cent.) found in blue water gas is due to interaction between carbon monoxide or dioxide and hydrogen promoted by the ash acting catalytically. The contention, however, is open to considerable doubt, particularly in view of the fact that for such interaction it would seem necessary for nickel to be present. The most feasible explanation of the presence of methane is that it appears as a distillation product from those portions of tacky coke which must inevitably find their way to the generators.

WATER-GAS SYSTEMS

The systems which have been introduced for the purpose of manufacturing water gas may be classified under the following three headings :—

(1) The Continuous System.
(2) The Intermittent System.
(3) The Neat-Oxygen Method.

Of these, the intermittent method is the only one to which serious consideration is given to-day. The continuous system, in which it was sought to replace the lost heat by independent external firing, received much attention in the early days of water gas ; and was in one respect to be commended, in that it endeavoured to provide for the uninterrupted manufacture of the gas and obviated the periods of blowing. Practical difficulties, heat losses by radiation, and general inefficiency, however, soon sounded its knell, with the result that there are no examples of the method now extant. The intermittent process, with " run " and " blow " succeeding each other at regular intervals, has shown itself, by the test of time, to be the only practicable method.

A scientific and by no means impracticable system is that embodying the use of neat oxygen. The process operates on continuous lines and results in a gas practically free from nitrogen, but containing from 65 to 70 per cent. of carbon monoxide. Steam is admitted to the base of the generator in the ordinary manner ; and, along with it, is passed a stream of pure oxygen. In this way, whilst steam is combining with a portion of the carbon to form water gas, the heat lost by the endothermic nature of the reactions is replaced by the exothermic combination of the oxygen with part of the carbon. If steam and oxygen are regulated in accordance with theoretical requirements the process will proceed with little trouble. The chief drawback, which has as yet prevented the system from making any great headway, is the impossibility of obtaining oxygen at a price which would permit the gas to compare in cost with that produced by the more general methods.

Some mention should be made here of the distinction between carburetted water gas and oil gas, the latter misnomer being still in somewhat common use for the former product. Oil gas, in the true sense of the name, is the gaseous mixture of hydrocarbon vapours resulting from the direct conversion of oil into gas, in an iron retort, such as takes place in the Peebles and Pintsch processes. In this way a gas having an illuminating power of from 60 to 70 candles is obtained. An important feature of such processes is the further washing of the gas in oil, whereby any vapours

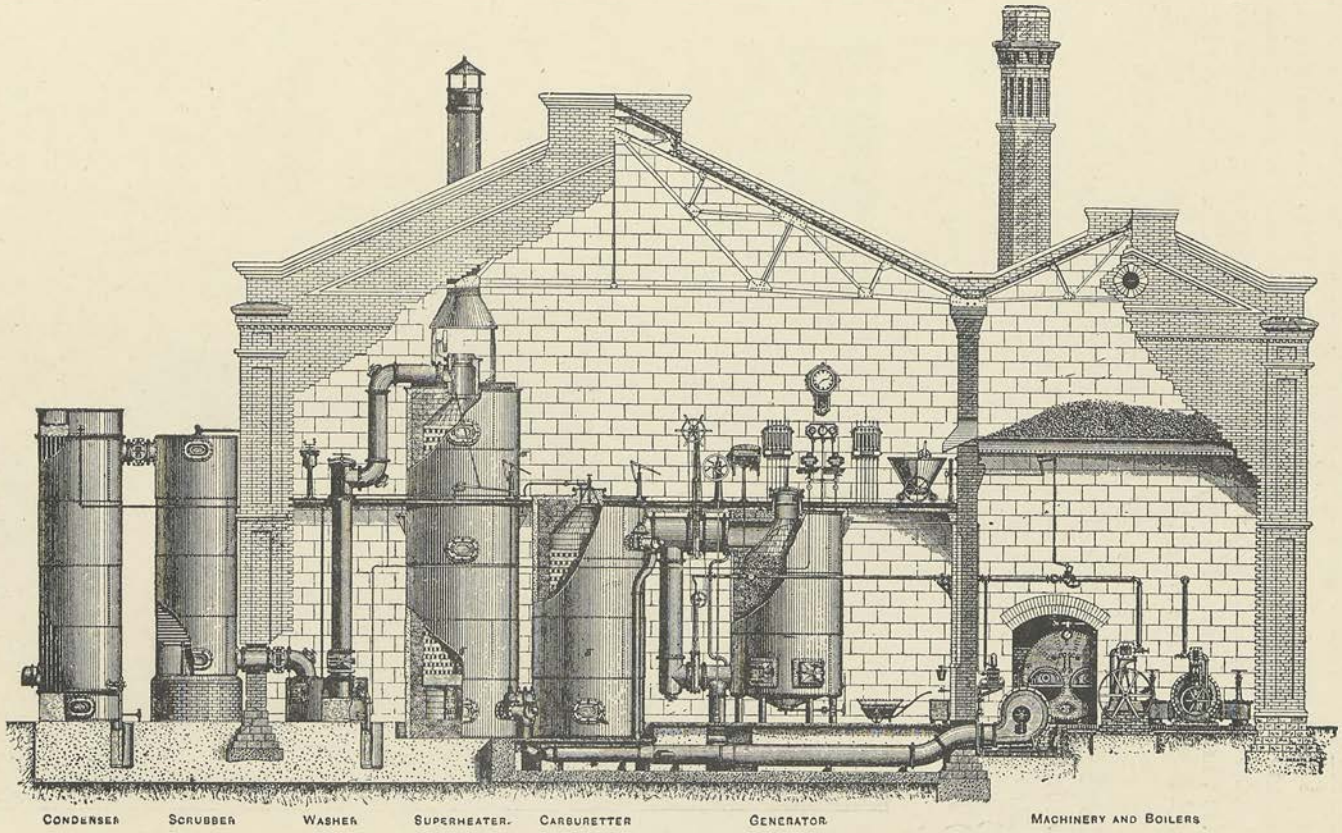


FIG. 429.—DIAGRAM SHOWING CONSTRUCTION OF HUMPHREYS AND GLASGOW WATER-GAS PLANT.

not rendered permanently gaseous are removed. This oil is returned to the retort again and again, the residue remaining behind as a coke. In this country the process has chiefly been applied in connection with the well-known Scottish shale oils, about 100 cubic feet of gas being obtained from one gallon of the oil. In countries where a mineral oil is only obtained with some difficulty the gas has been produced from animal or vegetable varieties.

TYPES OF WATER-GAS PLANT

The plants now in use for the purpose of generating water gas are many and varied. In general, however, the apparatus may be classified under two distinct headings, namely :—

(*a*) Plants employing an enriching agent, *i.e.* carburetting plants.

(*b*) Plants in which no enrichment of the gas takes place, *i.e.* "blue" gas plants.

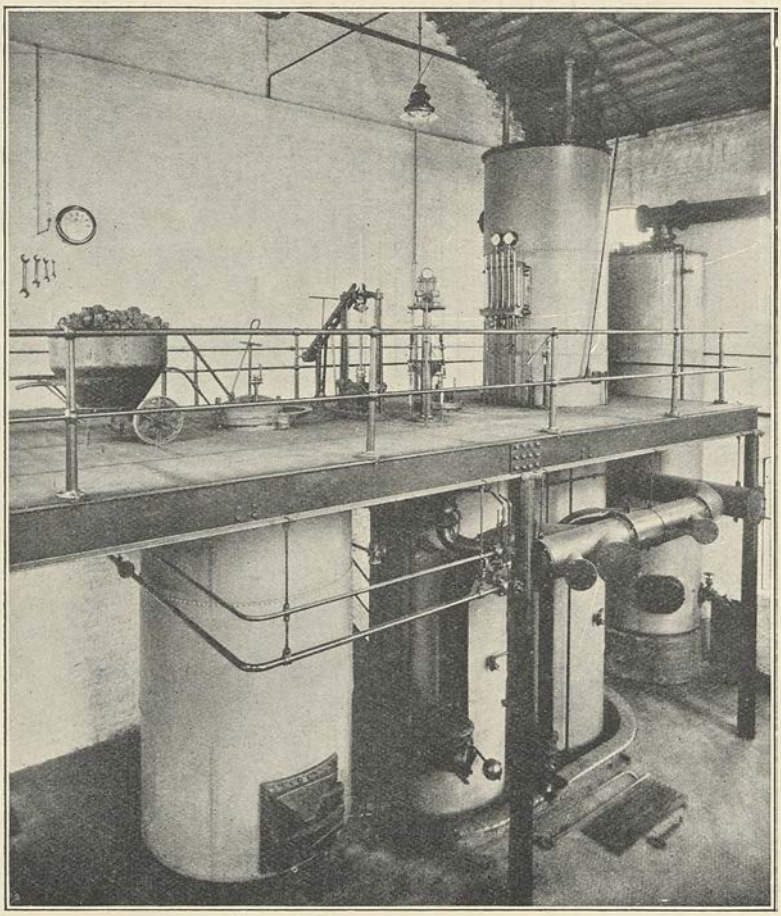


FIG. 430.—A SMALL HUMPHREYS AND GLASGOW INSTALLATION.

It must be understood, however, that with the carburetting plant "blue" gas may, if so desired, be readily produced, and in the same way many of the recognized "blue" plants are now fitted with a small carburettor, which enables them to yield enriched gas. Of the carburetting plants, that originally introduced in the United States by Lowe, and improved by Humphreys and Glasgow, has undoubtedly gained the greatest popularity.

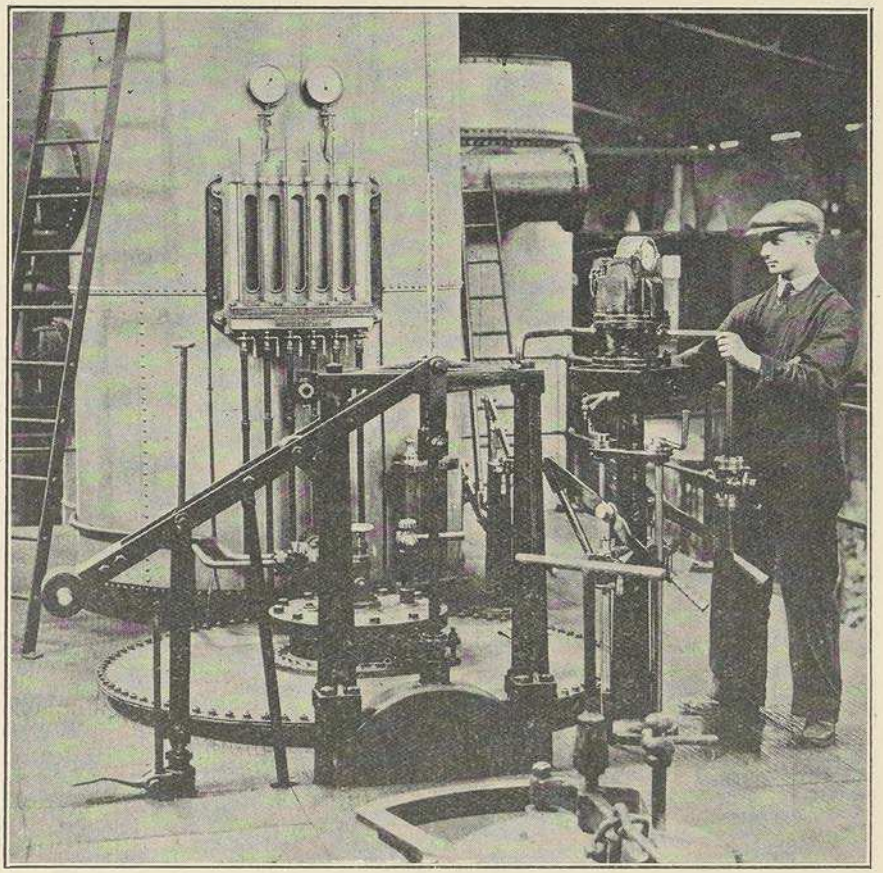


FIG. 431.—OPERATING FLOOR OF HUMPHREYS AND GLASGOW PLANT, SHOWING INTERLOCKING VALVE-GEAR, GAUGES, ETC.

The apparatus (Fig. 429) consists of a generator, carburettor, superheater, oil-heater, washer or seal, and condenser. The generator, carburettor and superheater are cylindrical in shape; the shells are formed of $\frac{3}{8}$-inch steel plates, and are lined with special firebricks. In order to reduce to a minimum the heat lost by radiation, an annular space, about two inches wide, is left between the shell and the firebrick lining, and this is tightly packed with slag wool. The generator is charged through a circular door in the top; cast-iron doors being provided at the base for

the removal of the clinker. A two-way pipe, the function of which will be explained later, connects the generator and carburettor. Fitted to the top of the carburettor is a centrifugal oil spray. A steam pump, connected with the storage tank, delivers oil to the distributor at a pressure of about 60 lb. per square inch, the oil having been previously passed through the heater and considerably raised in temperature. Both the carburettor and superheater are filled with firebricks laid chequer-wise,

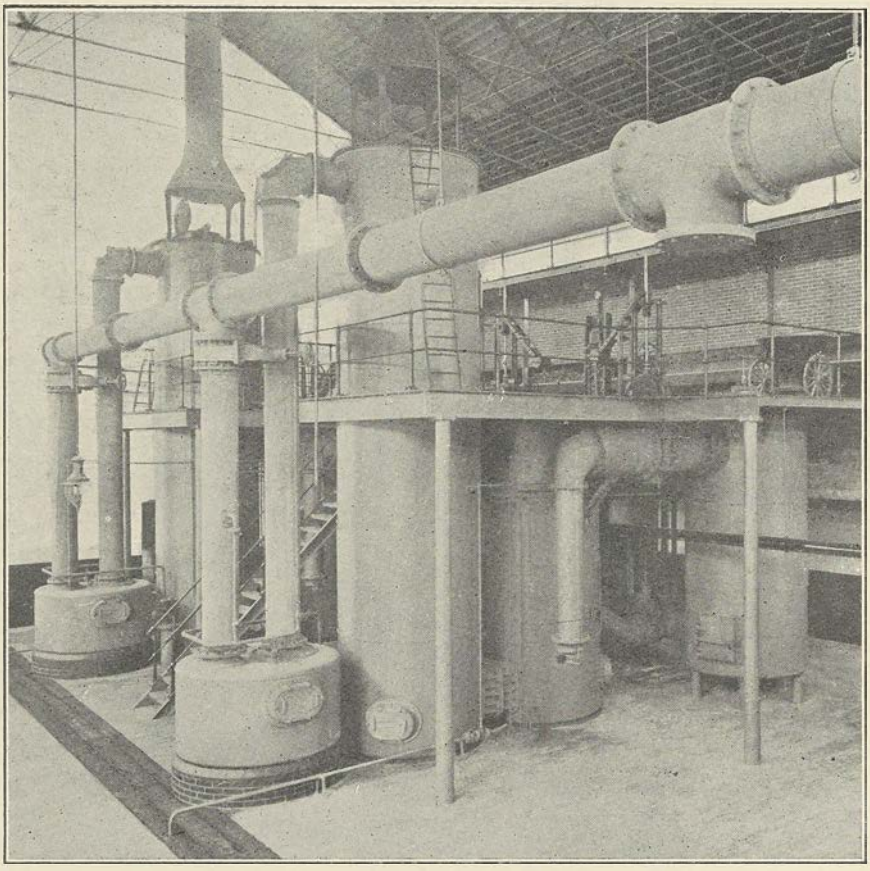


FIG. 432.—AN INSTALLATION OF TWO HUMPHREYS AND GLASGOW PLANTS, SHOWING DOWN-PIPES FROM SUPERHEATERS, AND WASHERS.

the disposition of the bricks affording extensive heating surface for the permanent gasification of the oil. A stack valve is placed at the top of the superheater, and through this the final products are expelled during the "blow"; during the "run" this valve is closed, and the carburetted gas makes its way through the remainder of the apparatus. As will be seen from the figure, the oil heater is placed in the outlet pipe from the superheater, and meets the full volume of the hot gas. With the exception of clinkering, the plant, in all but the smaller installations, is entirely

manipulated from an elevated floor, flush with the top of the generator, and all valves, levers and gauges are collected at this level. Any risk of the operator moving the wrong levers is obviated by the insertion of a special interlocking valve-gear.

A special feature of the apparatus is the reversal of the "run" in the generator, so that steam may be admitted either below the coke-bed or above it; it is to enable this to be done that the two-way pipe, previously referred to, is employed.

Experience shows that if steam is continually admitted to the base of the generator, in time the lower portion of the fuel-bed, which has continually to perform the heaviest duty of decomposition, becomes cool and inactive, the steam condensing instead of being converted into gas. The succeeding "blow," therefore,

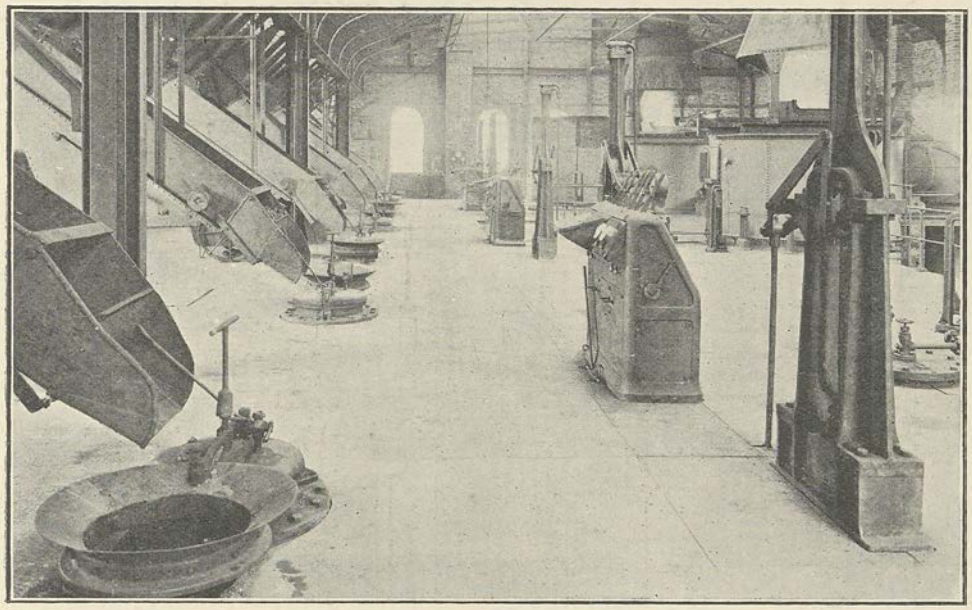


FIG. 433.—BECKTON PLANT, SHOWING LEVERS FOR HYDRAULIC OPERATION.

instead of rekindling the fire, chills down the lower layers of coke still more. To rectify this, after every few runs the steam is admitted above the fuel and makes its way downwards and thence to the carburettor as usual. The reversal of flow is completely effected in one movement, the valves being controlled by interlocking gear which renders confusion or mistake impossible. The function of the washer, which corresponds with the hydraulic main of the coal-gas plant, is to provide a safety seal which precludes the gas from being pushed back into the superheater (by the pressure thrown by the relief holder) during the periods of the "blow." The washers are well illustrated in Fig. 432. The purpose of the scrubber and the condensers is to remove the vesicles of tar and oily matter which remain suspended in the gas, and to cool the gas down to a normal temperature prior to condensation.

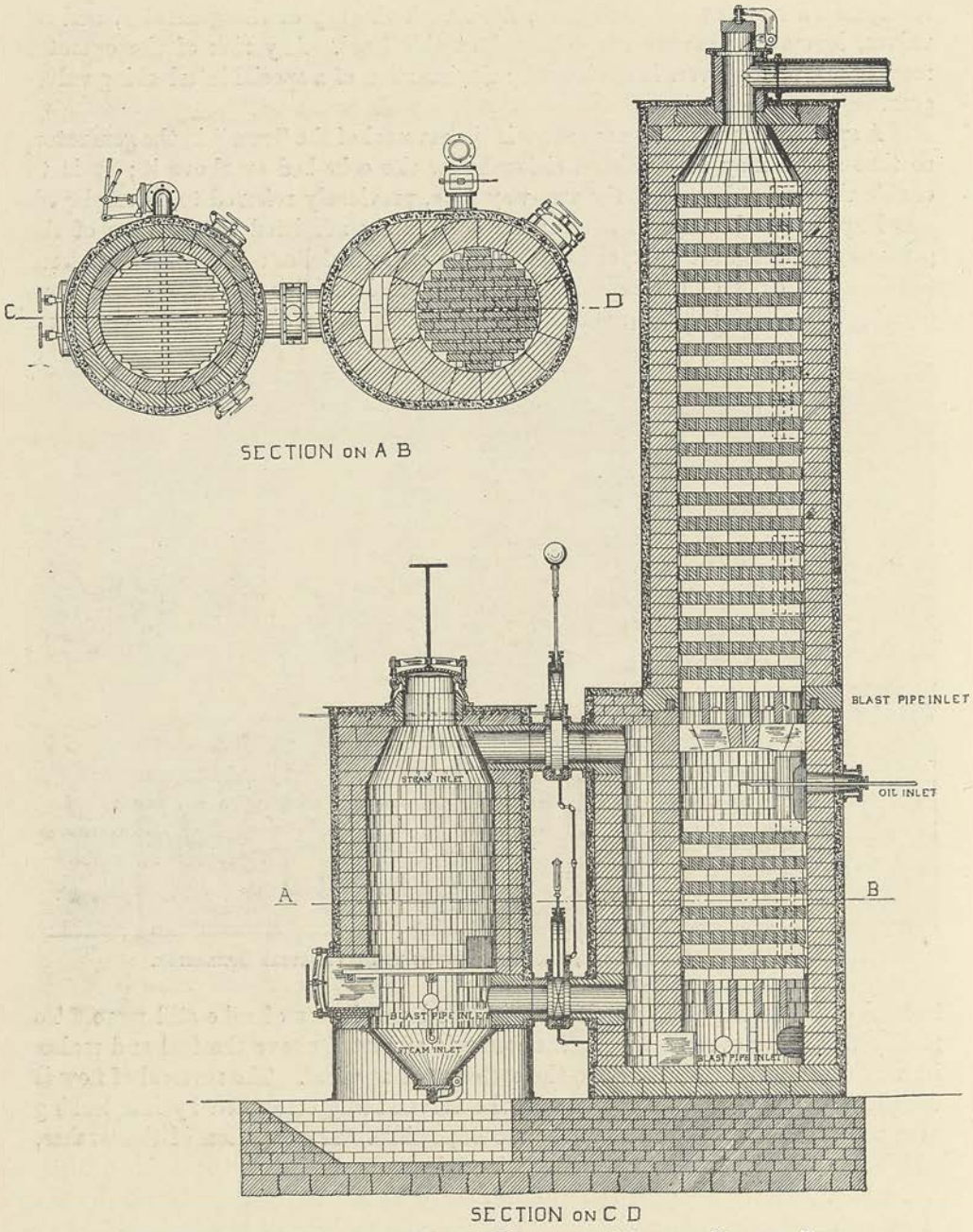


FIG. 434.—SINGLE SUPERHEATER PLANT, MERRIFIELD-WESTCOTT-PEARSON TYPE.

The Humphreys and Glasgow plants are made in sizes ranging from 100,000 cubic feet to 3 million cubic feet per twenty-four hours. One of the most interesting

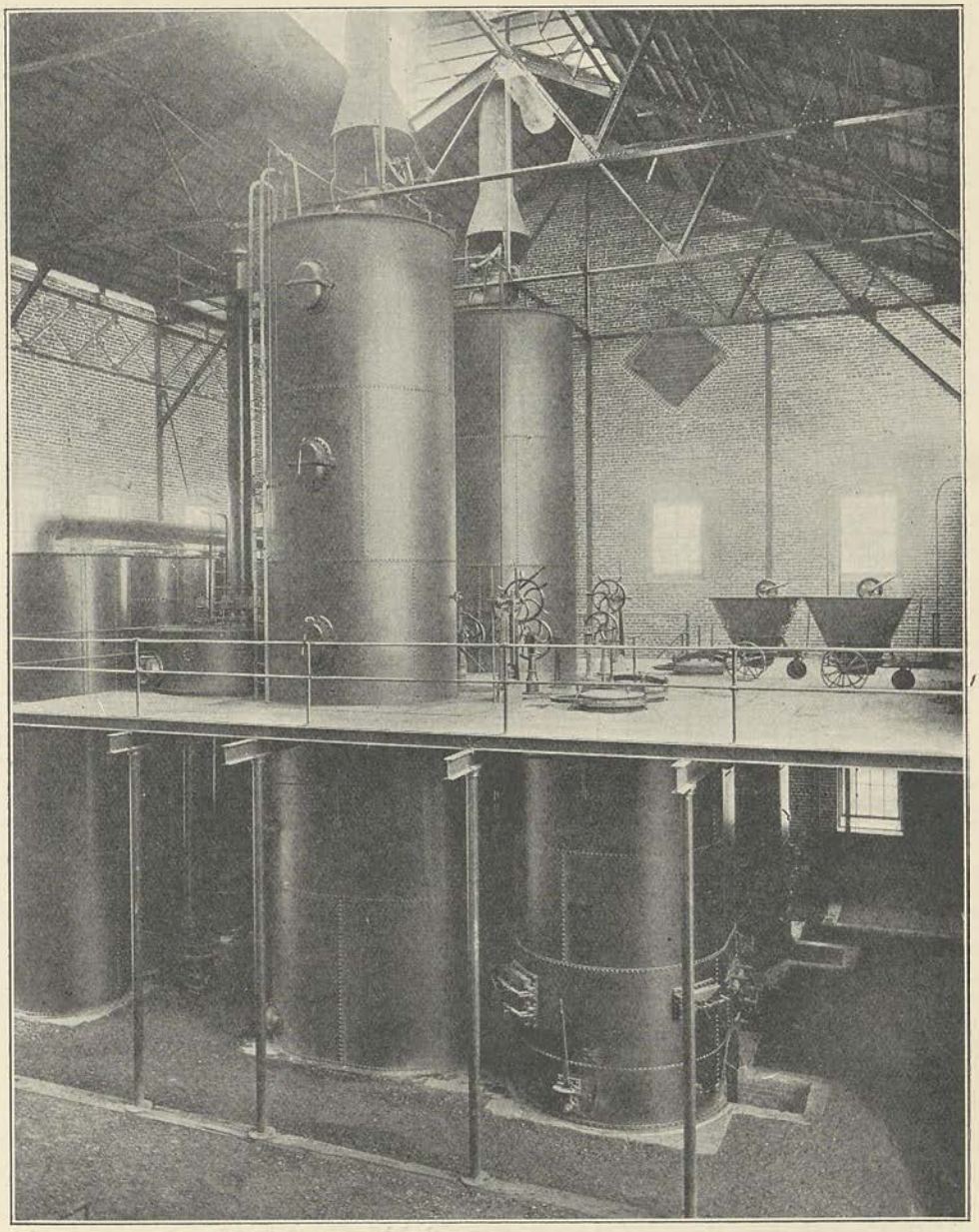


FIG. 435.—THE MERRIFIELD-WESTCOTT-PEARSON PLANT, SHOWING SINGLE SUPERHEATER.

installations is that at the Beckton gasworks. In this case the plant, consisting of five sets, has a maximum capacity of 18 million cubic feet per diem, and the whole of the operation is performed by means of hydraulic power, which controls all valves, at a pressure of 500 lb. per square inch. The gasmaker attached to each unit has

merely to stand at his station, and by the turn of a lever can change from cycle to cycle. The working floor of the Beckton plant is seen in Fig. 433.

Single Superheater Plants

A good deal of attention has been given to the single superheater type of plant, some examples of which now exist in this country. In such plants the carburettor and superheater are merged into a single vessel of rather larger capacity than the superheater of the more common plant. There is some conflict of opinion as to which method is to be preferred from the point of view of getting the utmost efficiency from the oil, but the single superheater plant is certainly less costly in the first place.

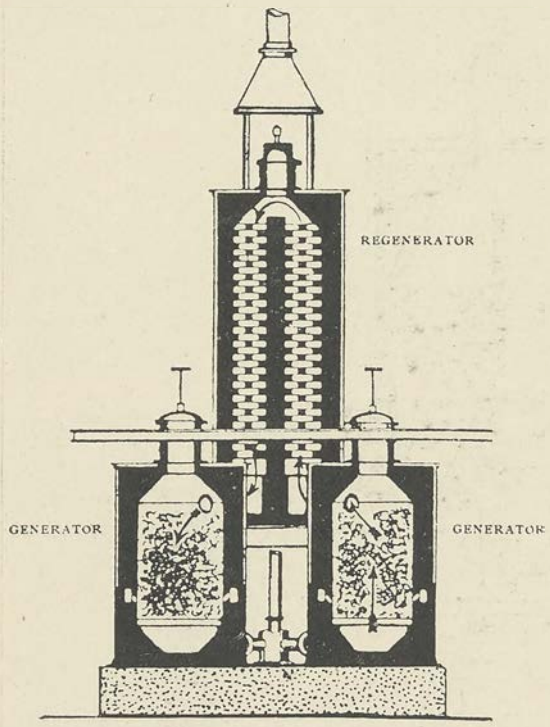


Fig. 436.—The "K. & A." Blue Gas Plant.

In this type of plant, it has been said that by introducing the oil at an intermediate point in the superheater the more volatile constituents separate out immediately, ascend, and make their escape before undergoing decomposition. Meanwhile, the heavier constituents of the oil fall to the base of the vessel and are then swept forward again by the current of water gas entering from the generator, traversing the entire height of the chamber.

The most important plant operating on this principle in this country is that known as the Merrifield-Westcott-Pearson. As before explained, it differs from the double superheater plant in that the carburettor and superheater consist of one vessel, and the oil is injected at three distinct points round the periphery of the vessel instead of from one spray at the top. The oil, moreover, is sprayed in a direction contrary to that of the gas, whereas in the Humphreys plant it travels with the gas. An additional feature is that the hot gas passes through the condenser before being scrubbed, while in the original installations the main valves were cooled by a system of water circulation. The advocates of the double superheater system point out that the primary consideration affecting the economical gasification of oil is that the oil shall be exposed, at a high rate of travel, to a proper fixing surface at a moderate and carefully adjusted temperature. Accordingly, this surface must consist of length in the direction in which the gas travels, rather than of cross-section; for the vapours must never approach a

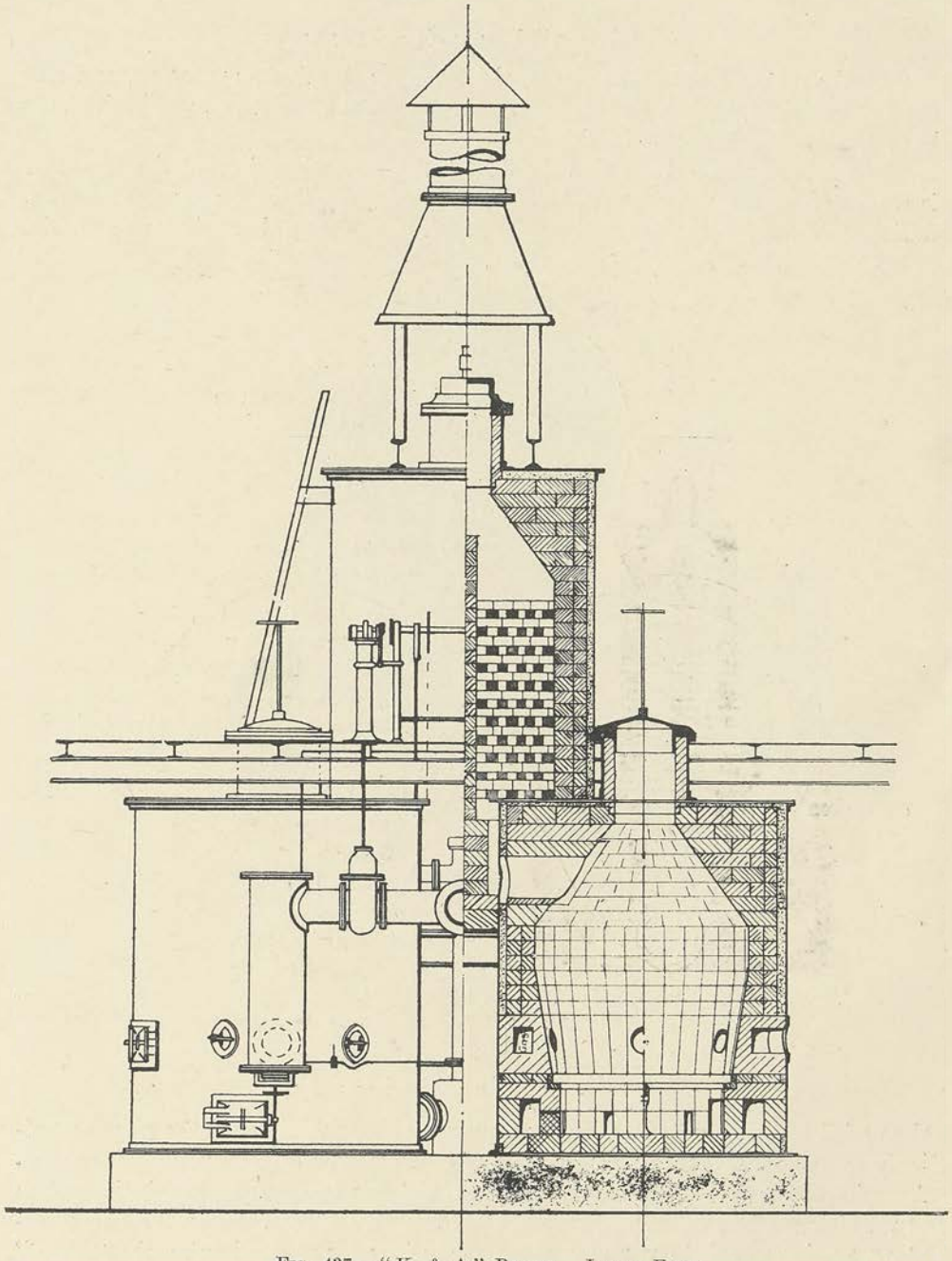


FIG. 437.—"K. & A." PLANT. LATER FORM.

condition of rest in contact with the hot surface in the fixing chambers. For this reason, the oil should be introduced with, and not against the current of gas.

"Blue" Water-Gas Plants

Of the "blue" water-gas plants, the Kramers and Aarts apparatus, and also the Dellwik plant, have been extensively adopted on the Continent, and both plants have made some headway in this country.

The former plant—known as the "K. & A."—is unique in that the generator is composed of two vessels, and, while during the "run" these are used in series, during the "blow" they are worked in parallel. It is found that this device permits

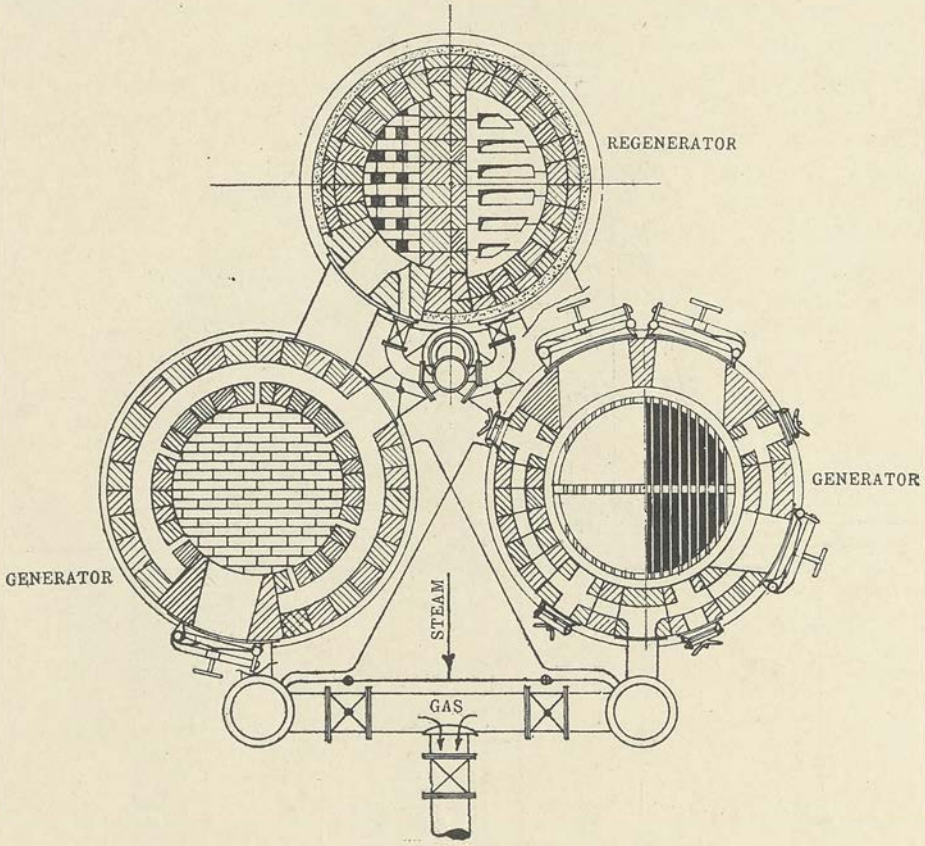


Fig. 438.—Sectional Plan on Fig. 437.

the period of blowing to be about one-quarter of that required in the plants previously described, and therefore the time of gasmaking is correspondingly increased. A section of the apparatus is depicted in Fig. 436, and by referring to this the system of working can be readily followed. It will be noticed that between the two generators, a third vessel, known as a regenerator, is interposed. During the "blow," this is heated up by the hot gases from the fires. During the "run," steam is introduced to one of the generators and is converted into carbon dioxide and monoxide; it then traverses the regenerator, where the surplus steam is split up and

the gas superheated; finally it makes its way through the second generator, in which the carbon dioxide is reduced to carbon monoxide. For the next "run" the direction of the steam is reversed, that is, the final generator now becomes the first.

This system combines a shallow fuel-bed for the blast, together with a deep fire and long contact with the incandescent coke during the "run." The fact that while during the "blow" a shallow bed of fuel is required and during the "run" a deep fire is desirable has proved a difficulty to many designers of water-gas plant, but the introduction of the split generator has effectively overcome this.

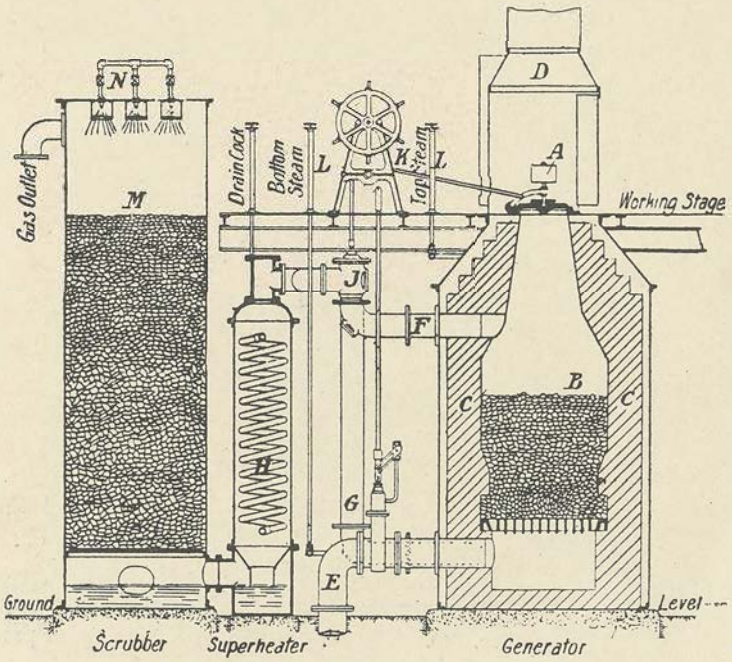


FIG. 439.—DELLWIK "BLUE" GAS PLANT.

It is interesting to note that in the large hydraulically controlled installation at the Beckton works the units are fitted with generators on the "twin" principle and that by the movement of a lever the generators may be set during the "run," for operating either in series or in parallel. In this case the generators are no more shallow than is the ordinary single generator, and the chief advantage lies in the fact that when they are operated in parallel during the "run" the capacity of the plant is increased by some 25 to 30 per cent. On the other hand, when the demand for gas may be less they can be steamed in series when a rather better quality gas containing a smaller percentage of CO_2 will be obtained.

The Dellwik blue-gas plant (Fig. 439), while yielding a gas very similar to that produced in the "K. & A." apparatus, materially differs from it in construction. In this case there is a single generator preceded by a superheater through which the steam passes before entering the generator. It will be noticed that the door at the top of the generator performs the double duty of a stack valve and charging door for replenishing the coke. The gas passes direct from the generator to the superheater, and thence through a coke scrubber. As in the other plants, an interlocking valve-gear precludes the possibility of any danger which might arise from carelessness on the part of the operator.

In this process the air supply from the blower is most carefully regulated, and the level of the fuel-bed should be kept constant.

A French plant which has recently been introduced is illustrated in Fig. 440. The plant is more particularly suited for small works, the process consisting mainly of obtaining a high and uniform temperature throughout the fuel, without any appreciable production of carbon monoxide during the "blow." The generator consists of an upper and a lower portion, the latter being cylindrical while the upper portion is tapered. It will be observed that air inlets are provided both under the grate and at a point level with the top of the lower chamber. The blast is first admitted under the grate, by which means the lower portion of the fuel-bed is raised to incandescence. As the fuel in the upper chamber is raised in temperature slowly, no carbon monoxide appears at the generator outlet during the early period of the "blow." When, however, the characteristic CO flames make their appearance at this point the air blast is diverted to the central inlet.

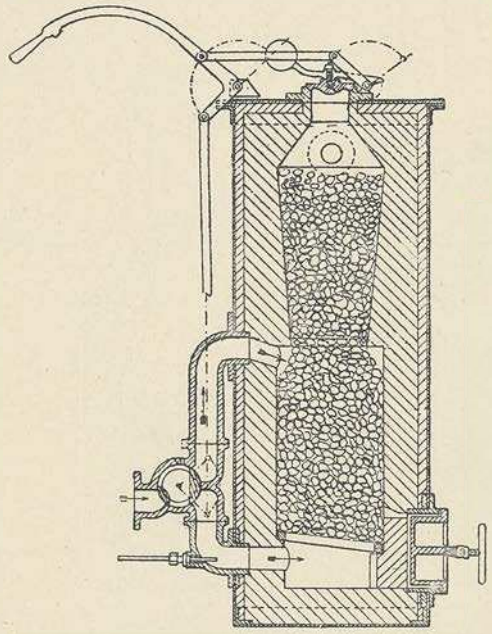


Fig. 440.

The upper part of the fuel is in its turn brought to the same temperature as the bottom, without any material production of carbon monoxide, owing to the decrease by half of the height of the blown layer. As soon as the flames appear again at the throat the blast is stopped, and gasification is proceeded with.

In the construction illustrated the upper valve and the air inlet cock, which constitute the only mechanical parts of the producer, are each provided with an operating lever. The two levers are in engagement with a safety lug provided on the lever of the air cock. With this lug it is impossible to open the air cock without having first opened the charging valve, which precludes any possibility of accident.

The Simplex Plant

The Simplex plant is in reality the development of an improvised attempt to meet, at small cost and with a minimum of delay, the abnormal demands which have recently been imposed on most gas undertakings. The plant is, of course, mainly suitable for the smaller gasworks, and as such it has met with no little success. The construction and operation of the apparatus will be readily followed from Fig. 441. It should be noticed that carburation is effected with tar, while another unusual feature is the construction of the generator of brickwork alone, *i.e.* without

the usual external steel shell. In normal cases the quantity of tar used for carburetting is about $1\frac{1}{4}$ gallons per 1,000 cubic feet of water gas made.

It may be mentioned here that within the past few years a number of experiments have been made with the object of eliminating the outer steel shell of water-gas generators. On the whole, it would not seem advisable to build up the generator from brickwork, for trouble is likely to result from the numerous joints which such a method introduces. On the other hand, reinforced concrete, if built monolithically

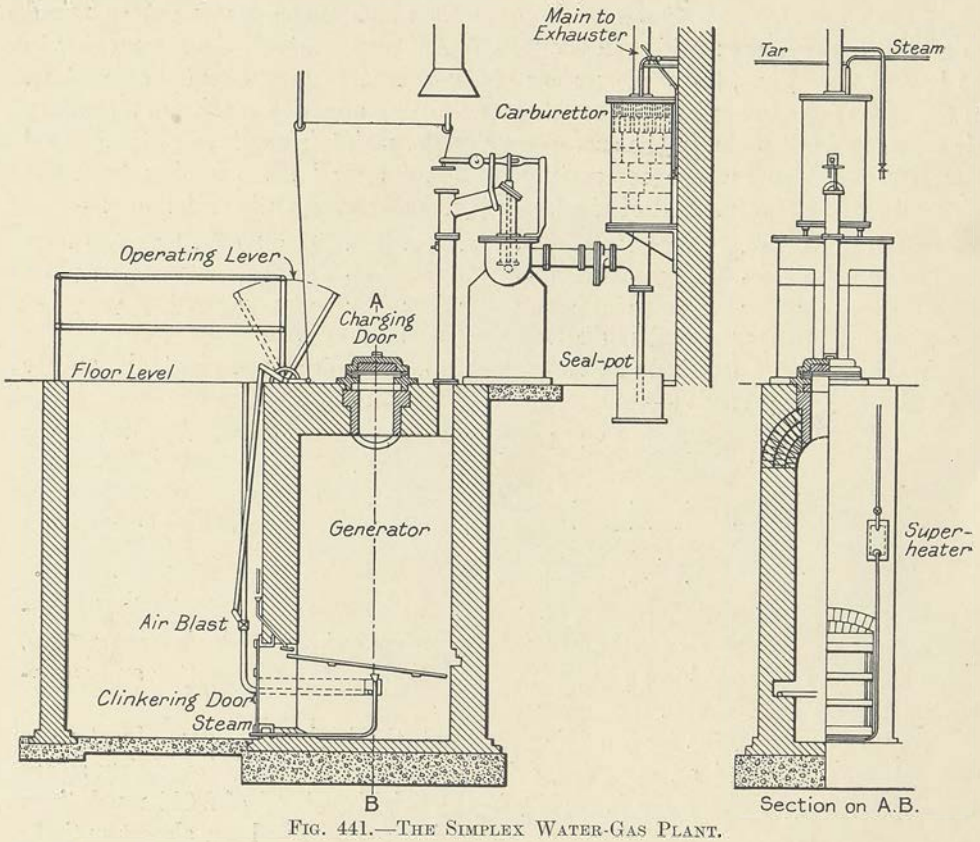


FIG. 441.—THE SIMPLEX WATER-GAS PLANT.

and lined with firebrick, appears to be more or less satisfactory. Concrete has been successfully applied in this way in America.

PRODUCTS OF THE "BLOW"

When air is admitted to the base of a deep fuel-bed, CO_2 is formed in large proportion in the first place; but on travelling through the remainder of the fuel it is partially reduced to carbon monoxide so that a semi-producer gas results. The percentage of the CO present in the products varies inversely with the speed of the blast, and directly with the depth and temperature of the fuel-bed. At first sight the presence of CO might appear to be a distinct disadvantage, for it is produced

by permitting an endothermic reaction to take place during the period when maximum heat expulsion is desirable. Moreover, by burning carbon to CO_2 about three times as much heat is evolved as when it is burnt to CO only. It has to be borne in mind, however, that in many plants the case of succeeding apparatus comes in for consideration, although with the growing tendency for carburetted gas to disappear it becomes more and more important to retain as high a proportion of the liberated heat as possible in the generator. In the Lowe plant the generator is followed by two vessels which themselves must be raised to a high temperature; whilst in the "K. & A." plant there is the regenerator to be heated up. Thus, the producer gas issuing from the generator (or generators, in the case of the twin plants) is burnt, by admitting a small quantity of secondary air from the blast main, in the succeeding vessels, maintaining these at the desired temperature. The average composition of the "blow" gases issuing from the generator when the fuel-bed of the latter is moderately deep is as follows:—

Carbon monoxide	. . . . .	17	per cent. by volume.
Carbon dioxide	. . . . .	10	„ „
Nitrogen	. . . . .	73	„ „

Traces of hydrogen and methane may also be found.

Working with a fuel-bed of 6 feet 6 inches in the Lowe type plant, the author finds the following result:—

"BLOW" GASES

	CO_2.	CO.
End of 1st minute	18·6 per cent.	2·9 per cent.
„ 2nd „	14·6 „	9·4 „
„ 3rd „	12·0 „	16·4 „
„ 4th „	7·6 „	19·8 „

From the above it will be seen that the proportion of carbon monoxide in the producer gas gradually increases as the "blow" proceeds and the fuel gains in temperature.

The main overhead blast pipe, with connections to the carburettor and superheater, is seen in Fig. 430.

As regards apparatus for providing the blast, this in the early days of water gas invariably consisted of an open fan driven by a high-speed reciprocating steam engine. The speed of the fan is usually in the neighbourhood of 2,000 revolutions per minute. For modern work the reciprocating engine has been almost entirely superseded by the steam turbine; or, in isolated cases, by electric motors. A common arrangement, namely, a steam turbine coupled to a Sturtevant fan, is shown in Fig. 442. In some cases the speed of the turbine is governed down in a ratio of about 10 to 1 so as to give the requisite fan speed, while in other instances low-speed turbines are used, the turbine motor running at the same speed as the fan. As regards the electric drive, this has proved quite suitable, but it cannot be said that it affords the same elasticity as is obtained with the steam motor.

Positive Blowers

The ordinary water-gas fan is a high-speed machine with a limited capacity in the way of producing a discharge pressure. On the other hand, the positive blower

is an enclosed pressure-raising device which can be regulated to give almost any desired discharge pressure up to the safe limit. In the case of the open fan, if the main delivery pipe is suddenly closed the pressure increase will amount to no more than 1 or 2 inches w.g. With a positive blower, however, if the main outlet was closed the pressure in the casing and pipe would go on building up until something gave way, or the engine was pulled up. The most notable example of these blowers is the Roots type. Dellwik plants invariably employ a positive blast, and in this way it is said that rekindling can be done more rapidly, and, therefore, the duration of the " blow " may be curtailed. When such a blower is used, however, it is essential to fit a relief-valve on the main blast pipe.

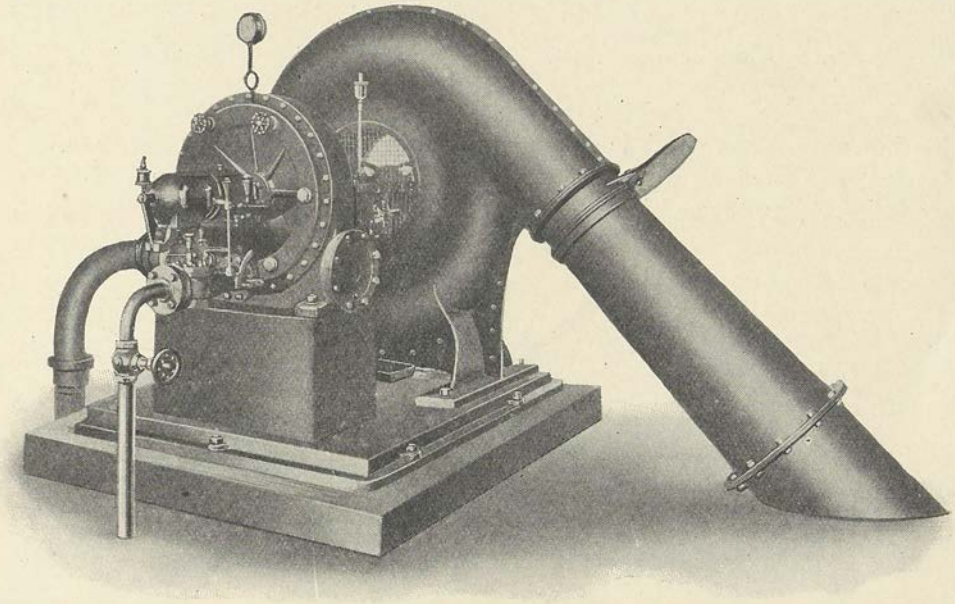


FIG. 442.—TURBO-DRIVEN WATER-GAS FAN.

In general, the high-speed fan blower is usually preferred, mainly owing to the fact that it is cheaper and occupies less room than the positive type. The discharge pressure of the fan varies in accordance with the tangential velocity of the blades ; accordingly, increase of pressure is obtained only by increase in speed. Its economy of operation is decidedly impaired by the fact that it is invariably kept running while the gasmaking run is proceeding. Thus, for five minutes out of every cycle of eight minutes the fan is consuming, to no useful end, from 40 to 50 per cent. of the power taken when operating at full load. As against this the positive blower may be automatically governed so that it is running at a reduced speed during gas-making. When, however, two or more water-gas plants are being operated from the same blower it becomes almost imperative to employ a fan, in view of the fact that the positive machine will not give sufficient uniformity of pressure.

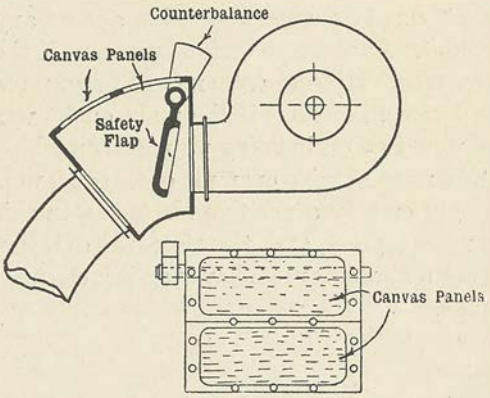


FIG. 443.—DETAIL OF FIG. 444.

Explosions in the blast main, occasionally resulting in the wrecking of the fan, are by no means an unknown occurrence. They are essentially the outcome of a badly fitting hot-gas valve, *i.e.* the valve between blast main and generator, which may permit a small portion of water gas to get by during the "down runs." This gas meeting with the air in the blast main, forms an explosive mixture, which may be ignited by a spark from the fan. A safety appliance, designed to minimize the damage caused by such a contingency, is shown in Figs. 443 and 444. It consists of a cast-iron flap swinging in a special box which is attached to the outlet of the fan. During the time when the blower is at work the flap remains in the position shown. Should any explosion occur in the blast main the force of it drives back the flap on to its

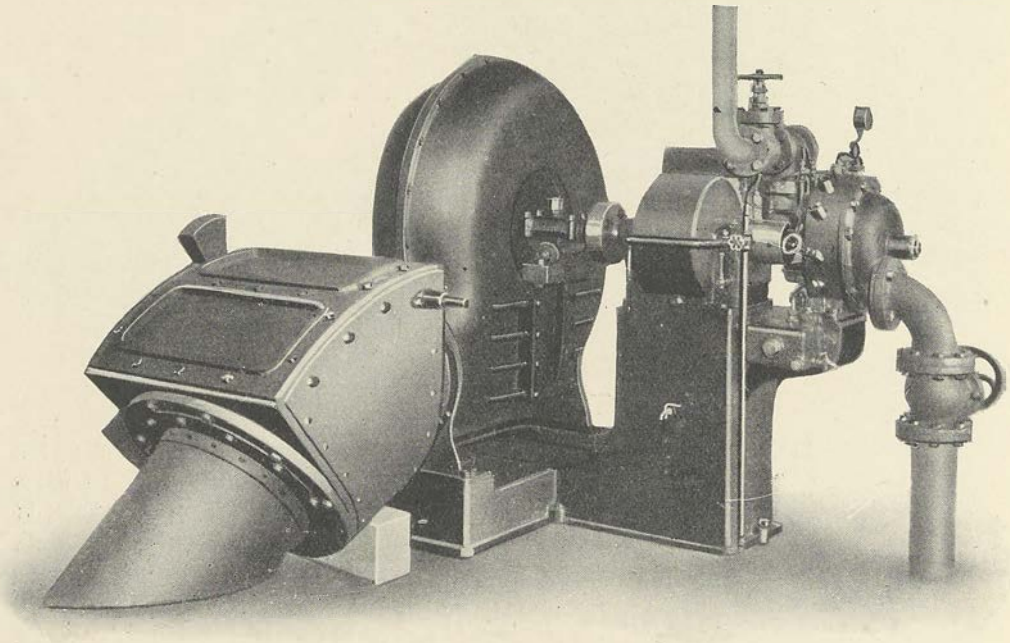


FIG. 444.—STEAM TURBINE BLOWING PLANT FITTED WITH AUTOMATIC SHUT-OFF.

seating, thus protecting the fan from damage, and expends itself by breaking through the canvas panels of the box.

As stated above, it is customary on water-gas plants for the blower engines to

remain running at full speed during the period of the " run," when they are performing no useful work. Those having an eye to small items have pointed out the wastefulness of such procedure, with the result that in some instances a cut-out is arranged to reduce the consumption of steam in the blower engine while the " run " is proceeding. The arrangement may be easily effected in the case of turbines, but it presents a greater problem with reciprocating engines. There is, moreover, some question as to its advisability, for the amount of throttling which may safely be practised with a turbine is limited, as the latter must not be checked so that its critical speed be passed. In addition, the effect of the air blast pressing up against the hot-gas valve during the " run " is desirable, in that, if the valve is not perfectly gas-tight, gas from the generator will be prevented by the blast pressure (which is usually greater than the gas pressure in the generator) from leaking back into the blast main, although such an occurrence is unlikely with modern valves and interlocking gear.

PRACTICAL CONSIDERATIONS

In order to ensure the effectual and economical operation of a water-gas plant it is essential that frequent attention be given to what to many may be considered only minor features of the process. Exceptional results, however, as in the manufacture of coal gas, are obtained by observing the utmost care in connection with details rather than by concentrating upon the more apparent items. The following may be considered amongst the chief factors influencing working efficiency :—

(1) *The Fuel-bed.* In the single generator plant (as opposed to the twin variety) it is generally laid down as a golden working rule that the depth of the fuel-bed must always be maintained. If a shallow fuel-bed is employed it must inevitably follow that the reduction of CO_2 to CO will not take place to the same extent as with a deep fuel-bed—hence, the final product will contain an abnormal proportion of the former gas. At the present day the presence of a small extra quantity of CO_2 is of material importance ; for, as gas is now sold in therms, CO_2 is a constituent which yields nothing in the way of revenue and which occupies valuable space that may be better employed. The author recommends that in no case should the fuel be permitted to fall below 7 feet in depth. On the other hand, too great a depth of fuel means a higher proportion of CO in the escaping blow gases which to-day (in view of the general tendency to manufacture blue gas) have few or no subsidiary duties to perform. By working with a depth of 7 feet the period of blowing may be curtailed (with a corresponding gain in available gasmaking time), and the capacity of the setting will be appreciably increased. The additional amount of gas obtained will have an important effect in reducing cost of manufacture. If this depth of fuel is employed the coke should be moderately small, nothing greater than 3-inch pieces being permitted. If a particularly heavy coke is made use of, less of it will be required as compared with the normal gasworks variety, therefore there need be no hesitation in reducing the fuel depth. The purity of the coke is an important factor, a high percentage of ash causing the clinker to arch over and hang up. The most effective remedy for troubles of the kind is to arrange for a system of periodical

"down runs." In this way the clinker is driven down towards the grate bars and will form in larger pieces, which may be more readily dealt with than can a number of small isolated lumps. A "down run" should be arranged for after every three or four "runs" in the upward direction; but it is as well to admit no top steam for at least an hour before clinkering takes place. As regards purity of the material, it may be noted that retort carbon makes an admirable fuel for water-gas manufacture, entirely obviating the tedious process of clinkering; but its commercial value and the small quantities in which it is produced on gasworks preclude the possibility of its use. It must be remembered that the fuel-bed and the fireclay walls of the generator are the stores of heat, and the heat retained by them only is available for the reactions. Temperatures must therefore be maintained, the generator being worked up to at least 1,100° C. before the "run" is commenced. By the time the "run" is completed the temperature will have fallen to 850°–900° C. The effect of this is shown by the manner in which the make of gas falls off towards the end of the "run," with a gradual increase in the CO_2 content. Stelfox, experimenting with seven-minute and eight-minute "runs," found the following results :—

	Seven-Minute "Run."	Eight-Minute "Run."
Gas made during 1st minute	1,882 cubic feet	1,840 cubic feet
„ „ 2nd „	1,554 „	1,595 „
„ „ 3rd „	1,472 „	1,513 „
„ „ 4th „	1,472 „	1,308 „
„ „ 5th „	1,144 „	1,103 „
„ „ 6th „	982 „	941 „
„ „ 7th „	492 „	410 „
„ „ 8th „		410 „
Total	8,998 cubic feet	9,120 cubic feet

As regards the rate of increase of the CO_2 content, the author finds that, working under the conditions of a comparatively shallow fuel-bed as suggested above, the following may be taken as an average example with a six-minute "run" :—

Generator Gas

	Per cent. CO_2.	Per cent. CO.
End of 1st minute	2·8	46·1
„ 2nd „	4·0	41·5
„ 3rd „	7·3	39·3
„ 4th „	11·8	31·7
„ 5th „	14·7	29·4
„ 6th „	15·9	27·3

It should be emphasized that the above figures were obtained under conditions of constant steam flow. That is to say, the flow of steam was the same during each minute of the 6-minute period, an unscientific practice which is allowed to prevail on the majority of water-gas plants. One of the main causes of poor quality gas is the fact that steam is usually permitted to pass through the fuel-bed in unrestricted quantities, without any thought as to the theoretical amount which is required. The introduction of steam-flow meters has done a good deal towards remedying the trouble; but the difficulty with a water-gas plant lies in the fact that, from the beginning of the gasmaking "run" onwards, a gradual cooling of the fuel-bed is taking place, so that its capacity to decompose steam is far less in the later periods than in the earlier minutes of the "run." In the past, little attention has been given to the fact that as the steam valve is full-open during the whole period, the supply of steam remains constant in spite of the gradual decrease in the temperature of the fuel. It is, accordingly, towards the end of the gasmaking period that inerts begin to make their appearance in large quantities, while in addition a considerable amount of fuel is wasted in providing excess steam from which no gas is obtained.

AUTOMATIC CONTROL OF STEAM

Fig. 445 illustrates an automatic governor [1] which is designed to reduce, without any attention from the operator, the flow of steam in accordance with the gradual reduction in temperature of the fuel-bed. In the main steam supply pipe to the

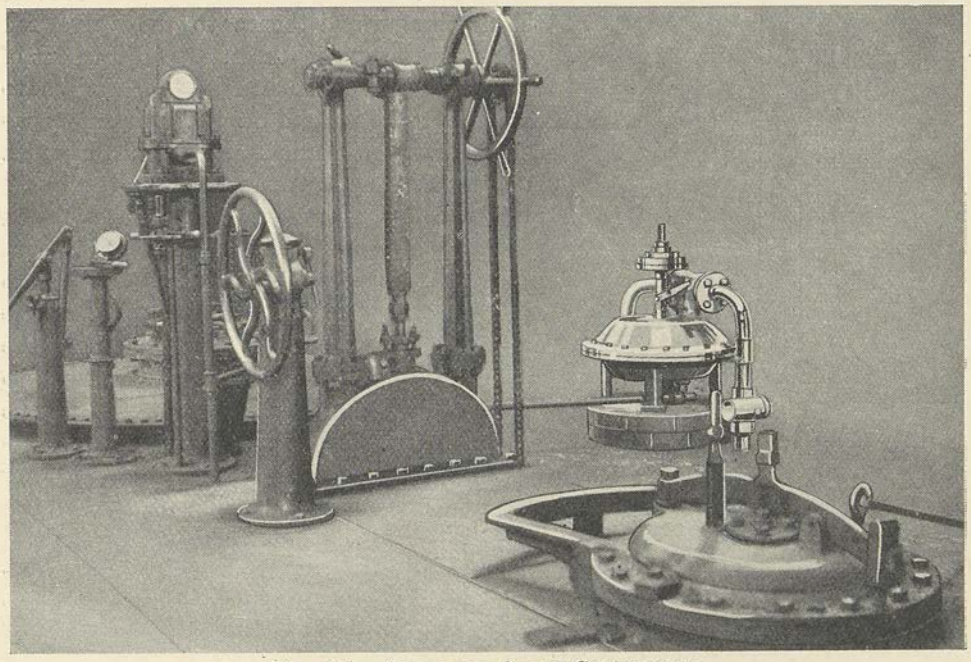


FIG. 445.—AUTOMATIC STEAM CONTROLLER.

[1] The author's patent, 16311/19.

generator is interposed a specially designed throttle which is operated by a valve rod connected to the governor. The latter consists of a cast-iron chamber across the centre of which is stretched a flexible diaphragm. The valve rod is attached at one end to the centre of the diaphragm, and at the other end to the valve in the steam main. Accordingly, any movement of the diaphragm is communicated to the throttle valve.

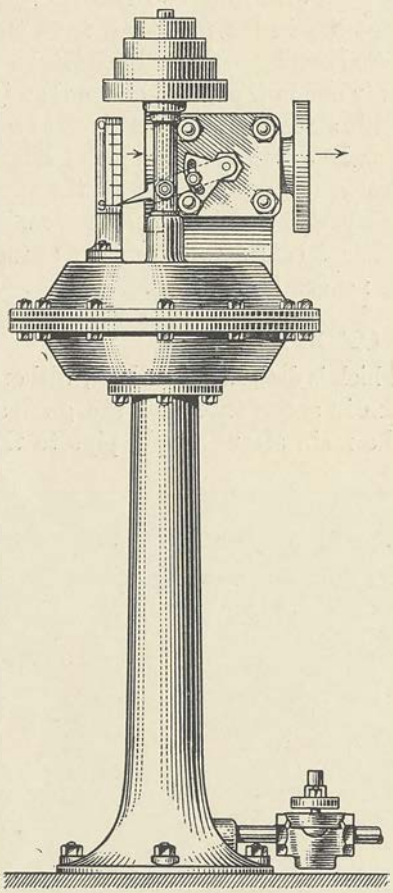


FIG. 446.—STEAM CONTROLLER FOR WATER GAS. NEW TYPE.

The arrangement depends for its operation on the fact that the pressure in the gas outlet pipe above the fuel in the generator (or, in the case of carburetted water-gas plants, in the short pipe connecting generator and carburettor) varies in accordance with the volume of gas passing at a given time. As the temperature of the fuel is at a maximum at the beginning of the gasmaking period, it follows that the pressure also is at a maximum at the same time, for the maximum gas yield is then obtained. In the same way, as the temperature drops so does the yield of gas, and consequently the pressure in the off-take pipe. It is this gradual drop in pressure during the "run" which is communicated to the underside of the diaphragm and thence to the valve rod operating the steam throttle. Adjustment of the governor is effected in such a way as to enable it to be utilized on plants of any capacity. First, the maximum flow of steam which is required during the early stages of the "run" is set at the desired figure by means of an ordinary valve in the steam main. The next adjustment is for minimum flow—that is to say, the governor, having been set to provide a certain maximum flow at the beginning of the "run," is then set, by means of a by-pass, to give a definite minimum flow at the end of the "run." The third adjustment is for the purpose of varying the time taken by the governor to effect a reduction from maximum to minimum steam flow, and is carried out by weighting the diaphragm in accordance with the rate of flow reduction required.

Many water-gas plants are still unprovided with steam-flow meters, so that adjustment is, more often than not, carried out by guesswork, the steam valve being set to give a maximum gas output with but little regard to the carbon dioxide content of the final gas. The effect of arranging for a gradual reduction of steam flow as the temperature of the fuel falls is well illustrated by the following series of results actually

obtained from a plant having a capacity of 650,000 to 700,000 cubic feet of gas per diem :—

Comparison between Constant Steam Flow and Regulated Flow

	1. Steam Flow Ungoverned.	2. Steam Flow Governed.	3. Steam Flow Ungoverned.	4. Steam Flow Governed.
Steam Flow, lb. :—				
1st minute	35	35	30	30
2nd „	35	34·75	30	30
3rd „	35	33·0	30	27·5
4th „	35	29·0	30	24·0
5th „	35	24·0	30	21·0
CO_2 per cent. :—				
1st minute	2·8	2·0	2·0	2·0
2nd „	4·1	3·7	3·8	3·4
3rd „	7·8	5·4	6·9	4·2
4th „	13·8	8·6	11·0	7·2
5th „	15·4	10·2	13·4	8·4
CO_2 in 5 minutes, Run Sample	8·0	4·8	6·4	3·8
Make of Gas c. ft. per run	4,940	4,707	4,800	4,700
Make of Gas c. ft. per minute :—				
1st minute	—	—	1,248	1,363
2nd „	—	—	1,152	1,269
3rd „	—	—	912	846
4th „	—	—	816	658
5th „	—	—	672	564

As compared with constant flow, the results obtained with a regulated flow show a very considerable reduction not only in CO_2 content of the gas, but also in steam and fuel consumption. Thus—

	35 lb. max. flow.	30 lb. max. flow.
As compared with constant flow :—		
CO_2 reduced by	40 per cent.	40·6 per cent.
Steam Consumption reduced by	11 „	11·7 „

It should be noted that the slight reduction in gas yield of the plant is nearly all accounted for by the CO_2 which has been eliminated.

The policy of superheating the steam before its admission to the generator is one on which much discussion has taken place. Certainly, by this means a greater store of heat is ensured in the generator. If the practice can be carried out without introducing structural complications, and by making use of heat which would otherwise be wasted, it is, no doubt, to be commended. But in any case the effect will be limited. Glasgow has pointed out that even when superheated to 800° C. the steam carries scarcely 9,000 additional heat units, or but 2½ per cent. of the energy absorbed in the manufacture of the carburetted product. The provision of a dry steam is, however, essential; and to this end the boilers should be adjacent to the

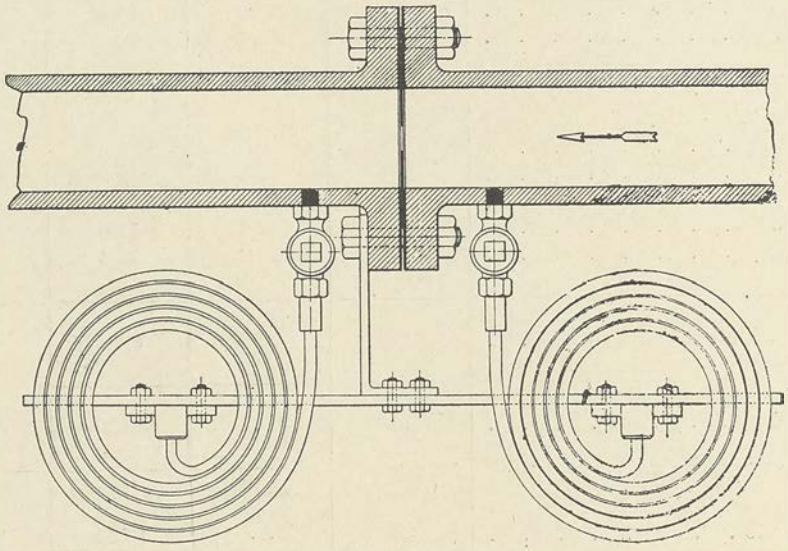


Fig. 447.—Diagram showing Principle of Steam Meter.

plant, the steam mains being adequately lagged, and, if necessary, trapped. Sufficient and uniform boiler pressure is essential, for if the steam pressure is permitted to fluctuate to any marked extent it will be followed by disastrous results on the output of the plant. Many installations are designed to operate with steam at 130 lb. per square inch, though 100 lb. pressure is, perhaps, more common. In the latter case, some appreciable improvement will frequently be followed by increasing the pressure to 110 lb., if the boilers are capable of taking the increase. Steam meters are an undoubted asset to any plant, and enable accurate adjustment to be made. The factor of the quantity of steam admitted is of greater importance than might at first sight be supposed. Whilst a sufficiency of steam is imperative, an excess is to be rigidly avoided. In general, it will be found that for effective results the consumption of steam will amount to from 27 to 30 lb. per 1,000 cubic feet of gas. Thus, with a plant making 8,000 cubic feet per "run" of five minutes the steam should be set at

a rate of about 45 lb. per minute. It will be found that the "down run" supply can be adjusted to give a rather greater flow than the up steam, roughly about 2 lb. per minute more.

Steam meters, as used on water-gas plants, are calibrated to read pounds of steam passing per minute. There are many types, most of which are constructed to read direct on a dial, or to give an autographic record. Kent's steam meter (Fig. 447) is based upon the principle that steam flowing through a constriction in a pipe falls in pressure, the pressure drop being approximately proportional to the square of the velocity of flow. The constriction consists of an orifice plate which is bolted between two flanges, the size of the orifice being such that the desired pressure drop at the maximum discharge is obtained. The pressures from the inlet and outlet sides of the orifice are conveyed through copper pipes to the two portions of the diaphragm, the movement of which corresponds to the differential pressure created by the steam flow. The diaphragm movement is then transmitted through a gland to the indicating mechanism. The loss of pressure due to the insertion of the orifice amounts to about $\frac{3}{4}$ lb. per square inch at maximum flow.

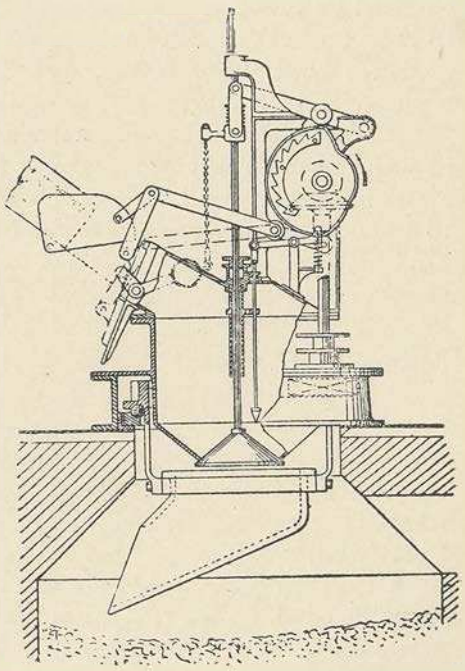


FIG. 448.—FUEL-BED SPREADER.

LEVELLING THE FUEL-BED

If the best results are to be obtained the surface of the fuel-bed should be levelled as far as possible. Owing to the fact that the charging door for coke is invariably situated above the centre of the generator the fuel tends to heap up in a conical mound, the apex of which is just beneath the point of charging. Consideration of the isothermals in the fuel-bed, however, will show that they are of a concave form with the lowest point of the curve in the centre of the bed, and the higher extremities reaching up towards the periphery of the fuel. The surface of the fuel should, therefore, conform to the line of isothermals. That is to say, the shape at the surface should be concave rather than convex. In order to overcome the drawbacks resulting from the heaping of the coke towards the centre, various forms of mechanical spreaders have from time to time been experimented with. Thuman [1] proposes to preclude heaping of the fuel-bed by means of the apparatus shown in Fig. 448. It will be noted that distribution around the periphery of the

[1] B.P. 7532/18, and 15537/17.

generator is effected by a revolving spreader. The spreader is suspended from a spur wheel mounted on a ball race and is rotated by means of bevel gearing. The illustration also shows an arrangement for automatically feeding the fuel into the generator without bringing the interior of the latter into direct communication with the atmosphere.

Removal of Clinker

The operation of clinkering the generator is the most arduous task connected with the water-gas process. With fuels of present-day quality it is usually necessary to clean out the base of the generator every four to six hours, and although mechanical devices for the continuous removal of ash and clinker have been introduced, there are but few examples of their use in this country. Several methods have been tried with the object of curtailing the labour involved, but in the main relief is best obtained by introducing a periodical "down run" of steam. When clinker tends to hang up in the fuel-bed, or when it commences to form an arch over the cross-section of the generator, it may usually be dispersed and driven down to the grate by a succession of "down runs" carried out just prior to the cleaning time.

Various attempts have been made with the object of bringing down the clinker in such a manner that its removal is rendered easier. The author has found that a certain amount of relief from the formation of large and hard masses which adhere to firebars and brickwork is obtained by throwing over the bars, when the generator has been cleaned, a few handfuls of ordinary grey lime. In America it is a common practice to spray with cold water the clinker adhering to the surface of the generator brickwork. This has the effect of making the clinker very friable, thus facilitating its removal. The practice would appear at first sight to have a very detrimental effect on the refractory lining, but the engineers of several American gasworks have pointed to the fact that there is no harmful influence whatever. At any rate it is essential that the water should be kept away from the cast-iron producer doors.

(2) *The Blow.*—In this country the direction of the blast is always upward, no reversal being effected as in the case of the steam. The pressure of the air as delivered from the fan usually varies between 17 inches and 22 inches of water, but much depends upon the type and size of the plant and the fan capacity available. It must be borne in mind, however, that the blast must under all circumstances provide an excess of air, otherwise the extent to which combustion to CO_2 takes place will be limited, with the result that less heat is dispersed. It will be remembered, in this connection, that the partial combustion of coke to CO accounts for only one-third of the heat derived from complete combustion.

In some modern forms of producer (*e.g.* the Loomis type) the air is admitted to the top and travels in a downward direction through the fuel-bed. The primary objection to the upward blow is that an appreciable quantity of coke dust is carried forward beyond the generator. Harger suggests that the loss of fuel from this cause may amount to from 2 to 5 per cent. of the total coke used. With a downward blow, however, the chief difficulty would seem to be that of clinker formation and removal, so that it would appear necessary to run off the ash in the molten state.

As is to be expected, the construction of blowing fans has undergone some considerable modification since the introduction of water gas.

Some twenty or more years ago, when the manufacture of water gas was in its infancy, a blast pressure of from 8-inch to 15-inch water-gauge was considered suitable for the generators, and any good blowing fan would do the work.

A few years later the output of gas plants was largely increased by running the fans at greater pressures, and, as the speeds required for the new conditions were too high for the fans then in use, the results in many cases were disastrous. In order to meet the conditions a special extra heavy fan was then introduced. This new type of fan, made exclusively for water-gas purposes, is capable of supplying air at a pressure of from 15-inch to 25-inch water-gauge, or even greater pressures if necessary.

Bearing in mind the very important duty performed by the blowing fan in the manufacture of water gas, it cannot be emphasized too strongly that, in order to eliminate as far as possible all risk of breakdown, the blowing apparatus should be specially designed and suitable for long "runs" with a minimum of attention.

The following table gives the approximate size of fan (Sturtevant type) required for a given size of water-gas plant :—

Standard Size of Fan.	Capacity of Water-gas Plant. Cubic feet per diem.	B.H.P. absorbed by Fan.	Speed of Fan. Revs. per minute.
4	150,000	10·25	3,400
5	200,000	14·50	2,920
6	300,000	15·50	2,475
7	500,000	23·50	2,175
8	650,000	32	1,625
9	850,000	44	1,425
10	1,000,000	58	1,225

In view of the fact that fans operating in conjunction with water-gas plants have to work intermittently, it would not seem advisable to employ blowers of the positive type. For instance, when no blast is required a positive blower must be stopped altogether, or a valve must be fitted on the blast main to release the air when the pressure rises above a predetermined figure. The latter, however, is a somewhat wasteful proposition. With this type of blower, moreover, the questions of wear and tear and noise during working have to be considered. With a centrifugal fan it is possible to regulate the delivery of air by a valve placed in the blast main, the speed of the fan being kept constant. As the valve is closed or opened, less or more air is allowed to pass to the generator, and the power absorbed by the fan rises or falls according to whether the valve is opened or closed.

(3) *Amount of Air Required.* The amount of air which should be required during the period of the "blow" is most readily gauged upon the gas-producing capacity of the plant. As a general rule it may be taken that the quantity of air should not

exceed from 2,000 to 2,500 cubic feet per 1,000 cubic feet of gas made. Thus, with a medium-sized plant, making 8,000 cubic feet during a five-minutes' "run," the total air passed should lie between 4,000 and 5,000 cubic feet per minute. It has been previously pointed out that as the "blow" proceeds, so does the proportion of carbon monoxide in the producer gas increase. For this reason it has been suggested that the fan should be gradually speeded up so that a greater volume of air is passed towards the end of the "blow." An arrangement which is occasionally found is that of gradually increasing the secondary air to the carburettor and superheater during the "blow." This can be conveniently done in a hydraulically operated plant such as that at the Beckton works. Air meters fitted to the blast main are more or less a luxury, but are occasionally found. Fig. 449 shows an air meter of the Venturi type.

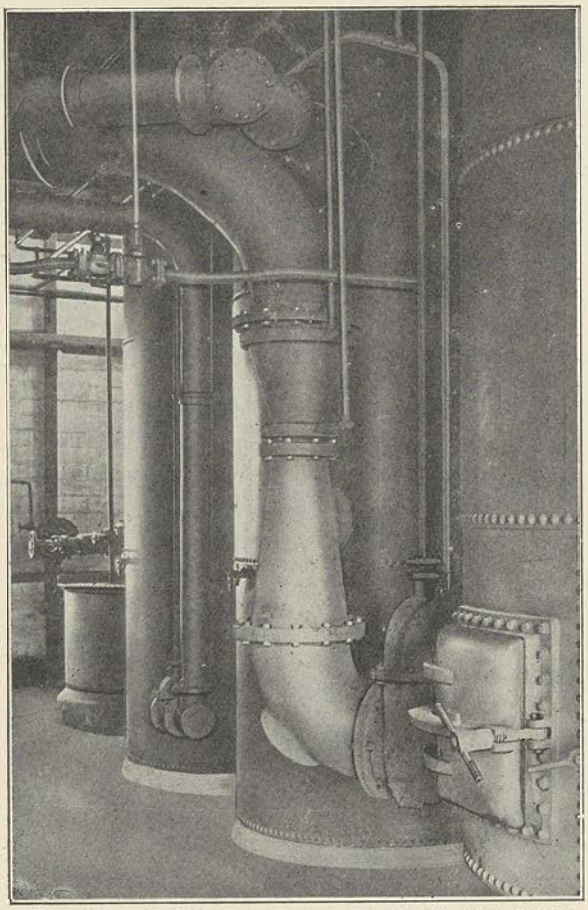


FIG. 449.—AIR METER ATTACHED TO GENERATOR BLAST MAIN.

The satisfactory regulation of the blast is a considerable factor in water-gas operation, for it must be remembered that very much more fuel may be consumed during the "blow" than is actually made use of for gas-making. With extravagantly operated plants, in which the blast may be excessive, the fuel burnt during the "blow" may amount to three times the quantity disposed of during the "run." A. G. Glasgow in a test with a plant consuming hard coal found that, working under favourable conditions, the consumption of carbon during "blow" and "run" was as 13·88 to 9·62, or, about 60 per cent. was accounted for during the "blow," and 40 per cent. was used for gasmaking.

For effective results it is essential that local blowing, or imperfect distribution of the air blast and the steam supply, should be avoided. For this reason the fuel supplied to the generator should be as uniform in size as possible. If clinkering is imperfectly carried out and large lumps are allowed to form and remain lodged

up in the generator effective distribution is impossible. Thus the air blast will find its way through certain portions only of the bed, which portions will be raised to an abnormally high temperature, whilst the remainder of the bed is in a condition of comparative coolness. Local steaming of the bed may, in the same way, be due to the formation of clinker, although it frequently occurs from the steam supply nozzle being non-central, partly choked, or broken.

Owing to the gradual reduction in temperature of the fuel-bed during the "run" it has become essential that the steam supply should undergo reduction as the period of gasmaking proceeds. In this way a much better quality gas will be obtained. The gradual diminution of the steam is unfortunately the exception rather than the rule, although it is now becoming more general.

(4) *Periods of "Run" and "Blow."* The duration of the "run" and "blow" differs in accordance with the type of plant. The following show the average conditions of working :—

	"Run."	"Blow."
Lowe Plant	5 minutes and	3 minutes.
	or 6 minutes and	4 minutes.
"K. & A." Plant	5 minutes and	70 seconds.
Dellwik Plant	6 minutes and	60 seconds.

With the standard type of carburetting plant the author has found that the most favourable results are obtained by working on the five-minutes' "run" and three-minutes' "blow" cycle, but that the "run" immediately prior to recharging the generator may be prolonged to six minutes. At such stages the fire is moderately shallow and exceedingly hot, and there appears to be a good yield of gas during the extra minute. After coking up, moreover, it is as well to prolong the "blow" to four minutes.

Clinkering on water-gas plants must be carried out at frequent intervals, for if once the mass is allowed to grow it will gradually arch over in the generator until the latter is almost completely choked. With the Lowe plants it is advisable to perform the operation at intervals of four hours, although in cases where a good quality coke is procurable the period may be prolonged to six hours. In many of the "blue" gas plants with double generators clinkering takes place only once in ten or twelve hours. In recent years mechanical grates, which obviate the greater portion of the labour entailed in clinkering, have been introduced, but they are as yet confined to generators of the larger capacities. Briefly, they consist of specially designed firebars which are caused to rotate and scrape out both clinker and ashes. A generator fitted with such a grate, designed by Humphreys and Glasgow, is seen in Fig. 450. The Kerpely producer, which is built with a specially revolving ash-extracting grate, has already been referred to in Chapter III.

(5) *Carburation.* In the original plants employed for the manufacture of carburetted water gas it was usual to spray the oil direct on to the fuel in the generator. This procedure, however, proved decidedly wasteful, with the result that a separate vessel was soon introduced for purposes of carburation. The duty obtained from the carburetting medium employed will largely depend upon the manner in which

the vessel is operated and maintained, whilst temperature is a factor of considerable importance. The main consideration to bear in mind is that the heat must be sufficient to crack up the oil into vapours which will as far as possible be retained as permanent gases, but it must not be so great as to cause such degradation as gives rise to over-cracking and the deposition of free carbon. Frequently, it is stated that a desirable working temperature for both carburettor and superheater is 930° C., or thereabouts. The author finds, however, that for high results in the direction of " candles per gallon " the American oil as now almost universally used is preferably decomposed at lower temperatures. Moreover, it will be found advantageous to work

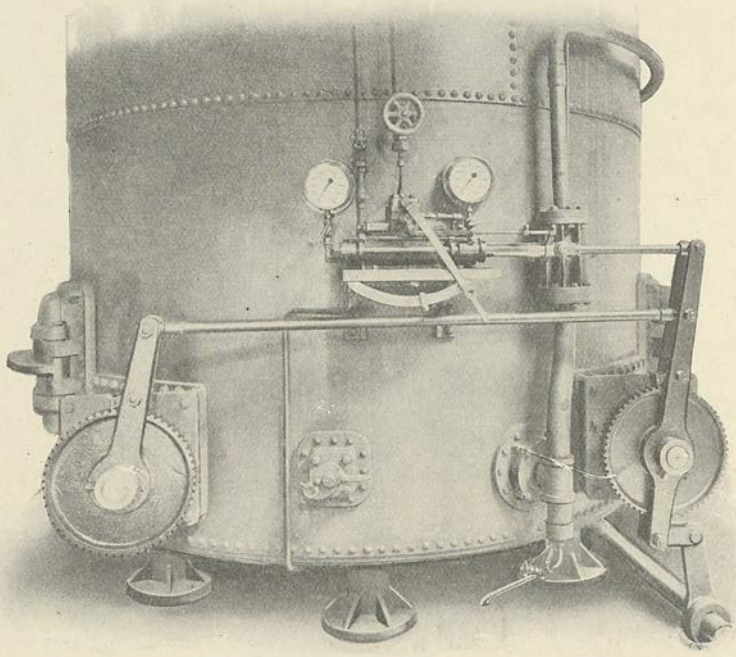


Fig. 450.—Generator fitted with Automatic Clinkering Device.

the superheater at slightly higher temperatures than the carburettor. The temperatures suggested when under normal working conditions are :—

Carburettor	between 700° and 760° C.
Superheater	„ 760° and 800° C.

This, however, must not be considered as a hard-and-fast rule, for very much depends upon the quantity of oil being injected during the " run." For instance, if a poorer quality gas is being manufactured, and only about half the normal quantity of oil is in use, the temperature must be regulated in accordance. Another

factor is the time taken to inject the oil. The quantity sprayed in must not be so apportioned that oil is running in during the whole of the gasmaking period. Such procedure would lead to inevitable waste, for the carburettor and superheater would not be swept clean from oily matter before the commencement of the "blow." Generally, it may be said that it is as well to arrange for the desired quantity of oil to be sprayed in during the first half of the "run" or thereabouts. For instance, with a five-minutes' "run" the oil may be got rid of in the first three minutes, leaving two minutes for the manufacture of "blue" gas, which will perform the necessary scavenging of the remaining vessels. The oil spray is a matter of importance, and thorough atomization should be aimed at. It would seem that rather than the oil should be injected under a pressure of 40 lb. per square inch it is preferable to employ higher pressures of from 80 to 100 lb. Such pressure in conjunction with a spray of the Brighton type (Fig. 451) gives the most effective mechanical subdivision and uniform distribution. The extremely fine distribution of the oil in this manner tends towards maintaining the chequer-work of the carburettor in a more cleanly condition, whilst patchiness in heating is avoided. It is customary on gasworks in arriving at an indication of the efficiency obtained from the oil to note from day to day the yield of "candles per gallon." This figure is arrived at by taking the average candle power of the gas, and dividing it by the oil used per 1,000 cubic feet of gas made over the same period. In practice the result varies between 7 and 8 candles per gallon, but the latter figure should be easily obtainable when the set is worked on effective lines. To-day, however, little oil, if any, is used for enrichment, so that a criterion based on candle power has lost the significance it had in pre-war days. It may be stated here that the amount of gas yielded per gallon of American gas oil varies from 70 to 90 cubic feet.

A rough-and-ready test which may be applied to the superheater in order to determine whether the most is being made of the oil is merely that of holding, during the "run," a piece of clean blotting paper to a small jet of the gas taken off from the

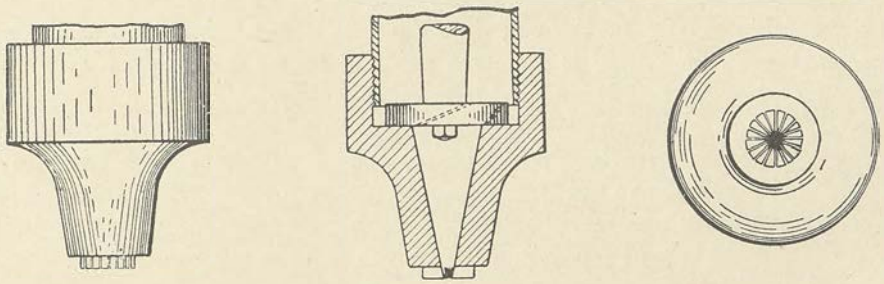


Fig. 451.—Details of "Brighton" Oil Spray.

down pipe from the superheater. If the oil is being subjected to too great a heat a small black deposit of free carbon will be found on the paper; if, on the other hand, it is insufficiently cracked, a slight deposit of an oily nature will result. In

the majority of carburetting plants a device is in use whereby the oil, before being passed into the carburettor, is preheated by the hot gas leaving the plant. The heater is usually placed in the down pipe leading from the superheater, and raises the temperature of the oil to about 110° C. In this way the "candles per gallon" are appreciably enhanced; but the author would point out that in some instances he has found that the removal of the oil heater has been followed by a general improvement in results. This fact is ascribed to the reason that the heater appropriates a considerable portion of the area of the main gas outlet, with the result that the latter is insufficiently large for the gas to get away with the ease it should do. A point which is patent to all users of water-gas plant is the necessity for scavenging the apparatus prior to commencing the "blow." When the steam is shut off at the end of the "run" the vessels, the cubic capacity of which is fairly considerable, remain full of water gas. To open the stack valve at once and to commence with the "blow" would be to discharge this water gas into the air. To preclude this, after the steam is shut off the stack valve should remain closed, not being opened until the air blast has been passing through for a few seconds. In this way, the gas will be driven forward to the holder, and the plant will be effectively cleared out.

In the early days of carburetted water gas in this country the enriching medium employed was almost solely a Russian Solar distillate. At the present day, however, the centre of supply has moved to America, from which country the residual petroleum, having a specific gravity of about 0·85, is obtained in large quantities. The gas engineer, so long as he can obtain his oil for a reasonable price, does not trouble very much about its quality, although an inferior product will soon make its mark on the working results of the plant.

It has been more or less conclusively proved that the laboratory analysis of gas oil is of little avail in determining the suitability of the oil for carburetting purposes. On this account it is unusual to subject consignments of the oil to anything more than the crudest tests.

It is general for the gasworks' chemist to draw off his sample carefully and to note the specific gravity of the oil; but the result affords him no indication of the gasmaking qualities, and is merely a guide as to the origin, upon which this property to a large extent depends. So far as the origin of gas oil is concerned, it has already been pointed out that practically all of that imported now comes from America. The other suitable types, Russian Solar distillate, also Galician—these being high-grade oils—have not been imported for some years. Rumanian oils are of a poorer character and rarely reach this country.

An average sample of present-day American gas oil will show on distillation approximately the following fractions:—

DISTILLATES FROM AMERICAN GAS OIL

(Specific gravity, 0·8520.)

Temp. 0° C.	Per cent. by Volume.	Specific Gravity.	Characteristics.
Up to 120°	0·5	0·7790	Clear white
120° to 200°	1·0	0·7881	Do.
200° to 225°	9·0	0·7886	Do.
225° to 240°	7·0	0·8224	Pale straw colour
240° to 260°	16·0	0·8373	Do.
260° to 275°	6·5	0·8409	Yellow
275° to 300°	16·0	0·8517	Greenish yellow
300° to 350°	25·0	0·8610	Do., slightly viscous
350° to 380°	14·5	0·8980	Dark green, viscous
380° to 400°	3·0	0·9130	Dark red, glutinous
Residue	0·5	—	Black solid
Loss on distillation	1·0		
	100·0 per cent.		

(*Note.*—Sulphuretted hydrogen evolved throughout distillation.)

With regard to gasworks tests, the only true indication of the suitability of an oil is a practical trial run by an engineer who knows the ins and outs of the working of his plants. Oils have frequently been known to give satisfactory laboratory tests in every way, and yet to yield unsatisfactory results. Petroleum, being a natural product, is liable to considerable variation, and no agents for gas oil will guarantee results or "candles per gallon." For American oils the specific gravity should fall between 0·845 and 0·865; but within recent years there has been a growing tendency to remove a greater quantity of the lighter constituents owing to their enhanced value. Specific gravity, therefore, has increased and now frequently approaches 0·90. The test for flash point is important, owing to the fact that if this falls below 73° F. a special licence for storing is required, while higher rates will be demanded for railway carriage. The test may best be carried out by means of the Abel "closed" apparatus, and affords a fair indication as to the percentage of volatile constituents. The details of the test need not be described here, and it will be sufficient to recall that the flash point of an oil is the temperature at which it gives off sufficient vapour to ignite momentarily on the introduction of a spark or flame. The oil is heated at a prescribed rate, and a definite ignition agent is applied in a given manner.

One of the most satisfactory methods of testing a gas oil destined for water-gas manufacture is to ascertain by fractional distillation whether or not it is of a homogeneous nature; that is to say, not merely a mechanical mixture of different oils likely to separate out when stored in a tank. A suitable homogeneous oil would give fractions coming away with fair regularity between the second and eighth or ninth 10 per cent. periods. The proportion of the oil distilling over at a temperature

of less than 300° C. should also be noted; this should be as low as possible, for the reason that a high yield of these fractions indicates a tendency towards undue volatility. More than 10 per cent. remaining at 400° C. would show the presence of undesirably heavy constituents; while the specific gravity of the various fractions should show a fairly uniform progressive rise. Uneven jumps at various temperatures are not a recommendation.

A Standard Test

The solid residue remaining after the completion of fractionation is of no little importance, and should never exceed 2 per cent. by weight of the original quantity of oil taken; in many cases the figure will be found to be below 1 per cent. Mexican oil will usually leave a far greater solid residue, occasionally amounting to more than 5 per cent.

A standard test for oil which is carried out at many of the larger gasworks is to distil 10 fluid ounces in a special apparatus, and to carry the temperature up to 350° F., this latter point being gradually arrived at in a period of 40 minutes. The residue remaining behind is then cooled, and its specific gravity noted. If the oil is of a desirable quality the gravity will be 0·900. Probably one of the most important items is the sulphur content, and this should not be allowed to exceed 0·4 to 0·5 per cent. The quantity of water is also to be watched, and may be conveniently estimated by use of a "Sutherland bulb." The rougher test for all oils which lose an inappreciable percentage of hydrocarbons on being heated to 110° C. is to weigh 25 grammes in a glass dish, heating to this temperature on a sand bath, and continually stirring until bubbles of steam cease to form. The sample is then allowed to cool, and is reweighed, when the loss of weight in grammes, multiplied by four, represents the percentage of water present.

Although of considerable importance, owing to its effect on the sulphur impurities of the gas, the test for sulphur is seldom carried out on gasworks. A convenient method of obtaining an idea as to the quantity of sulphuretted hydrogen is to hold at intervals a piece of moistened lead acetate paper above the outlet of the condenser; if sulphuretted hydrogen is present the paper will be blackened in the usual manner, the degree of blackening giving a fair indication of the amount of sulphur in the oil. The total sulphur present can conveniently be arrived at by Carius's method, or by the use of the bomb calorimeter; but for gasworks purposes a ready means would be that of taking a weighed quantity of oil, mixing it with a spirit (such as alcohol) entirely free from sulphur, and then burning it in a suitable lamp. The products are collected in an apparatus similar to that prescribed by the metropolitan gas referees for testing sulphur compounds. Other refinements of oil testing include the use of the colorimeter and tintometer. But such apparatus is usually beyond the scope of the average gasworks.

ATMOSPHERE IN WATER-GAS PLANTS

Some interesting work in connection with the effect of atmosphere on the ultimate quality of water gas has been carried out by Downing and Pohlman.[1]

[1] *American Gas Inst.*, 1917.

As regards the heat units obtained in the gas per gallon of oil used, it was found that the highest results were given by the hydrogen atmosphere, this being accounted for by an abnormal production of saturated hydrocarbons. On the other hand, the most effective illuminating power results were obtained with a methane atmosphere, the suggestion being that methane has a preservative influence on the illuminants, since its presence introduces equilibrium conditions which prevent the more valuable light-giving hydrocarbons from reacting with hydrogen to form saturated hydrocarbons. Methane, in fact, is shown to behave more or less like an inert atmosphere, such as nitrogen, which generally brings about a considerable yield of tar and free carbon. A remarkable fact is that when the oil is cracked in a nitrogen atmosphere there is an appreciable evolution of hydrogen, whereas when the atmosphere consists solely of hydrogen there is actually an absorption of this element.

As regards the effect of carbon dioxide, it is shown that when oil is cracked in an atmosphere of particularly poor gas the loss in illuminating power is 5·5 per cent. for each per cent. difference in carbon dioxide in the finished gas, or 3·6 per cent. loss for each per cent. difference in carbon dioxide in the " blue " gas.

As regards carbon monoxide, it is shown that this gas is instrumental in preserving the illuminants from decomposition, although it appears to be a direct cause of the production of tar—a greater quantity of tar being produced in this atmosphere than in any of the others experimented with. The explanation is that carbon monoxide exerts a tendency towards the production of the lighter olefines which enhance the proportion of illuminants in the gas, while a certain proportion of the heavier olefines go to swell the tar yield.

Experiments conducted with an atmosphere of typical " blue " gas as obtained direct from the water-gas generator led to the conclusion that no advantage is to be gained over " blue " gas by the substitution of any single atmosphere. With " blue " gas generally the most favourable results were obtained in all directions. As regards temperatures, the light-giving constituents formed from a gallon of oil reach a maximum at 700° to 730° C., and higher temperatures than these are followed by uneconomical degradation. This point is one of extreme importance, and should prove a useful illustration to those who still continue to operate their carburettor and superheater on the old-fashioned principle which advocated a temperature approaching 1,000° C. At the lower temperatures it seems very probable that the oil is cracked without the formation of hydrogen, for the American investigators found less of this element in the finished gas than in the " blue " gas. At temperatures above 800° C., however, the reverse was the case, and there can be little doubt that methane decomposes into hydrogen and free carbon.

The outlet gas from the generator invariably contains a small proportion of undecomposed steam, which must always be looked upon as detrimental because of its tendency to react with carbon monoxide, with the formation of carbon dioxide. In addition, this steam has an injurious effect upon candle power, and its presence is followed by a lower yield of tar and larger deposits of free carbon. The reduction noticeable in illuminating power is attributed to the reaction of the steam with hydrocarbons, such as ethylene, which are decomposed into carbon monoxide and hydrogen.

Little work has been done in connection with the determination of the character of the unsaturated hydrocarbons in carburetted water gas, although it is known that these are mainly olefines with a smaller proportion of benzene hydrocarbons. B.T. Brooks,[1] in studying the mode of existence of the hydrocarbons in oil gas produced by the cracking of American petroleum, has given the following results :—

Composition of Oil Gas

Temp. of Cracking, ° C.	600	650	700	730
Ethylene, per cent.	19·3	19·0	17·7	17·5
Propylene, „	28·0	28·4	23·9	20·0
Higher olefines, „	3·2	4·2	3·5	3·1
Total olefines, „	50·5	51·6	45·1	40·6

RECOVERY OF BENZOL FROM CARBURETTED WATER GAS

During the war various attempts were made to recover the benzene hydrocarbons from carburetted water gas. The effectiveness of the process entirely depends upon the quantity of oil used for carburation, while the temperature prevailing in the carburettor influences the result. Temperatures between 700° and 760° C. appear to produce the maximum amount of toluene. Higher temperatures tend to increase the proportion of benzene, while lower temperatures produce paraffins and olefines. The recovery of light oils in this country during the war was not followed up, partly owing to the paraffins present in the recovered spirit, and also on account of the attenuated nature of the water gas which resulted from the shortage and expense of gas oil.

L. J. Willian [2] has given the following figures as an illustration of the effect of stripping carburetted water gas :—

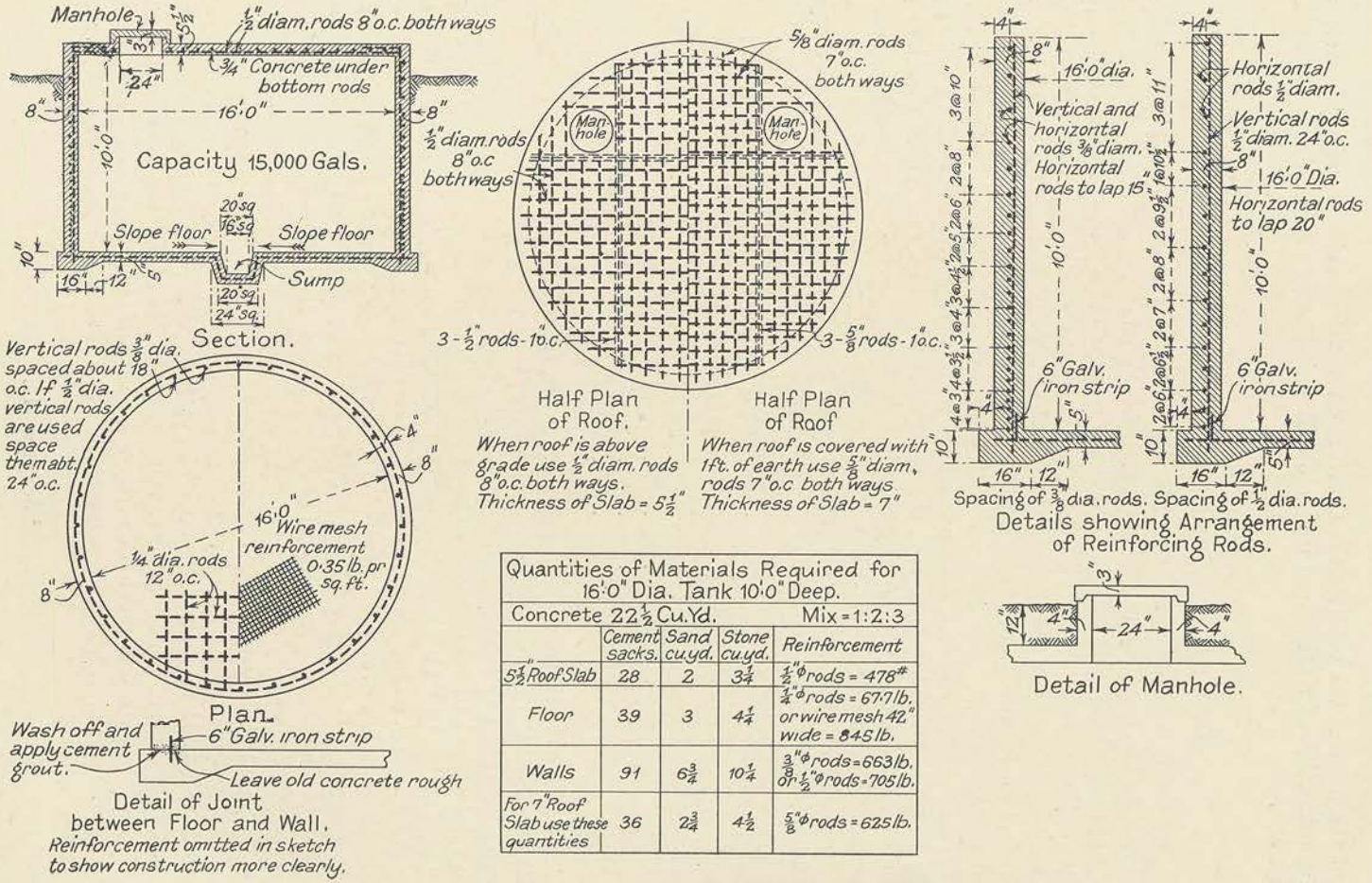
Effect of Stripping Carburetted Water Gas

Crude spirit obtained consists of—Benzol, 35 per cent.
Toluol, 25 per cent.
Solvent naphtha, 10 per cent.
Heavy naphtha and wash oil, 30 per cent.
Crude spirit recovered amounts to 10 per cent. of oil used for enrichment.
Loss of candle power due to scrubbing = 50·8 per cent.
„ „ calorific power „ „ = 4·2 „ „

THE STORAGE OF OIL

On gasworks in this country enriching oil is nearly always stored in cylindrical steel tanks. Recently, however, reinforced concrete has been employed in the construction of storage vessels for all types of oil, and has given every satisfaction. The main problem is that of rendering the concrete impervious to oil, and this condition is met by treating the surface of the tank with a paint-like coating which ensures

[1] *Chem. and Metallurgical Eng.*, April 7, 1920.
[2] *American Gas Inst. News*, Dec., 1917.



Quantities of Materials Required for 16'0" Dia. Tank 10'0" Deep.				
Concrete 22½ Cu. Yd.				Mix = 1:2:3
	Cement sacks.	Sand cu. yd.	Stone cu. yd.	Reinforcement
5½" Roof Slab	28	2	3¼	½" ϕ rods = 478#
Floor	39	3	4¼	¼" ϕ rods = 67.7 lb. or wire mesh 42" wide = 84.5 lb.
Walls	91	6¾	10¼	⅜" ϕ rods = 663 lb. or ½" ϕ rods = 705 lb.
For 7" Roof Slab use these quantities	36	2¾	4½	⅝" ϕ rods = 625 lb.

FIG. 452.—REINFORCED CONCRETE OIL TANK.

that the pores of the concrete are closed and a resistant skin formed. The details of construction of a reinforced concrete tank suitable for oil storage are shown in Fig. 452.

MATERIALS REQUIRED FOR MANUFACTURE

With different installations and in different localities a good deal of variation is found in the quantity of materials used in the manufacture of water gas. The coke consumed varies largely in accordance with its quality and physical condition, and whether or not it is carried (by telpher or other means) direct to the generators in an incandescent state or is charged cold. The type of plant, ratio of "run" to "blow," etc., also have their effect. Oil, of course, may be varied in quantity at will, and merely depends upon the quality of gas it is desired to produce. Steam, again, is dependent largely upon the steps which are taken to ensure as thorough decomposition as possible. That is to say, the consumption will be reduced in those cases where the steam flow is gradually curtailed during the "run" in accordance with the temperature of the fuel-bed.[1]

In general, the following figures may be taken as conforming with average practice:—

Coke (generator only)	35 to 45 lb.	per 1,000 cubic feet of gas.
Oil (for 18 candle-power gas)	2¼ to 2½ gallons	„ „ „
„ (for 10 „ „)	1½ to 1¾ „	„ „ „
Steam (if flow is constant)	32 to 35 lb.	„ „ „
„ (if flow is controlled)	28 to 32 lb.	„ „ „
Air (for "blow")	2,000 to 2,500 cu. ft.	„ „ „
Fuel for steam raising	12 to 17 lb.	„ „ „

A figure of 35 lb. for coke consumption is probably the most favourable obtained with plants of the Lowe type, but some reduction on this may be expected in those cases where the pan coke is extracted from the generator refuse and deducted from the total weight of coke shot into the generator. Plants designed essentially for the production of "blue" gas are generally able to economize in the direction of fuel, and figures so low as 25 lb. of coke per 1,000 cubic feet have been claimed. As an average, however, the quantity will vary between 32 and 36 lb. These figures as in the case of those given for carburetting plants, are exclusive of the fuel required in the boilers for steam raising. The steam-raising plant will, with the mixture of breeze and coke usually employed on gasworks, require an additional 12 to 17 lb. of fuel per 1,000 cubic feet of gas made.

The cost of manufacture of water gas must depend largely upon the current market values of the raw products, coke and oil, the latter accounting for from 50 to 65 per cent. of the whole. For this reason it will be seen that the manufacture of "blue" gas is a very much less costly undertaking than is the case with a carburetted gas. In general, the following statement shows how matters stood prior to 1914:—

[1] *See* page 717.

18 Candle-power Carburetted Gas (Pre-war Cost)

Coke for generators		4*d.* per 1,000 cubic feet of gas.
Coke for steam raising		1½*d.* „ „ „
Oil, 2¼ gallons at 4*d.*		9*d.* „ „ „
Wages		1½*d.* „ „ „
Wear and Tear		1*d.* „ „ „
		1*s.* 5*d.* „ „ „
Less Residuals—		
Tar	0·6*d.*	
Pan coke	0·07*d.*	
Sulphur	0·03*d.*	
	——0·7*d.*	

Net cost 1*s.* 4·3*d.* per 1,000 cubic feet.

The above represented the case for a medium-sized plant. It will, of course, be quite evident that as the size of the unit increases so do the various individual items undergo reduction, for the gas-producing capacity of the attendant and general working efficiency are enhanced *pro rata*. The above example illustrates in a marked degree the influence of the current value of oil on the cost of the gas. At one time oil could be obtained for somewhat less than 2*d.* per gallon, but the extent to which it is likely to fluctuate is emphasized by the fact that during the European War large consumers were obliged to pay 1*s.* 6*d.* As regards capital cost, much again depends on the size of the installation ; but in pre-war times the cost of a complete plant of the Lowe type, including housing, boilers, exhausters, purifiers, relief holder, etc., lay between £20 and £25 per 1,000 cubic feet of capacity. The approximate present-day cost of the various portions of the apparatus is exemplified in the instance given in Chapter I.

Cost of Manufacture of "Blue" Water Gas (Present Day)

	Per 1,000 cubic feet.
Coke, for generator[1]	9·0*d.*
Coke, for steam	3·0*d.*
Water, for steam	0·125*d.*
Wages	3·50*d.*
Maintenance	2·50*d.*
Purification	0·45*d.*
Establishment charges	1·00*d.*
Total	19·575*d.*
Cost per therm	6·5*d.*

From the above it will be noted that the present-day cost of "blue" water gas is considerably greater than the pre-war cost of 18 candle-power carburetted water gas. As a contrast it may be pointed out that with coal at 45*s.* per ton the present-day cost of manufacturing coal gas of 480–500 B.Th.U. per cubic foot calorific power is, after deducting the revenue obtained from residuals, approximately 2*s.* per 1,000

[1] The ultimate cost depends very largely on the coke market.

cubic feet, or 5*d.* per therm. The above figures apply, of course, to the larger gas undertakings.

THE COMPOSITION OF WATER GAS

With the exception of the diluents nitrogen and carbon dioxide, straight or "blue" water gas consists almost solely of hydrogen and carbon monoxide. A small percentage of methane is usually, but not necessarily, present. The final composition of carburetted water gas necessarily depends to a large extent upon the proportion of oil used in its manufacture. Under any circumstances, the constituents differ to some considerable extent from those of coal gas. As regards hydrocarbons, those of the unsaturated variety absorbed by bromine will be present to the extent of about 10 per cent. in a gas of 18 candle-power. The same quality gas will also contain about 13 per cent. of paraffins, the greater portion of which will consist of methane. The unsaturated hydrocarbons, with present-day heats, consist largely of the benzene series.

As regards the mixture of coal gas and carburetted water gas as supplied prior to 1914, with the usual proportion of carburetted gas, that is from 25 to 30 per cent. by volume, having an illuminating power of from 17 to 18 candles, and admixed with coal gas of from 13 to 13½ candles, the composition of the mixture approached the following :—

Composition of Mixed Gas, about 14½ Candle-Power

Hydrogen	44·0	per cent. by volume.
Methane	22·0	„ „
Unsaturated hydrocarbons	5·8	„ „
Carbon monoxide	16·5	„ „
Carbon dioxide	3·5	„ „
Nitrogen	8·0	„ „
Oxygen	0·2	„ „

To-day the high-grade carburetted gas has been displaced by "blue" water gas or a semi-carburetted in the manufacture of which from 0·75 to 1 gallon of oil per 1,000 cubic feet is employed. In the case of a mixture consisting of 70 to 75 per cent. coal gas and 25 to 30 per cent. semi-carburetted gas the mixture as distributed will approximate to the following composition[1] :—

Composition of Coal Gas and Semi-carburetted Water Gas

Hydrogen	45·8	per cent. by volume.
Methane	21·5	„ „
Unsaturated hydrocarbons	3·0	„ „
Carbon monoxide	18·0	„ „
Carbon dioxide	3·0	„ „
Nitrogen	8·5	„ „
Oxygen	0·2	„ „
Candle-power	10	(approximately)
Calorific power (calculated)	495	B.Th.U. per cubic foot, gross.

[1] The composition of mixtures of coal gas and "blue" gas is given in Chap. XII, p. 421.

When used for the purpose of enriching a coal gas of low quality, carburetted water gas appears to possess the property of enhancing the illuminating power of the mixture to a greater extent than is shown by theoretical reckoning. For instance, if 75 per cent. of the mixture consists of coal gas of 13 candles and 25 per cent. is made up from water gas of 18 candles, the final candle-power obtained should, by computation, be 14·25. In practice, however, the actual candle-power of the mixture will be in the neighbourhood of 15 candles, thus showing the additional enriching effect obtained. The explanation, no doubt, is one of flame temperature, water gas burning with a smaller flame than coal gas ; and, when admixed with the latter, the carbon particles of the coal gas are raised to a higher degree of luminosity than when the coal gas is burned by itself.

The impurities in water gas consist of sulphuretted hydrogen and carbon disulphide. The gas is generally free from ammonia, but occasional traces of this may be found. The proportions in which the impurities are present are approximately as follows :—

Sulphuretted hydrogen	110 to 120 grains per 100 cubic feet, or about 0·2 per cent. by volume.
Carbon disulphide and other sulphur compounds .	10 to 15 grains per 100 cubic feet.

Recently, there has been some question as to the presence of sulphur dioxide in " blue " water gas, but little definite knowledge of its existence is as yet available. That it should be present in quantities greater than a small trace is unlikely owing to the fact that it is soluble in water and should, therefore, be readily absorbed in the scrubbers. In purified " blue " gas the author has not succeeded in tracing sulphur dioxide.

The specific gravity of water gas is higher than that of coal gas, the gravity of the carburetted gas being in the neighbourhood of 0·65 as against an average figure of 0·47 for coal gas.

The manner in which the specific gravity of water gas increases with the candle-power is shown by the following results obtained by F. H. Shelton :—

Candle-Power.	Specific Gravity (Air = 1).
19·5	0·571
20·0	0·630
22·5	0·589
24·0	0·60 to 0·67
25·4	0·64
26·3	0·602
28·3	0·70
29·6	0·65
30 to 31·9	0·65 to 0·71

COMPOSITION OF VARIOUS GASES

	Coal Gas.	Carburetted Water Gas.	"Blue" Water Gas.	Mond Gas.	Suction Gas.	Dowson Gas.
	Per cent.	Per cent.				
Hydrogen	47	35·0	52·0	26·0	16·0	20·0
Carbon monoxide	7·75	32·0	38·0	15·0	34·0	24·0
Carbon dioxide	3·5	4·5	4·5	12·0	3·0	6·0
Methane	27·5	13·0	1·0	3·0	nil	1·0
Heavy hydrocarbons (CnHm).	3·5	10·0	nil	nil	nil	nil
Nitrogen	10·5	5·3	4·3	44·0	47·0	49·0
Oxygen	0·25	0·2	0·2	—	—	—
Candle-power	13·5	18	nil	nil	nil	nil
Calorific power gross. B.Th.U. per cubic foot	520	580	300	165	160	155

WATER-GAS TAR

The quantity of tar thrown down during the scrubbing and condensation of carburetted water gas will amount to from 12 to 16 gallons per 100 gallons of oil gasified. This tar is, unfortunately, a frequent source of trouble in two directions. First, the lighter tarry vesicles which are difficult to remove from the gas in the preliminary stages remain suspended therein and are eventually extracted as the gas passes through the oxide purifiers. The tar, being deposited on the oxide, not only reduces its activity and gives rise to excessive back-pressure, but it renders the spent material of little commercial value. Many mechanical devices have been employed with a view to removing the suspended particles of tar before the gas arrives at the dry purification plant. One of these is the "Hurricane" trap shown in Fig. 453, which is fitted in a vertical main where the flow of gas is downwards. The apparatus consists of a cone, A, having its apex against the flow of gas and its base formed into a ring plate, B, about 6 inches in depth. An annular space is formed around the ring plate by fixing a second ring, C, mounted on a foundation plate, D, the other end of which, E, forms another ring. A second cone, F, is suspended below the upper one, the diameter of this cone being some 3 inches less than that of the main. The gas to be treated is obliged to pass through the narrow annular space, where it is

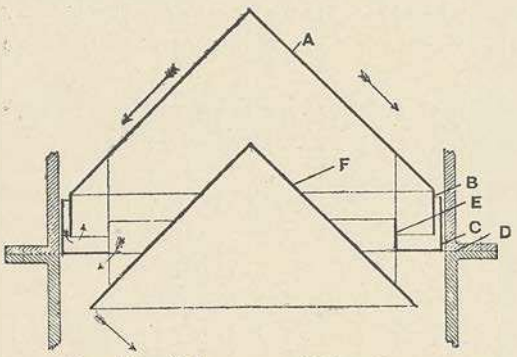


FIG. 453.—"HURRICANE" TAR EXTRACTOR.

wire-drawn, the vesicles being made to agglomerate and form a rain. The gas is then deflected upwards on to the underside of the top cone, which again deflects it downwards on to the top of the lower cone. This lower cone receives the deposit of tar rain, which trickles from the edges and runs away to the seal.

There is no doubt that wire-drawing, if effectively carried out, can be used successfully for the removal of tarry vesicles. It would appear, however, that the principle of bubbling as embodied in washers of the Livesey type is difficult to improve upon. A washer of this description (into which a small stream of liquor from the water gas scrubber is constantly permitted to run), fitted prior to the carburetted water-gas purifiers, will usually eliminate almost the whole of the suspended particles in the gas. It must not be forgotten, moreover, that efficient condensation is an important item in this respect, and if the gas is permitted to leave the condensers at an abnormally high temperature, trouble must be expected.

In the second direction water-gas tar is in many cases an annoyance in that, being of practically the same specific gravity as water, it admixes with the latter and forms an emulsion of a very permanent character. The consequence is that the tar as made ready for sale may contain so much as 40 per cent. of water. Various means, including centrifugal treatment, heating, etc., have been experimented with for the purpose of effecting separation, but the matter still remains something of a problem.

The main characteristics of water-gas tar are low specific gravity of the tar itself and the creosote obtained from it, low proportion of free carbon, and practical absence of naphthalene and phenols. Also in all fractions a large amount of paraffin bodies are found.

On fractionation an average sample ot carburetted water-gas tar shows the following result :—

Distillates from Water-Gas Tar

	Yield per 1,000 gallons of tar.
Water	35·0 gallons.
Benzol, 90 per cent. at 100° C.	0·75 ,,
Toluol, 90 ,, ,, 120° C.	13·5 ,,
Naphtha, 90 ,, ,, 160° C.	28·0 ,,
Heavy naphtha, 90 ,, ,, 190° C.	14·5 ,,
Creosote	539·0 ,,
Pitch (sp. gr. 1·199)	1 ton 18 cwt.
Loss	about 12 gallons.

The proportion of benzene to toluene varies considerably and is mainly dependent upon the temperature at which the carburettor and superheater are operated, also upon the point at which the tar is collected. W. Kirby, for instance, shows by the following analysis that while the yield of benzol and toluol together is practically identical with the sum of the two in the above figures, the proportion of benzol is very much higher.

WATER-GAS TAR (sp. gr. 1·055)

Free carbon, 0·2 per cent.

	Yield per 1,000 gallons of tar.
Water	40 gallons.
Benzol	5 ,,
Toluol	10 ,,
Solvent naphtha	6 ,,
Heavy naphtha	65 ,,
Creosote	500 ,,
Naphthalene	trace
Tar acids	,,
Heavy oil	180 gallons.
Anthracene (40 per cent.)	trace
Pitch (medium)	1 ton 6 cwt.

WATER GAS FROM COAL

As enrichment by means of oil is likely to drop out entirely in future gasworks practice, it is possible that a solution of the enrichment problem may be found in the utilization of the hydrocarbons evolved from coal. In other words, some means may be found for employing a coal and coke mixture in existing water-gas plant, so that the gas produced and used as a combustible diluent would have a calorific power of some 400 B.Th.U. per cubic foot, as against 300 B.Th.U. given by "blue" gas, and 430 B.Th.U. as found with the semi-carburetted gas which is generally made to-day. The primary objection to the use of coal in the water-gas plant of ordinary construction is the loss of the greater proportion of the secondary by-products, tar and ammonia, which are recovered when the coal is treated in the retort. Again, during the "blow" a serious loss of valuable hydrocarbons is involved.

Anthracite coal is used very largely in America for water-gas production, but many difficulties arise when coals of the bituminous type are employed. That soft coals can be utilized for the purpose, however, has been shown by American experience, as an instance of which the two following examples may be quoted. At Danville (Ill.) a coal containing 34·5 per cent. of volatile matter has been used with success, while the same type of coal has been employed by the Union Gas and Electric Company of Bloomington (Ill.) and gave little trouble from the beginning. An exact comparison between conditions in that town and those in this country at the present time cannot, perhaps, be made, for the Bloomington undertaking is compelled to supply gas with a calorific power of 565 B.Th.U. Thus, in spite of using coal in lieu of coke, it was still found necessary to carburate with oil. The main consideration, however, is that when the change from coke to coal was effected a considerable reduction in the quantity of oil used was found to be possible without any drop in gas quality. In this instance, in fact, the uncarburetted gas had a calorific power of 355 B.Th.U. per cubic foot.

The question of employing coal for water-gas manufacture has been very fully considered by the United States Bureau of Mines, while a special study of the matter has been made by R. B. Harper, of the Chicago gas undertaking. The main points which have been established are that when coal is used there is very much more

difficulty in the way of clinkering and ash removal, while the gas-producing capacity of the plant is reduced by at least 5 per cent. As before mentioned, the liberation of a considerable amount of volatile matter from the coal is objectionable, for during the period of the " blow " this appears at the open stack-valve as smoke ; moreover, the increase in calorific power of the producer gas tends to result in overheating of and damage to the chequer brickwork of the carburettor and superheater. As would be expected, too, the free space for gas passage in the generator fuel is constantly fluctuating owing to the tendency of bituminous coals to form channels in the fuel-bed, an effect which is contributed to by the caked condition which the fuel assumes. It has to be remembered, of course, that the depth of fuel employed is primarily a function of its density, so that whereas a 7 ft. bed is used with coke as the fuel, with coal the depth will only be some four feet. The shallower bed is essential, in fact, to permit of the passage of the primary air from the blast. American experience tends to show that the quantity of steam used per 1,000 cubic feet of gas made is very much more with coal than with coke ; a natural disadvantage, too, is that the crude gas from coal gasification contains considerably more sulphuretted hydrogen than does ordinary "blue" water gas. Thus purification costs are increased. However, in spite of the rather formidable list of disadvantages enumerated above, it is still found practicable to employ coal ; and, as oil is unlikely to return to its pre-war price, there is no reason why an effort should not be made in this country, not necessarily to utilize coal alone, but to ascertain the effect and practicability of employing a coal and coke mixture.

As a matter of fact, the American investigations in connection with the utilization of bituminous coal suggest that the only practicable way of producing a high quality uncarburetted gas is by means of some form of plant in which the volatile constituents of the coal are first removed, and the fixed residue is then subjected to gasification with steam. This, of course, merely brings one back again to the principle of complete gasification which, so long as a mixed town's gas is provided, appears to be a scientific solution of the problem. Complete gasification, however, possesses the disadvantage that it cannot be reasonably conducted in water-gas plant of existing design, and thus the question of capital expenditure is immediately opened up. On the other hand, the expenditure should be by no means excessive, for existing blowers, steam plant, relief holders and purifiers could all be made use of, and the only new portion of plant to be introduced would be the special gas generators.

EXHAUST STEAM FOR WATER-GAS MANUFACTURE

The substitution of exhaust steam for the live steam more commonly employed for water-gas production has been experimented with for a number of years. In the early experiments the wet steam taken direct from engine exhausts was used, the entrained moisture giving rise to a great deal of trouble.

Various methods for removing the free water were tried, including very extensive trapping systems and separators of all styles. While most of the free water was removed in this way the water in suspension still remained, due to the steam being saturated at a comparatively low temperature.

A certain amount of success has more recently been achieved by the introduction of means for superheating the steam, the rougher grades of coke and breeze usually being employed for firing the superheater. In practice it is found that the most effective results are obtained if the steam is raised to a temperature of about 230° C.

The method has been operated on a fairly large scale at Chicago, where all the exhaust steam from the engines, turbines, pumps, etc., was gathered into one common header which led into the inlet of the superheater, the size of the inlet pipe in this case being 20 inches. At two points, preferably some distance from the superheater, 18-inch back-pressure atmospheric valves were installed, with exhaust heads leading to the air. They were kept away from the superheater to avoid unnecessary fluctuations in pressure near the latter, because the auxiliary live steam admission valve was very sensitive to any sudden changes in pressure. The back-pressure valves were usually set at about 3½ lb.

Each superheater was capable of superheating 33,000 lb. of steam per hour to a temperature of 240° C., at 5 lb. maximum pressure. They were made of any desired capacity, and with grates for solid fuel or with tar burners. The latter type of firing seemed to be the most economical.

The following figures give a comparison between the actual results obtained when using live steam and superheated exhaust steam.

Live and Exhaust Steam. Comparative Figures

	Live Steam.	Superheated Exhaust.
Total gas made per 24 hours on 4 12-foot machines, cubic feet	10,954,000	11,807,000
Pounds of carbon per thousand cubic feet of gas	28·37	27·09
Boiler fuel per thousand, including superheater fuel	13·56	9·67
Total water used in boilers, pounds per thousand	97·5	70·0

The tests show that the steam used per thousand cubic feet of gas made is reduced by from 25 to 35 per cent., or approximately the whole of the live steam necessary for gas making is saved.

H. E. Smith [1] points out that in the usual intermittent water-gas plant the fan is kept running continuously during both "blow" and "run." Moreover, the quantity of exhaust steam from turbo-blowers is frequently in excess of the amount required for gasmaking. He proposes, therefore, to bring all available exhaust steam to a collecting main and to utilize it for gasmaking, the pressure in the collecting main being controlled by an adjustable relief valve. A liquid seal is provided between the collecting main and the inlet valves of the generators, so that the steam pressure may be readily adjusted by the depth of liquid in the seal pot, any excess of steam

[1] B.P. 23052/14.

escaping through the seal. In the event of the amount of exhaust steam being insufficient to maintain the gasmaking requirements of the plant, a supplementary supply is taken from the boilers.

THE RECOVERY OF WASTE HEAT

The thermal losses which occur on water-gas plants have assumed very much more importance lately owing to the fact that, as the use of oil has been greatly curtailed or discontinued altogether, the hot products and combustible gases leaving the generator during the " blow " have practically no function to perform. It will be readily appreciated that in the "blue" water-gas plant the sensible heat of the waste gases and the carbon monoxide they contain are lost. In order that this waste heat may be turned to useful account, suitably designed boilers have been attached at the outlet of the generator. These boilers have for some time been extensively employed in America, and have recently been installed in this country with considerable success. The majority of water-gas plants in operation in this country are of the Lowe type fitted with carburettor and superheater, in which case the boiler (of the vertical multitubular type with separate steam drum) is placed immediately following the superheater. All combustibles remaining in the "blow" gases are burnt, by the admission of secondary air, during the "blow," and the heat evolved, together with the sensible heat in the "blow" products, is sufficient to raise all the steam required for gasmaking in addition to a surplus which may be employed for driving part of the auxiliary machinery. When a Lowe-type plant is being employed for making "blue" gas, the latter is also taken through the boiler, so that the sensible heat of the "blue" gas gives rise to an additional quantity of steam. In fact, under efficient conditions a "blue" gas plant may be made practically "self-steaming."

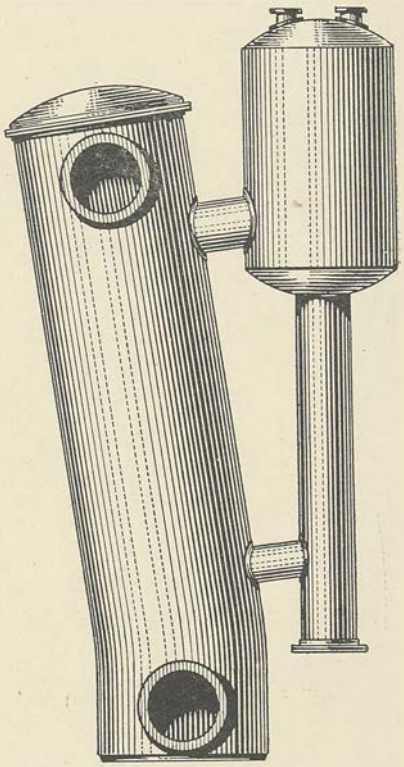


FIG. 454.—WASTE-HEAT BOILER FOR WATER-GAS PLANT.

The Humphreys and Glasgow waste-heat boiler (Fig. 454) consists of a slightly inclined cylinder provided with gas chambers at top and bottom. The middle portion of the cylinder forms the water chamber, from top to bottom of which run 3-inch tubes about 200 in number. The water circulates around the tubes, the "blow" gases passing through them. The steam drum is connected to the multitubular boiler by means of two branches. Steam is usually raised at a pressure of

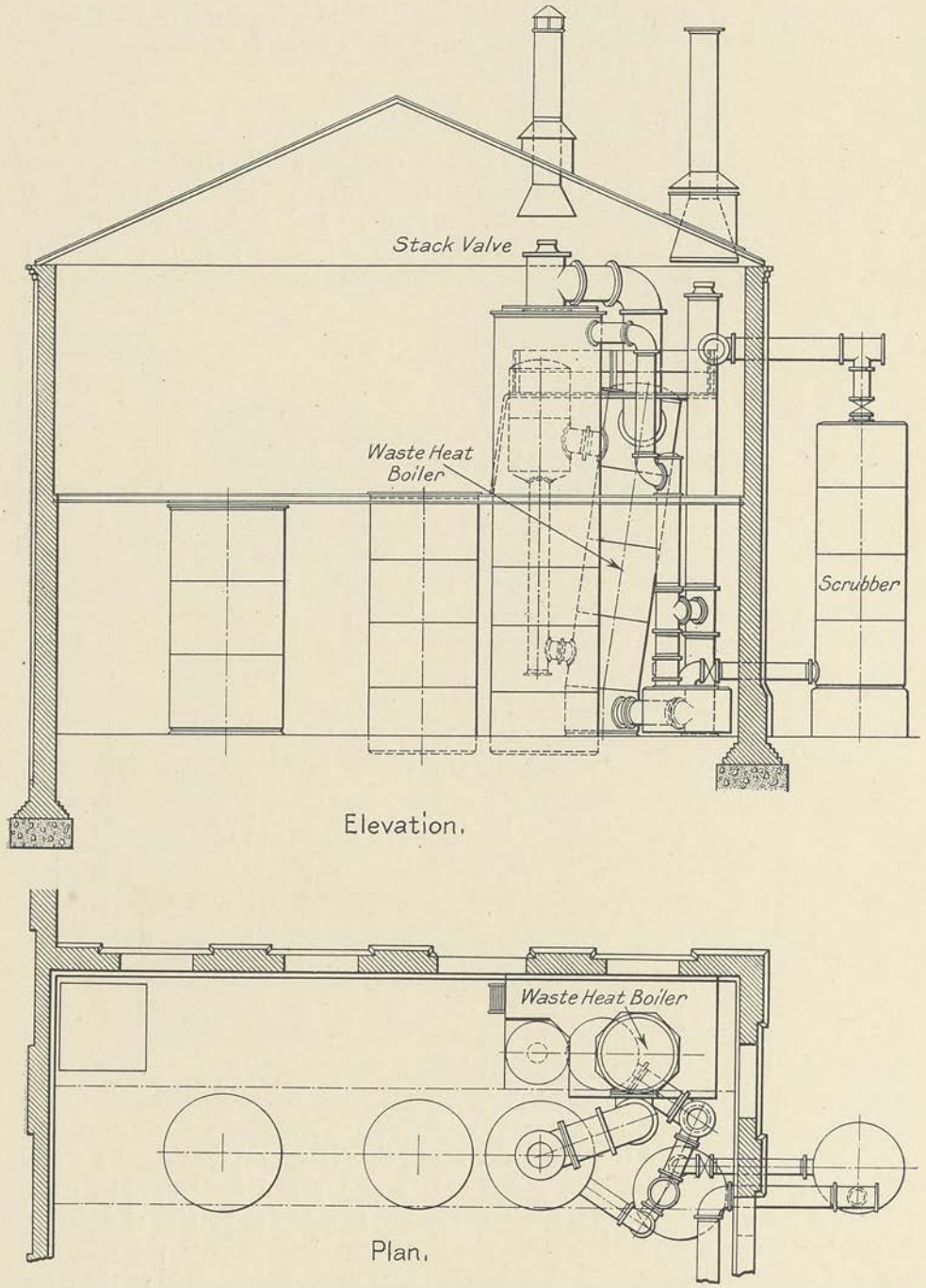


FIG. 455.—DIAGRAM SHOWING WASTE-HEAT BOILER FITTED TO CARBURETTED WATER-GAS PLANT.

100 lb. per square inch, the temperature of the "blow" gases at the base of the boiler being approximately 980° C. (1,800° F.). After contact with the water tubes the temperature of the gases is reduced to between 200° and 260° C. In comparison with boilers of the usual type it should be remembered that a waste-heat boiler is entirely self-contained and requires no brickwork setting, flues, or chimney. The manner in which the boiler is connected up to the ordinary Lowe-type plant is shown in Fig. 455.

BLAU GAS

Blau gas, it should be noted, has no connection with "blue" gas with which it is often confused. Blau gas is the invention of Hermann Blau, a German chemist, and is really a compressed oil gas. Gas oil is led into retorts and is vaporized and cracked at temperatures between 550° and 600° C. The comparatively low temperature is employed in order to prevent the production of a large proportion of permanent gas. The gas obtained is cooled and purified in the usual manner, and is taken directly from the holder into a compressor, where the hydrocarbons not desired in the final process are liquefied by compression. The remaining gas is compressed up to 100 atmospheres, the final product consisting of liquefied hydrocarbons in which permanent hydrocarbons are dissolved. The mixture, in fact, remains liquid under pressure, and is conducted into steel bottles for transportation. When the pressure is reduced to that of the atmosphere the hydrocarbons immediately volatilize. The gas has a calorific value of about 1,800 B.Th.U. per cubic foot, and is mainly employed in districts (in America and Germany) where there is no town gas supply. The illuminating power of the gas is 80 candles per foot.

THERMAL EFFICIENCY OF A WATER-GAS PLANT

By means of a series of experiments carried out in America, A. G. Glasgow has calculated the efficiency [1] of a carburetted water-gas plant. The plant, however, was operated with anthracite, and not coke, and it was first necessary to ascertain the weights, temperatures, composition, etc., of the raw materials and finished products. With regard to some of the data obtained, the following list of temperatures will prove interesting to all producers of water gas:—

Gas issuing from superheater	788°	C.	1,450°	F.
Blast gases issuing from superheater	843°	„	1,550°	„
Oil leaving preheater	113°	„	235°	„
Blast entering generator	24°	„	76°	„
Steam „ „	166°	„	331°	„
Ash, etc., withdrawn from generator	849°	„	1,560°	„

The heat absorbed by the apparatus is represented, on a basis of 1,000 cubic feet of the carburetted gas, first by the amount of fuel fed into the generator. This was found to be 23·5 lb. per 1,000 cubic feet, after deducting unconsumed anthracite found with the ash. Secondly, there is the total heat entering with the steam;

[1] For thermal efficiency of various gasmaking processes, *see* Chap. XXI, p. 759.

and, thirdly, the sensible heat entering with the blast. The various sources in which this heat is dispersed are shown in the following table :—

DISTRIBUTION OF ENERGY PER 1,000 CUBIC FEET

	B.Th.U.	Equivalent in Pounds of Carbon.
A, heat of combustion of carbon	340,750	23·5
B, total heat in entering steam	18,359	1·266
C, sensible heat in entering blast	715	·049
Total heat above 60° F. fed into apparatus on fuel account	359,824	24·815
D, energy of CO in water gas	90,591	6·248
E, energy of H_2 in water gas	108,908	7·511
F, sensible heat in escaping illuminating gas, vapours, etc.	35,583	2·454
G, sensible heat in escaping blast products	70,838	4·885
H, heat lost by radiation from shells	12,454	·859
J, heat carried away from shells by convection	15,696	1·083
K, heat rendered latent in gasification of oil	21,393	1·475
L, sensible heat in ash and unconsumed coal recovered	3,712	·256
Total energy accounted for	359,175	24·771
Unaccounted for (·18 per cent.)	649	·044

The final profit and loss account is, therefore, as follows :—

	B.Th.U.	Lb.
Energy utilized	220,892	15·234
„ wasted	138,283	9·537
„ unaccounted for	649	0·044
Total	359,824	24·815

Assuming the unaccounted-for energy to be wasted, this leaves a heat efficiency of 61·4 per cent.

If the oil fed into the plant is taken into consideration as a further source of heat the result will be somewhat modified. In Glasgow's experiments 5 gallons of crude petroleum were admitted per 1,000 cubic feet of gas. The oil had a calorific power of approximately 18,500 B.Th.U. per lb., and 5 gallons weighed 35 lb. Therefore :—

Heat entering with oil $= 35 \times 18{,}500 = 647{,}500$ B.Th.U. Adding this to the above, the total energy supplied

$= 359{,}824 + 647{,}500 = 1{,}007{,}324$ B.Th.U. per 1,000 cubic feet of gas

The calorific power of the gas was found to be 720·987 B.Th.U. per cubic foot, and the quantity of tar recovered was 5 lb., its calorific value being assumed the same as that of the petroleum. Therefore the heat recovered was :—

1,000 cubic feet of gas × 720·987 =	. . .	720,987 B.Th.U.
5 lb. of tar × 18,500 =	. . .	92,500 „
Total	. . .	813,487 „

On this basis, the heat efficiency arrived at is equivalent to 80·76 per cent.

MODIFICATIONS OF WATER-GAS PLANT

During recent years various modifications of water-gas plant have been introduced with the result that in some cases apparatus of a novel character is to be found. The main development has been in the direction of the complete gasification of coal, which is fully discussed in the next chapter.

Mention may be made here of the carburetted hydrogen or " Methane-Hydrogen " plant, which produces a semi-water gas enriched by means of coal tar.

Methane-hydrogen gas differs from ordinary water gas in many respects. It burns with a decided yellow, instead of a blue, flame, this being due to the high percentage of methane present, whilst the proportion of CO shows some considerable reduction as compared with " blue " gas. The approximate composition of methane-hydrogen gas is as follows :—

Methane	19 per cent.
Carbon monoxide	29 „
Carbon dioxide	3 „
Hydrogen	42 „
Unsaturated hydrocarbons	1 „
Nitrogen	5·8 „
Oxygen	0·2 „

In the plant for the manufacture of this type of gas the depth of fuel in the generator is nearly double that in the ordinary carburetted water-gas generator, but the lower portion only is raised to incandescence by the air blast admitted to the base. About midway up the generator the products of the " blow " are removed through special ports, thus maintaining the upper portion of the fuel-bed at a moderate heat. During the " run " tar is injected as well as steam, the former being split up into carbon and methane. The carbon is filtered out by the cool upper portion of the bed, and gradually descends into the zone of combustion.

C. B. Tully[1] has introduced a process for the manufacture of a mixture of hydrogen and carbon monoxide. The plant consists of a fuel-bed shaft placed above a combustion chamber. Around the lower part of the shaft there is a chamber filled with iron ore, and around the upper part a chamber filled with chequer brick. The products resulting from the blasting up of the fuel-bed in the combustion chamber pass first through the iron ore, reducing it to a spongy condition, then

[1] B.P. 16932/15.

through the chequer work to the exit valve. When the proper temperatures have been attained the air blast is turned off and steam is turned on through the chequer brick and the iron chamber. The resulting hydrogen and remaining steam may be led directly away or be passed downward through the incandescent fuel and then led away. In the first case the undecomposed portion of the steam mixed with the hydrogen can be condensed out. In the second case the uncondensed portion of the steam mixed with the hydrogen will be decomposed on passing through the incandescent fuel into hydrogen and carbon monoxide, which will become mixed with the hydrogen produced in the iron chamber. In each case steam or liquid hydrocarbon or both may be injected directly into the mass of incandescent fuel independently of the steam admitted to the iron chamber, and be mixed with hydrogen produced in that chamber in order to vary the constituents of the resulting gas to suit requirements.

By admitting air to the bottom of the chequer-brick chamber carbon monoxide in the gases entering that chamber from the iron chamber can be burned to form carbon dioxide before being discharged into the atmosphere, and the resulting heat utilized to heat the chequer-brick chamber preparatory to passing steam to the iron chamber.

H. E. Smith [1] proposes to modify water-gas plant of the double generator type (*see* K. and A. plant) so as to produce a gas with variable proportions of hydrogen and carbon monoxide.

In many processes which depend upon catalytic action it is an advantage to have water gas with varying proportions of hydrogen and carbon monoxide. For instance, in the process for the purification of coal gas from sulphur compounds where the surfaces of the catalyzing agent are liable to be covered with deposits, the presence of water gas of suitable composition greatly prolongs the life of the material used.

The twin generator plant, blown in parallel and run in series, is adapted to produce a gas containing a high percentage of CO, by the installation of a separate fireclay-lined chamber arranged between the two twin generators and provided at the top with charging hopper and at the bottom with discharging hopper. This chamber is so arranged that the walls are heated by the products of combustion during the blowing period, and is also provided with a division wall so that the hot gas leaving the first generator passes up at one side and down at the other. The chamber is filled up with limestone of suitable quality, which, when heated to the necessary temperature and brought in contact with the hot water gas from the first generator, will evolve CO_2, which gas will join the hot water gas from the first generator and be reduced to CO in its passage through the second generator. In order that the necessary amount of contact may be secured, dampers may be provided in the division wall to short-circuit the stream of gas and vary the contact with the limestone as needed.

Where a high percentage of hydrogen is required and a low percentage of CO, the plant is operated in the ordinary manner for producing "blue" water gas, but a

[1] B.P. 116,582/17.

secondary jet of steam is admitted to the second generator, which, passing through the hot chequer brickwork, meets the rising stream of water gas and oxidizes a proportion of the CO into CO_2. By this means it is possible to reduce the CO contained to as low as 15 per cent.

The Rincker-Wolter Plant

The system known as the Rincker-Wolter has been working for some years at the Utrecht gasworks, and the plant seems to have proved itself an effective and economical adjunct to the coal-gas apparatus. Its chief dissimilarity from other plants lies in the fact that waste oil, however inferior, may be employed for carburetting purposes. Both coal-gas and water-gas tar have been used.

As can be seen from the diagrammatic sketch (Fig. 456), the plant consists

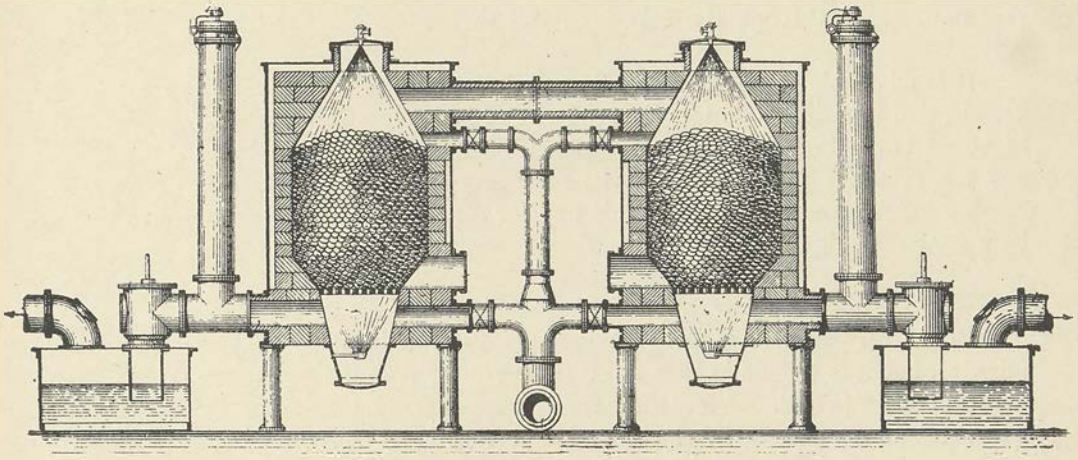


Fig. 456.—The "Rincker-Wolter" Water-Gas Plant.

of two identical generators, and no other vessels are used for the production and enrichment of the gas. The generators are lined throughout with firebricks, and the fuel sprays pass through the centre of the charging-door lids. In order to follow out the principle of the system, it is essential that the functions of the various connections on the generators should be understood. Near the top of each generator is a tube connecting the two shells, and by means of this the gas produced in one generator may pass to the other. In addition, both generators are fitted with primary and secondary air supplies from a central blast pipe. The primary air inlets are below the firebars, whereas the secondary air is admitted at a point on a level with the top of the fuel-bed. There is a gas outlet to each generator. These are below the firebars, and they split up into a two-way pipe, one branch of which leads to a stack-pipe, the other passing to a hydraulic main which connects the generator to the cooling and washing apparatus. Each generator is fitted with a steam supply, the steam being introduced beneath the fuel-bed in the usual way.

The apparatus is started in the same way as the ordinary water-gas plant;

that is, a wood fire is first kindled and the coke-bed is gradually built up on this. When the fires in both generators are thoroughly started, and the coke is on a level with the secondary air inlets, the air blast is admitted below the fuel in (say) the right-hand generator and above the fuel in the left-hand generator. For the sake of simplicity in describing the operations, it will be of advantage to designate the right-hand generator as No. 1, the left-hand being No. 2.

Before blowing is commenced, the stack-valve on No. 1 generator is, of course, shut, whereas that on No. 2 generator is opened. In this way, the direct air-blast raises to a certain extent the temperature of the fuel-bed in No. 1 generator, but, as combustion is incomplete, a stream of producer gas is passing through the top connecting tube into the second generator. This combustible gas then comes into contact with the secondary air blast, and its consequent combustion provides sufficient heat for raising the temperature of the fuel in this generator. The hot gases pass downwards through the coke-bed, and then away through the open stack-valve.

It is advisable to secure, as far as possible, nearly equal temperatures in both vessels, and in order to do this the sequence of generators is reversed after a period of about two minutes. Thus the primary blast is admitted to No. 2 generator, and the producer gas meets with the secondary air in the top of No. 1.

By heating the generators in this way for some time a temperature sufficiently high for gasmaking is obtained.

Cycle of Operations

In the Rincker-Wolter plant the gasmaking "run" usually lasts for about six minutes, but it is unique in that no steam is admitted to the generators during the first half of the period. Before the "run" is commenced, the various air valves and flue dampers are necessarily closed, and a passage is made for the gas by opening the valve at the outlet of the hydraulic main or "dipper." The generators are, of course, always operated in series for blowing, whilst gasmaking is carried on in each one alternately. Assuming that a "run" has just commenced in No. 1 generator, then the oil, or other carburetting agent employed, after passing through a meter, is sprayed on to the coke in this generator.

On coming into contact with the incandescent coke the oil is immediately gasified, and passes off through the bottom of the generator to the hydraulic main, where the tarry matter and particles of carbon are retained. At the expiration of about three minutes the oil is shut off and steam is blown through the same spray —partly for cleaning purposes—for a period of about seventy-five seconds. The No. 1 "dipper" valve is then closed, the corresponding valve on No. 2 being opened. Steam is then injected under the firebars of No. 1 generator for one minute, and the gas produced passes through the connecting pipe and second fuel-bed to the opposite hydraulic main. The steam is now shut off, and gives way to a blast of air, which is continued for a few seconds, and thoroughly scours the apparatus.

From the above description it may appear that a somewhat complicated series of operations are comprised in the "run." The cycle is, of course, more or less intricate

when compared with the water-gas systems in common use in this country. It will easily be grasped, however, by tabulating the working as follows :—

Oil sprayed in (say) No. 1 generator	3 minutes.
Steam blown through spray	75 seconds.
No. 1 "dipper" valve closed and No. 2 "dipper" opened.	
Steam admitted under firebars of No. 1	1 minute.
Air admitted to No. 1	about 10 seconds.
Total period of "run" about 6 minutes.	

After the completion of the above "run," the blowing cycle, as previously described, commences, and continues for about two minutes. The "run" is then resumed, but with the difference that the first generator in the preceding cycle now becomes second in the sequence. This alternate operation of the generators causes practically similar working conditions for both vessels as regards temperature and consumption of coke and oil.

THE INDUSTRIAL USES OF WATER GAS

In addition to being used as an auxiliary to coal gas, "blue" water gas has within recent years been applied, with very satisfactory results, to the welding of plates and heating of furnaces and forges. This method has proved of great practical advantage in welding tubes for gas, water and steam mains, for boiler work and also for melting steel. Tests conducted by the Admiralty show the strength of a "blue" gas weld to be equal to that of the plate. Having a very much higher calorific power than producer or suction gas, "blue" water gas may be used for driving gas-engines, the consumption being about 35 cubic feet per B.H.P. hour. The consumption of ordinary suction gas is about 80 cubic feet per B.H.P. hour. No water gas, however, is entirely satisfactory when used for power, for the large proportion of hydrogen prevents high compression in the cylinder of the engine.

By far the most important property of "blue" gas is its exceedingly high flame temperature. Dr. Roessler has found that by admixture with heated air a temperature considerably above the melting point of platinum may be easily obtained. Under general conditions, however, the temperature of the hottest part of the flame is about 1,500° to 1,600° C. It is owing to this property that "blue" gas is applicable to such processes as welding and forging, and for use in furnaces.

In all processes of the above kind there is no necessity to purify the gas from sulphuretted hydrogen—merely an ordinary water-scrubber is used. It is, in fact, an advantage to leave the gas unpurified, for it then has a distinct smell, and any escape may be quickly perceived. Thus one of the greatest drawbacks to "blue" gas—its freedom from smell—is more or less overcome. In Germany it has in some cases been thought advisable to impart a distinct odour to the gas, by passing it through a heavy hydrocarbon oil, such as mercaptan.

A process for which water gas may be employed, and one which will probably be largely developed in the future, is that of producing hydrogen.

Cement manufacturers are now making use of water gas, which is introduced

into the revolving kiln for the finishing-off process, and it is also finding its way into the brickmaking industry.

STEAM GENERATION ON GASWORKS

The large extent to which water-gas manufacture has been adopted in modern gasworks has placed gas authorities amongst the chief users of steam for manufacturing purposes. The importance of this section of the works equipment warrants a more detailed study than it is possible to include in the present work, and it is proposed only to consider broadly the more important factors which usually govern the selection, lay-out and operation of steam generating plant.

Selection

The principal factors which usually determine the type of boiler selected are unit evaporative capacity for a given floor space, where this is an important consideration ; but in a lay-out for a new works more importance would be attached to convenience of handling fuel and ash, arrangement of main flues, and provision for spare plant and extensions. Steam generating plant is usually designed and rated on the assumption that some kind of natural coal fuel will be the staple fuel used, and the influence of coke or breeze (which may be taken as the staple solid steam-raising fuel of the gasworks) on the steaming capacity of the boilers has to be borne in mind in making a selection.

Types of Generators

Broadly, there are in present use two types of boilers, each having their special features, namely, the water-tube or externally fired boiler, typified in the Babcock and Wilcox pattern, and the fire-tube or internally fired Cornish and Lancashire types. When capacity and limited floor space are the chief factors, the range of selection is limited to the various patterns of the former type, which have usually a ratio of heating surface to grate area of 50 or 60 to 1, as compared with about 25 to 1 available in the Lancashire type. For rapid steaming and quick response to sudden heavy demands, the water-tube boiler is now recognized as the more sensitive, but the greater steam and water reserve capacity of the Lancashire type boiler renders it the more suitable for the intermittent heavy pulls of the water-gas plant. To realize the advantages of both types a combination battery working in parallel has been found to be most effective in responding to the severest conditions imposed. In the matter of thermal efficiency there would appear to be little, if any, in favour of either type.

Grate Area

The economic rate of combustion of fuel and the area of the boiler fire-grates determine the normal evaporative capacity. With coke as fuel, 22 lb. to 25 lb. per square foot of grate area per hour represent the economic average maxima for hand-fired fixed grates. Higher rates may, of course, be attained, but only at the expense of efficiency. Probably 18 lb. to 20 lb. would represent the best normal working

rate for average coke or breeze. The limiting factor in grate area in the Lancashire type boiler is the length of grate which a man may efficiently stoke and clinker, usually 6 feet 6 inches to 7 feet 6 inches, measured from the furnace front. This factor limits the total effective area to 36 or 38 square feet in the larger capacity boilers of this type. Now, assuming evaporative values for coke and breeze respectively of 9 lb. and 5 lb. of steam per lb. of fuel, as fired, the steaming capacity at the various rates of firing indicated may be accurately arrived at. To the gas engineer, the relatively large proportion of grate area obtainable in the water-tube boiler is certainly an attractive feature, having in mind the characteristics of the staple fuel.

Draught

Except perhaps where an existing chimney shaft provides the necessary draught, some system of impelled draught may be "induced" or "forced," *i.e.*, by means of an exhaust fan located near and discharging into the chimney shaft; or a pressure

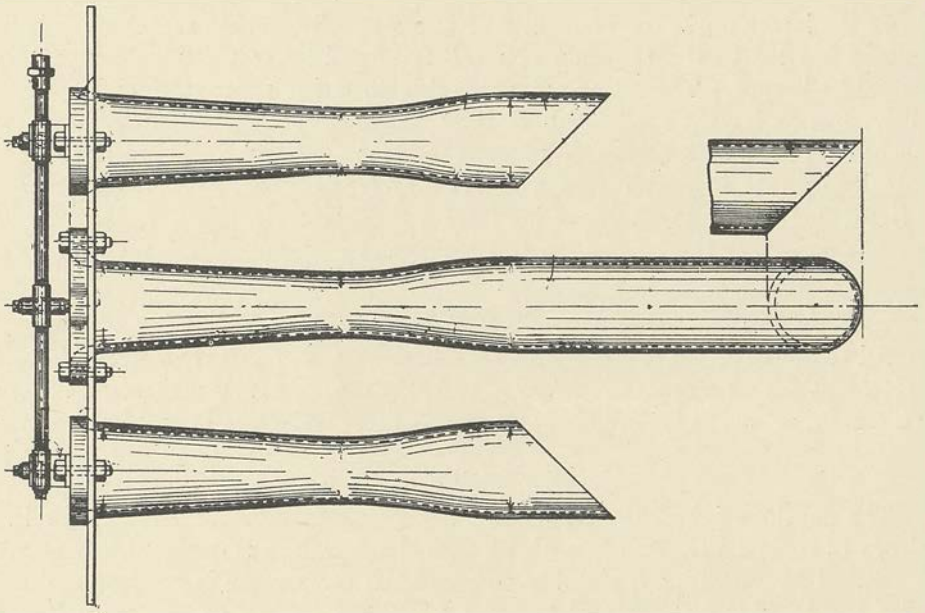


Fig. 457.—London Coke Committee's Apparatus for "Impelled" Draught.

fan applied to the under-side of the fire-grate. The induced system depends upon the maintenance of a partial vacuum over the fire, but possesses the disadvantage of increasing the cold air infiltration through the brickwork setting, etc., while it tends, by increasing the speed of the waste gases, to carry over and discharge at the chimney a portion of the grit and dust, which, with the "forced" system properly applied, remains on the grate or falls immediately beyond the bridge wall or first baffle. The various types of steam-jet forced draught furnaces, with one or more short chimney shafts of large area, are among the most favoured systems now adopted. The height to which the boiler shaft is carried, and consequently the cost of con-

struction, will be largely determined by the system of draught adopted, whether "natural," "induced," or "forced." The apparently beneficial effect of a limited supply of steam on the combustion of coke warrants due consideration of the steam-jet impelled system, applied either on the closed ash-pit or hollow firebar principle.

Various types of steam-jet forced draught furnaces, permitting a comparatively short chimney shaft to be used, have been employed in conjunction with coke and breeze burning for some years, but in many cases the alterations have been cumbersome and expensive. The blower introduced by the London Coke Committee may best be described as providing an "impelled" draught, which is admitted beneath the firebars by either two or three delivery pipes fashioned somewhat on the lines of a Venturi tube. The whole can be fitted to a coal-burning boiler in a few hours, and requires for its operation only two to three per cent. of the steam raised.

Mechanical Stoking

In the larger works the possibility of automatically stoking and cleaning boiler furnaces has led to the adoption of mechanical stokers of the travelling-grate or "sprinkler" type. The latter are applicable to either water-tube or Lancashire boilers, but so far the application of the travelling-grate of the "underfeed" or Babcock type has been limited to water-tube boilers of fairly high capacity. These generally operate in conjunction with some system of forced draught. Rates of 30 lb. of fuel per square foot per hour are said to be maintained, so that the full normal capacity of the boiler with this equipment may be realized with coke fuel.

Superheat

All steam engines are essentially heat engines, and the manufacture of water gas is essentially a heat process. Accordingly, the use of steam superheaters, either as an integral part of the boiler unit or separately fired, is the trend of modern practice.

Economizers, etc.

The development of the economizer has followed the recognition of the inefficiency of coal as a boiler fuel, with which fuel as much as 20 per cent. saving may be effected by installing a suitably proportioned economizer between a coal-fired boiler and its chimney shaft. The same would not, of course, apply in the case of coke-fired boilers, in which the heat of combustion appears to be largely transmitted to the water and steam inside by radiation, and consequently there is a smaller proportion of heat carried off in the waste gases. Moreover, as the proportion of excess air necessary for the complete combustion of coke is so much less than that required with coal, a relatively smaller volume of gas comes in contact with the economizer tubes. Reliable tests show that where an average increase of 108° F. in feed temperature was obtained with a coal-fired boiler fitted with an economizer of the ordinary type, an average increase of only 78° F. was maintained when the same boiler was working with coke fuel on a forced draught grate. For each 10° F. increase in feed temperature, a saving in fuel of about one per

cent. is effected. so that it would appear to be somewhat problematical whether the initial cost and maintenance of economizers would be justified when coke or breeze is used as the fuel.

It is well known that uncovered steam mains and unlagged boilers lose a large amount of heat by radiation, but few realize that an unprotected surface of a steam pipe of 1,000 square feet with steam at, say, 100 lb. per square inch involves a loss of something like 300 tons of coal per annum. Trials recently made in Pennsylvania with two similar locomotive type boilers of 80 and 60 h.p. have produced some interesting figures in this connection. The boilers had an exposed external surface of about 630 square feet. The tests continued for twenty-four hours. One boiler was unlagged and the exposed surfaces of the other were covered with a non-conducting composition (manganese cement) to a depth of about 2 in. During the first trial 5·39 lb. of water were evaporated per lb. of coal ; in the second, 6·35 lb. per lb., and, moreover, more water was evaporated for less coal fired. The figures proved that the lagging had resulted in a saving of 15 per cent. of fuel, although the boiler only had been so treated and the steam pipes were uncovered.

This proved economy represents throughout a working year of 300 days a saving of 37 tons of coal for each 100 square feet of protected surface.

Trials conducted in America to determine the effect of air leakages into the furnace and flues of boilers by cracks in brickwork indicated that the cooling effect brought about by the introduction of air in the flues in this manner is from 1·75 to 2·0 per cent., in terms of evaporative efficiency. A test upon a water-tube boiler showed that, while the excess of air in the furnace was 45 per cent., analysis showed an excess of air in the flue at the base of the chimney of 96 per cent. ; producing a loss of efficiency of 4·63 per cent. when burning about 22 lb. of coal per hour per square foot of grate surface.

CHAPTER XXI

THE COMPLETE GASIFICATION OF COAL.

When coal is treated in the ordinary manner in retorts the volatile matter is gasified, about 70 per cent. of the weight of the coal remaining behind in the fixed form as carbon and ash. In many cases the fixed residue is wholly or partly treated with steam for the production of a leaner gas (" blue " water gas) which is eventually admixed with the higher quality straight coal gas. Such a method involves two entirely distinct processes and two separate plants differing considerably in structural features. In the early days of water-gas production an attempt was made to combine in one plant the two separate processes. At that time, however, progress was rendered difficult owing to the universal institution of illuminating power standards, while mechanical and structural knowledge had not reached a stage of development sufficiently advanced to overcome practical defects. The recognition of calorific power, the official approval of the leaner types of gas, and the introduction of the therm basis of selling have, however, completely changed the situation, with the result that to-day the most efficient method of gas production must be regarded neither as that which yields the greatest number of cubic feet of gas per ton nor the system which yields the richest form of gas, but that which produces the cheapest British thermal unit. It has been recognized, though not definitely proved, that a British thermal unit, whatever company it keeps, will always yield a definite duty on combustion. In other words, a gas containing 500 B.Th.U. per cubic foot will, when consumed, do twice the work of a gas having a calorific power of 250 B.Th.U. per cubic foot. Degree of concentration of heat units, in fact, does not affect the proclivities of individual units. Comparison on such a basis is, of course, dependent upon the supposition that all gases, whatever their thermal concentration, are burned in such a manner that the whole of their potential heat energy is liberated.

By the complete gasification of coal is meant the treatment of the coal under such conditions that no solid residue other than ash remains. Complete gasification may, of course, be conducted in two distinct ways, namely, the treatment of the coal in two stages for the production firstly of straight coal gas and secondly of " blue " water gas in distinct plants, the two gases being subsequently mixed either in the crude or purified state. The alternative is to employ plant of special design in which the above two processes are carried out simultaneously. From the standpoint of gas production the two methods may be contrasted as follows :—

A. *Dual Process.*

1 ton of coal yields :—	B.Th.U.
13,000 cubic feet of straight coal gas at 520 B.Th.U. = and 11 cwt. surplus coke.	6,760,000
11 cwt. coke yields :—	
20,500 cubic feet of "blue" gas at 300 B.Th.U. =	6,150,000
Total yield in gaseous form from 1 ton of coal =	12,910.000

B. *Single Process.*

1 ton of coal yields :—	B.Th.U.
50,000 cubic feet of mixed gas at 370 B.Th.U. =	18,500,000

In the second case the author prefers to assume that on an average no more than 50,000 cubic feet of gas will be obtained per ton of coal, although some experimenters place the yield at 60,000 or even 70,000 cubic feet. In many cases a certain proportion of coke of a semi-burnt character is recovered when the single-stage plant is cleaned for the removal of ashes.

The composition of the two types of gases may be compared as follows :—

Composition of Complete Gas Mixtures

	Two-Stage Process.	Single-Stage Process.
Hydrogen	49·5 per cent.	51·0 per cent.
Carbon monoxide	27·0 ,,	30·0 ,,
Methane	10·5 ,,	8·0 ,,
C_nH_m	2·0 ,,	1·4 ,,
Carbon dioxide	4·0 ,,	4·6 ,,
Nitrogen	6·85 ,,	5·0 ,,
Oxygen	0·15 ,,	—
Yield per ton of coal (c. ft.)	33,500	50,000
Calculated calorific power (gross B.Th.U.)	385	370
Therms per ton of coal	129	185

It may be asked why coal, per unit of weight, should yield so much greater a number of gaseous thermal units when treated in the combined plant as compared with the two-stage process. The main reason is to be found in the fact that the fuel demanded for the production of gas is very much less in the combined plant than when two plants are brought into use. For instance, two-stage manufacture demands some 3 cwt. of coke for heating the coal gas retorts, the incandescent coke is pushed out of these retorts at the conclusion of the distillation period, it is quenched with the destruction of a large quantity of sensible heat, and it is then charged cold (and partly wet) into the water-gas generator where a considerable proportion of its own bulk is demanded for raising it again to the temperature at which it was discharged from the retorts. Obviously this is an uneconomical process,

but at the same time it must be borne in mind that the single-stage plant cannot be operated without some expenditure of fuel. The significant point is that an attempt is made (not, perhaps, wholly successful) to effect both operations, *i.e.*, carbonization and subsequent gasification, with the same quantity of heat as is commonly employed to gasify coke only in the ordinary water-gas plant. That is to say, the sensible heat and combustibles obtained in the blow gases are utilized for carbonization of the coal; accordingly, as compared with the two-stage process, the combined plant effects, theoretically, the saving of the fuel used in the retort bench producers. It is beginning to be realized, however, that to effect thorough carbonization of the coal before it enters the water-gas zone it is necessary to employ around the coal zone a portion of the "blue" gas produced in addition to the heat derived from the blow gases.

When it comes to a question of by-products, *i.e.* tar and ammonia, the complete gasification of coal in the combined plant does not compare favourably with the two-stage process. Certainly the single-stage process yields both of these products, but experience has shown that in order that the more valuable constituents of the mixed gas may be transformed into permanent vapours it is necessary to fix the gas by further heat treatment, and as a result of this procedure both ammonia and tar are partly destroyed.

Again, with the single-stage plant of ordinary construction it is usually necessary to confine the process to special coals the physical condition of which is such that carbonization and travel from coal-gas to water-gas zone may proceed without difficulty. Success, for instance, could scarcely be looked for with coal containing a high proportion of fines, and probably one of the most favoured varieties of gas coals, namely, Durham coals, would have to be screened before use.

COMPOSITION OF COMPLETE GAS

The analysis of complete gas which has been given on page 757 must be looked upon as a model or theoretical composition, the attainment of which in practice can scarcely be looked for with the process in its present stage of development. General experience has shown that, unless steps are taken to preclude it, an appreciable proportion of the unsaturated hydrocarbons will be deposited in the liquid state when the gas is cooled to atmospheric temperature. It would appear, in fact, that the process demands a choice between two evils. That is to say, the gas may be produced in such a way that portion of the hydrocarbon vapours it contains are condensible, in which case a fairly high tar yield will be obtained. On the other hand, the gas may be submitted to a fixing process, in which case it will retain a greater proportion of hydrocarbons as permanent gas, but the effect of fixation is to destroy in part the tar and ammonia.

Theoretically, it should be possible to retain the incombustibles in complete gas within a proportion of 10 per cent. by volume, but in practice this is rarely accomplished, primarily owing to the fact that a portion of the blow products invariably manage to travel forward with the gases issuing from the retort proper. This is a difficulty which will, no doubt, be solved by time and experience, and

the solution probably lies in the employment of some form of automatic compensating arrangement which would control the pressure during the two periods of run and blow.

As an illustration of what may be expected in the way of incombustibles the author might quote from a recent report which he has upon the working of a plant of the kind. In this case the carbon-dioxide content of the gas was found to be 16·8 per cent. by volume.

The question of clinker formation is one of extreme importance, and means should be provided for ensuring that no hard masses of slag are used, but that the mineral constituents of the coal are brought down in friable form. It will usually be found, with plants as at present constructed, that when the producer is cleaned the material removed will contain a large proportion of a partly burnt coke which, if picked over, may be employed under the steam boilers. This waste fuel has been known to amount to as much as 3 cwt. per ton of coal dealt with.

THERMAL EFFICIENCY OF GAS PRODUCTION

The ordinary method of comparing the thermal efficiencies of gas production with different methods of treating coal is to an extent misleading in that the gas generated is made to bear the whole of the thermal losses which occur. It will be appreciated that by-products cannot be obtained without the expenditure of heat, accordingly they should bear a reasonable proportion of the heat which is consumed and lost in the process. In order to deal with the matter in this way, however, assumptions would have to be made at the outset, and the fact that they would necessarily be of a hypothetical nature would largely vitiate the value of the results obtained. The only practical method of arriving at comparative figures, therefore, is to assume that all thermal losses are debited to the gas account.

The thermal efficiency of a gasification process is merely the percentage ratio of the potential heat in the fuel employed before gasification and the useful energy which is recovered after treatment of the fuel. A ton of coal contains approximately 30 million B.Th.U. in the form of potential heat energy, while a ton of coke, in the normal undried state, contains on an average (2,240 lb. × 12,000 B.Th.U. per lb.) 27 million B.Th.U. When coal is the fuel employed the by-products enter into the reckoning, with coke (as there are no auxiliary products) the calculation is more straightforward. The following examples may be taken as illustrative of the results obtained when a good quality (say, Durham) coal is carbonized under conditions approaching the best found in practice.

Efficiencies have been calculated upon the following basis :—

$$\text{Efficiency of whole process} = \frac{\text{Useful heat recovered}}{\text{Total heat supplied}} \times 100$$

$$\text{Efficiency of gas production} = \frac{\text{Total heat in gas}}{\text{Total heat in gas} + \text{Heat lost and used}} \times 100$$

THERMAL EFFICIENCY OF STRAIGHT COAL GAS PRODUCTION
(Horizontal retorts.)

HEAT SUPPLIED.	B.Th.U.	HEAT RECOVERED.	B.Th.U.
1 ton of coal	= 30,000,000	13,000 c. ft. gas at 520 B.Th.U. per c. ft.	= 6,760,000
2¾ cwt. coke used to heat retort setting at 12,100 B.Th.U. per lb.	= 3,726,809	13¾ cwt. coke and breeze at 12,100 B.Th.U. per lb.	= 18,634,000
		130 lb. tar at 15,500 B.Th.U. per lb.	= 2,015,000
		32 gal. 10 oz. of liquor containing	105,000
		8 lb. retort carbon at 14,500 B.Th.U. per lb.	= 116,000
		8 lb. free sulphur at 4,100 B.Th.U. per lb.	= 32,800
		Total recovered	27,662,800
		B.Th.U. used and lost . . .	6,064.000
Total	33,726,800	Total	33,726,800

$$\text{Thermal efficiency of process} = \frac{27{,}662{,}800}{33{,}726{,}800} \times 100 = 82{\cdot}2 \text{ per cent.}$$

$$\text{Thermal efficiency of gas production} = \frac{6{,}760{,}000}{12{,}824{,}000} \times 100 = 52{\cdot}7 \text{ per cent.}$$

In calculating the thermal efficiency of gas production it will be seen that in the production of 6,760,000 gaseous thermal units 6,064,000 units are lost. That is to say, out of a total of 6,760,000 + 6,064,000 = 12,824,000 units 6,760,000 units are recovered as gas.

THERMAL EFFICIENCY OF STEAMED CHARGE IN VERTICAL RETORTS
(30 per cent. steaming. Wet basis.)

HEAT SUPPLIED.	B.Th.U.	HEAT RECOVERED.	B.Th.U.
1 ton of coal	= 30,000,000	18,000 c. ft. gas at 445 B.Th.U. per c. ft.	= 8,010,000
30 per cent. steaming = 672 lb. steam per ton of coal. Fuel for steam = 75 lb. coke at 12,100 B.Th.U. per lb.	= 907,500	12½ cwt. coke at 12,100 B.Th.U. per lb.	= 16,940,000
		210 lb. tar at 15,500 B.Th.U. per lb.	= 3,255,000
		45 gal. 10 oz. liquor containing	150,000
Fuel required to heat setting, and gasified in retort = 3 cwt. coke at 12,100 B.Th.U. per lb. .	= 4,065,600	4 lb. retort carbon at 14,500 B.Th.U. per lb.	= 58,000
		9 lb. free sulphur at 4,100 B.Th.U. per lb.	= 36,900
		Total recovered	28,449,900
		B.Th.U. used and lost . . .	6,523,200
Total	34,973,100	Total	34,973,100

$$\text{Thermal efficiency of process} = \frac{28{,}449{,}900}{34{,}973{,}100} \times 100 = 81{\cdot}3 \text{ per cent.}$$

$$\text{Thermal efficiency of gas production} = \frac{8{,}010{,}000}{14{,}533{,}200} \times 100 = 55{\cdot}1 \text{ per cent.}$$

THERMAL EFFICIENCY OF "BLUE" WATER GAS PRODUCTION

HEAT SUPPLIED.	B.Th.U.	HEAT RECOVERED.	B.Th.U.
1 ton of coke at 12,100 B.Th.U. per lb.	= 27,000,000	60,000 c. ft. "blue" gas at 300 B.Th.U. per c. ft.	= 18,000,000
750 lb. of coke for steam in generator and driving fan, etc., at 12,100 B.Th.U. per lb.	= 9,075,000	9½ lb. free sulphur at 4,100 B.Th.U. per lb.	= 38,950
		Total recovered	18,038,950
		B.Th.U. used and lost	18,036,050
Total	36,075,000	Total	36,075,000

$$\text{Thermal efficiency of process} = \frac{18{,}038{,}950}{36{,}075{,}000} \times 100 = 50{\cdot}0 \text{ per cent.}$$

$$\text{Thermal efficiency of gas production} = \frac{18 \times 10^6}{36{,}036{,}050} \times 100 = 49{\cdot}9 \text{ per cent.}$$

If the sensible heat of the blow gas and the combustibles therein are made use of after leaving the generator and are employed in a steam boiler, then the efficiency of gas production becomes—

$$\frac{18 \times 10^6}{26{,}961{,}050} \times 100 = 66{\cdot}8 \text{ per cent.}$$

In calculating the thermal efficiency of complete gasification the figures taken for yield of products must naturally be more or less hypothetical, for at the present stage no really consistent results can be referred to. In view, however, of the considerable experience of H. Strache as an inventor and operator of plants of the kind it is admissible to assume that the yields he has obtained in practice (tar was found to yield 6·8 per cent. of the heat of the coal) approximate fairly closely to the results which might be generally expected under good working conditions. In the following balance Strache's gas and tar yields [1] are taken, while ammonia and recovered fuel as sources of heat have been neglected.

[1] See page 767.

THERMAL EFFICIENCY OF COMPLETE GASIFICATION
(Single-stage process.)

HEAT SUPPLIED.	B.Th.U.	HEAT RECOVERED.	B. Th.U.
1 ton of coal	= 30,000,000	57,400 c. ft. gas at 374 B.Th.U. per c. ft.	= 21,467,600
Fuel for steam used for gasmaking, fan, etc., at 12,100 B.Th.U. per lb.		132 lb. tar at 15,500 B.Th.U. per lb.	= 2,046,000
600 lb.	= 7,260,000	10 lb. free sulphur at 4,100 B.Th.U. per lb.	= 41,000
		Total recovered	23,554,600
		Heat used and lost	13,705,400
Total	37,260,000	Total	37,260,000

$$\text{Thermal efficiency of process} = \frac{23{,}554{,}600}{37{,}260{,}000} \times 100 = 63{\cdot}2 \text{ per cent.}$$

$$\text{Thermal efficiency of gas production} = \frac{21{,}467{,}600}{35{,}173{,}000} \times 100 = 60{\cdot}1 \text{ per cent.}$$

If the fuel employed for generating steam is neglected (an error too common in the calculation of thermal efficiency) then the result will be as given below. This figure, in fact, represents the thermal efficiency which would result if it were possible to derive from the process sufficient heat for carbonization as well as for steam raising.

Thermal efficiency of gas production =

$$\frac{21{,}467{,}000}{21{,}467{,}000 + 6{,}445{,}400} \times 100 = 77 \text{ per cent.}$$

COMPARISON OF COST

From a financial standpoint a comparison between the various gasmaking processes dealt with above must essentially be influenced by the prevailing values of raw materials and by-products. In the following statements the prices of various materials have been considered as follows :—

Coal	50*s.* per ton.
Coke	45*s.* „ „
Breeze	15*s.* „ „
Tar	7½*d.* „ gallon.
Liquor	8*d.* „ „

(*a*) *Straight Coal Gas* (*horizontal retorts*)—

	£ *s.* *d.*	£ *s.* *d.*
1 ton coal		2 10 0
Less 10 cwt. coke	= 1 2 6	
1 cwt. breeze	= 0 0 9	
11 gal. tar	= 0 6 10	1 13 0
32 gal. liquor	= 0 2 2	
Sulphur and carbon	= 0 0 9	
1 ton coal (net cost)		0 17 0

yielding 6,760,000 B.Th.U. in gas.

Cost of gas = 3·01*d.* per therm.

(*b*) *Vertical Retorts*, 30 *per cent. steaming*—

	£	*s.*	*d.*
1 ton coal	2	10	0
75 lb. coke for steam	0	1	6
	2	11	6
Less 9 cwt. coke =	1	0	3
0·5 cwt. breeze =	0	0	5
17·5 gal. tar =	0	11	0
45 gal. liquor =	0	3	0
Sulphur and carbon =	0	0	7
	1	15	3
1 ton coal (net cost)	0	16	3

yielding 8,010,000 B.Th.U. in gas.

Cost of gas = 2·43*d.* per therm.

(*c*) "*Blue*" *Water Gas*—

	£	*s.*	*d.*
1 ton coke	2	5	0
750 lb. coke for steam	0	15	0
Materials for manufacture	3	0	0

yielding 18,000,000 B.Th.U. in gas.

Cost of gas = 4*d.* per therm.

Self-steaming Cost of gas = 3*d.* „ „

(*d*) *Complete Gasification*—

	£	*s.*	*d.*
1 ton coal	2	10	0
600 lb. coke for steam	0	12	0
	3	2	0
Less 13 gal. tar =	0	8	2
10 lb. sulphur =	0	0	8
	0	8	10
Net materials for manufacture	2	13	2

yielding 21,467,600 B.Th.U. in gas.

Cost of gas = 2·90*d.* per therm.

	Efficiency of process. Per cent.	Efficiency of gas production. Per cent.	B.Th.U. used and lost per 1,000 B.Th.U. recovered as gas.	Cost per therm of crude gas.
1. Straight coal gas (horizontal retorts)	82·2	52·7	897	3·01*d.*
2. Vertical retorts (30 per cent. steaming)	81·3	55·1	814	2·43*d.*
3. "Blue" water gas	50·0	49·9	1,002	4·0*d.*
4. "Blue" water gas (self-steaming)	66·8	66·8	498	3·0*d.*
5. Complete gasification	63·2	60·1	638	2·90*d.*

COMPLETE GASIFICATION PLANT

The use of coal for the production of producer gas and water gas, a process which has been referred to in the previous chapter, is comparatively common in America, and although in the case of producer gas (where air and steam are blown in simultaneously) considerable success is met with, the same cannot altogether be said when the ordinary water-gas plant is considered, as in this case the requirements of a fuel are far more exacting.

Several attempts have been made to gasify coal completely. One of the earliest plants designed for the purpose was the Fahnehjelm apparatus (Fig. 458). The plant consisted of a generator with a retort placed above the former. Around the retort was arranged a heating chamber filled with chequer brickwork, and from the illustration it will be observed that the whole apparatus bears a striking resemblance to plants which are in operation to-day.

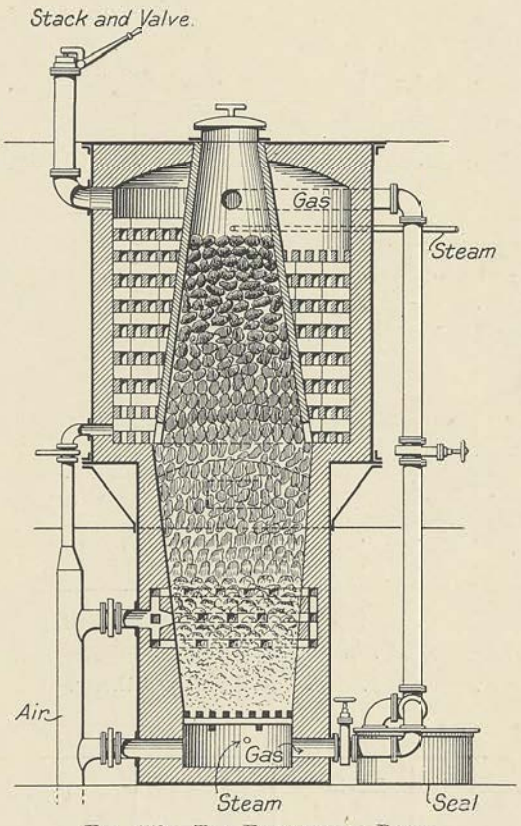


FIG. 458.—THE FAHNEHJELM PLANT.

A contemporary plant was that known as the Rose-Hastings which appeared in many slightly different forms. The primary generator (A, Fig. 459) was charged with coal about once every hour, while the secondary chamber (B) was filled with coke. The depth of fuel in both vessels was about 8 feet. During the blow the stack valve attached to generator A was opened, those on the chamber B and superheater C being closed. The blast was admitted simultaneously to A and B, secondary air being admitted at a point just above the top of the fuel-beds and also to the branch connection between the two chambers. After blowing for five minutes the stack valve on B was opened, while some two minutes later the stack valve on C was opened and that on B closed, secondary air meanwhile being admitted to the base of C. In this way both the fuel-beds and the superheater were raised to the required temperature.

The run was then commenced, steam being admitted at the base of the coal bed. The mixture of coal gas and water gas passed firstly through the chequer brickwork at the top of the generator, thence through similar chequers in the

chamber B where oil was sprayed in by means of steam. The mixed vapours then passed downward through the coke bed and away through the superheater. If the coke bed attained too high a temperature steam was passed through it also, but in a downward direction.

The object of the coke bed was, it seems, to fix the oil vapours and to improve the quality of "blue" water gas by reducing carbon dioxide to the monoxide. Working difficulties and uncertain gas quality prevented the process from surviving.

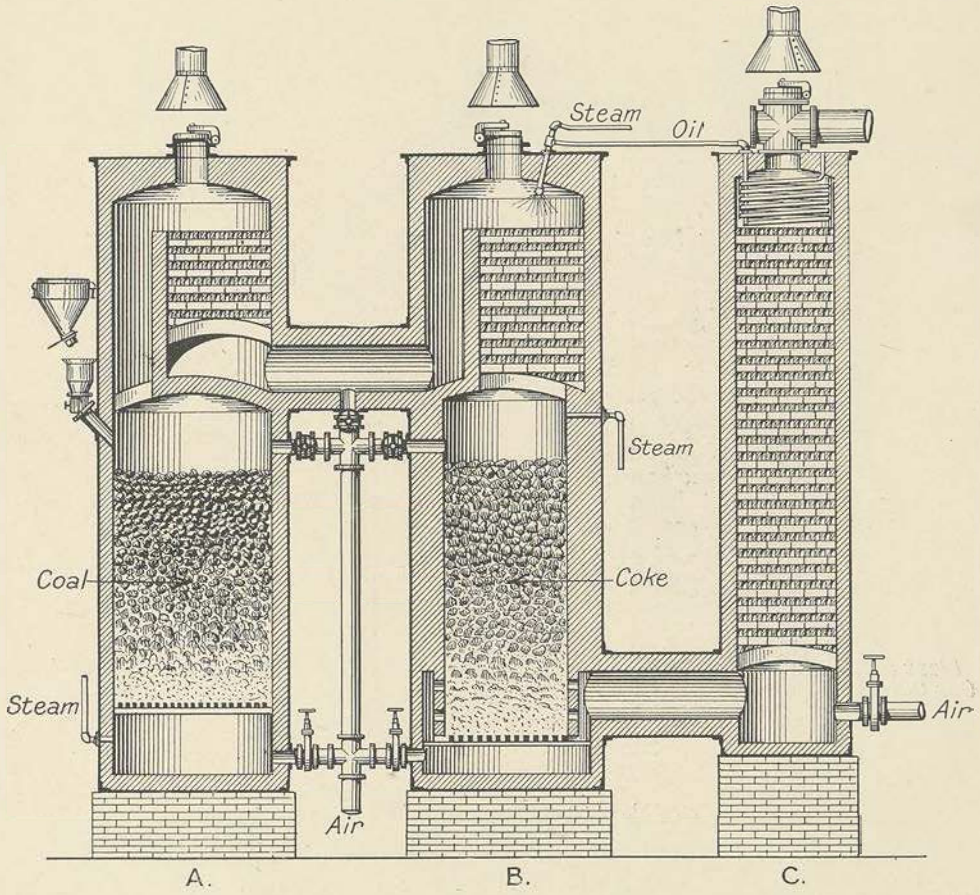


FIG. 459.—THE ROSE-HASTINGS PLANT.

The Rew apparatus (Fig. 460) was a decided novelty. It was built in pairs, the blast being admitted simultaneously at the base of the two generators (A). The products of the blow passed over the bed of coal lying in the inclined coking chambers and finally travelled downwards through the regenerators (B). Secondary air was admitted through apertures below the inclined chambers and also to the top of the regenerators.

During the run steam was admitted to the base of one regenerator where it was superheated, afterwards travelling down over the bed of coal and sweeping out the hydrocarbons. Travel of the mixture continued down through the fuel-bed in the first generator, up through the adjacent generator, thence over the second inclined layer of coal and out through the second regenerator. The process was undoubtedly ingenious, but in practice it was never found possible to carbonize completely the coal, with the result that the generator became clogged with a pasty semi-carbonized mass.

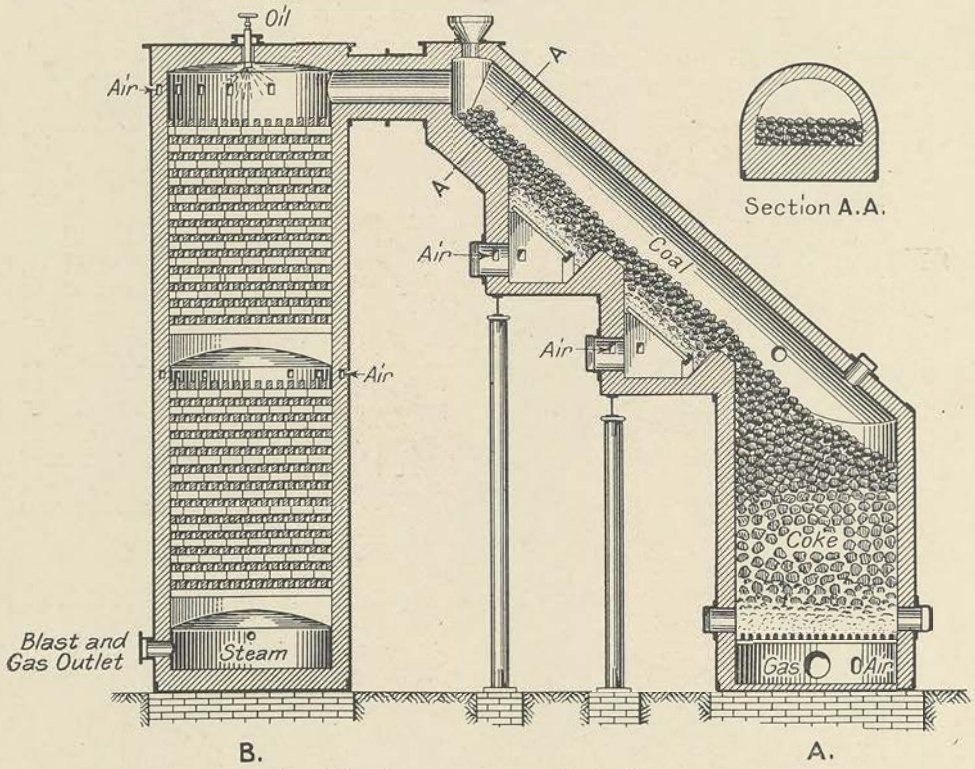


FIG. 460.—ARRANGEMENT OF REW'S PLANT.

Some fifteen years ago Kramers and Aarts introduced the plant shown in Fig. 461. The apparatus consisted of two generators, two regenerators, and a recuperator. The generators were placed side by side, and behind each, on a higher level, were the regenerators. The generators were blown in parallel, and the carbon monoxide contained in the blow gases was burned just above the fuel by the admission of secondary air. The hot products then travelled out by way of the regenerators and recuperator. After the blow the surface of the fuel in one generator was covered with a layer of coal, and steam was admitted below the fuel in this generator. The steam was decomposed with the formation of water gas, and the inventors claimed

that the sensible heat of this gas was sufficient to carbonize the layer of coal during the run, thus giving a mixture of water gas and hydrocarbons. The mixture passed through the regenerators and downwards through the fuel in the second generator, whereby the hydrocarbons and ammonia were decomposed. The air for the blast, as will be seen from the illustration, was preheated by passage through the recuperator placed above the stack valve.

There is no question that one of the pioneers of complete gasification on successful lines was H. Strache, whose plant is shown in Fig. 462. It will be seen that the plant consists of a short vertical retort superimposed on a water-gas producer. The plant is operated in the ordinary manner with runs and blows, the water gas during the run passing out by way of the retort and sweeping the coal gas with it to the mixed gas outlet, while the blow products are caused to flow through nostrils into a chamber encircling the retort where, by the admission of secondary air, the combustibles they contain are burnt and assist in providing heat for the carbonization of the coal. Strache introduced his plant in 1895, and called the gas mixture "Doppelgas." On an average the plant yields 57,400 cubic feet of gas per ton of coal utilized, the calorific power of the gas being 374 B.Th.U. per cubic foot. Strache asserts, but the statement is open to question, that the yield of subsidiary

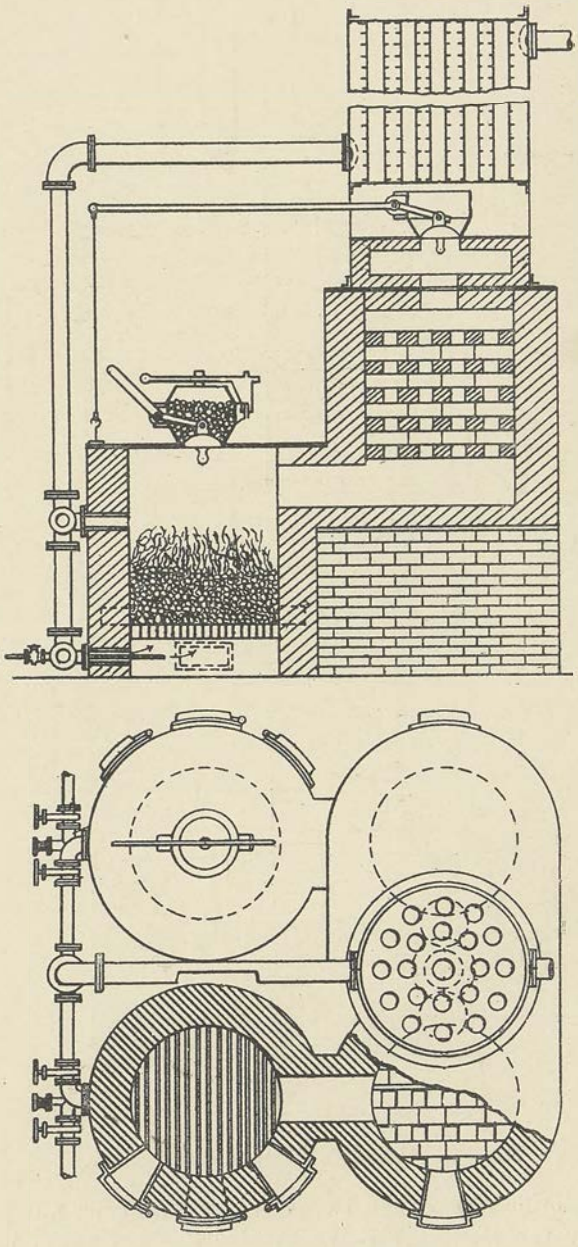


FIG. 461.—AART'S GAS PLANT.

by-products is greater than if coal gas and water gas are produced separately. The yield of tar is about 20 gallons per ton of coal, it has a specific gravity of 1·02, but contains 33·7 per cent. of water. When distilled the tar gives the following fractions :—

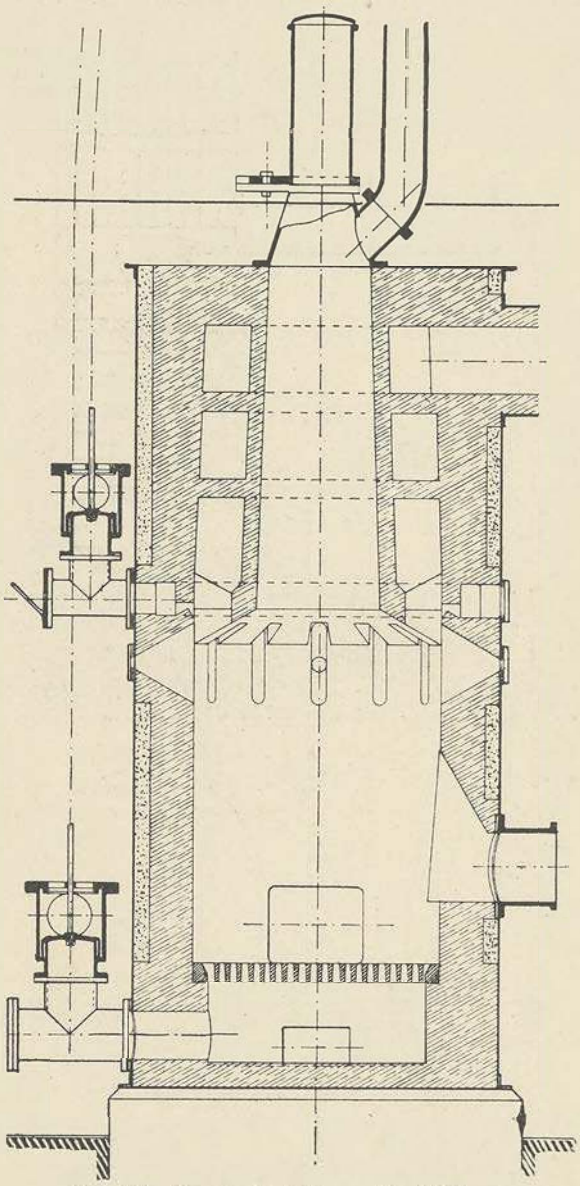


FIG. 462.—STRACHE'S "DOPPEL-GAS" PLANT.

DOPPELGAS TAR

Water.	33·70	per cent.
Paraffin	1·50	,,
Light oils	19·40	,,
Heavy oils	24·30	,,
Ammonia	0·91	,,
Pitch	18·90	,,
Ash	0·28	,,

It should be understood that complete gasification may yield two distinct types of gas. The gas engineer is more directly concerned with those processes which give a gas having a calorific power of about 360 to 390 B.Th.U. per cubic foot, and is not directly interested in the alternative processes (such as Mond gas, semi-water gas, and producer gas) which yield a gas having a calorific power varying between 125 and 175 B.Th.U. per cubic foot. Gases produced by the latter processes have a nitrogen content of 50 per cent. or over, while in the case of the former the nitrogen content should not exceed 6 per cent.

THE TRI-GAS PLANT

Tri-gas is a mixture of coal gas, water gas, and producer gas, and has a lower calorific power than Doppelgas, and a higher nitrogen content. The plant is made by the Dellwik-Fleischer Water Gas Company, who claim to have succeeded in perfecting the complete gasification of coal. An attempt was first made to decompose

the tar vapours in the gas, but this was soon given up because the tars were themselves of value and because the results could not be called good. Carbonizing processes left the coal still smoky when the blow began; and it was found that the heat must be developed inside the coal. For this purpose the blast was directed from the middle of the producer downwards, and also from the bottom upwards, so that the zone between distillation and gasification was quite hot, and the water gas from the lower part of the producer was so hot that it effectively distilled the coal above as it passed through it. The temperatures of this distillation were, however, relatively low, so that there was a good yield of ammonia, and the tars obtained were low-temperature tars, free from naphthalene. Instead of decomposing the

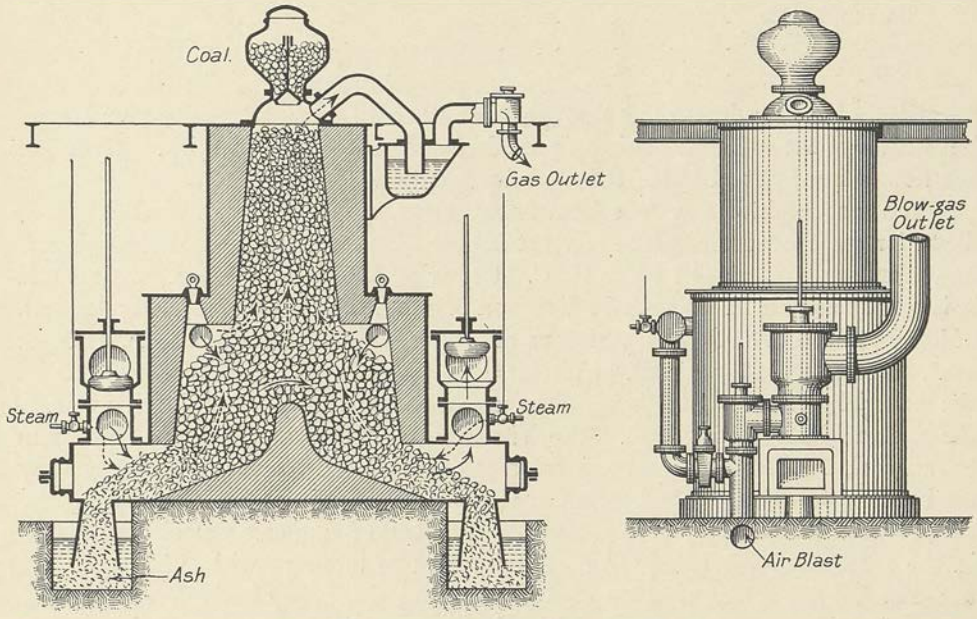


Fig. 463.—Dellwik-Fleischer "Tri-Gas" Plant.

tars, as had at first been attempted, the new process preserved the tars from overheating. The first successful experiments were made in Vienna, where a producer of a capacity of 2,800 to 5,250 cubic feet per hour gave gas of 281 B.Th.U. per cubic foot, Ostrau coal gave gas of 338 to 394, and Bosnian brown coal a gas of 336 B.Th.U. per cubic foot. The Stinnes collieries, after seeing the Vienna experiments, built three special producers of a capacity of 28,000 to 52,000 cubic feet per hour, with rotary hearths. The coal was of a very caking quality; but the difficulties were overcome. The first of the three producers began continuous working on April 6, 1918, and continued it for five months without a break and without any overhauling. On September 6, 1918, the producer was stopped for a short time, in order to deal with slag which had begun to accumulate. After that the working of all three producers was continuous for six months.

The coal used was a mixture of ordinary coal and brown coal. The former contained 11 per cent. of ash and 5·5 per cent. of moisture, while the brown coal contained 3·15 per cent. of ash and 55 per cent. of moisture.

The yield of gas was 63,450 cubic feet per ton of the mixed coal, its calorific value being 315 to 338 B.Th.U. per cubic foot. The average composition of the gas was as follows :—

Composition of Tri-Gas (Mixed Coal)

Hydrogen	51·5 per cent.
Methane	5·5 „
C_nH_m	0·3 „
Carbon monoxide	23·9 „
Carbon dioxide	13·3 „
Nitrogen	5·1 „
Oxygen	0·4 „

Each of the producers put through from 12 to 15 tons per twenty-four hours ; but with coal not so highly caking a good deal more could be dealt with. Producers are now being built of twice the capacity mentioned.

The tar obtained was free from naphthalene, and met all the conditions laid down for good low-temperature tar. It is port-wine red when looked through and has, when dry, a sp. gr. of 1·04 at 15° C. 62 per cent. of it is soluble in benzene, and it is wholly soluble in benzol. It gives, on distillation in a vacuum, 26·7 per cent. of lubricating oils, 32·5 of very viscous oils, 3·3 per cent. of hard paraffin, 11·5 per cent. of resin and 26 per cent. of pitch. In amount it came to 5 to 6 per cent. of the material gasified ; but it is hoped to raise this percentage materially by avoiding the use of highly caking coal. The Vienna experiments gave 15 per cent. from brown coal, but there the coal was not a caking coal and the tar vapours got away freely, and, in addition, the heating of the coal in the upper part of the producers was, for the same reason, more uniform. The yield of ammonia was also good, but, in the same way, caking of the coal was found to interfere with this.

The Tri-gas plant consists of a producer at the base of which water gas is manufactured, thus gas ascends through the superimposed column of coal and transforms it into coke. The lower portion of the producer is divided into two by a partition, the higher part of which is below the zone in which the coal is coked. Two pipes containing heated compressed air run one to each side of the partition. Two superheated steam nozzles are also provided. The plant carries at the top the usual fittings for the discharge of waste gas and the run gases.

The plant is worked by successive introduction of air and superheated steam. During the first period, all the valves are shut, except that for the intake of compressed air, and one for the discharge of waste gas into the chimney. The hot air thus blown in burns the coke ; and the products of combustion rise through the column of coke on the right of the producer, to pass out through the waste-gas valve, after descending from top to bottom of the second half of the producer. In this way the coke bed is raised to a temperature of about 1,400° C.

The run is then commenced. A current of steam is admitted to the plant, and

the water gas thus formed rises through the coke and passes through the column of coal. As at the time of formation the water gas is at a temperature of 800° to 1,300° C., it cokes the coal and liberates the volatile products. Passing through the coal, the gases are gradually cooled, and leave the top of the producer at a temperature of 100° to 300° C. Thence they are successively conveyed to the condensers, washers, purifiers, and gasholder.

The periods of run and blow vary with the kind of coal employed, the average being three minutes blow with five to ten minutes run.

As the operation of coking absorbs a great deal of heat, and cannot be sustained with the heat of incandescent water gas, air must be introduced during gasification. The superheated air is conveyed into the coking zone through two pipes, fitted with valves.

The air oxidizes part of the water gas with the formation of carbon dioxide and water, and as both of these reactions are exothermic the requisite amount of heat is supplied for carbonization. Owing to the diluent effect of nitrogen and CO_2 it is, of course, necessary to limit the amount of air to the minimum just necessary for carbonization. The composition of Tri-gas obtained from a mixture of coal and lignite has been given above. It is interesting to note, however, that when a good quality coal alone is employed the composition of the gas obtained approximates to the following :—

Composition of Tri-Gas (Good Quality Coal)

Hydrogen	50 per cent.
Methane	10 „
C_nH_m	1 „
Carbon monoxide	30 „
Carbon dioxide	5 „
Nitrogen	4 „

The "Double-Gas" Plant

This plant is generally known as Smith's modification of the "K. & A." patents.

In the original "K. & A." plant the system entails the use of two distinct generators, which are run through in series and blown through in parallel, thus complying with the necessity of arranging for a deep fuel-bed during the run and a shallow fuel-bed during the blow. In the latest type (Fig. 464) of plant the same procedure is arranged for, but there is only one generating vessel, instead of the two, thus reducing capital outlay and minimizing heat losses. The outside shell, being of an oval cross-section, is divided into two parts by a plate suspended from the centre and reaching within a short distance of the base. The spaces on either side of this mid-feather form the two generators, whilst room is also found for special compartments, known as regenerators. It will be noticed from the sectional sketch that each generator is made up of two distinct portions, namely, the larger round coke receptacle at the base, whilst the upper tapered portion is D-shaped and forms, among other duties, a charging pouch for the coke or coal. It will be seen that at the upper end of the lower generator a series of nostril holes is arranged

for. The grouping of these, together with the shape of the upper generators, can be best seen by referring to the sectional view.

The D-shaped portions of the generators are provided with an outlet at the top, whilst the regenerators have ports which serve the purpose of both inlets and outlets. A single blast inlet (the blow is a positive one) is provided midway between the two generators, beneath the fire-bars. The inlet, therefore, does duty for either generator.

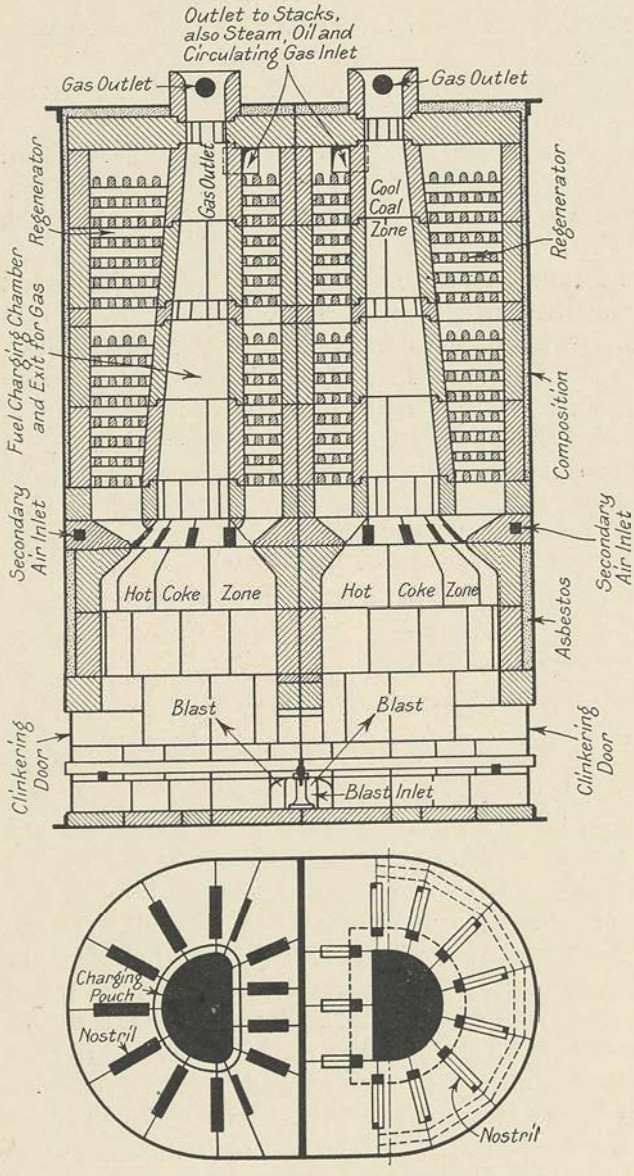


FIG. 464.—SMITH'S "DOUBLE-GAS" PLANT.

As the plants so far erected have been primarily put down with the idea of making "blue" water gas, the method of operating them for this purpose will be first described. Assuming that the generators, both upper and lower, are charged up and that the heats have been got up, a blow is first of all arranged for by admitting the blast through the inlet shown in the centre of the plant. This current of air then splits into two streams and travels through both coke beds simultaneously as far as the nostrils. Owing to the valves at the top of the D-shaped generators being closed, the products of the blow cannot force an exit this way; hence they pass through the nostrils, traverse the regenerators, and finally pass into the air by means of the stack valves. In this way the fuel in the generators is brought

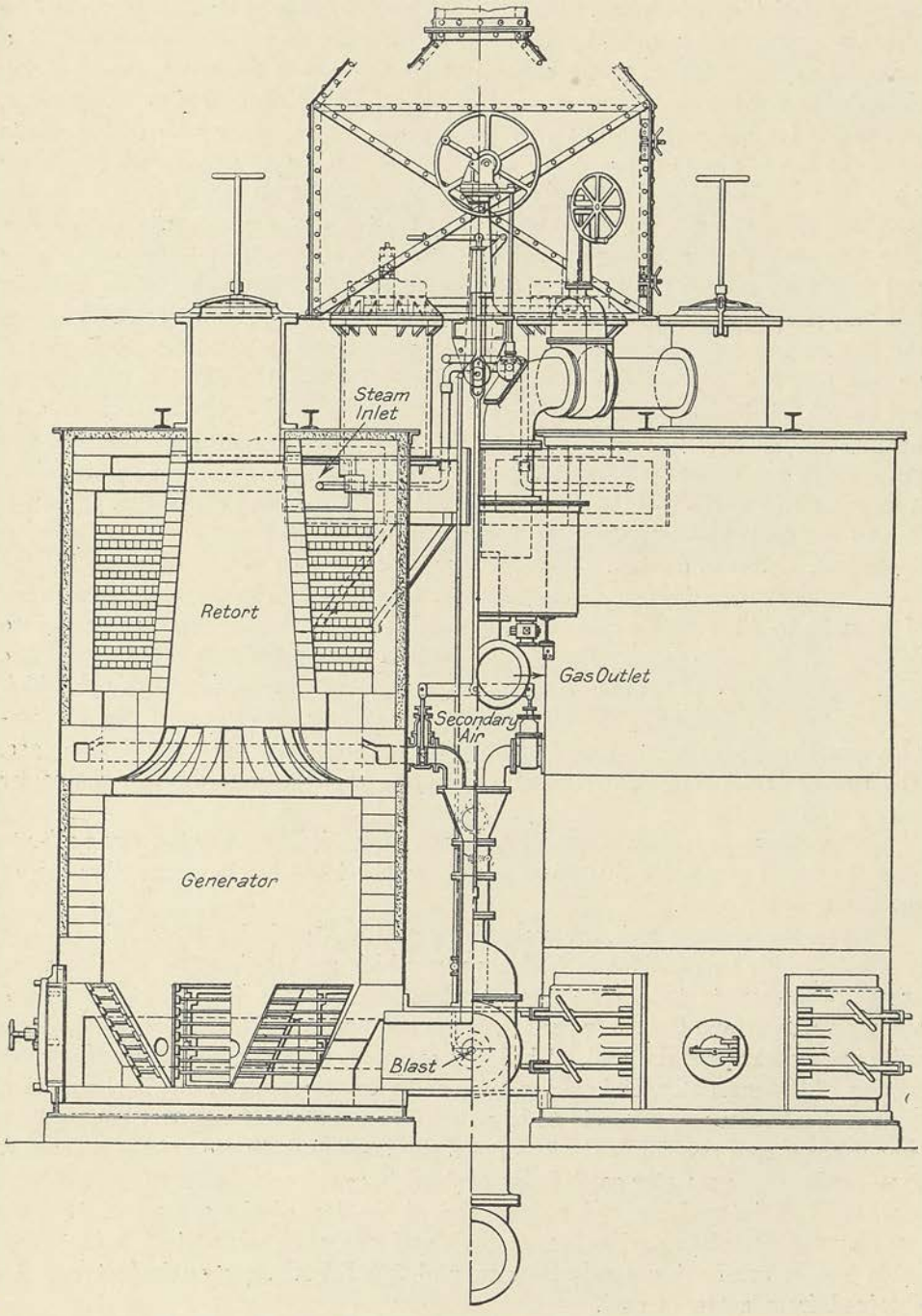


FIG. 465.—SMITH'S "DOUBLE-GAS" PLANT. LATEST FORM.

up to the desired temperature, whilst the products, in passing through the regenerators, give up a further quantity of heat, so that the latter are maintained at a considerable temperature. The gases leaving the lower generators and passing through the nostrils contain, on an average, about 10 per cent. of carbon monoxide, and this is further burned to CO_2 by the admission of secondary air at the points shown in the sectional figure. The blow in this way usually continues for rather more than a minute. At the end of this time, the blast having been shut off and the stack valves closed, steam is admitted at the top of the regenerator on one side only. Passing downwards around the heated chequer work, it is partly split up and then travels first through one coke bed and finally through the second. In this way long contact with the fuel and thorough reducing is assured. Leaving the second fuel-bed, the water gas already produced does not pass through the nostrils (the snift valve being closed), but forces its way through the cool core of fuel in the D-shaped pouch. It then passes into the special hydraulic main and, finally, through the scrubber. One of the chief advantages of passing the hot gas through the incoming coke in this way is that the greater part of the moisture is driven off from the fuel; and, moreover, the outgoing gas is thoroughly filtered.

In the cycle just described no mention has been made as to how carburation is effected, if this is desired. For this purpose air from a compressor is admitted to the surface of the oil in a storage receiver, when the oil is forced out at a pressure of from 30 to 40 lb. per square inch, through a special regulating spray and into the top of the regenerator. Each regenerator is fitted with such a spray, but the oil is only admitted to that one surrounding the top of the generator through which the gas is finally passing. The oil gas is accordingly forced downwards by its pressure, passes through the nostrils, and meets the upgoing stream of "blue" water gas. The two are then thoroughly intermixed during their passage through the cooler coke core.

With regard to the duration of runs and blows, it is usual, after a one-minute blow, to admit steam for five minutes. After the following blow the direction of the steam is reversed.

When the plant is used for carbonizing coal and gasifying the resultant coke it is fitted with two automatic feed hoppers which are regulated to provide what practically amounts to a continuous charge. During the five-minutes' run the hot gas evolved from the lower portion of the bed passes up through the cooler zone and partly carbonizes the coal. The latter gradually works its way down the upper portion of the generator, undergoing more and more complete carbonization during its travel. In general, it is said to be reduced to the state of ordinary coke by the time it has passed two-thirds the way down the D-shaped portions of the generator. Thus during the run water gas is being evolved from the coke and coal gas from the coal, the two intermixing and passing out at the top of the generator. In this way, by the complete gasification of both coal and coke, about 50,000 to 60,000 cubic feet of gas having a calorific power of 370 B.Th.U. per cubic foot may be obtained from a ton of coal.

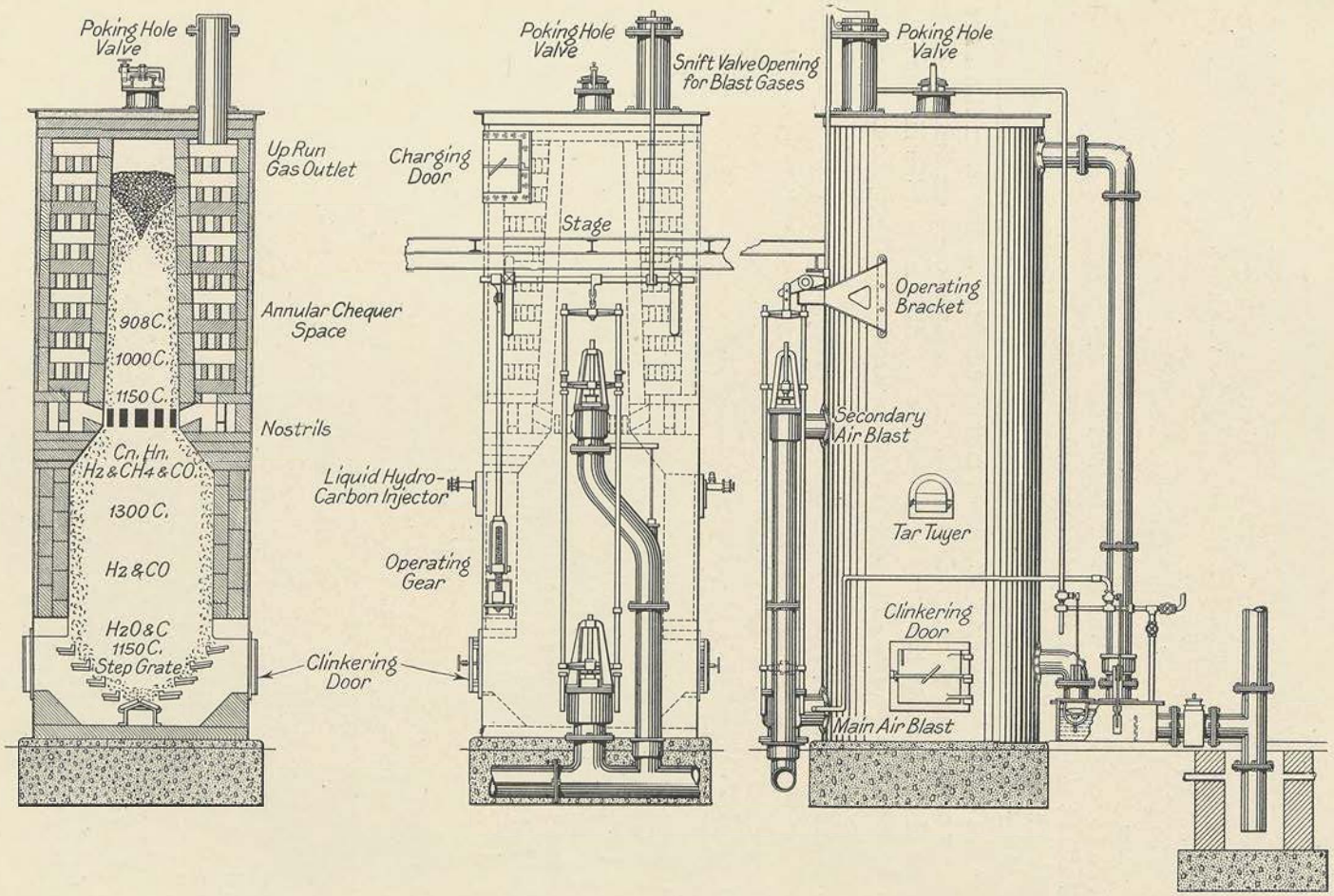


FIG. 466.—TULLY'S GAS PLANT.

The Tully Gas Plant

The Tully plant (Fig. 466) is practically a vertical retort fixed over a water gas producer. The fuel passes down the retort through various stages of carbonization, entering the producer in the form of coke which is then gasified as in the usual water gas apparatus.

The plant is brought into operation as follows :—

The producer is filled with hot fuel up to the bottom of the retort, it is then blown to incandescence, the blast entering below the grate and leaving at special nostrils at the bottom of the retort, at which point the secondary air is admitted, making a combustible mixture, and heating the chequer work round the retort.

After one or two runs the plant is charged with coal to a point about 2 feet from the top of the retort. The blast is then admitted as before, until a flame appears at the snift valve, which indicates that producer gases are being made in excess of the quantity burnt in the chequer work. At this point the blast is shut off by means of an operating wheel which automatically closes the main blast, secondary air, and snift valve.

The top outlet lever on the washbox is then opened, the one operation opening up steam supply to the bottom of the producer and allowing the gases to pass up through the producer, through the retort, then down through top outlet pipe, through the washbox, thence to the scrubber and relief holder. After five or six minutes' gasmaking the plant is again blown to incandescence ; and, after the closing of air valves and snift valve, the bottom outlet lever on the washbox is opened up, which in this case admits steam in the chequer work at the top of generator. The gases travel down and out at the bottom of the producer, thence away through washbox and scrubber to the relief holder.

The highest output as yet obtained from the Tully plant is a make of 63,000 cubic feet of gas of 360 to 370 B.Th.U. per cubic foot, and 8 to 9 gallons of tar per ton of coal.

Broadhead's Process

Broadhead [1] proposes to employ a plant for producing mixed coal gas and water gas as illustrated in Fig. 467. Air is first blown into the combustion chamber of a generator, above which a vertical retort, surrounded by a chamber containing chequer brickwork, is provided. The resultant gases pass through this chamber to heat the retort. When the generator is sufficiently heated the air is shut off and steam is passed through the incandescent fuel in the combustion chamber, the resultant gases passing through the coal contained in the retort. The object of the invention is to provide a process of manufacture whereby the two gases may be produced at the same time in an economical manner, and a low-temperature production of tar oil may be effected. With this object in view, coal is fed into the retort between the steam runs and the coal descending the retort is subjected to a low-temperature carbonization by the heat from the water gas, together with the heat transferred during the air blow to the chamber surrounding the retort.

[1] E.P. 122,179/19.

Air and steam are blown alternately into the generator. During the air blow the gas valve is closed and the products of combustion pass through ports into the annular space surrounding the retort, the heat generated being transmitted through the chequer brickwork therein to the retort and the waste gases passing through the snift valve and away into the atmosphere. When the generator portion of the plant is blown up to a sufficient heat the air is shut off and steam is turned on. The water gas so generated passes up through the vertical retort, and the heat of the water gas, together with that evolved around the retort during the blow, causes the coal descending the retort to be subjected to a low-temperature carbonization.

A supply of secondary air is admitted to the annular space surrounding the coal retort to burn the combustibles in the blow gases.

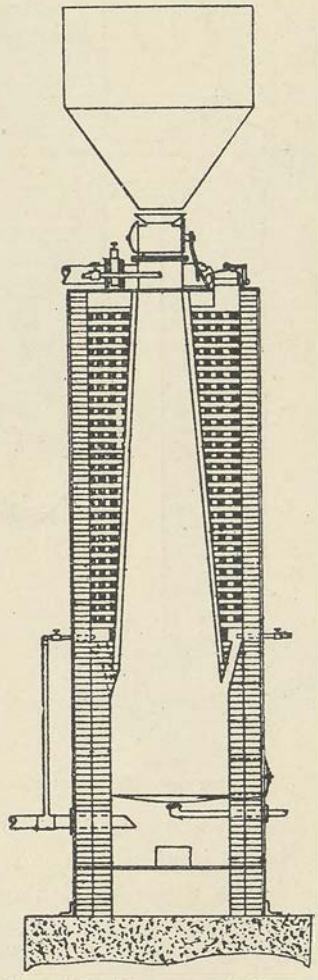


FIG. 467.—BROADHEAD'S PLANT.

DOHERTY'S PROCESS

The plant employed for the complete gasification of coal by H. L. Doherty [1] differs in many respects from those described above. A vertical section of the generating portion of the plant is shown in Fig. 468. The horizontal section of the fuel chamber and one regenerator is shown in Fig. 469.

The coal is fed intermittently through the charging opening at the top of the fuel chamber, and coke may be intermittently discharged through an extracting chamber at the base of the generator.

Gas is produced from the fuel in two distinct operations—namely, a blowing or heating operation and a gas-making operation. In the blowing operation, air is blown through the fuel column and passes into the base of one of a pair of regenerators; the products flow up through the regenerator, and then pass through a horizontal flue into the mid-portion of the fuel column. The blast exhaust gases pass out of the fuel column at a high temperature, and flow through one of the flues into one of the heat regenerators, where the heat is absorbed from the gases and the gases pass out comparatively cool through outlet pipes. When the heat of the exhaust gases has built-up the temperature of one regenerator, the incoming air from the blower is reversed by valves to admit the air through the heated regenerator, so as to exhaust the air through the regenerator previously used for preheating the air. The fuel

[1] E.P. 132,488/20.

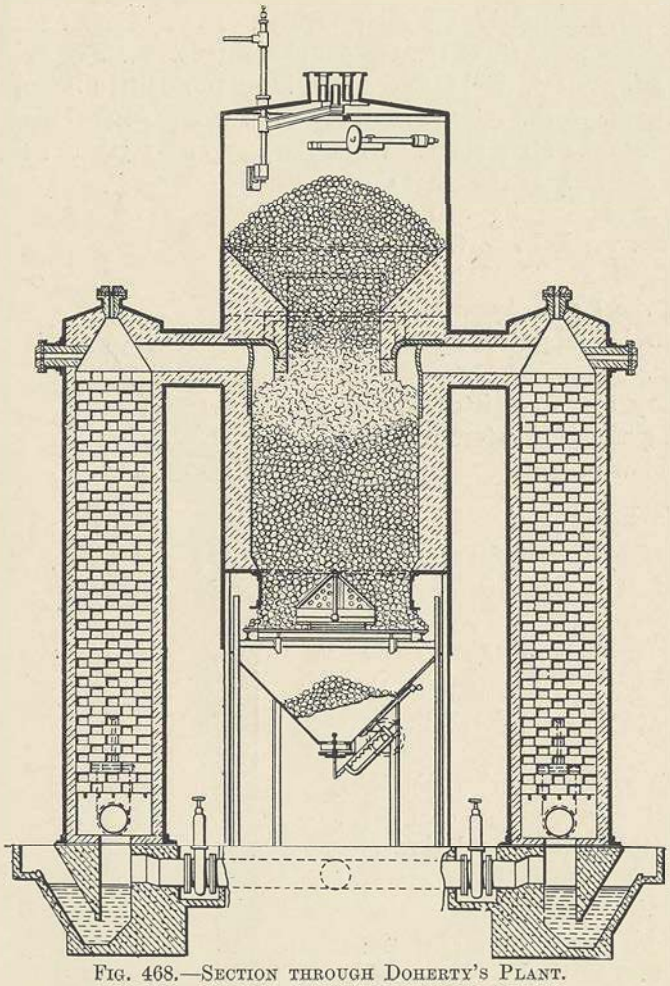


FIG. 468.—SECTION THROUGH DOHERTY'S PLANT.

column is blown intermittently, and the direction of the blow gas is generally reversed in successive blowing operations. In the gas-making operation, the air-blast is cut off; the regenerator exhaust pipes are closed; and a heat-transferring gas (generally a combustible gas, together with steam) is led into the furnace through an inlet near the bottom of the fuel column, and passes upwardly through it, counter-current to the movement of the fuel. The gas enters the column in a comparatively cool condition, absorbs heat from the coal in the lower portion, and carries it towards the hot mid-portion.

After the gas has passed through the hot mid-portion, it imparts heat to the fuel in the upper portion and leaves the column in a comparatively cool state. By means of the intermittent cross blast and the intermittent circulation of gas upwardly through the fuel column, four distinct zones are maintained in a column of fuel containing coal, viz. : (1) the hot mid-zone or combus-

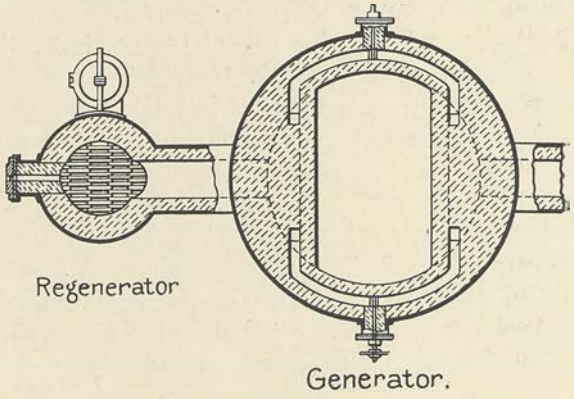


FIG. 469.

tion zone through which the cross blast is driven; (2) a relatively hot coal-carbonizing zone immediately above the combustion zone; (3) a coal-distilling and tar-condensing zone at the upper end of the column; and (4) a coke-cooling zone extending from the combustion zone to the bottom of the column. By a careful regulation of the cross blast, the heat-transferring gas, and the passage of the fuel downwardly through the furnace, the temperature in the fuel column may be controlled so that the fuel will enter and leave it in a comparatively cool state. The gases passing upwardly through the fuel column enter and leave the fuel column in a comparatively cool state, and the cross blast air enters and leaves the heat regenerators comparatively cool. In these operations, therefore, heat is always carried towards the hot mid-portion of the fuel column; the heat being recuperated from the products removed from the furnace, and utilized in the carbonization of coal and the production of gas.

The gases produced from the fuel and steam, together with the heat-transferring gas which may pass through the fuel column, are removed from the upper end of the furnace into a main and pass into a water condenser (*see* Fig. 470), whence they

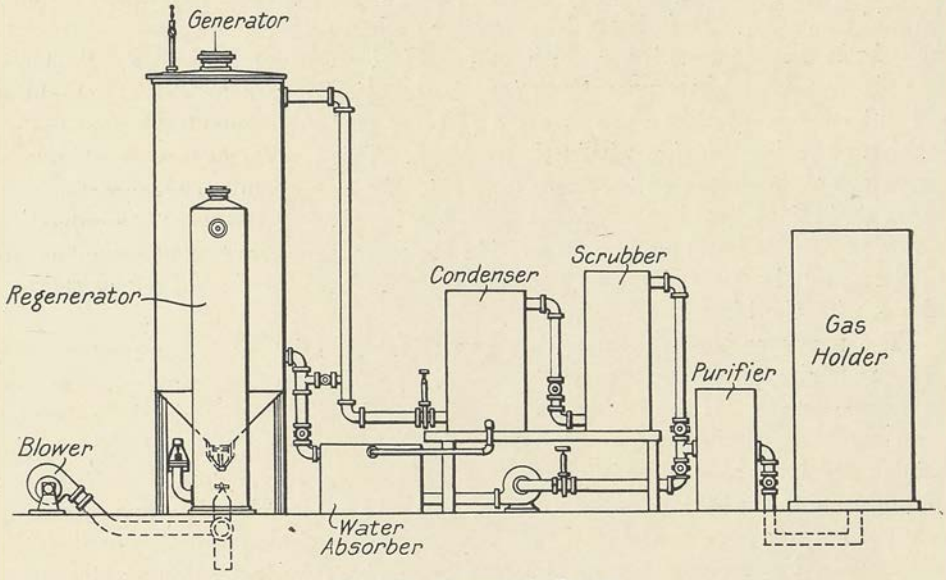


FIG. 470.—DOHERTY'S PLANT.

travel into a scrubber, then into a purifier, and finally into a gasholder. A portion of the gas advancing to the holder passes through a valve and is forced by a blower through a water-absorber. The water used in this absorber consists of that which has been previously heated in the condenser, and flows from it into the upper portion of the absorber. The increased temperature of the water over that of the incoming gas increases the temperature of the gas and results in a large amount of water vapour being carried out with the gas. The gas-water-vapour mixture passes into a conduit connected to the generator.

The furnace is arranged to support the fuel in a vertical column in such a manner that the fuel may be continuously advanced through it, while gas is being intermittently produced and coal in the fuel is being carbonized. The furnace consists of a cylindrical gas-tight metal shell provided with a refractory lining, and having a top cover in which is the charging opening, and a coke-discharging hopper at its lower end. The upper end of the lining is constructed to form a restricted opening for the passage of fuel through the coal-carbonizing zone ; and the restricted passage extends down to the upper end of the hot combustion zone. Below this the lining conforms to the shape of the shell, so as to increase the cross-sectional area of the fuel column, in order that the coal may expand and be in an open condition to assist the cross blast in penetrating through the column. Arches are arranged to form the lower portion of each side of the restricted passage immediately in front of the blast flues, and serve to direct the blast downwardly into the hot mid-zone. These arches confine the cross blast to the mid-zone and prevent a direct application of the cross blast into the coal-carbonizing zone, so that the temperature of this zone may be accurately controlled.

The fuel here consists mainly of coke ; and when the blast gases pass through the mid-zone, the coke is burned to produce carbon dioxide. The temperature of the coke in the mid-zone is very high, and the fuel-bed usually has such a thickness that the differential pressures which may be practically used for driving the blast will not entirely prevent the formation of some carbon monoxide by the decomposition of carbon dioxide within the fuel-bed. This carbon monoxide, therefore, passes out through one of the cross flues into the corresponding regenerator. To ensure that all the heat in the exhaust gases leaving the fuel-bed (heat of combustion as well as sensible heat) may be removed in the regenerators, sufficient secondary air is led around the fuel column to burn the carbon monoxide carried out of the fuel column with the blast gases.

The generator illustrated is said to be well adapted for use in conjunction with coal carbonizing plant, used for producing coke ; while the coke would be used for making water gas. If the fuel column consists entirely of coke, only three distinct zones would be maintained in the fuel column—namely : (1) the hot mid-zone through which the cross blast is forced ; (2) the coke-cooling zone extending from the hot mid-zone to the bottom of the column ; and (3) a coke-preheating zone extending from the hot mid-zone to the top of the column. Steam alone would be used as the heat-transferring medium for making gas from the coke-fuel column ; but it is preferable to use a mixture of water gas or other combustible gas and water vapours absorbed in the gas, since the gas acts as a carrying medium for introducing the water vapours into the fuel column without the necessity of heating water sufficiently high to generate steam. Further, the gas of the mixture would act as a heat-transferring medium for maintaining the distinct zones in the coke column and reducing the partial pressures at which the formation of gas takes place.

When coal is carbonized, coal (or a mixture of coal with coke—the mixture depending upon the amount of volatile material in the coal) is charged into the generator, and the four distinct zones above referred to are maintained in the fuel

column. During the gas-making operation, the air blast is shut off, the stack valves are closed, and the heat transferring gas, consisting of steam or a mixture of gas with water vapour, is circulated up through the fuel column. During the first part of the blasting operation, the heat-transferring gas is circulated up through the fuel column with sufficient velocity to hold the oils or tars condensed in the coal-distilling zone from running back into the coal-carbonizing zone. When the air blast is built-up to full pressure, the heat-transferring gas circuit is cut off, and sufficient back-pressure is placed on the final regenerator to force a portion of the blasting gas upwardly through the fuel column and so prevent the tar or oil in the column from running down into the coal-carbonizing zone. When the temperature of the hot mid-zone has been built-up sufficiently for making gas, the heat-transferring gas is circulated up through the fuel column before the air blast is entirely cut off. In this way, gas is always being circulated up through the fuel column above the hot mid-zone to prevent tar or oil from running down into the coal-carbonizing zone.

When carbonizing coal and producing gas, the temperature of the mid-zone is maintained sufficiently high to decompose the steam, and the temperature of the coal-carbonizing zone is maintained sufficiently high to decompose the pitch distilled from the coal, so that practically all the heavy tars and pitch, which condense in the coal-distilling zone and run back into the coal-carbonizing zone, are broken up into fixed gases and free carbon.

The heat-transferring gas used when carbonizing coal preferably consists of a mixture of water vapour and water gas, or any other combustible gas which will not be decomposed in passing through the hot mid-zone. In this way, the water gas acts as a carrying medium to introduce the vapour into the fuel-bed for making water gas, and a very large amount of coal can be carbonized for producing coke. If the water gas produced in the operation, however, contains coal-distillation products which will be decomposed by passing them through the hot mid-zone, it may be desirable to introduce steam only. The temperatures of the fuel column are so regulated that the gases leaving the generator will be of a temperature just sufficient to carry off steam and the low-boiling products. It is pointed out by the inventor that the sensible heat of the issuing gases is not lost, since it is employed to heat up the water of the condenser, which water is utilized in the absorber.

Carbon-Hydrogen Gas

T. O'Connell has introduced a process [1] for making what he calls carbon-hydrogen gas. Coal charged into a gas producer is subjected to a somewhat complicated series of runs and blows. The operations commonly employed are as follows :—

(1) Coal subjected to an air-blast, then a steam run, both periods being of equal duration.

(2) A second cycle similar to above.

(3) Air-blast, followed by a down run lasting five-eighths of the time of the blow.

(4) Up run, lasting three-eighths of the time of the blow.

[1] U.S.P. 1 340,495/May, 1920.

(5) Two cycles as described under (1).

(6) Three cycles as described under (3) and (4).

After the above series of operations coal is charged into the centre of the fuel-bed and the cycles as set out above are gone through again. Just prior to the time

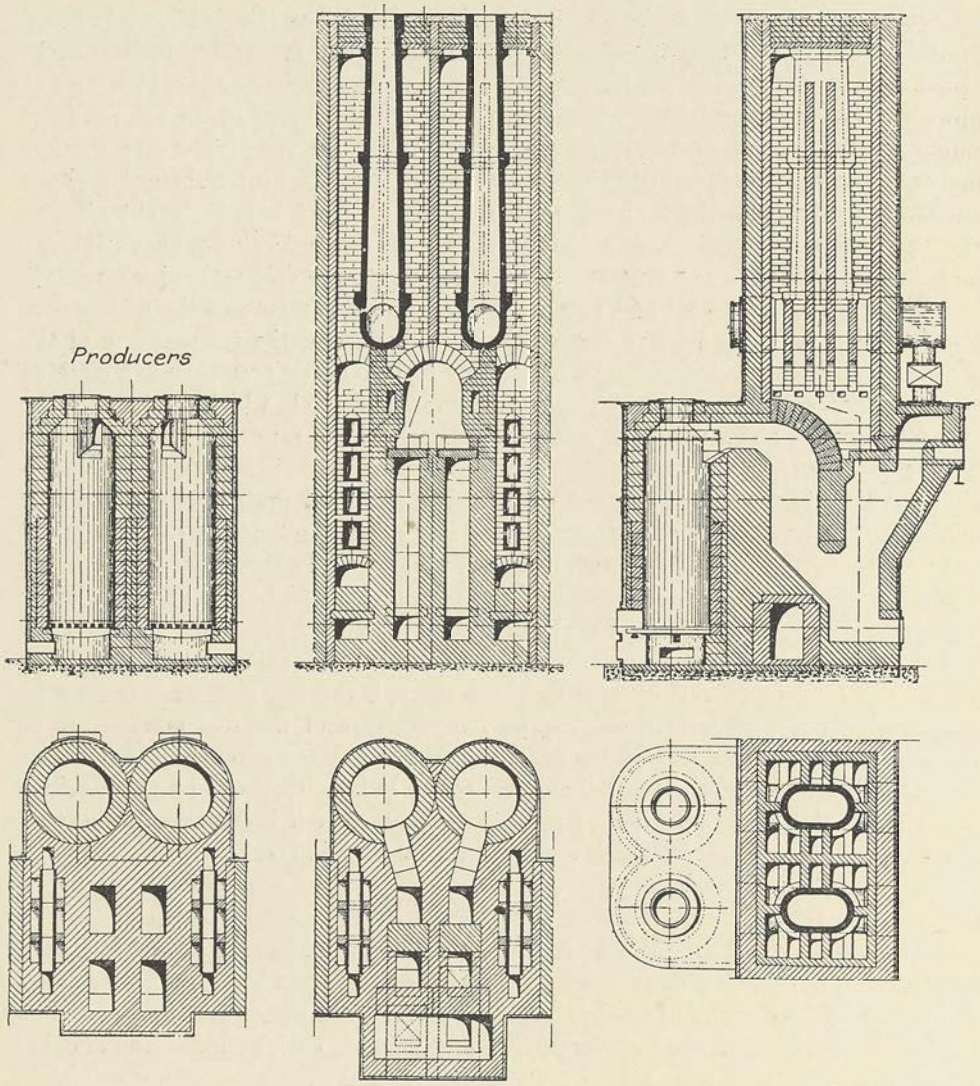


FIG. 471.—DRAKE'S COMPLETE GASIFICATION PLANT.

at which clinkering of the producer is carried out, the relative periods of up and down run are altered, the down runs being lengthened to seven-eighths of the blow period, followed by up runs of one-eighth of the blow period.

Drake's Mixed Gas Plant

Drake's plant for producing mixed gas is particularly novel in construction. It consists of two or more vertical retorts mounted upon a similar number of horizontal retorts, heated by means of special producers.

The inventors state that the plant is capable of yielding any grade of gas, the quality of which may be varied at will from a producer gas to a rich coal gas. The construction of the plant will be followed from the illustrations. Coal is fed continuously into the top of the vertical retorts which connect at their base with horizontal retorts. Carbonization of the coal is effected in the vertical portion, so that the horizontal portion contains coke only. This coke, when thoroughly carbonized, is discharged by a pusher into two producers situated directly beneath the discharged ends of the horizontal retorts. The part played by the producers is important in that they are operated with alternate runs and blows. While one of the producers is being steamed the other is being subjected to an air-blast. Thus one producer is generating " blue " water gas while the other is yielding producer gas. The blue gas is led through the coal charge in the vertical retorts, while the blow gases are passed around the combined retort system, secondary air (pre-heated by the waste gases) being admitted at the same time. Carbonization of the coal is partly effected by the sensible heat of the " blue " gas, and partly by transmitted heat of the blow products. If desired, the gases made during the blow may also be admitted to the retorts, in which case a lower quality mixed gas results. The system of runs and blows is alternately operated in the two producers.

Helps' Gas Plant

In connection with this process the inventor states that complete gasification presupposes low-grade gas, and inerts are invariably present in comparatively large quantities. Helps submits, however, that even nitrogen is not always a disadvantage, because " a high grade gas diluted with nitrogen may give a better duty than high-grade gas without it. The effect of nitrogen in flames has not, so far, been thoroughly investigated ; but where nitrogen enables the proper proportion of air to be admitted to the burner tube, through the power it exerts in injecting the necessary primary air, better results are obtained than when such power in the gas at the nipple of an atmospheric burner is wanting. The presence of nitrogen in the gas not only reduces the air required, but it has the same injective power as the air-requiring constituents of the gas."

If it is possible to use the sensible heat in the producer gas to carbonize coal or generate steam, or do other required work, the heat losses would be reduced in the proportion of the sensible heat utilized.

There is no difficulty in working when the heat required to carbonize the coal is contained in the "blue" superheated water gas made ; but if the superheated water gas does not contain sufficient heat for the purpose, such heat may be augmented by any of the following means separately or in combination : (1) The combustion of " blue " water gas or a mixed gas externally to the carbonizing retort ; (2) the sensible

heat in the blows, by leading blow gases into the carbonizing retort, or applied outside in the retort ; (3) the sensible heat in the producer gas, by leading producer gas into the carbonizing retort, or applied outside the retort ; (4) the combustion of producer gas externally to the carbonizing retort ; (5) high-pressure or superheated steam applied outside the retort.

The effect of using hot superheated water gas for the carbonizing process is to give a better quality of gas. When the sensible heat of producer gas or the heat of the combustion of producer gas is used, the quality of gas made is reduced.

Plant for carrying out a process of this type comprises, according to this invention, a generator, a vertical retort, separate from the generator, whose outlet is above the generator and in proximity thereto, and means for admitting gases from

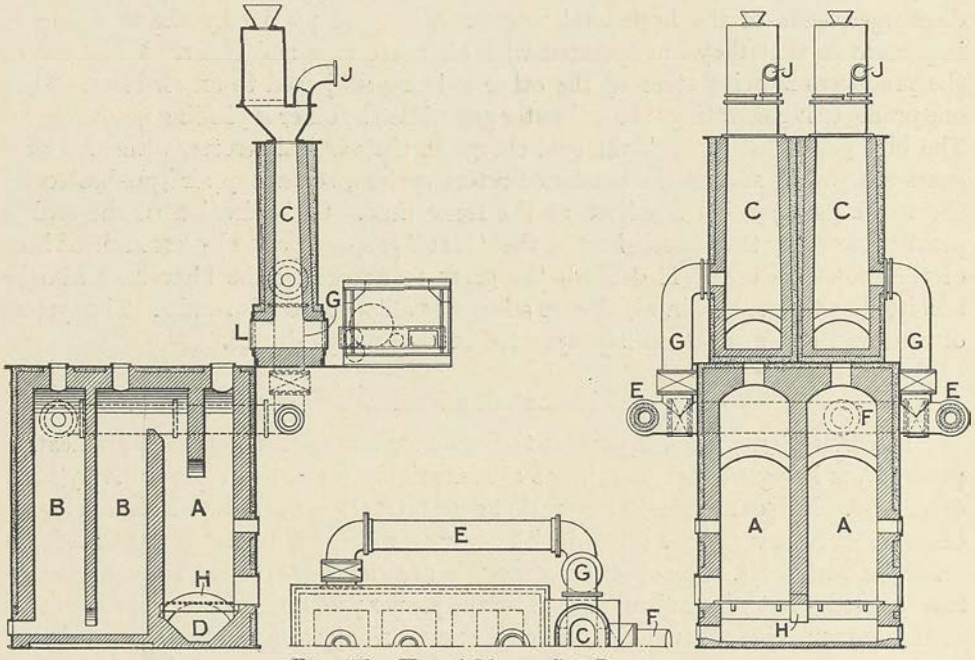


Fig. 472.—Helps' Mixed Gas Plant.

the generator into the retort. The generating element comprises in one structure a fuel chamber and a superheater, while the retort is of inverted tee-shape, the base, or horizontal portion of the tee being directly above an inlet to the fuel chamber. The plant is shown in Fig. 472. The generators are shown at A, the superheaters at B, and the retorts at C. The air-blast passes into the generators, down through the first superheater, and up through the second. Thence through pipes (E and F) to a boiler which generates the necessary steam. Steam is then introduced in one superheater at the top and, passing through the chequer work, reaches the generator. It travels through this in a downward direction under the arch H dividing the generators, and up through the second generator ; then on through the other pair of superheaters into the mains E and G, which lead to the retorts. Here the " blue "

gas becomes mixed with the coal gas it evolves from the coal in the retort, and goes forward through the pipe J to the collecting main, and so on through the washing

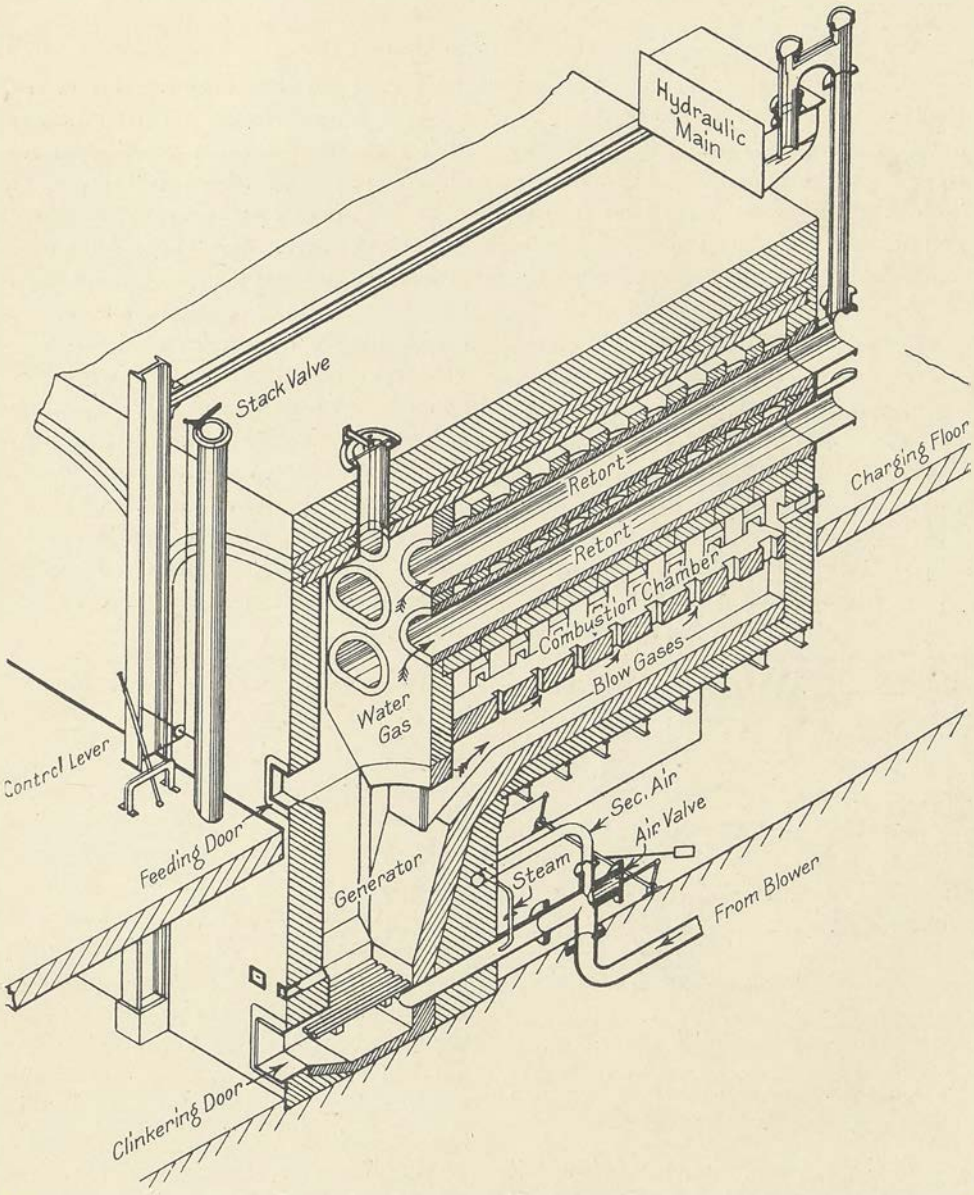


FIG. 473.—ROBINSON'S MIXED GAS PLANT.

and purifying plant to the holder. The coal enters the retort through the feeding hopper and, as it is converted into coke, it is discharged through openings L into the generator, or quenched and removed for sale.

When the vessel A is used for making producer gas or semi-water gas, the producer gas may enter the retort C through the pipes E and G or pass through the pipes F for any desired purpose.

Robinson's Mixed Gas Plant

A diagrammatic illustration of Robinson's mixed gas plant is shown in Fig. 473. Ordinary horizontal retorts of the "through" type are shortened, and terminate in a water-gas generator. The generator, which occupies the same position in the setting as the customary producer, is operated on the principle of "run" and "blow." The blow gases pass into the combustion chamber, around the retorts, and finally travel out of the setting by way of the stack valve. The "blue" water gas made during the run passes through the retorts above the coal charge and scavenges out the coal gas, the mixture travelling direct to the hydraulic main. The inventor states that by modifying the conditions of gas-making it is possible to vary the quality of the final mixture obtained between the limits of 280 and 460 B.Th.U. per cubic foot. Only ash and clinker are removed from the plant, and it is possible to obtain 18 million gaseous B.Th.U. per ton of coal employed.

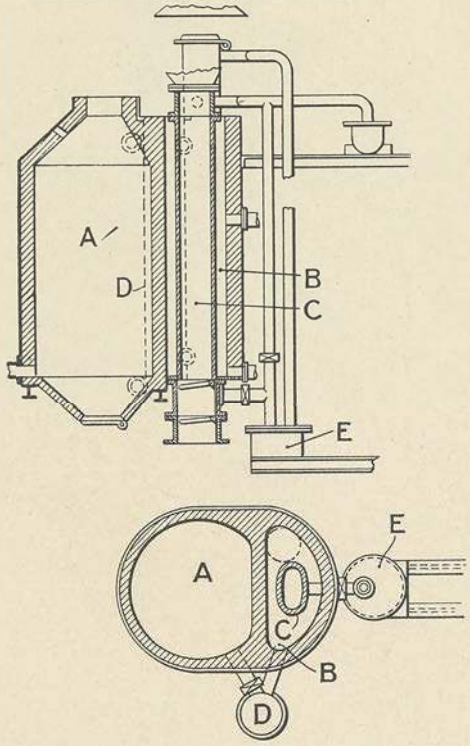


Fig. 474.—Knight and Siddall's Combined Plant.

Knight and Siddall's Combined Plant

This plant, as made by R. & J. Dempster,[1] consists, in one form, of a generator (A), Fig. 474, operated on the water-gas principle. A second chamber (B) erected within the same shell contains a vertical retort (C) provided with two bottom doors. Air is blown into the generator (A), the blow gases travelling by way of an external conduit (D) into the chamber (B), being burnt around the vertical retort and passing out by the stack valve. In this way the coal in the retort is partially carbonized; but, during the run, when steam is admitted to the generator, the water gas produced is partly burned in the chamber (B) until sufficient heat is obtained. At the end of this operation the water gas, instead of being burned, passes through the chamber (B) into a seal (E), and thence into the base of the vertical retort. Distillation is, therefore, carried out continuously.

[1] E.P. 18,076/1920.

Appendix

DENSITY OF VARIOUS GASES

	Density (Air = 1).	Cubic feet per lb. at 60° F. (15° C.).
Air	1	13·145
Acetylene	0·8988	14·625
Ammonia	0·5895	22·301
Carbon dioxide	1·5201	8·647
Carbon monoxide	0·9673	13·590
Cyanogen (CN)	1·7993	7·306
Ethane	1·0381	12·662
Ethylene	0·9784	13·435
Hydrogen	0·0696	188·800
Methane	0·5539	23·732
Nitrogen	0·9701	13·551
Oxygen	1·1055	11·890
Propylene	1·4527	9·049
Sulphur dioxide	2·2131	5·939
Coal gas (straight)	0·4200	31·300
Water gas (blue)	0·5570	22·860

USEFUL CONVERSION FACTORS

To Convert	*To*	*Multiply by*
Atmospheres	Mm. of mercury	760
Atmospheres	Pounds per sq. in.	14·7
British Thermal Units	Calories	0·252
British Thermal Units	Foot lb.	777
British Thermal Units	Watt hours	0·293
B.Th.U. per cub. ft.	Calories per centimetre	8·90
Calories	British Thermal Units	3·968
Calories per cubic centimetre	B.Th.U. per cub. ft.	0·1124
Calories per cubic metre	B.Th.U. per cub. ft.	0·1123

To Convert	*To*	*Multiply by*
Calories per kilo.	B.Th.U. per lb.	1·800
Centimetres	Inches	0·394
Cubic centimetres	Cubic inches	0·0610
Cubic ft.	Cubic metres	0·0283
Cubic ft.	Gallons	6·25
Cubic in.	Cubic centimetres	16·4
Cubic metres	Cubic feet	35·315
Cubic metres	Cubic yards	1·307
Cubic yards	Cubic metres	0·765
Feet	Metres	0·3048
Foot lb.	B.Th.U.	0·00129
Gallons	Litres	4·546
Gallons	Cubic ft.	0·160
Grains	Grammes	0·0648
Grammes	Grains	15·44
Grammes	Pounds (average)	0·002205
Grammes per cub. centimetre	Pounds per cub. ft.	62·4
Horse-power	Kilowatts	0·746
Inches	Centimetres	2·54
Inches (mercury gauge)	Atmospheres	0·0333
Inches (mercury gauge)	Inches (water gauge)	13·6
Inches (mercury gauge)	Pounds per sq. in.	0·490
Inches (water gauge)	Pounds per sq. in.	0·0360
Kilogrammes	Pounds	2·205
Kilos. per sq. centimetre	Pounds per sq. in.	14·22
Kilometres	Miles	0·6214
Kilowatts	B.Th.U. per sec.	0·949
Kilowatts	Calories per sec.	0·239
Kilowatts	Foot lb. per sec.	738
Kilowatts	Horse-power	1·341
Litres	Gallons	0·220
Metres	Feet	3·281
Metres	Inches	39·37
Metres	Yards	1·094
Millimetres	Inches	0·03937
Pounds (Avoir.)	Kilogrammes	0·454
Pounds per sq. ft.	Kilos. per sq. metre	4·88
Pounds per sq. in.	Kilogrammes per sq. cm.	0·0703
Square ft.	Square metres	0·093
Square metres	Square yards	1·196
Square miles	Square kilometres	2·59
Therms	B.Th.U.	100,000
Tons	Kilogrammes	1015·6
Tons per sq. in.	Atmospheres	152·4
Yards	Metres	·9144

DATA RELATING TO HEAT AND WORK

1 British Thermal Unit	=	778 ft. lb.
	=	0·252 kg. calorie.
3·968 ,, ,, Units	=	1 kg. cal.
2,545 ,, ,, ,,	=	1 h.p. hour (British).
	=	641 kg. cals.
	=	746 watts.
1·34 h.p. hours	=	1 k.w. hour.
	=	3,410 B.Th.U.
	=	858 kg. cals.
1 Therm.	=	39·3 h.p. hours.

SULPHATE OF AMMONIA

Average commercial salt contains :—

Ammonia	from $24\frac{1}{2}$ to $25\frac{1}{4}$%
Equal to—	
Nitrogen	20·2 to 20·8%
Free acid	0·4%
Moisture	2 to 3%

Materials required for the manufacture of 1 ton of sulphate of ammonia :—

Liquor, approximately	3,400 gallons of 8 oz. strength.
Acid	18 cwt. at 80% strength.
Lime	3 cwt.

The sulphate of ammonia recovered per ton of coal varies in this country between 24 and 28 lb.

Equation for formation :—

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4.$$

Gallons of liquor × ounce strength × 0·0823 = lb. of sulphate.

CAPACITY OF TAR AND LIQUOR PUMPS

DUPLEX PUMPS (*e.g.* "ODDESSE" TYPE)

Capacity, gal. per hour.		Diameter of Cylinders.		Stroke.	Minimum steam pressure required for lifting 50 feet.
Tar.	Liquor.	Steam end.	Pump end.		
2,000	3,000	6 inches	4 inches	6 inches	20 lb. sq. inch
2,400	3,600	6 ,,	$4\frac{1}{2}$,,	6 ,,	25 ,, ,,
3,000	4,500	7 ,,	5 ,,	6 ,,	25 ,, ,,
4,250	6,350	6 ,,	6 ,,	6 ,,	35 ,, ,,
5,900	8,800	6 ,,	7 ,,	6 ,,	50 ,, ,,
6,800	10,200	6 ,,	$7\frac{1}{2}$,,	6 ,,	55 ,, ,,
10,000	15,000	8 ,,	8 ,,	10 ,,	35 ,, ,,
15,000	22,500	10 ,,	10 ,,	10 ,,	35 ,, ,,
22,000	33,000	12 ,,	12 ,,	10 ,,	35 ,, ,,

When dealing with tar the stroke of the pump should not be less than 6 inches, while the effective plunger speed should not be greater than 50 feet per minute. To ensure smooth and consistent working with a viscous liquid such as tar it is essential that the suction pipe should be of ample size. The cross-sectional area of the suction pipe should, in fact, be 50 per cent. greater than the cross-sectional area of the suction inlet on the pump. Thus, for a pump with a 3-inch suction inlet a 4-inch suction pipe should be fitted.

SINGLE CYLINDER PUMPS

Capacity, gal. per hour.		Diameter of Cylinders.		Stroke.	Minimum steam pressure required for lifting 50 feet.
Tar.	Liquor.	Steam end.	Pump end.		
400	600	3 inches	2 inches	9 inches	20 lb. sq. inch.
630	900	3 ,,	2½ ,,	9 ,,	30 ,, ,,
900	1,350	3 ,,	3 ,,	9 ,,	35 ,, ,,
1,600	2,400	4 ,,	4 ,,	9 ,,	35 ,, ,,

With tar a single cylinder pump is preferable to a two-cylinder type for deliveries of under 2,000 gallons per hour. The above capacities in both tables are those given at normal (not maximum) working speeds.

HYDROMETERS

TWADDELL'S.—Each degree is equal to 5° Specific Gravity; to find the equivalent multiply by 5 and add 1,000.

BAUMÉ'S for liquids heavier than water.

To reduce Baumé's to Specific Gravity. $$\frac{144}{144-\text{Baumé.}} = \text{Specific Gravity.}$$

To reduce Specific Gravity to Baumé. $$144 - \frac{144}{\text{Specific Gravity}} = \text{Baumé.}$$

Baumé for liquids lighter than water.

To reduce Baumé to Specific Gravity. $$\frac{144}{\text{Baumé} + 134} = \text{Specific Gravity.}$$

To reduce Specific Gravity to Baumé. $$\frac{144}{\text{Specific Gravity}} - 134 = \text{Baumé.}$$

WATER

	Fresh.	Salt.
Greatest density at	39·2° F.	Freezing-point
1 cub. ft. at 39·2° weighs	62·348 lb.	64 lb.
1 cub. in. ,, ,, ...	·036081 lb.	·037037 lb.
1 cub. ft. ,, equals	6·228 gal.	6·2 gal.
1 gal. weighs	10 lb.	10·3 lb.
1 ton equals	35·943 cub. ft.	35 cub. ft.
1 ton contains	224 gal.	217 gal.
Freezes at	32° F.	27° F.

GAS METERS

Size of Meter.	Normal Capacity.	Safe Maximum Capacity.
Lights.	Cub. ft. per hour.	Cub. ft. per hour.
5	30	60
10	60	100
20	120	200
30	180	300
50	300	450
60	360	480
80	480	600
100	600	750
150	900	1,100
200	1,200	1,500
250	1,500	1,900
300	1,800	2,300
400	2,400	3,000
500	3,000	3,700
600	3,600	4,500
800	4,400	6,000
1,000	5,000	7,500

DISCHARGE OF GAS THROUGH PIPES

Pole's formula :—

$$V = 1350 d^2 \sqrt{\frac{p.d.}{s.l.}}$$

$$\text{or } d = \sqrt[5]{\frac{V^2 s.l.}{(1350)^2 . p}}$$

where V = gas discharged in cubic feet per hour.
d = diameter of pipe in inches.
p = pressure in inches of water.
s = specific gravity of gas (air = 1).
l = length of pipe in yards.

Pole's formula gives sufficiently accurate results in cases where gas is supplied under normal low pressure (*i.e.* up to 6 inches water gauge). For high pressure distribution Unwin's formula should be used.

Unwin's formula :—

$$O = 1{,}323{,}250 \sqrt{\frac{P_1^2 - P_2^2}{P_1^2} \times \frac{P_1^2}{P_2^2} \times \frac{D^5}{C.S.L.}}$$

where O = gas discharged in cubic feet per hour.
P_1 = initial pressure in lb. per sq. in. (absolute).
P_2 = final ,, ,, ,, ,,
D = diameter of pipe in feet.
S = specific gravity of gas (air = 1).
L = length of pipe in feet.
C = coefficient of friction = $0{\cdot}0044 \left(1 + \frac{1}{7D}\right)$.

STANDARD SOCKET AND SPIGOT PIPES

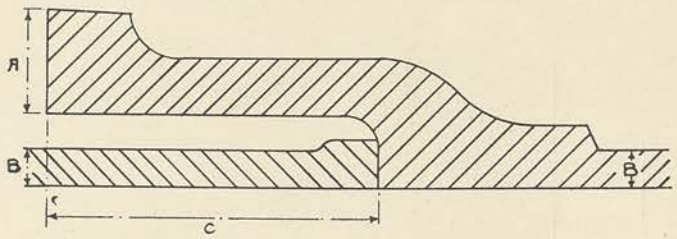


FIG. 475.

Internal Diameter of Pipe.	A.	B.	C.	Length of Pipe.		Weight of Pipe.			
Inches.	Inches.	Inches.	Inches.	Ft.	In.	Tons.	Cwt.	Qrs.	Lb.
2	$\frac{3}{4}$	$\frac{5}{16}$	3	6	0	0	0	1	0
3	$1\frac{1}{16}$	$\frac{3}{8}$	$3\frac{3}{4}$	9	0	0	1	0	0
4	$1\frac{1}{8}$	$\frac{3}{8}$	4	9	0	0	1	2	0
5	$1\frac{3}{8}$	$\frac{7}{16}$	$4\frac{1}{4}$	9	0	0	2	0	0
6	$1\frac{3}{8}$	$\frac{7}{16}$	$4\frac{1}{4}$	9	0	0	2	2	0
7	$1\frac{3}{8}$	$\frac{7}{16}$	$4\frac{1}{4}$	9	0	0	3	1	0
8	$1\frac{9}{16}$	$\frac{1}{2}$	$4\frac{1}{4}$	9	0	0	3	2	0
9	$1\frac{9}{16}$	$\frac{1}{2}$	$4\frac{1}{4}$	9	0	0	4	0	0
10	$1\frac{9}{16}$	$\frac{1}{2}$	$4\frac{1}{4}$	9	0	0	4	2	0
12	$1\frac{5}{8}$	$\frac{9}{16}$	$4\frac{1}{2}$	12	0	0	8	2	0
14	$1\frac{7}{8}$	$\frac{5}{8}$	$4\frac{1}{2}$	12	0	0	10	0	0
15	$1\frac{7}{8}$	$\frac{5}{8}$	$4\frac{1}{2}$	12	0	0	11	2	0
16	$1\frac{7}{8}$	$\frac{3}{4}$	$4\frac{1}{2}$	12	0	0	12	2	0
18	2	$\frac{3}{4}$	$4\frac{1}{2}$	12	0	0	14	2	0
20	$2\frac{1}{8}$	$\frac{3}{4}$	$4\frac{1}{2}$	12	0	0	17	3	0
21	$2\frac{1}{8}$	$\frac{3}{4}$	$4\frac{1}{2}$	12	0	0	18	3	0
24	$2\frac{3}{8}$	$\frac{13}{16}$	$4\frac{3}{4}$	12	0	1	1	2	0
30	$2\frac{3}{8}$	$\frac{7}{8}$	5	12	0	1	8	0	0
33	$2\frac{1}{2}$	$\frac{7}{8}$	5	12	0	1	13	0	0
36	$2\frac{5}{8}$	1	$5\frac{1}{4}$	12	0	1	18	0	0
42	$2\frac{13}{16}$	$1\frac{1}{8}$	$5\frac{1}{4}$	12	0	2	10	0	0
48	$2\frac{13}{16}$	$1\frac{1}{8}$	$5\frac{1}{4}$	12	0	3	0	0	0

APPROXIMATE WEIGHT OF JOINTING MATERIALS PER JOINT

Spigot and Faucet Pipes.			Flanged Pipes.						
			India Rubber.			Bolts and Nuts.			
Inside Diam.*	Lead.	Rope Yarn.	Inside Diam.*	Faced all over.	Faced on Strips.	No.	Diam.	Length.	Weight.
In.	Lb.	Oz.	In.	Oz.	Oz.		In.	In.	Lb.
$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	2	$1\frac{5}{8}$	$\frac{7}{8}$	4	$\frac{1}{2}$	$2\frac{3}{8}$	$1\frac{1}{4}$
1	$\frac{3}{4}$	1	$2\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{3}$	4	$\frac{9}{16}$	$2\frac{1}{2}$	$1\frac{1}{2}$
$1\frac{1}{4}$	1	1	$2\frac{1}{2}$	2	$1\frac{1}{3}$	4	$\frac{9}{16}$	$2\frac{1}{2}$	$1\frac{1}{2}$
$1\frac{1}{2}$	$1\frac{1}{4}$	1	3	2	2	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
$1\frac{1}{2}$	$1\frac{1}{4}$	1	3	2	2	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
2	$1\frac{3}{4}$	$1\frac{1}{4}$	3	2	2	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
2	$1\frac{3}{4}$	$1\frac{1}{4}$	3	2	2	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
2	$1\frac{3}{4}$	$1\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{2}{3}$	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
$2\frac{1}{2}$	2	$1\frac{1}{2}$	$3\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{2}{3}$	4	$\frac{9}{16}$	$2\frac{5}{8}$	$1\frac{1}{2}$
$2\frac{1}{2}$	2	$1\frac{1}{2}$	4	$2\frac{7}{8}$	$3\frac{1}{4}$	4	$\frac{9}{16}$	$2\frac{3}{4}$	$1\frac{3}{4}$
$2\frac{1}{2}$	2	$1\frac{1}{2}$	4	$2\frac{7}{8}$	$3\frac{1}{4}$	4	$\frac{9}{16}$	$2\frac{3}{4}$	$1\frac{3}{4}$
3	$2\frac{1}{4}$	2	4	$2\frac{7}{8}$	$3\frac{1}{4}$	4	$\frac{9}{16}$	$2\frac{3}{4}$	$1\frac{3}{4}$
3	$2\frac{1}{4}$	2	4	$2\frac{7}{8}$	$3\frac{1}{4}$	4	$\frac{9}{16}$	$2\frac{3}{4}$	$1\frac{3}{4}$
3	$2\frac{1}{4}$	2	$4\frac{1}{2}$	$3\frac{1}{4}$	4	4	$\frac{5}{8}$	3	$2\frac{1}{4}$
$3\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$4\frac{1}{2}$	$3\frac{1}{4}$	4	4	$\frac{5}{8}$	3	$2\frac{1}{4}$
4	$3\frac{3}{8}$	$2\frac{3}{4}$	5	$3\frac{1}{2}$	5	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
4	$3\frac{3}{8}$	$2\frac{3}{4}$	5	$3\frac{1}{2}$	5	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
$4\frac{1}{2}$	$3\frac{3}{4}$	$3\frac{1}{2}$	$5\frac{1}{2}$	$3\frac{3}{4}$	$5\frac{1}{2}$	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
5	6	4	6	$4\frac{1}{4}$	6	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
5	6	4	6	$4\frac{1}{4}$	6	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
$5\frac{1}{2}$	7	$4\frac{1}{2}$	6	$4\frac{1}{4}$	6	6	$\frac{5}{8}$	3	$3\frac{1}{2}$
6	8	$5\frac{1}{2}$	7	$5\frac{1}{4}$	8	6	$\frac{5}{8}$	$3\frac{1}{8}$	$3\frac{1}{2}$
6	8	$5\frac{1}{2}$							
7	$8\frac{1}{2}$	$6\frac{1}{4}$							
7	$8\frac{1}{2}$	$6\frac{1}{4}$							

* Macfarlane, Strang & Co., Ltd.

DIMENSIONS AND WEIGHT OF WROUGHT IRON PIPES

Nominal Bore in Inches.	Approximate Outside Diam. in Inches.	Threads per Inch.	Gas.		Water.		Steam.	
			I.W.G.	Weight in lb. per ft.	I.W.G.	Weight in lb. per ft.	I.W.G.	Weight in lb. per ft.
				Black.		Black.		Black.
$\frac{1}{8}$	$\frac{13}{32}$	28	14	·275	13	·3	12	·33
$\frac{1}{4}$	$\frac{17}{32}$	19	14	·38	13	·425	12	·47
$\frac{3}{8}$	$\frac{11}{16}$	19	13	·58	12	·64	11	·7
$\frac{1}{2}$	$\frac{27}{32}$	14	12	·81	11	·9	10	·97
$\frac{3}{4}$	$1\frac{1}{16}$	14	11	1·16	10	1·27	9	1·4
1	$1\frac{11}{32}$	11	10	1·6	9	1·78	8	1·96
$1\frac{1}{4}$	$1\frac{11}{16}$	11	9	2·36	8	2·6	7	2·84
$1\frac{1}{2}$	$1\frac{29}{32}$	11	8	3·0	7	3·25	6	3·5
$1\frac{3}{4}$	$2\frac{5}{32}$	11	8	3·6	7	3·8	6	4·0
2	$2\frac{3}{8}$	11	7	4·1	6	4·5	5	4·9
$2\frac{1}{4}$	$2\frac{5}{8}$	11	7	4·602	6	4·98	5	5·475
$2\frac{1}{2}$	3	11	7	5·334	6	5·775	5	6·318
$2\frac{3}{4}$	$3\frac{1}{4}$	11	7	5·842	6	6·325	5	6·921
3	$3\frac{1}{2}$	11	7	6·326	6	6·851	5	7·499
$3\frac{1}{2}$	4	11	7	7·162	6	7·759	5	8·5
4	$4\frac{3}{8}$	11	7	8·051	6	8·723	5	9·555
$4\frac{1}{4}$	$4\frac{1}{2}$	11	7	8·282	6	8·975	5	9·833
$4\frac{1}{2}$	5	11	7	9·083	6	9·839	5	10·776
5	$5\frac{1}{2}$	11	7	10·17	6	11·009	5	12·051
$5\frac{1}{2}$	6	11	7	11·494	6	12·438	5	13·61
6	$6\frac{1}{2}$	11	7	12·573	6	13·601	5	14·878

WEIGHT OF STEEL BARS IN LB. PER FOOT

Size.	Square.	Round.	Octagon.	Hexagon.
Inches.	Lb.	Lb.	Lb.	Lb.
$\frac{1}{4}$	·213	·167	·18	·19
$\frac{5}{16}$	·332	·261	·28	·29
$\frac{3}{8}$	·478	·376	·41	·42
$\frac{7}{16}$	·651	·511	·45	·57
$\frac{1}{2}$	·849	·668	·72	·75
$\frac{9}{16}$	1·076	·845	·91	·94
$\frac{5}{8}$	1·328	1·043	1·12	1·17
$\frac{11}{16}$	1·607	1·262	1·36	1·41
$\frac{3}{4}$	1·912	1·502	1·62	1·68
$\frac{13}{16}$	2·245	1·763	1·90	1·97
$\frac{7}{8}$	2·603	2·044	2·20	2·29
$\frac{15}{16}$	2·988	2·147	2·53	2·62
1	3·400	2·670	2·87	2·99
$1\frac{1}{16}$	3·850	3·030	3·25	3·37
$1\frac{1}{8}$	4·303	3·380	3·64	3·78
$1\frac{3}{16}$	4·810	3·790	4·06	4·21
$1\frac{1}{4}$	5·312	4·172	4·50	4·66
$1\frac{5}{16}$	5·880	4·630	4·96	5·14
$1\frac{3}{8}$	6·428	5·049	5·45	5·65
$1\frac{7}{16}$	7·050	5·550	5·95	6·17
$1\frac{1}{2}$	7·750	6·008	6·48	6·72
$1\frac{9}{16}$	8·330	6·560	7·03	7·29
$1\frac{5}{8}$	8·978	7·051	7·61	7·89
$1\frac{11}{16}$	9·720	7·650	8·20	8·50
$1\frac{3}{4}$	10·412	8·178	8·82	9·14
$1\frac{13}{16}$	11·210	8·830	9·46	9·81
$1\frac{7}{8}$	11·953	9·388	10·12	10·50
$1\frac{15}{16}$	12·810	10·090	10·81	11·21
2	13·600	10·681	11·52	11·95
$2\frac{1}{8}$	15·410	12·140	13·00	13·49
$2\frac{1}{4}$	17·280	13·610	14·58	15·12
$2\frac{3}{8}$	19·250	15·160	16·24	16·85
$2\frac{1}{2}$	21·330	16·800	18·00	18·66
$2\frac{5}{8}$	23·520	18·522	19·84	20·58
$2\frac{3}{4}$	25·810	20·330	21·78	22·59
$2\frac{7}{8}$	28·210	22·220	23·80	24·69
3	30·720	24·190	25·92	26·88

WHITWORTH STANDARD BOLTS AND NUTS

Diameter of Bolt.	Bolt Head and Nuts.			Threads per Inch.	Pitch in Inches.	Diameter of Tapping Hole.
	Width across Flats.	Width across Corners.	Height of Bolt Head.			
In.	In. In.	In. In.	In. In.			In. In.
$\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{2}$ and $\frac{1}{16}$	$\frac{1}{8}$ and $\frac{1}{32}$	24	0·041	$\frac{1}{8}$ and $\frac{1}{64}$
$\frac{1}{4}$	$\frac{1}{2}$ and $\frac{1}{64}$	$\frac{9}{16}$,, $\frac{3}{64}$	$\frac{3}{16}$,, $\frac{1}{32}$	20	0·050	$\frac{3}{16}$
$\frac{5}{16}$	$\frac{9}{16}$,, $\frac{3}{64}$	$\frac{11}{16}$	$\frac{1}{4}$,, $\frac{1}{64}$	18	0·055	$\frac{1}{4}$
$\frac{3}{8}$	$\frac{11}{16}$,, $\frac{1}{64}$	$\frac{13}{16}$	$\frac{5}{16}$,, $\frac{1}{64}$	16	0·0625	$\frac{1}{4}$,, $\frac{3}{64}$
$\frac{7}{16}$	$\frac{13}{16}$,, $\frac{1}{64}$	$\frac{15}{16}$,, $\frac{1}{64}$	$\frac{3}{8}$	14	0·071	$\frac{5}{16}$,, $\frac{3}{64}$
$\frac{1}{2}$	$\frac{7}{8}$,, $\frac{1}{32}$	$1\frac{1}{16}$	$\frac{7}{16}$	12	0·083	$\frac{3}{8}$,, $\frac{1}{32}$
$\frac{9}{16}$	1 ,, $\frac{1}{64}$	$1\frac{1}{8}$,, $\frac{1}{32}$	$\frac{7}{16}$,, $\frac{3}{64}$	12	0·083	$\frac{7}{16}$,, $\frac{1}{32}$
$\frac{5}{8}$	1 ,, $\frac{3}{32}$	$1\frac{1}{4}$,, $\frac{1}{64}$	$\frac{1}{2}$,, $\frac{3}{64}$	11	0·091	$\frac{1}{2}$,, $\frac{1}{64}$
$\frac{11}{16}$	$1\frac{3}{16}$,, $\frac{1}{64}$	$1\frac{3}{8}$,, $\frac{1}{64}$	$\frac{9}{16}$,, $\frac{1}{32}$	11	0·091	$\frac{9}{16}$,, $\frac{1}{64}$
$\frac{3}{4}$	$1\frac{1}{4}$,, $\frac{3}{64}$	$1\frac{1}{2}$	$\frac{5}{8}$,, $\frac{1}{32}$	10	0·100	$\frac{5}{8}$
$\frac{13}{16}$	$1\frac{3}{8}$,, $\frac{1}{64}$	$1\frac{9}{16}$,, $\frac{1}{32}$	$\frac{11}{16}$,, $\frac{1}{64}$	10	0·100	$\frac{11}{16}$
$\frac{7}{8}$	$1\frac{7}{16}$,, $\frac{3}{64}$	$1\frac{11}{16}$,, $\frac{1}{64}$	$\frac{3}{4}$,, $\frac{1}{64}$	9	0·111	$\frac{11}{16}$,, $\frac{3}{64}$
$\frac{15}{16}$	$1\frac{9}{16}$,, $\frac{1}{64}$	$1\frac{13}{16}$,, $\frac{1}{64}$	$\frac{13}{16}$	9	0·111	$\frac{3}{4}$,, $\frac{3}{64}$
1	$1\frac{5}{8}$,, $\frac{3}{64}$	$1\frac{15}{16}$,, $\frac{1}{64}$	$\frac{7}{8}$	8	0·125	$\frac{13}{16}$,, $\frac{1}{32}$
$1\frac{1}{8}$	$1\frac{13}{16}$,, $\frac{3}{64}$	$2\frac{1}{8}$,, $\frac{1}{32}$	$\frac{15}{16}$,, $\frac{3}{64}$	7	0·143	$\frac{15}{16}$,, $\frac{1}{64}$
$1\frac{1}{4}$	2 ,, $\frac{3}{64}$	$2\frac{5}{16}$,, $\frac{1}{64}$	$1\frac{1}{16}$,, $\frac{1}{32}$	7	0·143	$1\frac{1}{16}$
$1\frac{3}{8}$	$2\frac{3}{16}$,, $\frac{1}{32}$	$2\frac{1}{2}$,, $\frac{3}{64}$	$1\frac{3}{16}$,, $\frac{1}{64}$	6	0·166	$1\frac{1}{8}$,, $\frac{3}{64}$
$1\frac{1}{2}$	$2\frac{3}{8}$,, $\frac{1}{32}$	$2\frac{3}{4}$,, $\frac{1}{32}$	$1\frac{5}{16}$	6	0·166	$1\frac{1}{4}$,, $\frac{3}{64}$
$1\frac{5}{8}$	$2\frac{9}{16}$,, $\frac{1}{64}$	$2\frac{15}{16}$,, $\frac{1}{32}$	$1\frac{3}{8}$,, $\frac{3}{64}$	5	0·200	$1\frac{3}{8}$
$1\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{3}{16}$	$1\frac{1}{2}$,, $\frac{1}{32}$	5	0·200	$1\frac{1}{2}$
$1\frac{7}{8}$	$3\frac{1}{16}$	$3\frac{7}{16}$,, $\frac{3}{64}$	$1\frac{5}{8}$,, $\frac{1}{64}$	$4\frac{1}{2}$	0·222	$1\frac{9}{16}$,, $\frac{1}{32}$
2	$3\frac{1}{8}$,, $\frac{1}{32}$	$3\frac{5}{8}$	$1\frac{3}{4}$	$4\frac{1}{2}$	0·222	$1\frac{11}{16}$,, $\frac{1}{32}$
$2\frac{1}{4}$	$3\frac{1}{2}$,, $\frac{3}{64}$	$4\frac{1}{16}$,, $\frac{1}{32}$	$1\frac{15}{16}$,, $\frac{1}{32}$	4	0·250	$1\frac{15}{16}$
$2\frac{1}{2}$	$3\frac{7}{8}$,, $\frac{1}{64}$	$4\frac{7}{16}$,, $\frac{3}{64}$	$2\frac{3}{16}$	4	0·250	$2\frac{3}{16}$
$2\frac{3}{4}$	$4\frac{3}{16}$	$4\frac{13}{16}$,, $\frac{1}{64}$	$2\frac{3}{8}$,, $\frac{1}{32}$	$3\frac{1}{2}$	0·285	$2\frac{3}{8}$,, $\frac{1}{32}$
3	$4\frac{1}{2}$,, $\frac{1}{32}$	$5\frac{3}{16}$,, $\frac{3}{64}$	$2\frac{5}{8}$	$3\frac{1}{2}$	0·285	$2\frac{5}{8}$,, $\frac{1}{64}$
$3\frac{1}{4}$	$4\frac{13}{16}$,, $\frac{3}{64}$	$5\frac{9}{16}$,, $\frac{1}{32}$	$2\frac{13}{16}$,, $\frac{1}{64}$	$3\frac{1}{4}$	0·307	$2\frac{13}{16}$,, $\frac{3}{64}$
$3\frac{1}{2}$	$5\frac{1}{8}$,, $\frac{3}{64}$	$5\frac{15}{16}$,, $\frac{3}{64}$	$3\frac{1}{16}$	$3\frac{1}{4}$	0·307	$3\frac{1}{8}$
$3\frac{3}{4}$	$5\frac{1}{2}$,, $\frac{3}{64}$	$6\frac{3}{8}$,, $\frac{1}{32}$	$3\frac{1}{4}$,, $\frac{1}{32}$	3	0·333	$3\frac{15}{16}$,, $\frac{1}{64}$
4	$5\frac{15}{16}$,, $\frac{1}{64}$	$6\frac{7}{8}$	$3\frac{1}{2}$	3	0·333	$3\frac{9}{16}$,, $\frac{1}{64}$
$4\frac{1}{4}$	$6\frac{3}{8}$	$7\frac{5}{16}$,, $\frac{3}{64}$	$3\frac{11}{16}$,, $\frac{1}{64}$	$2\frac{7}{8}$	0·348	$3\frac{3}{4}$,, $\frac{3}{64}$
$4\frac{1}{2}$	$6\frac{13}{16}$,, $\frac{1}{64}$	$7\frac{7}{8}$	$3\frac{15}{16}$	$2\frac{7}{8}$	0·348	4 ,, $\frac{3}{64}$
$4\frac{3}{4}$	$7\frac{1}{4}$,, $\frac{3}{64}$	$8\frac{7}{16}$	$4\frac{1}{8}$,, $\frac{1}{32}$	$2\frac{3}{4}$	0·364	$4\frac{1}{4}$,, $\frac{1}{32}$
5	$7\frac{3}{4}$,, $\frac{3}{64}$	9 ,, $\frac{1}{64}$	$4\frac{3}{8}$	$2\frac{3}{4}$	0·364	$4\frac{1}{2}$,, $\frac{1}{32}$
$5\frac{1}{2}$	$8\frac{13}{16}$,, $\frac{1}{32}$	$10\frac{3}{16}$,, $\frac{1}{32}$	$4\frac{13}{16}$	$2\frac{5}{8}$	0·381	5 ,, $\frac{1}{64}$
6	10	$11\frac{1}{2}$,, $\frac{3}{64}$	$5\frac{1}{4}$	$2\frac{1}{2}$	0·400	$5\frac{7}{16}$,, $\frac{3}{64}$

WEIGHT OF A SQUARE FOOT OF SHEET METALS

Thickness.	Weight in lb.			Thickness.	Weight in lb.		
Inch.	Iron.	Copper.	Brass.	Inch.	Iron.	Copper.	Brass.
$\frac{1}{2}$	20·21	23·12	21·87	$\frac{1}{16}$	2·52	2·89	2·73
·450	18·19	20·80	19·68	·055	2·22	2·54	2·40
·437	17·66	20·20	19·11	·048	1·94	2·22	2·10
$\frac{3}{8}$	15·15	17·34	16·40	·042	1·69	1·94	1·83
·340	13·74	15·72	14·87	·035	1·41	1·62	1·53
$\frac{5}{16}$	12·63	14·45	13·67	·033	1·33	1·52	1·44
·284	11·47	13·13	12·42	·029	1·17	1·34	1·27
·261	10·55	12·06	11·41	·028	1·13	1·29	1·22
$\frac{1}{4}$	10·10	11·56	10·94	·025	1·01	1·15	1·09
·217	8·77	10·03	9·49	·021	·85	·97	·92
·208	8·40	9·62	9·10	·020	·81	·92	·87
$\frac{3}{16}$	7·57	8·67	8·20	·018	·73	·83	·79
·166	6·71	7·67	7·26	·015	·60	·69	·65
·158	6·38	7·30	6·91	·013	·52	·60	·57
·137	5·54	6·33	5·99	·012	·48	·55	·52
$\frac{1}{8}$	5·05	5·78	5·47	·010	·40	·46	·43
·109	4·40	5·04	4·77	·009	·36	·41	·40
·094	3·80	4·80	4·11	·008	·32	·37	·35
·080	3·23	3·70	3·50	·007	·28	·32	·30
·072	2·91	3·32	3·15	·005	·20	·23	·22

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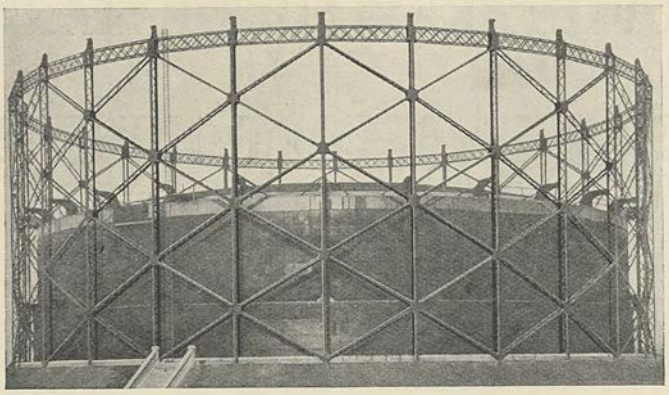

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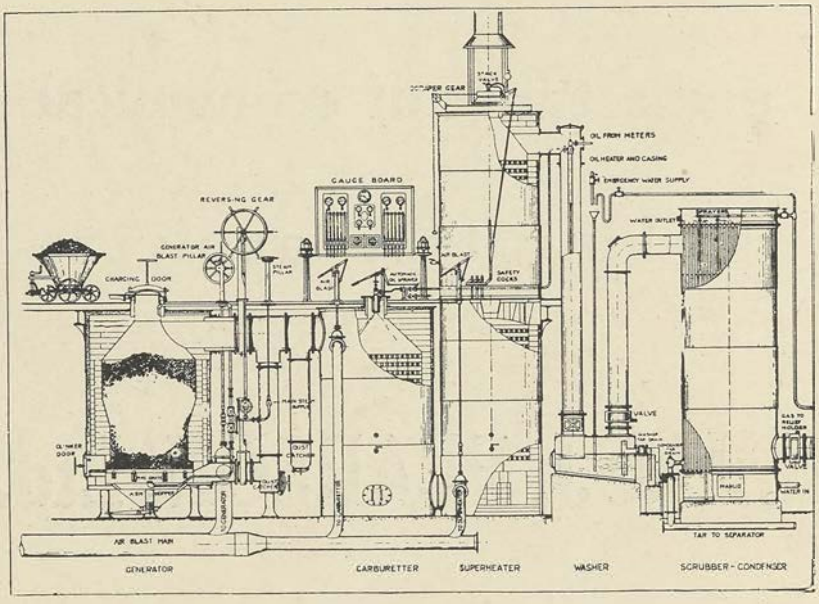

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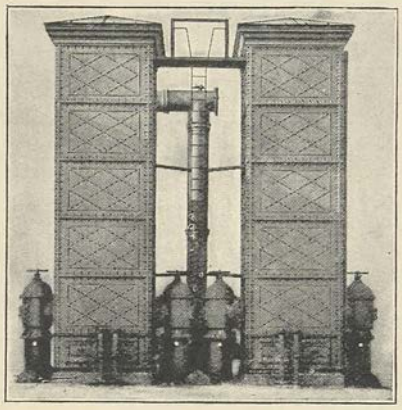

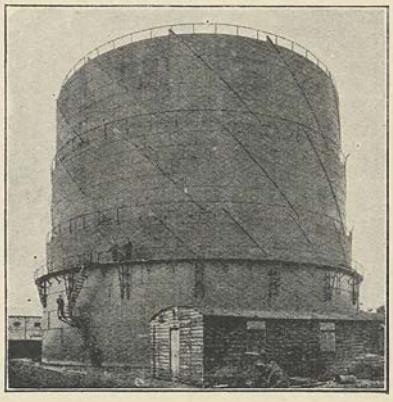

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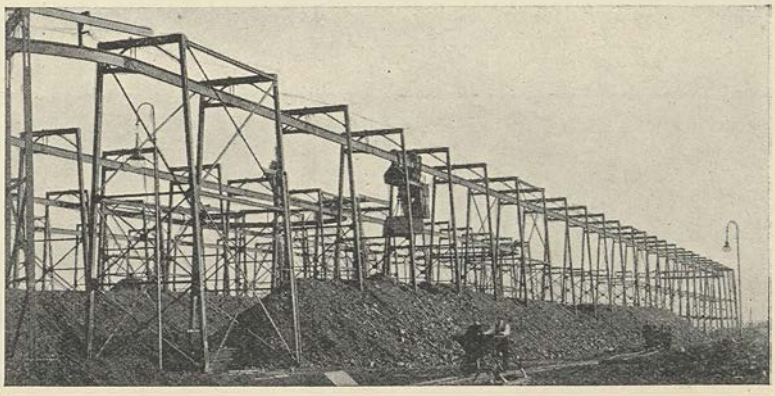

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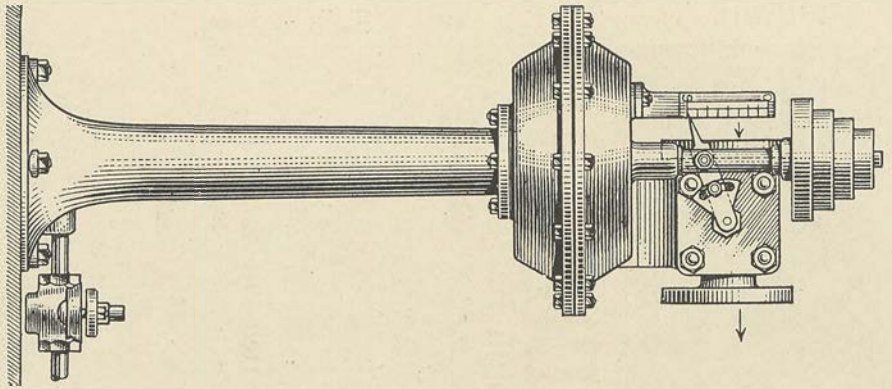

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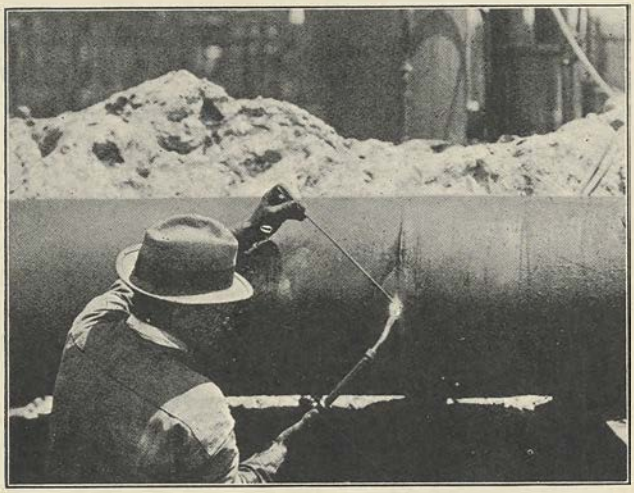

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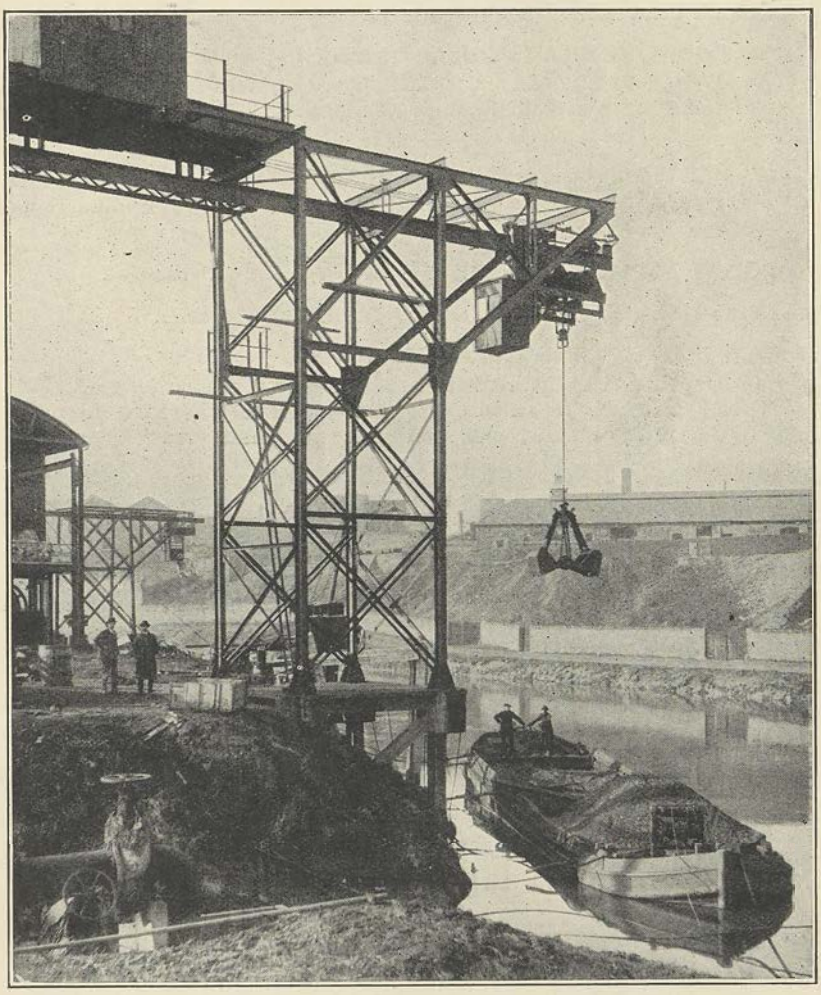

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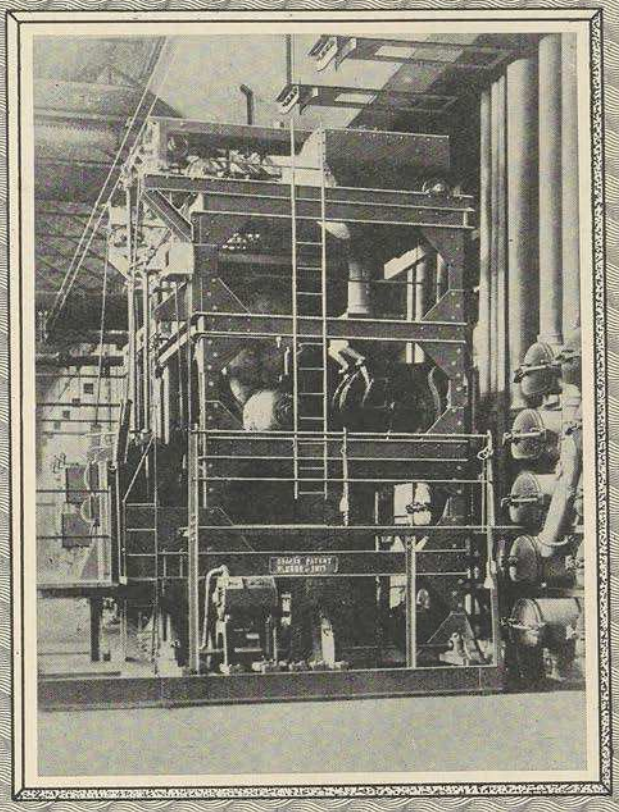

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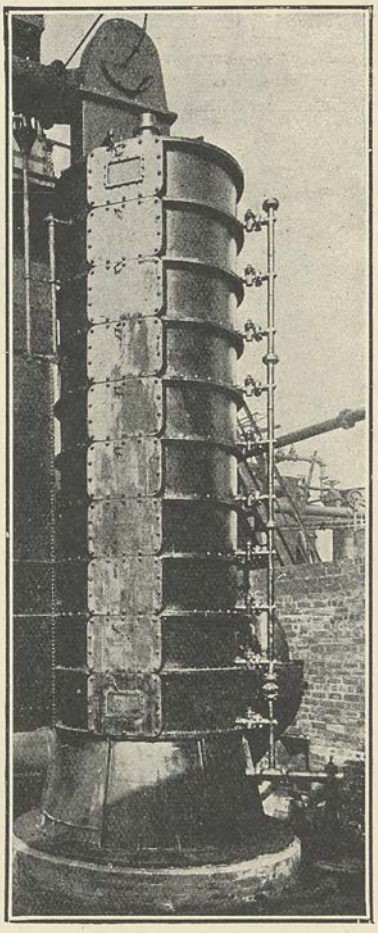

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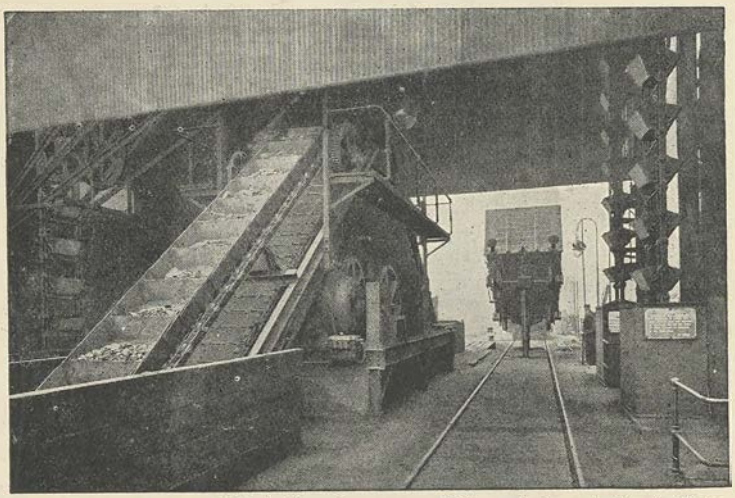

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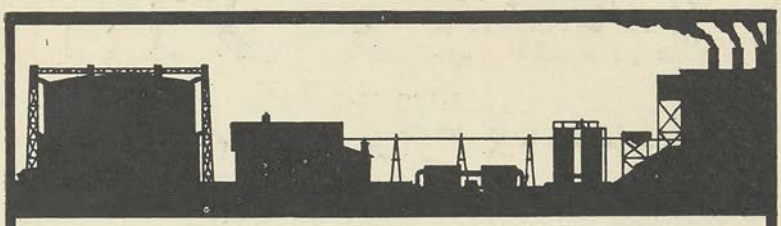

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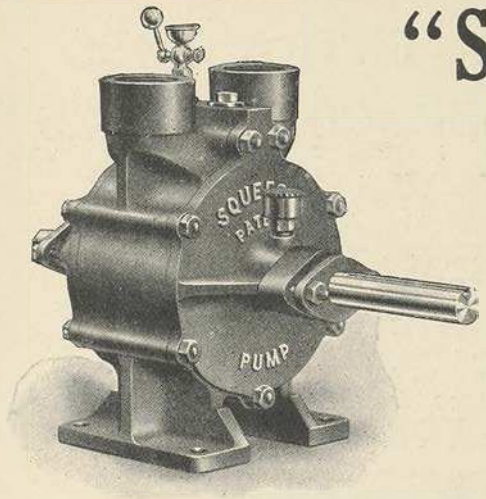

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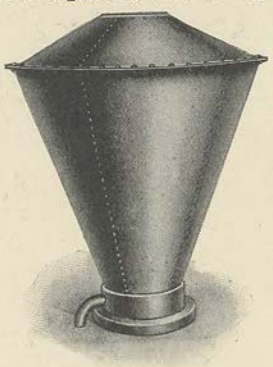

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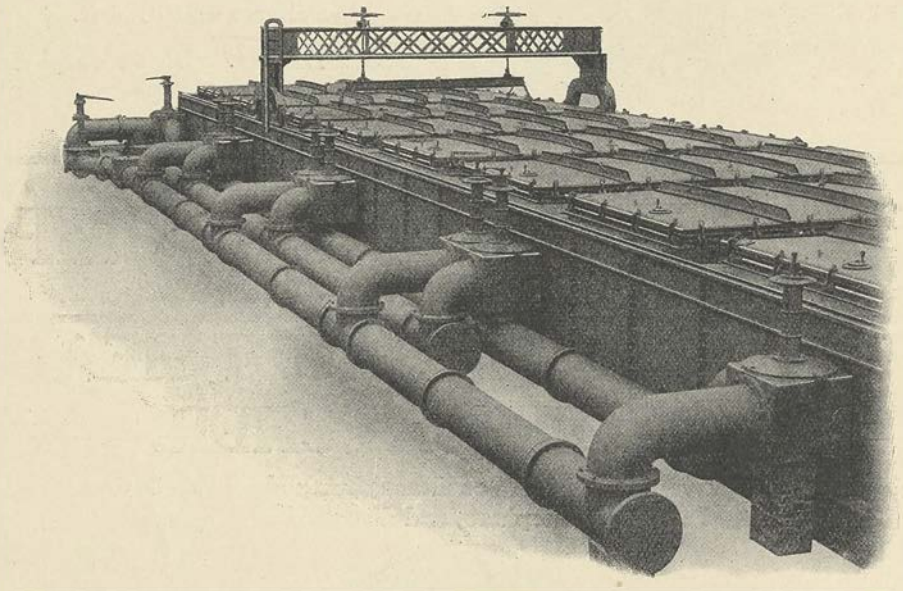

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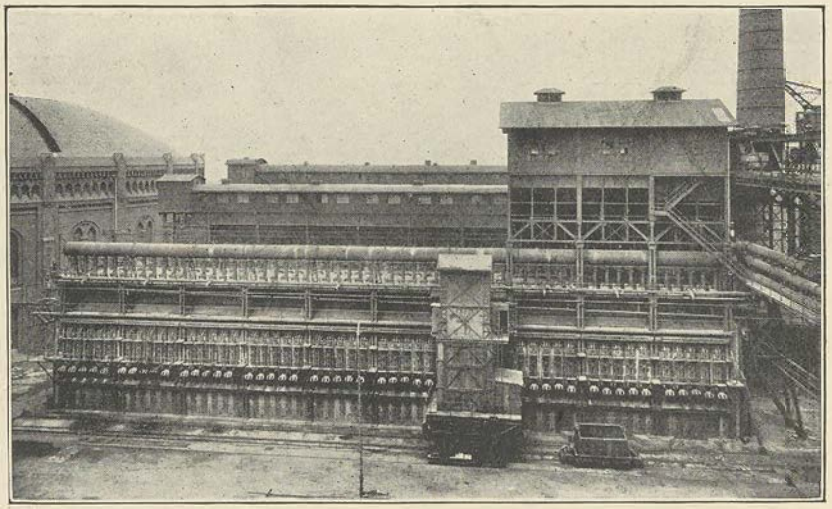

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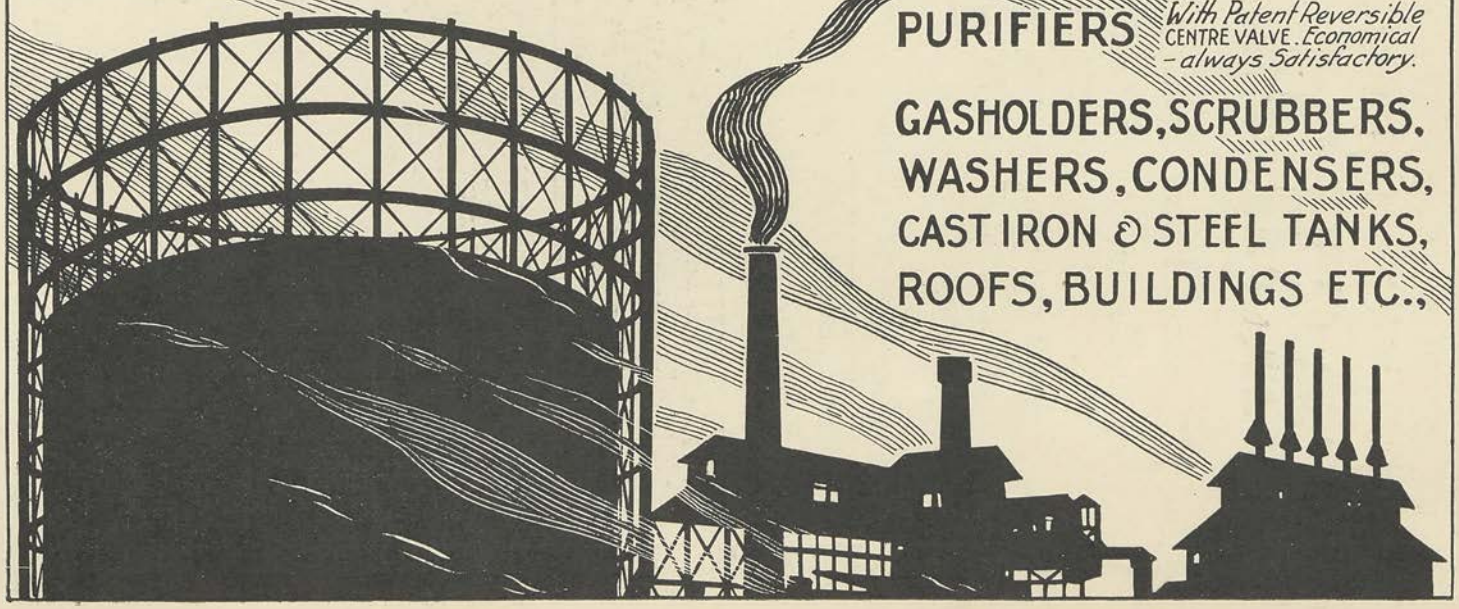

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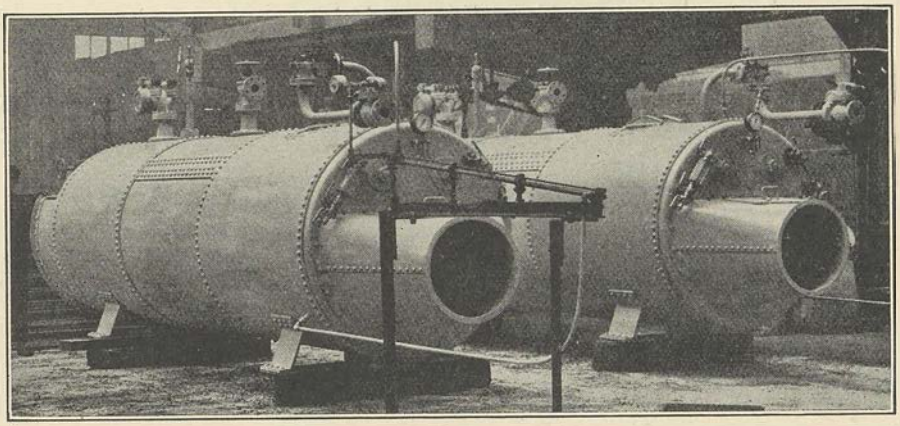

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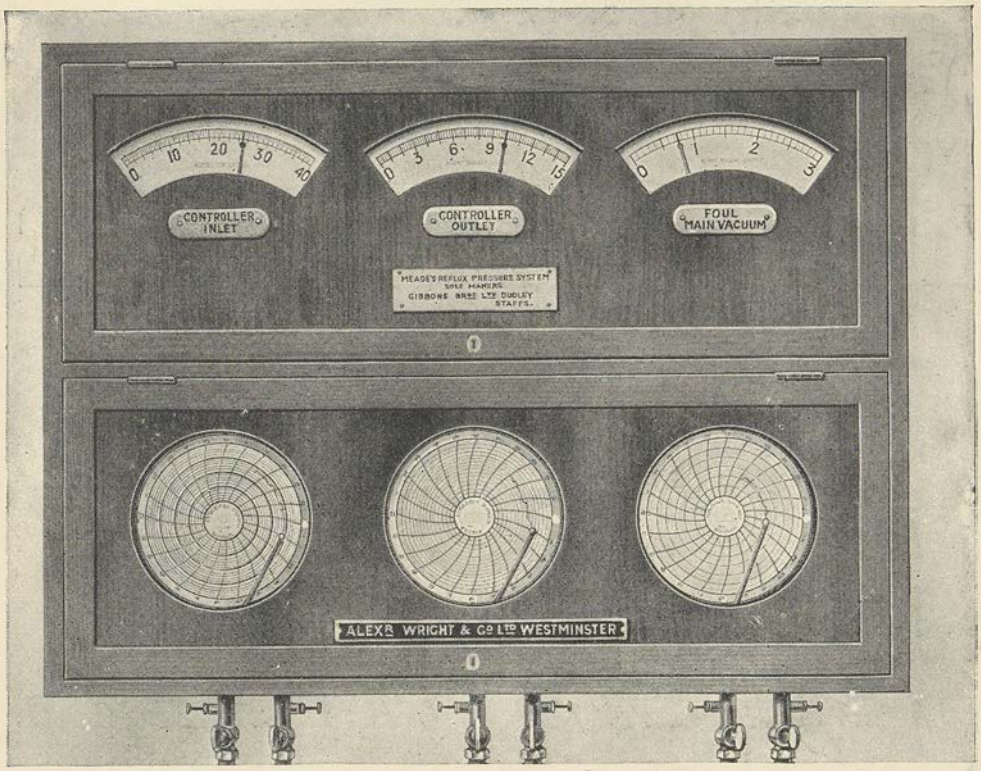

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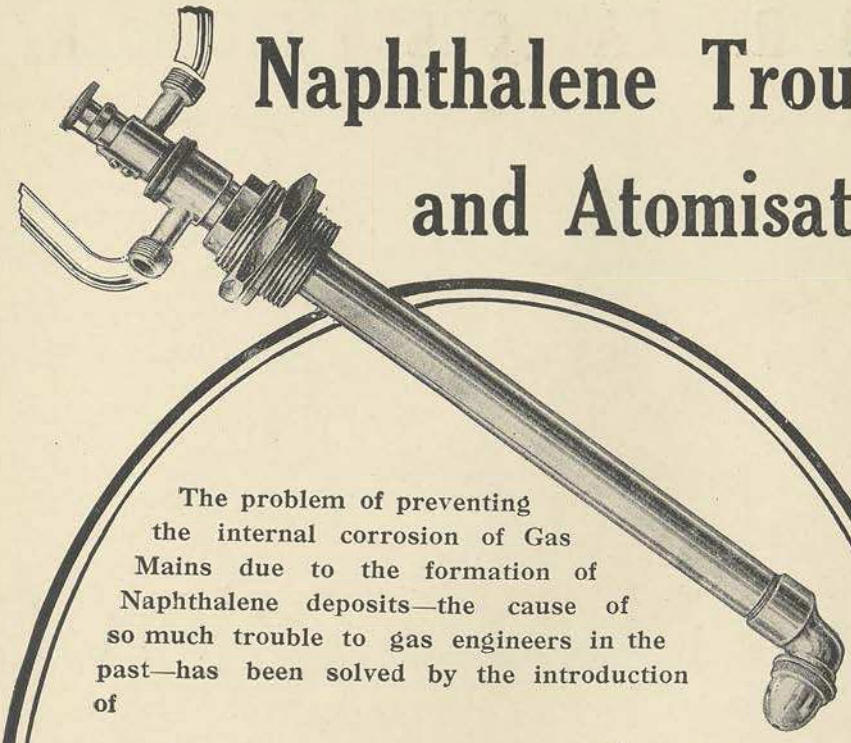
Naphthalene Trouble and Atomisation



The problem of preventing the internal corrosion of Gas Mains due to the formation of Naphthalene deposits—the cause of so much trouble to gas engineers in the past—has been solved by the introduction of

The Aerograph GAS MAIN OIL ATOMISER

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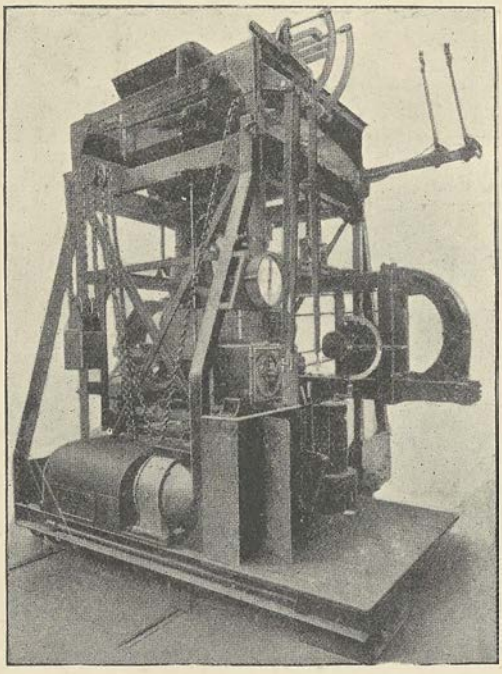

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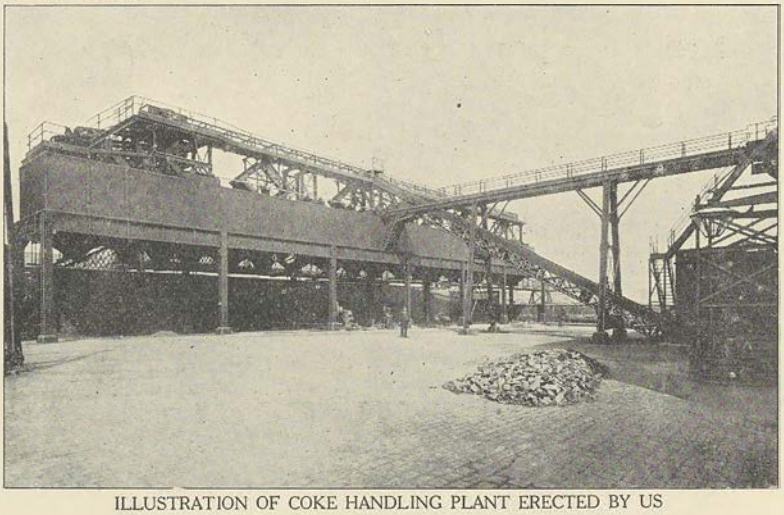

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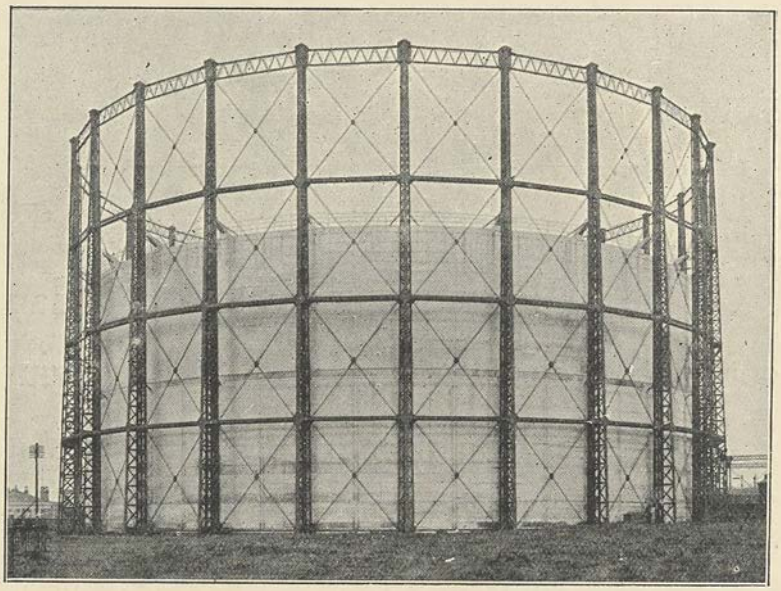

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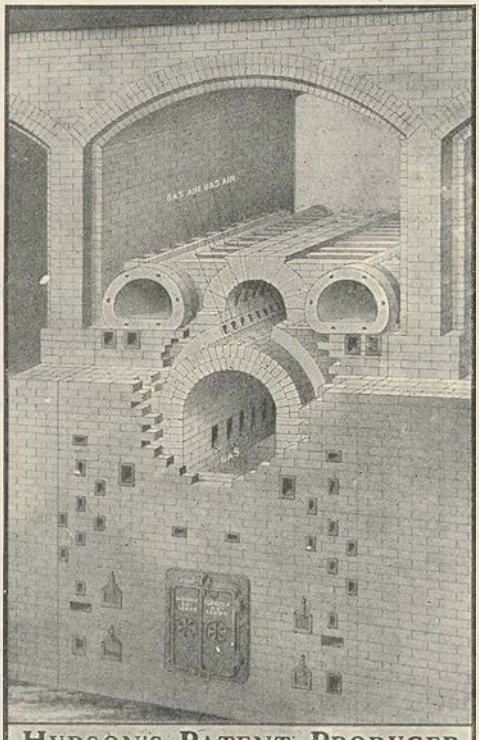

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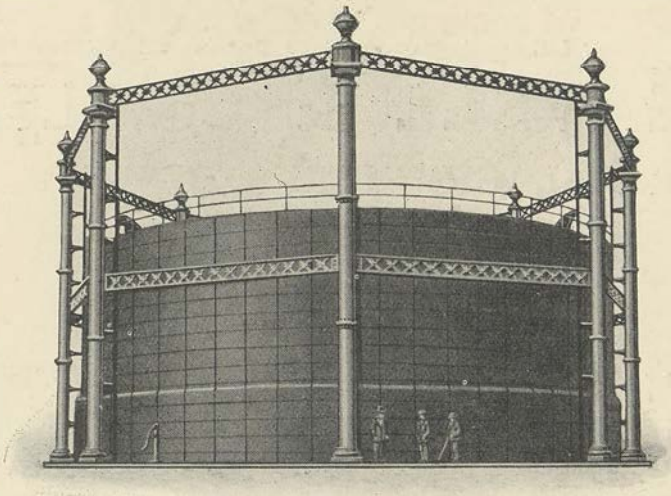

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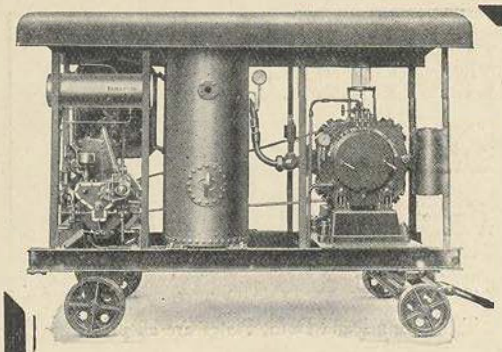

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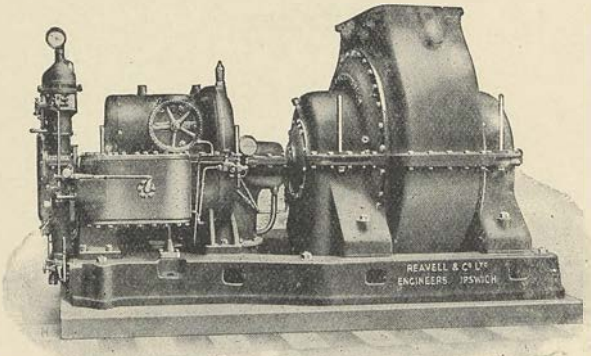

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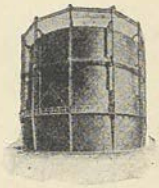



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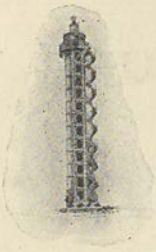
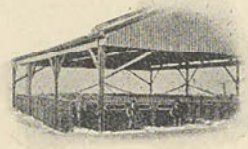


SCRUBBERS.



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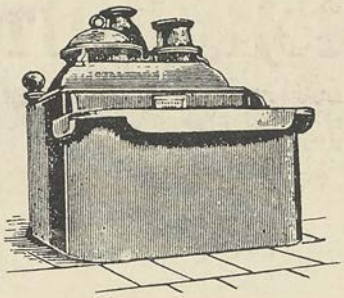

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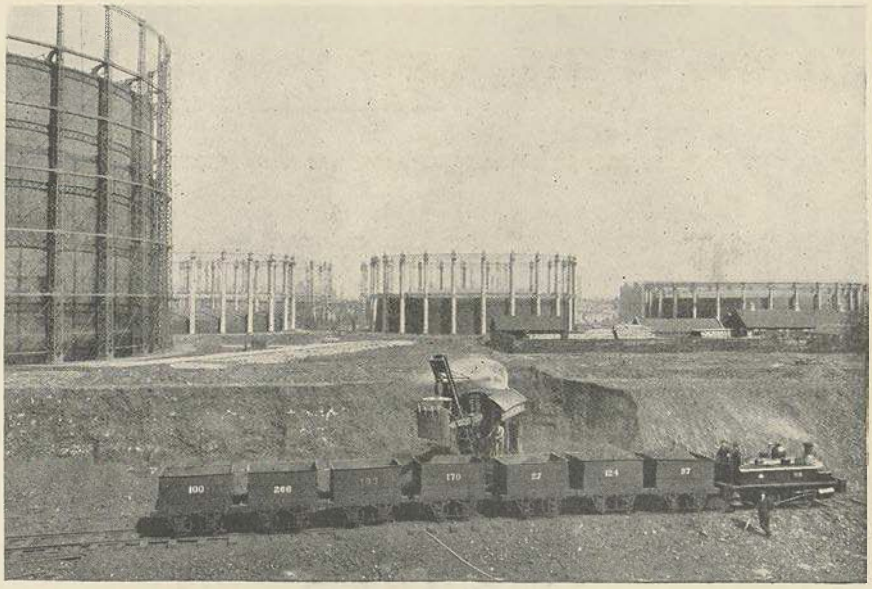

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