MODERN
POWER GAS PRODUCER

PRACTICE AND APPLICATIONS

BY

HORACE ALLEN

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A Practical Treatise Dealing with the
Gasification of Various Classes of
Fuels by the Pressure and
Suction Systems of
Producer

BY

HORACE ALLEN

Author of "Gas and Oil Engines," etc.

136 Illustrations and Numerous Tables

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PREFACE.

DURING the last decade the demand for power gas has been very greatly increased through the development of the internal combustion engine. From an engine capable of developing 200 H.P. being considered large, we now find gas-driven engines are being manufactured up to 5,000 H.P. capacity.

In the other direction, the field held by the smaller type of gas engine using illuminating gas has been encroached upon by the invention of the suction producer.

For the large power engines the cost of fuel becomes an important factor, so that while for moderate sized engines anthracite and coke are much more economical than illuminating gas, the new conditions require a still cheaper source of heat, such as gasified slack bituminous coal. Further, to permit of gas power being employed in the propulsion of vessels making long voyages, it will be necessary to devise a producer which will be capable of dealing with the various classes of fuel obtainable at different ports.

The Author's aim has been to define the ruling principles of the gasification of fuel, and describe the developed practical commercial types of producers. Besides this, by describing the most recent inventions, and the claims made by the inventors, it was the intention of the writer to place before the reader the problems which are occupying the minds of designers.

The Mond system of gasification of bituminous coal and recovery of by-products, as applied for the distribution of power and heating gas from a central station at Dudley Port, has, according to the Directors' Report for the year 1907, succeeded in obtaining by-products equivalent in value to 70 per cent of the cost of the fuel, and 62 per cent for the gas on coal gasified during the year, costing £10,158 16s. 5d., a result which will be improved upon as the local firms take up the further application of the gas for their various purposes.

The Automatic Gas Producer Syndicate Ltd. have fitted a producer to a char-a-banc motor car with very satisfactory results, indicating that gas power at one-tenth the cost of petrol will be obtained. The total weight of the fully-equipped and loaded car was about 5 tons, and the consumption of anthracite peas was, in a recent trial, $1\frac{1}{8}$ lb. per ton mile, which will no doubt soon be improved upon.

The Author desires to acknowledge his indebtedness to the authors of the numerous works consulted, and has endeavoured to give their names as far as possible.

In some instances improvements have been made since the appearance of the articles in the columns of *The Practical Engineer*, and where possible these have been subsequently incorporated.

Since setting up the earlier portion of this work, the Author has had the opportunity of examining a few further suction gas plants which have given notable satisfaction, and a description of these appears in the Appendix.

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Page 239, line 3 from top—156 should read 125.

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MODERN POWER GAS PRODUCER PRACTICE AND APPLICATIONS.

INTRODUCTION.

FOR the purposes of this work "power gas" may be defined as gas which is free to enter into combination with other gas and develop heat, and from which the resulting products are also gaseous.

From the commercial aspect of the subject the question of cost is the main consideration, so in a practical work on the subject it is necessary to combine the question of cheapness with all theoretical investigations.

Under these circumstances it will be obvious that the cheapest sources of power must be those provided by nature under normal conditions of temperature and pressure wherever such are available.

The most abundant source of a gas, free to enter into chemical combination, is the atmosphere with which the earth is surrounded.

Not only is the quantity of this gas abundant, but it is unlimited, and what is much more to the point, it is absolutely free of cost.

It is common knowledge that the atmosphere consists of two gases, mechanically mixed, not in chemical combination, in proportion by volume of four parts of nitrogen to one part of oxygen; also that nitrogen is an inert gas, while oxygen readily enters into combination with combustible gas with the development of heat.

Not only has oxygen a strong affinity for certain gases, but it also combines with a number of liquids and solids, a property which, it will be seen later, has considerable importance in regard to the subject being dealt with.

From the definition of power gas given in the text it will be seen that two different gases are required to combine to generate heat, so that unless nature has provided free combustible gas the abundant supply of oxygen referred to would be somewhat discounted in regard to its freedom from cost.

However, nature has provided a high quality of combustible gas, and in fairly abundant quantity, but unfortunately the supply is more or less limited to certain localities, as far as is known at the present time; the future may show that this is not the case.

This natural combustible gas is obtained from bore holes driven to a considerable depth into the crust of the earth, and when an accumulation is "tapped," it is generally found to be under such a pressure that it can be piped to great distances without the application of mechanical means.

Though up to the present the principal localities where natural gas can be obtained are situated in the American States, there is no reason to suppose that it is confined to any special part of the earth's surface, providing that wells are sunk to a sufficient depth.

CHAPTER I.

NATURAL GAS.

NATURAL GAS IN ENGLAND.

As the finding of an adequate supply of natural gas in this country would have an important bearing in regard to the development of power, it is worth while keeping in view the evidences already collected as to the possibilities in this direction.

About 18 years ago a supply of natural gas was struck at Hepburn Colliery, Newcastle, but the supply failed in the year 1897.

In a lecture delivered before the Halifax Literary and Philosophical Society in 1886, it was predicted that natural gas might be found at some 1,500 ft. below the salt beds of Cheshire. Since then its presence has been proved in the Middlesbrough district in the salt-bearing strata.

In 1887 it was seriously considered by the Salt Union. The opinion of the leading experts in the States was obtained, and they were strongly of opinion that the geological strata was of such a character as to thoroughly well justify a test down to 3,000 ft., and they were so satisfied at the promise of such a test that they undertook to carry out the boring down to 3,000 ft. at net cost to themselves, and the same drillers are the ones who discovered the natural gas at Pennsylvania, etc.

An half-hearted attempt was made by the Salt Union, but not having the experience of the American drillers to guide them, they did not succeed in getting below 1,000 ft.*

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* *Halifax Guardian.*

Further evidence of the existence of natural gas in this country was obtained in 1896 at Heathfield, Sussex, a station on the London, Brighton, and South Coast Railway, during boring operations for water, when gas was tapped at a depth of 312 ft. The bore hole in this case was only 6 in. diameter, and as water was not found in any quantity after reaching 377 ft., the tubes were withdrawn, with the exception of one length, in which the gas maintained a pressure of about 140 lb. per square inch. As the presence of combustible gas was found by the not uncommon method of detecting leakages of gas—*i.e.*, the application of a light, followed by a burst of flame which was only extinguished with great difficulty—the railway company made use of the new find to illuminate the station, but this was the extent of the application.

About 30 years ago the presence of natural gas was detected at Netherfield, where a light introduced into a bore hole caused an explosion.

About 1900 some American gentlemen, with experience gained in this direction in the States, began to make further investigation, and an English company was formed, The Natural Gas Fields of England Ltd., and commenced further boring operations.

One bore hole reached a depth of 400 ft. and others were being put down, and in the deepest the gas established a pressure of some 200 lb. per square inch, the pressure being found to increase as greater depths were reached. This pressure is sufficiently great to carry the gas to any of the principal cities in the country. The output of the deepest tube at Heathfield was given (1902) as about 15 million cubic feet per day, or about one-eighth of the daily sale of gas in London. The sale of lighting gas in the towns situated on the London, Brighton, and South Coast and the South-East Coast Railways is calculated at about 50 million thousands of cubic feet a year, which would be equal to the supply from 10 bore holes, and the Natural Gas Company has acquired rights to lay gas mains along the lines of the two railways.

The geological strata, from which the gas is extracted, is that known as the Kimmeridge clays, which extend over a very large area. That the gas is associated with liquid petroleum is indicated by the distinct odour, and it is possible that it is derived from the gasification of this material upon the release of pressure due to the bore hole.

In this connection the following comparison will be of interest:—

CHEMICAL COMPOSITION, PER CENT.

	Carbon.	Hydrogen.	Oxygen.
Caucasian light crude oil	86·3	13·6	0·1
Heathfield natural gas	71·8	23·8	4·4

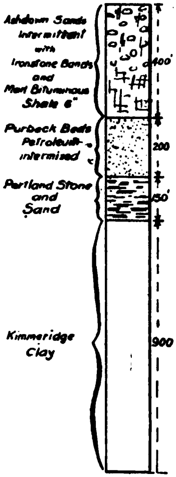
A further comparison between the natural gas found in the States of Ohio and Indiana and that from Heathfield, Sussex, is given in the following table:—

PERCENTAGE COMPOSITION OF NATURAL GAS.

Locality.	Hydrogen.	Marsh gas.	Olefiant gas.	Carbon monoxide.	Carbon dioxide.	Oxygen.	Nitrogen.	Hydrogen sulphide.
Ohio, U.S.A.:								
Fostoria*	1·89	92·84	·20	·55	·20	·35	3·82	·15
Findlay*	1·64	93·35	·35	·41	·25	·39	3·41	·20
St. Mary's*	1·94	93·85	·20	·44	·23	·35	2·98	·21
Indiana, U.S.A.:								
Muncie*	2·35	92·67	·25	·45	·25	·35	3·53	·15
Anderson*	1·86	93·07	·47	·73	·26	·42	3·02	·15
Kokomo*	1·42	94·16	·30	·55	·29	·30	2·80	·18
Marion*..........	1·20	93·57	·15	·60	·30	·55	3·42	·20
Sussex, England:								
Heathfield†	..	72·5	5·5	4·0	Nil	18·0	..	Nil

* *Eng. and M. J.*, April 21, 1894.
† *Times*, September 10 1902.

The natural gas tapped at Heathfield has greater illuminating properties than that found in the States, being of from 12 to 14 candle power; this renders it suitable for use in ordinary batswing burners; as, however, it has a high thermal value, it can be more economically



Section of Bore.

Section from London to St. Leonards.

Fig. 1.

applied to use by rendering mantles incandescent, and for the same reason it is suitable for internal explosion engines, an engine of only 1½ horse power being stated to only require 15 cubic feet per horse power hour, or one half the quantity of coal gas.

The geological strata, Kimmeridge clays, from which this gas is obtained, attained a thickness of 900 ft. at Battle, and is covered with other strata, having a total thickness of 750 ft., as shown by the section of the bore hole in fig. 1.* A geological section extending from St. Leonards-on-Sea to London is also given, showing the different strata and their inclination, and from which it would appear that any other boring on the line on which the section was taken would have to reach very considerably greater depth to reach the source of gas supply. Much of the above is culled from the *Times* of September 10th, 1902, and other sources.

From the foregoing we find that the earth is not only the most ancient power gas producer, but the largest and the best, for the gas produced is of high heating value, permanent, and free from tarry compounds. We have not only to seek for the places at which it can be obtained, but the process of gasification, for even if liquid petroleum is the origin, we have yet to discover how to turn this fuel into a permanent gas of a quality equal to natural gas.

Therefore, while continuing our search for a local supply of natural gas, we have to make use of artificially-prepared power gas of the best quality available at the lowest cost.

CHAPTER II.

MANUFACTURED GAS.

THE BLAST FURNACE.

THE most abundant supply of artificial power gas is a by-product accompanying the manufacture of iron, and the largest artificial gas producer is the iron-making blast furnace.

Though the quantity of gas available from this source is very great, the supply is circumscribed by being con-

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* *Engineer*, September 26th, 1902

fined to certain localities, and before the gas can be employed in gas-engine cylinders it has to be treated to remove dust and fume carried by it in its crude state.

In this country alone the blast furnaces consume from 16 to 18 million tons of coal per annum, but only about one half of the heat value is utilised in the production of iron, the gases being capable of developing about the same proportion on complete combustion.

COKE OVEN GAS.

As very little crude coal is suitable for use as fuel for the blast furnace; the bulk of it has to be deprived of its volatile gases by means of coking ovens, and as the resulting gases are of high heating value, and when purified suitable for use in gas-engine cylinders, the large amount of coke required for the world's supply of iron results in the liberation of huge volumes of power gas. In the process of coking from about one quarter to one-third of the weight of the coal is driven off in the form of gas of high heating power, and after providing for the heat required by the process itself, there is about one half of this gas available for power purposes.

Coking coal, like smelting iron, is carried out only in certain districts, so that the application of the by-product gas for power purposes is somewhat circumscribed; but in both cases the localities most favourable for these industries are the centres of manufacturing districts, where the exploiting of cheap power would meet with a large demand.

Up to the present time neither blast-furnace gas nor coke oven gas have been fully exploited for the development of power for reasons which will appear later when dealing with each class of gas in detail, so other more expensive sources of gas supply have had to be resorted to, such as (1) illuminating gas, made by distilling coal in retorts; (2) coal gas, made by gasifying coal with a limited amount of air, either with or without the addition of steam or water vapour; (3) coke gas; (4) anthracite gas; (5) liquid petroleum, either crude or refined, gasified on the engine itself immediately before use; (6) spirits, vaporised on their passage to the combustion cylinder.

In the application of any gas for power purposes, the efficiency of the apparatus employed to convert heat into power must enter largely into the question of economy, and as the internal-combustion engine now considerably exceeds the most highly-developed steam plant, the general treatment of the subject of power gas production must necessarily be from the suitability of the gas for developing power in internal-combustion engines, although applications in other directions will also be referred to.

The aim of the modern power gas engineer is to devise a gas producer for gasifying small coal slack, this being the cheapest available material when its thermal value is taken into consideration.

Besides there being considerable accumulations of this class of fuel at the collieries, the method of getting the coal in the pits and the subsequent handling continuously provide a more or less considerable proportion according to the nature of the coal, etc.

To appreciate and understand the obstacles to be overcome in the perfect gasification of coal it will be necessary to review the physical and chemical properties of coal.

Though found in the earth in considerable abundance, coal varies considerably in physical properties and chemical composition; the seams of coal occurring in the geological strata differ greatly in thickness; some coal is considerably harder than others, and has been roughly classified as follows: Brown coal or lignite, bituminous coal, non-bituminous coal, anthracite coal, the commonest and cheapest of these being the second or bituminous class.

The principal physical feature of bituminous coal, and one which renders the burning of it in open or closed fires, or gasification, a difficult problem, is the liberation of volatile matter on the application of heat, instead of being a solid fuel, when the temperature is raised to a certain degree, and it cannot be burnt or gasified without having to pass that stage of heat; from one quarter to one-third, or more, of its weight is liberated in the form of gas, the remainder consisting of solid carbon or coke. The perfect combustion, or partial combustion, as in the case of gas production, with air, cannot be effected for the two portions at the same rate of time; the volatile portion, when released and mixed with air, can enter into combustion with great rapidity, while the solid carbon can only combine with oxygen as its surface becomes exposed, and at a sufficiently high temperature.

With non-bituminous coal, anthracite, or coke the case is different, owing to the absence of the gaseous volatile matter.

Also, in the case of bituminous coals the constitution of the volatile gases varies with different classes, as will be noticed when dealing with the question of the thermal value of different coals of almost similar chemical composition.

Mr. A. Lamberton, in his presidential address on "Improvements in Gas Power Plants," said: "It is beyond question that where fuel has to be burned for the supply of motive and heating purposes, the system of first gasifying the coal . . . ensures very distinct economy."

The chief reason why the preliminary gasification of coal is advantageous is that the direct combustion of raw coal can only be effected by the employment of a very considerable excess of air.

The thermal power of coal is due to the combustion of (1) the volatile hydro-carbons and (2) the fixed carbon, and the volatile constituents are driven off completely at a temperature below the ignition point of the fixed carbon, or at any rate it may be stated that the fixed carbon does not commence to combine with oxygen until after the liberation of the volatile gases.

Again, after the hydro-carbon gases are liberated from coal by the increase of temperature to a certain point, they are capable of extremely rapid combustion or explosion, while the combustion of the fixed carbon constituent is gradual.

The partial combustion of fuel in the gas producer results in the heat-giving constituents being transformed into such a condition that the thermal power can be completely developed, both with great rapidity and with only the theoretical weight of oxygen or air.

As long ago as 1845 Messrs. Bunsen and Playfair made some very exhaustive and instructive experiments upon the gasification of coal,* a careful study of which will well repay any student of power gas production. The report, however, intermingles the details of the apparatus employed in the analyses and experiments upon distillation with the results obtained, so as to show that the conclusions formed were on a scientifically-accurate basis.

The following important results were arrived at by experiments previously made, and confirmed by the further experiments, regarding the action of oxygen upon the fuel in the furnace: (1) That the oxygen introduced by the blast is burned in the immediate vicinity of the tuyere; (2) that the oxygen is converted to carbonic oxide also in the immediate vicinity of the tuyere; and finally, (3) that the coal loses all its gaseous products of distillation much above the point at which its combustion commences.

A further experiment consisted of subjecting a sample of Gosforth coal to a red heat in a closed vessel and collecting products of distillation for the purposes of analysis.

Of the weight of coal employed, 16·7457 grammes, the loss of volatile matter at a red heat was found to be 5·2037 grammes, the total therefore consisting of—

Fixed constituents......	68·92	(coke)
Volatile ,, ...	31·08	(gaseous)
	100·00	

Further, the fixed portion, or coke, remains in a solid form whether the heat be either raised or lowered as long as oxygen is excluded. The products liberated in a gaseous form, however, do not consist of permanent gases, nor are they of a uniform composition; some portion consists of fixed gases, other of condensible gases, and still other, such

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* Bunsen and Playfair's report to the British Association on the gases evolved from iron furnaces, etc.

as water vapour, which condenses to a liquid when the temperature is lowered.

The results of analysis of the Gosforth coal by Bunsen and Playfair are given herewith :

RESULTS OF DRY DISTILLATION OF GOSFORTH COAL.

Products.	Weight in grammes.	Per cent.	Remarks.
Carbon (coke)*	11·5420	68·925	Solid.
Tar*	2·0479	12·230	Condensible.
Water	1·2674	7·569	Condensible.
Light carburetted hydrogen*	1·1758	7·021	Fixed gas.
Carbonic oxide*	0·1901	1·135	Fixed gas.
Carbonic acid	0·1797	1·078	Fixed gas.
Condensed hydrocarbons and olefiant gas*	0·1262	0·753	Part condensible. Part fixed.
Sulphuretted hydrogen*	0·0918	0·549	Fixed gas.
Hydrogen*	0·0836	0·499	Fixed gas.
Ammonia	0·0353	0·211	Fixed gas.
Nitrogen	0·0059	0·035	Fixed gas.
	16·7457	100·000	

* These products are combustible, but under different conditions.

This dry distillation constitutes the method of manufacture of illuminating gas; the process further involving the removal of condensible products and the purification of the gas by the removal of all deleterious ingredients.

The small proportion of gas obtained from the coal by this method renders it expensive as a fuel for power purposes, and the object of the power gas engineer is to gasify the fixed carbon constituent of coal, forming, as it does, the principal part.

If now this same coal is employed to charge a furnace such as is used for smelting iron, but without the iron-forming ingredients, and air is blown in at the closed hearth, the composition of the evolved gases can be readily calculated. As Messrs. Bunsen and Playfair have shown, the coal loses its gases by distillation near the top of the furnace, and the corresponding weight of coke must burn at the tuyeres, so that it is only required to add to the composition of the volatile matter of the coal the carbonic oxide produced by the burning of the 68·92 per cent of carbon and the nitrogen of the air expended in combustion. By calculation the composition of the gases evolved from the top of the furnace was found to be:

Composition of the Gas Resulting from the Partial Combustion of Gosforth Coal in a Blast-furnace Type of Gas Producer, with Air.

	Weight.	Per cent by weight.
Nitrogen	{53·8625 ·0059} 53·8684	62·639
Carbonic oxide	{26·9313 ·1901} 27·1214	31·537
Tar	2·0479	2·381
Water	1·2674	1·473
Light carburetted hydrogen	1·1758	1·367
Carbonic acid	0·1797	·209
Condensed hydro-carbons and olefiant gas	0·1262	·146
Sulphuretted hydrogen	0·0918	·114
Hydrogen	0·0836	·097
Ammonia	0·0353	·041
	85·9975	100·004

The above results differ from those obtained in practice, as there is always a certain amount of the carbon burnt to carbonic acid, as will be shown later, and no allowance has been made for the ash of the coal, this being included as fixed carbon in the above calculation.

Though all the above constituents leave the top of the producer in a gaseous state, they do not all remain fixed gas, for as cooling takes place the tar vapours commence to condense, and as the gases cool down to about normal temperature the water vapour also becomes condensed. Of all the deleterious constituents of the gas from producers tar is the most difficult to remove, for, although it readily commences to condense upon cool surfaces, the last traces of tar vapour are difficult to remove.

The small percentage of ammonia accompanying the gases is absorbed by the condensed water vapour. When reduced to normal temperature and pressure the fixed gases would have the following percentage composition:—

	Weight. Grammes.	Per cent by weight.	Per cent by volume.
Carbonic oxide	27·1214	32·852	32·104
Light carburetted hydrogen	1·1758	1·424	2·438
Olefiant gas	·1262	·153	·166
Hydrogen	·0836	·101	1·381
Carbonic acid	·1797	·218	·138
Nitrogen	53·8684	65·251	63·749
	82·5551	99·999	99·976

Pure carbon subjected to partial combustion with air having the average proportion of moisture would, according to theory, yield gases having the following proportions:—

Per Cent by Volume.	
Carbonic oxide	33·5
Hydrogen	1·1
Nitrogen	65·4
	100·0

The above is nearly approached in the case of coke employed in a gas producer, when steam is not used.

PER CENT BY VOLUME.

Carbonic acid	1·6
Carbonic oxide	32·3
Hydrogen	4·0
Marsh gas	·8
Nitrogen	61·3
	100·0

As there is no carbonic acid found in the gases from a blast furnace within a very short distance above the tuyeres, it follows that a properly-constructed gas producer for using coke and air only should show no CO_2 in the evolved gases if worked at a certain temperature.

All the oxygen entering the producer combines with carbon to form carbonic acid in the immediate vicinity of the point of contact, but the carbonic acid gas so formed, on coming in contact with the hot carbon or coke through which it has to pass, takes up carbon and becomes corbonic oxide.

M. O. Boudouard has found that at 1,112 deg. Fah. $CO_2 + C$ yields 23 per cent carbonic oxide, and 1,832 deg. Fah. $CO_2 + C$ yields 99·3 per cent carbonic oxide, so that the proportion of carbonic acid in producer gas depends upon the temperature of the fire and the velocity of the gas through it (see diagram fig. 2).

The proportion of carbonic oxide in the gas from a producer is greater the hotter the fire is worked, and the slower the carbonic acid gas passes through this heated portion, as well as the reduction in the size of the fuel so as to present a large surface of contact.

From this it would appear that the grate area should be considerably less than the area of the producer in the zone in which the reduction of CO_2 is effected.

This conclusion is confirmed by blast-furnace practice, the walls of the bosh of the furnace rising from the hearth, where the blast is introduced under some pounds per square inch pressure, not being carried up vertically, but at an angle of about 70 deg. This method of reducing the velocity of the gases rising from the fire by increasing the area of the chamber was almost universally adopted in gas producers designed for gasifying coal for heating metallurgical furnaces, etc., and is still followed by most of the high-capacity producers of the day.

However, it is a notable feature of the smaller class of producer now employed to work on the "suction" principle that the walls are generally carried up vertically above the grate.

This is probably due to convenience of construction combined with the small size of the apparatus, but the producer in working corrects this, owing to the accumulation of ash and clinker round the grate.

The writer, by analysing the gas from a suction producer at intervals during an eight hours' test, found that the percentage of carbonic acid in the gas gradually reduced, and the gas became richer in combustible during

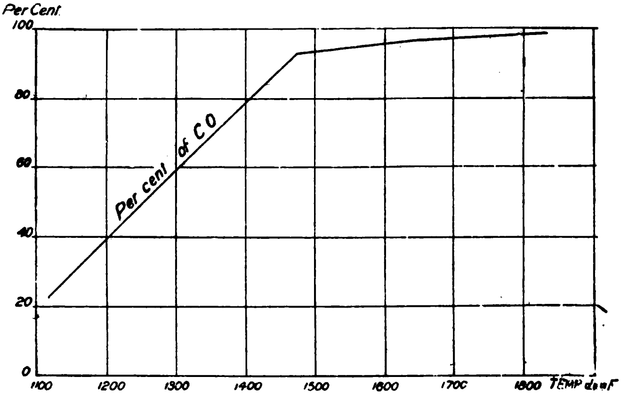


FIG. 2.

the progress of the test, besides which, on opening the fire door to withdraw the fire at the termination of the test, it was plainly seen that while the central portion of the fire was at a very high temperature there was, between the fire and the brickwork, a surrounding mass of partly-burnt fuel and ash, which restricted the actual working area of the fire, tapering away to the brickwork a short distance up.

Turning again to Bunsen and Playfair's report, they calculated that in the case of a furnace filled with Gosforth coal, and used as a gas producer only, with air blown in at the bottom, the combustible power of the gases amounts to 83·7 per cent of the total heat value of the fuel, the heat used in the gasifying process amounting to only 16·3 per cent. However, even this amount of heat is more than is required, and by using a mixture of steam and air, in place of air only, the heat requirements of the producer are less than 10 per cent of that of the fuel. Another feature in regard to the distilled gases from coal used in gas producers was proved by the experiments of Bunsen and Playfair, and one of extreme importance to the power gas engineer, viz., that if the products of distillation have to pass through highly-heated fuel, the composition and proportions of the products are changed.

Two experiments of distillation of Gosforth coal were made in small tubes. In one case the heat was applied first at the end of the tube furthest from the collecting apparatus, the products of distillation in this case only having to traverse cold materials. In the other experiment the tube was first heated at the end nearest to the exit to the collecting apparatus, and gradually worked along the tube to the other end, so that the distilled matter had to traverse hot fuel. The difference between the results obtained are shown by the table on page 18.

A comparison of the above results shows:—

(1) That the proportion of coke resulting from the distillation of coal is affected by the method employed. This is found to be the case in the manufacture of coke. With the same quality of coal more coke results with one class of coke oven than with another, a point which will be referred to more particularly when dealing with the application of coke-oven gas for power purposes.

(2) In the matter of tar, it is shown that decomposition of a *portion* has taken place through causing it to pass through red-hot fuel. An examination of the most recent inventions of producers for gasifying bituminous coal will

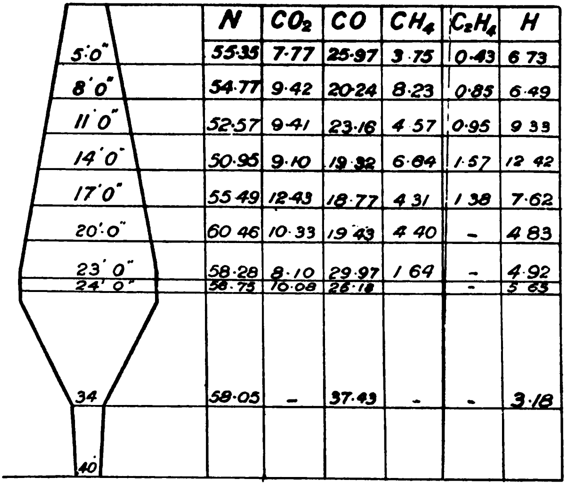
show that the distilled gases are in many cases caused to pass through the hottest part of the fire, with the object of decomposing the tar. If the results obtained with Gosforth coal are in any way typical for all classes of fuel containing tarry matter, there would not appear to be much benefit derived from this method. Though in the second experiment the weights of tar and water are given together, it would seem that though some of the tar and water had

PERCENTAGE RESULTS BY WEIGHT.

	Cooled distillates.	Heated distillates.
Carbon	67·228	65·123
Tar	9·697	16 594
Water	12·397	
Carburetted hydrogen	6·638	6·233
Carbonic oxide	1·602	6·328
Carbonic acid	1·139	2·289
Condensed hydrocarbons	0 513	1·559
Sulphuretted hydrogen	0·253	·172
Hydrogen	0·370	1·421
Ammonia	0·163	·281
	100·000	100·000

re-acted upon each other, causing an increase in carbonic oxide and hydrogen, the reaction was not limited by either the quantity of the water or the tar. If this had been the case the promises in this direction would have been more hopeful.

In modern power gas-producer practice attention is being given to the matter of drawing off the gas at some other point than the top of the fuel, and in this connection the results obtained by Bunsen and Playfair when examining the composition of the gas at different depths in an iron furnace at Alfreton are of considerable importance. In this furnace Gosforth coal was used, but the furnace contained the necessary materials for producing iron, so that the composition of the gas would be modified by those gases resulting from the ore and flux; however, valuable information in regard to gas manufacture is to be derived from a comparison of the analyses.



	N	CO_2	CO	CH_4	C_2H_4	H
5' 0"	55·35	7·77	25·97	3·75	0·43	6 73
8' 0"	54·77	9·42	20·24	8·23	0·85	6·49
11' 0"	52·57	9·41	23·16	4 57	0·95	9 33
14' 0"	50·95	9·10	19·32	6·64	1·57	12 42
17' 0"	55 49	12·43	18·77	4 31	1 38	7·62
20' 0"	60 46	10·33	19 43	4 40	-	4 83
23' 0"	58·28	8·10	29·97	1 64	-	4·92
24' 0"	58·75	10·08	26·18		-	5 63
34	58·05	-	37·43	-	-	3·18
40						

FIG. 3.

These have been arranged alongside a scaled diagram of the interior of the furnace in fig. 3. As carburetted hydrogen—marsh gas—is distinctly a product of distillation, its presence down to 24 ft. indicates that distillation is not complete at that point, while its absence at 34 ft. shows that the volatile constituents of the coal are completely driven off between those two levels, while the proportions of nitrogen, olefiant gas, carburetted hydrogen, and hydrogen at 14 ft. indicate that distillation proceeds at a maximum rate about this level.

The presence of tar in the gases was found to be at a maximum at a depth of 17 ft., while at the depth of 14 ft.

there was little evidence of tar. In this connection, however, when the author visited the Alfreton furnaces, some few years ago, he was informed that a peculiarity in the working of these furnaces was the fact that, for periods extending sometimes to three months, the evolved gases would be rich in tar, as evidenced by the quantity of this material found in the gas tubes, etc., while at other periods there would be no tar, but carbonaceous dust in place of it. The change could not be accounted for, but the working of the furnaces during these periods differed very greatly.

It is most probable that the differences were due to changes of temperature in the zones of the furnace, though how brought about it was not easy to discover; however, it proves that under certain conditions no tar is carried out by the gases, while under other conditions a large amount of tar was condensed, from the same class of coal in each case.

Bunsen and Playfair, at the time of their examination of the gases from the coal-fuel iron furnace at Alfreton, made numerous experiments in regard to the recovery of the ammonia in the gases as a valuable commercial bye-product, showing that nearly the whole of the nitrogen of the coal could readily be condensed, even without the employment of acids, as on cooling the gas, as is necessary when it is to be used in gas engines, the water vapour carried by the gas itself on condensation was found to have about 99 per cent of the ammonia absorbed by it.

This subject will be fully dealt with in connection with the Mond and other types of coal slack producers, bye-product recovery coke ovens, and blast-furnace gas, where coal is employed in the smelting of iron.

The combustible constituents of manufactured power gas are principally carbonic oxide and hydrogen, with which is usually a small proportion of marsh gas, and sometimes also olefiant gas or ethylene; these latter are usually distillates from the fuel, while the former result from combinations brought about in the producer, and to follow the general principles of power gas manufacture it will be necessary to treat the subject of combustion theoretically.

CHAPTER III.

THE CHEMISTRY OF MANUFACTURE AND COMBUSTION OF POWER GAS.

As the chief duty of the gas producer is to gasify the solid carbonaceous constituent of the fuel, this must become the first consideration. Carbon has the property of combining with oxygen in two degrees, thus:

Elements	Carbon +	oxygen
Symbol	C	O
Atomic weight	12	16
Molecular weight	24	32

First combination.

$$C + O = CO \text{ (carbonic oxide).}$$
$$12 + 16 = 28$$

Second combination.

$$C + 2O = CO_2 \text{ (carbonic acid).}$$
$$12 + 16 \times 2 = 44$$

It is this property of solid carbon, of forming a combustible on partial combustion, which renders it possible to convert the solid fuel into a suitable gaseous form for use in internal-combustion engine cylinders.

Now, 1 lb. of carbon, in combining with oxygen to form carbonic oxide, develops 4,451 B.Th.U., and the resulting weight of carbonic oxide is capable, on further combustion, of developing 10,093 B.Th.U. If the 1 lb. of carbon was completely burnt to carbonic acid, the total heat developed would be 14,544 B.Th.U. However, it must be borne in mind that under normal conditions of temperature carbon and oxygen have no action on each other, and to bring about combination heat has to be applied to one or other, or both, of the constituents. Further, the bringing about of this chemical combination by the application of heat is more dependent upon the intensity of the heat than the quantity, as when combustion has been brought about, in however small a degree, the heat developed by the combustion causes the continuation of the combination until either one or other of the constituents is consumed.

However, there is required a continued expenditure of heat to bring each particle of carbon up to the combustion temperature, and if this temperature is taken at 600 deg. Fah., and the specific heat of carbon as ·236, this = 600 + ·236 = 141 B.Th.U. per lb. of carbon oxidised; but this is not included in the results of calorimetric determinations, so that in a gas producer the only expenditure of heat required is that for bringing about the distillation, about 237 B.Th.U., and the loss by radiation.

It follows that in the manufacture of carbonic oxide gas from carbon there is considerably more heat rendered sensible than is required by the process, and this is communicated to the gas, the fuel, and the producer itself.

Thus :—

1 lb. C to CO = 4,451 B.Th.U. rendered sensible
= 2·33 lb. CO, capable of developing 10,093 B.Th.U.

Another method of gasifying carbon is its partial combustion by steam.

$$\begin{array}{ccccc} C & + & H_2O & = & CO + 2H \\ 12 & & \underbrace{2 + 16}_{18} & & 28 + 2 \end{array}$$

If we take the atomic weights as lbs., we find the heat reaction to be as follows:

Heat capable of being developed by

28 lb. CO	121,100 B.Th.U.
2 lb. H	124,000 B.Th.U.

Heat absorbed in decomposing the water vapour
= 2 lb. H, 124,000 B.Th.U.

Heat generated, or rendered sensible, by combustion of
12 lb. C to CO = 53,412.

In this reaction the heat absorbed is greater than that generated, so that heat has to be provided from some outside source.

By combining the two reactions described by mixing steam with the air used in the producer, the extra heat developed in the oxidation of carbon to carbonic oxide goes to bring about the decomposition of water vapour and formation of hydrogen and additional carbonic oxide, and it must be noted that the gases, resulting from the reaction between water and carbon, are free from dilution by nitrogen; gas made from steam and air is therefore richer than that made when air only is used.

When referring to the blast furnace as a producer the question of the removal of the earthy ingredients was not dealt with. Owing to the furnace having a closed hearth, with heated blast at considerable pressure applied, the temperature developed in the hearth is sufficiently high to melt suitable earthy mixtures, and render them fluid enough to be run out of the bottom of the furnace. If, however, steam was to be mixed with the air to economise the heat, the ash could not be melted, and would have to be removed periodically. The mixture of steam with the air therefore cools down the fire, and causes the proportion of carbonic acid formed to be increased in the manner already described. When the proportion of water vapour applied is excessive, as in the Mond class of producer, it has not the effect of quenching the fire in the hearth, as might be expected—2½ tons of steam being applied per ton of coal—but a portion of the steam passes undecomposed through the bed of fuel, from which it would appear that local action takes place, carbon being burnt to carbonic acid and carbonic oxide, accompanied by heat generation in certain parts, while the decomposition of water and formation of hydrogen and carbonic oxide, with cooling effect, takes place at other parts.

In gas producers of the blast-furnace pattern, where air is blown in at the bottom and the earthy materials are to be rendered liquid, no increase in efficiency can be effected by causing the hot gases to heat the incoming air, for the gasification of the fuel is accompanied by the continued development of an excess of sensible heat, so that economy could only be effected by causing the heat of the gas to be conserved by applying it to some purpose outside the producer.

When a firegrate is employed, and water vapour mixed with the air, the heat of the gas can be applied to vaporising water for the purpose of gasification, as is common practice in modern suction producers.

It has already been pointed out that with bituminous coal fuel the volatile gases are completely driven off before the carbon commences to become oxidised, and the greater the proportion of volatile matter the richer the gas will be; but, besides this, there is another property which forms a serious problem in gas making, and that is the difference between the rate at which distillation proceeds and that of the oxidation of carbon. Distillation is only dependent upon a certain temperature beng communicated to the coal, while oxidation requires the contact of air with the incandescent carbon.

After the volatile gases have been liberated the remaining coke is more or less bulky in form; most bituminous coals, in fact, cake to a considerable degree in coking, so that the surface only is available for combining with oxygen. These properties cause the composition of the gas to vary in richness during the intervals between the admission of the charges. A very simple but interesting experiment, and one that can readily be carried out by the aid of a porcelain plate, a bunsen burner (an ordinary gas stove heating ring answers the purpose), and a stop watch, was devised by the writer when making a study on the combustion of coal.

The coal to be tested should be ground to a very fine powder, and placed in a piece of fine wire gauze; when the porcelain plate has been brought to a very high temperature (still remaining over the burner), a minute portion of the finely-powdered coal is dropped upon the plate by a slight tap being given to the wire gauze, and the time noted. The period of distillation can be observed by the emission of smoke, and the time again noted when this ceases; in a short interval the oxidation of the carbon commences, being evidenced by the particles glowing brightly. Complete oxidation is indicated by the termination of the glowing period.

In the experiments made by the writer the following results were obtained: The period of oxidation was found to be about ten times longer than that of distillation, while there was always a distinct period between the completion of distillation and the commencement of oxidation about equal to the period of distillation. The success of the experiment depends upon only a very minute quantity of coal being employed, so as to ensure the free access of air to the particles of incandescent coal.

Summing up the reactions occurring in the different zones of the producer, we have—

1. The charging of raw fuel into the hot upper part of the gasifying chamber, accompanied by rapid distillation of the most volatile of the distillable gases and absorption of heat.

2. Continued distillation at slower rate until complete, heat still being absorbed. Distillation does not usually become complete until a temperature of about 1,300 deg. Fah. has been reached.

3. Carbonic oxide formation zone. In this part of the producer carbonic acid formed in the lower zone, coming in contact with incandescent coke, becomes reduced to carbonic oxide of double the volume of the carbonic acid entering into the reaction. At this stage the temperature of the producer is much lower than the zone below it.

4. The zone in the neighbourhood of the grate bars, where air and steam come in contact with the glowing fuel. In this zone two actions go on simultaneously:

(1) Carbon becomes completely oxidised, or burnt, to carbonic acid, with full development of the heat of the carbon, this being therefore the hottest part of the producer.

(2) The water vapour, on coming in contact with the incandescent fuel, decomposes with the liberation of hydrogen and oxygen in a free state; the former directly

enriches the gas, but the latter at the temperature ruling has a greater affinity for carbon than its discarded associate hydrogen, and passes up the producer as carbonic oxide. These reactions are only effected by a large absorption of heat, but combustible additions are made to the gas without dilution with nitrogen.

The theoretical temperatures due to the complete oxidation of carbon on the grate, and that of the zone where further carbon is taken up and carbonic acid is completely reduced to carbonic oxide, is shown by the following:

1 lb. of carbon, on complete combustion, develops 14,544 B.Th.U.

$$1 \text{ lb. C} + 11{\cdot}6 \text{ lb. air} = 3{\cdot}66 \text{ lb. } CO_2 + 8{\cdot}94 \text{ lb. N.}$$

Dividing the heat developed by the weight of the products of combustion, multiplied by their specific heat, we have:

$$\frac{14544}{(3{\cdot}66 \times {\cdot}2486) + (8{\cdot}94 \times {\cdot}2497)} = 4628 \text{ deg. Fah.}$$

$$3{\cdot}66 \text{ lb. } CO_2 + 1 \text{ lb. C} + 8{\cdot}94 \text{ lb. N} = 4{\cdot}66 \text{ lb. CO} + 8{\cdot}94 \text{ lb. N,}$$

and the heat developed is that from 2 lb. of C burning to CO, or 4541 × 2 = 8902 B.Th.U.; and

$$\frac{8902}{(4{\cdot}66 \times {\cdot}2479) + (8{\cdot}94 \times {\cdot}2497)} = 2628 \text{ deg. Fah.}$$

In the Alfreton iron furnace Bunsen and Playfair found no carbonic acid present at a height of 2 ft. 9 in. above the air inlet, so that in this short distance the temperature must have fallen about 2,500 deg.

An examination of the analyses of the gases taken at different heights in the Alfreton furnace indicates that if the gases were withdrawn at a level of 2 ft. 9 in. above the tuyere, the most suitable gas for power purposes would be obtained; but then it must be borne in mind that the issuing gas would be at a temperature of about 2,500 deg. Fah., and in carrying this sensible heat out of the furnace at this zone the zones above would be considerably changed in temperature, while the distilled gases would be changed in physical properties through having to pass out at the CO zone.[*] Only 70 per cent of the heat value of the fuel would be available as combustible in the gases, the remaining 30 per cent being carried as sensible heat, according to—

$$\frac{4451 \times 100}{14544} = 30 \text{ per cent.}$$

CHAPTER IV.

SPECIFIC HEAT.

THIS term has been adopted to represent the capacity for heat of solids, liquids, and gases, and the British unit for specific heat is defined as the quantity of heat required to raise 1 lb. of water at 32 deg. Fah. to 33 deg.

TABLE I.—SPECIFIC HEAT OF GASES.

	Deg. Fah.	Constant pressure.	Constant volume.
Air	50— 392	·2371[†]	·16847
	68— 824	·2366[†]	....
	68—1166	·2429[†]	....
	68—1472	·2930[†]	....
Oxygen	50— 392	·2175[†]	·15507
	68— 824	·2240[†]	....
	68—1166	·2300[†]	....
Nitrogen	50— 392	·2438[†]	·17273
	68— 824	·2419[†]	....
	68—1166	·2464[†]	....
	68—1472	·2497[†]	....
Carbonic acid	50— 392	·2168[†]	·1535
	68— 824	·2306[†]	....
	68—1166	·2423[†]	....
	68—1472	·2486[†]	....
Carbonic oxide		·2479	·1758
Olefiant gas		·404	·173
Hydrogen		3·40900	2·41226
Marsh gas		·5929	467

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[*] Tar is not decomposed below a temperature of 2,000 deg. Fah.

[†] L. Holbarn and L. Austin, Berliner Berichte, 1905.

Fah., viz., 1 deg. The figures given in Table I. therefore represent the ratio of capacity for heat of different gases compared with that of water:

TABLE II.—SPECIFIC HEAT OF GASES AT HIGH TEMPERATURES.*

	1 lb. B.Th.U.	1 cubic foot B.Th.U.
Hydrogen, up to 3,600 deg. Fah...	6·660 ÷ 0·0003 t	0·0341 ÷ 0·000017 t
,, 3,600 to 7,200 ,, ..	4·95 ÷ 0·0008 t	0·0290 ÷ 0·0000045 t
Nitrogsn, up to 3,600 ,, ..	0·4329 ÷ 0·000021 t	0·0341 ÷ 0·0000017 t
,, 3,600 to 7,200 ,, .	0·3679 ÷ 0·000057 t	0·0290 + 0·0000045 t
Oxygen, up to 3,600 ,, ..	0·3837 ÷ 0·0000187 t	0·0341 ÷ 0·0000017 t
,, 3,600 to 7,200 ,, ..	0·3218 ÷ 0·00005 t	0·0290 + 0·0000045 t

SPECIFIC HEAT OF COAL GAS AND AIR.

When

$$R = \frac{\text{volume of air}}{\text{volume of gas}}$$

$$\text{specific heat at constant volume} = \frac{R \times 0{\cdot}168 + 0{\cdot}286}{R + 0{\cdot}48}$$

$$\text{specific heat at constant pressure} = \frac{R \times 0{\cdot}237 + 0{\cdot}343}{R + 0{\cdot}48}$$

TABLE III.—SPECIFIC HEAT OF SOLIDS AND LIQUIDS.

Water = 1.

Wood, desiccated	·253†
Coal, average	·246†
Anthracite	·201
Carbon	·236†
Charcoal	·241
Coke	·236†
Sulphur	·203
Petroleum	·43—·47
Alcohol	·659
Benzine	·393

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* J. W. Richards, Ph. D., "Electro-chemical and Metallurgical Industry," N.Y.
† D. K. Clark, "The Steam Engine."

CHAPTER V.

CALCULATING THE VOLUME OF GAS PRODUCED FROM FUEL.

FOR calculating the volumes of gases produced from any weight of solid, liquid, or gaseous substance, Professor W. Richards, of the Franklin Institute, has arranged some abridgments in chemical calculations, which will be of considerable convenience to the power gas engineer.

The following simple relations will render the calculations very clear and easy: The molecula formula of a gas represents in an equation, relatively, one volume of that gas, and the molecular weight also represents a relative weight. If the total relative weights entering into the reaction be taken as pounds, then each molecule of gas entering into the equation will represent the volume of molecular weight in pounds of a gas which, by Avogadro's law, is the same for all gases.

For hydrogen this volume is

$$\frac{2}{\cdot005592} = 357\cdot6 \text{ cubic feet.*}$$

from which it follows that if the relative weights entering into an equation be taken as pounds each molecule of gas in the equation will represent 357·6 cubic feet of that gas.

Thus

$$\begin{array}{ccccc} C & + & O & = & CO \\ 12 & & 16 & & 28 \end{array}$$

where 12 lb. of carbon, combining with 16 lb. of oxygen, give 28 lb. of carbonic oxide, having a volume of 357·6 cubic feet

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* Volumes being taken at 32 deg. Fah. and 30 in. Bar.

As equal volumes of all gases contain equal numbers of molecules, if a gas molecule of any gas whatever contains one atom of carbon, hydrogen, or of oxygen, then for any such gases it can be said that equal volumes of them contain equal numbers of atoms of carbon, hydrogen, oxygen, etc., and therefore equal weights of each of those elements respectively.

In one cubic foot of CO there is ·0335 lb. of carbon; therefore any other gas containing one atom of carbon in its molecule will contain the same weight of carbon per cubic foot—for instance CO_2, CH_4, etc.; and gases with two atoms of carbon per molecule, as (C_2H_4), etc., will contain just twice the above weight of carbon, or ·0670 lb.

In a similar manner the weight of the elements in any molecule can be determined, and the following figures give the weight of each element for each atom contained in a molecule:

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Weight in lbs. in 1 cubic foot...	·0335	·00279	·0447	·0391

To apply these figures to any gas it is only necessary to multiply them by the number of atoms of any element occurring in the molecular formula of the gas.

Example.—Calculate the weight of the different elements entering into the composition of one cubic foot of natural gas of the following composition:

	Per cent, by volume.		
Carbonic oxide, CO	1·0	=	·010
Marsh gas, CH_4	95·0	=	·950
Hydrogen, H_2	2·0	=	·020
Oxygen, O_2	1·3	=	·013
Olefiant gas, C_2H_4	0·7	=	·007
	100·0		1·000

To find the weight of carbon:

CO	·010
CH_4	·950
C_2H_4 ...·007 × 2...	·014

·974 × ·0335 = ·0326 lb. per c. ft.

To find the weight of hydrogen:

CH_4 ...·950 × 4...3·800
H_2 ......·020 × 2...·040
C_2H_4 ...·007 × 4... ·028
3·868 × ·00279 = ·0108 lb. per c. ft.

To find the weight of oxygen:

CO .... ·010
O_2 ......·013 × 2... ·026
·036 × ·0447 = ·0016 lb. per c. ft.
Total......... ·0450

CHAPTER VI.

COAL: ITS PRODUCTION, AND THE NECESSITY FOR ITS ECONOMICAL EMPLOYMENT.

THE Board of Trade report on the production of coal in this country for the year 1904 gives a total weight of 232,428,000 tons, of which 166,609,000 tons were consumed for power, light, and heat in the United Kingdom. The average value of this coal during the same period at the collieries was 7s. 8d. per ton. Although there is ample evidence that the supply of coal, even at the above rate, shows no prospect of failing for some considerable period, it is quite certain that it is a case of drawing on capital, for at this stage in the earth's age, as far as the United Kingdom is concerned, coal formation is practically a thing of the past.

It follows that the strictest economy should be observed by users, of whatever class, so as to obtain the maximum of benefit from this natural supply of heat-providing material, and from what has already been stated it requires little consideration to show that the heating effect of coal can be more economically applied to the use of man in a gasified form than when employed in a crude state in open fires.

COAL: ITS COMPOSITION AND HEATING POWER.

To give a general idea of the different classes of coal and the variation in the proportion of the volatile matter, the following diagrams have been prepared from figures given by G. Kemensky:

CLASSIFICATION OF COAL (G. Kemensky, Iron and Steel Institute).

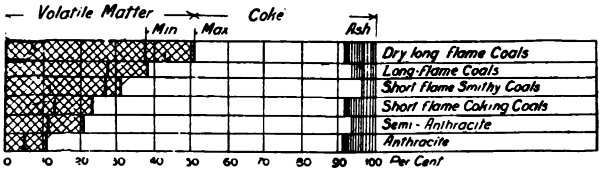

FIG. 4.

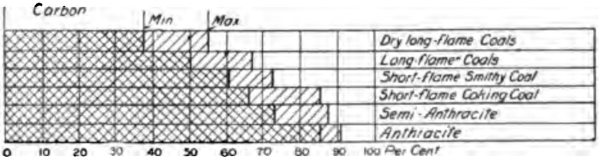

FIG. 5.

It will be seen from figs. 4 and 5 that "bituminous coal" includes varieties in which the percentage of volatile matter varies from 12·4 per cent up to 50·1 per cent, so that it is necessary, when considering the question of employing coal slack for the manufacture of gas for power purposes, to know the class of coal available, by analysis, as the proportion of tar is related to the volatile matter, and if the tar cannot be decomposed in the producer, apparatus must be provided to accomplish its removal from the gas before it enters the cylinder of the engine.

The following analyses, showing the range in quality of coal of different classes, are given in *The Practical Engineer* Pocket-book :

	Anthracite.	Semi-bituminous.	Bituminous.
Water	1·00— 2·00	1·00— 3·00	1·00— 4·00
Volatile matter	5·00— 5·00	18·00— 15·00	40·00— 34·00
Fixed carbon	88·50— 75·00	75·50— 67·00	53·50— 46·50
Sulphur	·50— 2·00	·50— 3·00	·50— 3·50
Ash	5·00— 16·00	5·00— 12·00	5·00— 12·00
	100·00—100·00	100·00—100·00	100·00—100·00

LANARKSHIRE COAL.*

	Ell.	Ell.	Splint.	Triping.	Washed dross.
Volatile matter—					
Water	7·60	10·20	10·60	9·00	11·50
Gas, tar, &c	41·78	36·14	33·42	34·17	30·66
Sulphur	·12	·11	·22	·43	·24
Coke—					
Fixed carbon	45·60	44·65	51·36	49 50	49·10
Sulphur	·81	·85	·08	·25	·31
Ash	4·09	8·05	4·32	6·65	8·19
	100·00	100·00	100·00	100·00	100·00
Thermal value—B.Th.U.	13,289	12,758	12,672	13,266	11,682

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* West of Scotland Iron and Steel Institute, Mr. F. Mills, 1897-8.

DURHAM COAL.*

	Screened.	Best.	Double nuts.	Wigan (Lancashire) Bickershaw Collieries.
Volatile mattter—				
Water	1·40	1·80	1 60	2·32
Gas, tar, &c.	31·84	30·30	30·79	29·22
Sulphur	·66	1·30	·99	
Coke—				
Fixed carbon	63·20	61·80	62·37	60·91
Sulphur	·64	·64	·37	
Ash	2·46	4·16	3·88	7·55
	100·00	100·00	100·00	100·00
Thermal value—B.Th.U.	14,058	13,878	13,572	12,075

* West of Scotland Iron and Steel Institute, Mr. F. Mills, 1897-8.

Besides the particulars regarding the proximate and ultimate analysis of coal, the power-gas engineer requires to know further how the coal behaves upon being subjected to heat: some classes, such as Scotch splint coal, do not coke; others form dense coke by caking during the period of distillation, while some classes become almost liquid before distillation is complete. Coal of the latter class, when charged into a boiler fire, becomes so liquid as to run through the bars.

Anthracite does not cake, but passes freely down the producer, and is therefore a very suitable fuel for power gas manufacture.

THE HEAT VALUE OF COAL.

Owing to the peculiarities in physical composition it is not possible to accurately determine the thermal value of coal from its chemical composition.

Before perfect combustion can take place the volatile portion has to be liberated, and this change is accompanied by absorption of heat, the quantity of which depends, of course, upon the proportion of volatile matter.

The most accurate method of arriving at the thermal value is, therefore, to burn some of the coal in the calorimeter. In this case, as the heat required to gasify the volatile matter is derived from the coal itself, the result obtained represents the *net* amount of heat which the coal is capable of communicating to water.

It is important to bear this fact in mind when considering the thermal efficiency of apparatus employed for gas making.

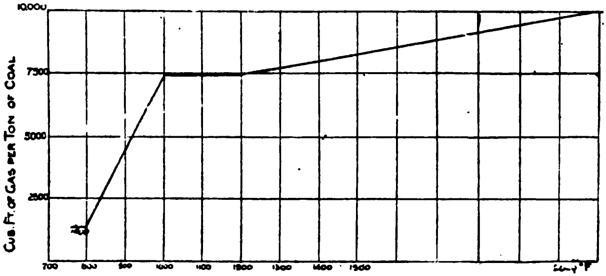

FIG. 6.—Rate of Evolution of Gas in Gas Works Retorts.

In the manufacture of gas for illuminating purposes, and such as is used for small gas engines to a very large extent, the coal is subjected to distillation in retorts externally heated. The heat of the coal in the interior of the retort ranges up to 2,100 deg. Fah. from that at which the retort is when charged.

The evolution of gas is very rapid during the early stages of increasing temperature, as will be seen from the following figures and diagrams, figs. 6 and 7:

Temperature.	Cubic feet of gas per ton of coal.
750 deg. to 800 deg. Fah	1,400
1,000 „ to 1,200 „ „	7,450
2,100 „	10,000

If the retorts are heated by generators there is required, to provide the heat for distillation, about 20 per cent of the coke made by the retorts.

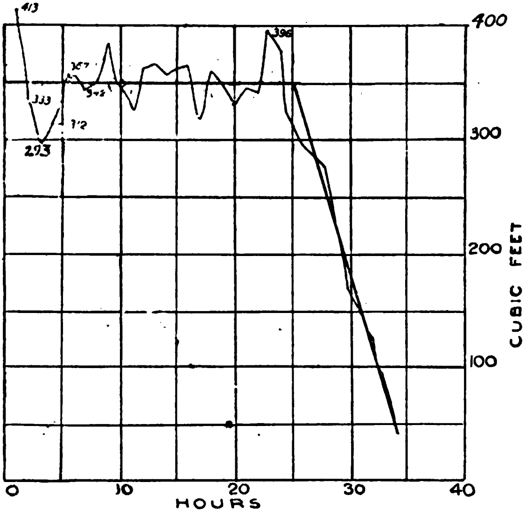

FIG. 7.—Gas Produced per Ton of Dry Coal (F. Schniewind, Ph. D. of New York, International Engineering Congress, Glasgow, 1901.)

On these lines we may calculate as follows:

Thermal value of 1 lb. of coal, net	14,700 B.Th.U.		
Heat required to release the volatile matter	1,842 ,,		
Gross thermal value	16,542 ,,		
			Per cent.
·68 lb. coke at 13,548	9,212	=	55·7
·136 lb. coke = 20 per cent of above for gasification ...	1,842	=	11·1
4·464 cubic feet of gas at 630 B.Th.U.	2,812	=	17·0
·32 lb. gas × 0·725 specific heat × 2,000 deg.	464	=	2·9
Tar and other losses..	2,212	=	13·3
	16,542		100·0

Analysis of various coals.	Carbon.	Hydrogen.	Oxygen and nitrogen.	Sulphur.	Ash.	Water.		Thermal value per lb.
English coal, average of 47 samples.	81·979	5·156	7·946	1·295	3·387	..	G. Turner	..
South Wales, Primrose 6 ft.	86·63	4·33	2·16	·99	4·70	·89	„	..
Carmarthen anthracite (Rockcastle)	93·10	8·10	·86 1·59	·56	·79	..	„	..
Lancashire coal	80·30	7·66	4·99 1·62	·64	3·52	1·57	..	..
Welsh, 37 samples as used in navy ..	83 78	4·79	4·15 ·98	..	..	..	H. de la Bache and Playfair	14,858
Newcastle, 18 samples	82·12	5·31	5·69 1·35	1·24	3·77	..	„ „	14,820
Derby and Yorkshire, 7 samples	79 68	4 94	10·28 1·41	..	..	..	„ „	13,860
Lancashire, 28 samples	77·90	5·32	9·53 1·30	..	..	..	„ „	13,918
British, average	80·00	5·00	8·00 1·20	1·25	4·00	..	..	14,130
Bowling, Yorkshire (Better Bed)....	75·76	4·71	9·93 1·07	·48	8·05	..	..	12,882
Wigan 4 ft.	78·86	5·29	1·19 ·86	1·19	4·23	..	Muspratt..................	..
Wigan, Bickershaw Colliery	76 36	5·16	5·55 ·93	2·08	7·55	2·32	..	12,075

The development of heat by the combustion of fuel is due to chemical action between elementary substances, all chemical action being accompanied by either the development or absorption of heat.

Under normal conditions of pressure and temperature combinations take place which do not occur when the pressure and temperature are changed, the affinity of substances for oxygen not being the same for all conditions of temperature or pressure.

For instance, free hydrogen and oxygen under normal conditions can exist as a mixture without combination taking place, but if by any means a minute portion of the mixture is brought up to a temperature of 1,124 deg. Fah., then combination takes place with extreme rapidity, and in proportions represented by the formula:

	By weight.		By volume.				
Symbols ...	$2\,H+O=H_2O$	or	▭▭	+	▭	=	▭▭
Weights ...	$2+16=18$		H 2 vols.		O 1 vol.		H_2O 2 vols.

1 lb. of H + 8 lb. of O become 9 lb. of water vapour. However, if the temperature is raised to such an extent as to be about that of incandescent carbon, these gases will not enter into combination.

Taking the case of a mixture of carbon, hydrogen, and oxygen, if these are at normal temperature, and ignition is effected by an electric spark, the hydrogen and oxygen will combine without altering the condition of the carbon; but if the carbon be raised to incandescence, it will be found to have a greater affinity for the oxygen than the hydrogen, and in place of water vapour resulting from the combination, the hydrogen will remain free and the carbon will unite with such a proportion of oxygen as to become changed to carbonic oxide, providing that an excess of oxygen has not been present:

$$C + 2H + O = CO + 2H.$$

Therefore it has been found that the affinity for gases for oxygen varies with the conditions of temperature, and that reactions which take place under certain pressures and temperatures do not always occur when either the temperature or pressure is changed. The unit of heat adopted as the British standard is the amount necessary to raise 1 lb. of water under normal conditions through 1 deg. Fah., and careful experiments have been made by different experts, which give the following heat values for carbon and the combustible gases:

HEAT OF COMBUSTION OF CARBON AND GASES FOR 1 LB. OF EACH SUBSTANCE.

Fuel.	Products.	B.Th.U.	Authority.
Carbon ....to	CO	4,451	Faure and Silbermann.
,, (Wood charcoal).	CO_2	14,544 14,220 14,647	Faure and Silbermann. Andrews. Berthelot.
,, (Diamond)......	CO_2	14,146	Berthelot.
,, (Graphite)	CO_2	14,222	Berthelot.
Carbonic oxide	CO_2	4,325 4,376 4,293	Faure and Silbermann. Andrews. Thomsen.
CO per unit of C..	CO_2	10,093	Faure and Silbermann.
Marsh gas, CH_4........	H_2O CO_2	23,616 23,594 23,513	Thomsen. Thomsen. Faure and Silbermann.
Olefiant gas, C_2H_4......	H_2O CO_2	21,344 21,496 21,523	Faure and Silbermann. Andrews. Thomsen.
Hydrogen, H............	H_2O	62,032 53,388*	....

It will be noticed from the table (IV.) given that the direct determination of the heating power of hydro-carbon gases does not give constant results comparable with the theoretical estimations, some giving a lower and others higher values than that obtained by multiplying the weights of the different elements by their ascertained heating value.

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* When the vapour is not condensed to liquid.

TABLE IV.—THE HEAT OF COMBUSTION OF HYDRO-CARBON GASES.

(The Author, in "Fielden's Magazine.")

Name of gas.	Chemical formula.	$\frac{C_x}{C_x\ H_x}$	In 1 lb. of gas.		Heat of combustion.		Theoretical total heat of combustion of 1 lb. of gas.	Actual heat of 1 lb. of gas.	Name of operator or source.
			Carbon.	Hydrogen.	Carbon.	Hydrogen.			
			Lb.	Lb.	B.Th.U.	B.Th.U.	B.Th.U.	B.Th.U.	
Methane, Marsh gas..	$C\,H_4$	·2	·749	·251	10,974	15,570	26,544	23,517 25,413 26,400 24,022	Dr. Gintl. Sexton. Pullen. Thomsen.
Ethane	$C\ H_6$	·25	·8	·2	11,721	12,406	24,127	24,017 22,400	Herman Poole Thomsen.
Propane	C_3H_8	·2727	·817	·183	11,970	11,351	23,321	21,825	”
Pentane	C_5H_{12}	·294	·833	·167	12,205	10,359	22,564	....	....
Butylene	C_4H_8	·333	·857	·143	12,557	8,870	21,427	....	....
Ethylene, Olefiant gas	C_2H_4	·333	·857	·143	12,557	8,870	21,427	21,330 21,345 21,300 21,523 21,898	Dr. Gintl. Sexton. Pullen. Thomsen. Herman Poole.
Propylene	C_3H_6	·333	·857	·143	12,557	8,870	21,427	21,223	Thomsen.
Amylene	C_5H_{10}	·333	·857	·143	12,557	8,870	21,427	....	....
Acetylene	C_2H_2	·5	·923	·077	13,524	4,776	18,300	21,501 21,856	Thomsen. Herman Poole.
Benzene	C_6H_6	·5	·923	·077	13,524	4,776	18,300	18,595 22,338	Thomsen. Herman Poole.
Hexane	C_6H_4	·6	·946	·054	13,860	3,350	17,210	....	....

In working out the table Berthelot's determination of 14,652 British thermal units per 1 lb. of carbon burnt to carbonic acid has been adopted.

In this connection it is a notable fact that different values for the heat effect of carbon are given both by the same experimenter with different forms of carbon and by various workers. As the product of combustion is the same in all cases—*i.e.*, carbonic acid gas—it must be evident that a satisfactory determination of the amount of heat developed in the production of a weight of carbonic acid containing 1 lb. of carbon has not yet been accomplished; it would appear that a more correct result would be obtained from the decomposition of carbonic acid gas by some means in which the absorption of heat could be measured.

CHAPTER VII.

THE GASIFICATION OF FUEL.

THOUGH it is not intended in this series of articles to deal with the historical side of the gasification of fuel to any great extent, it may be pointed out that this method of increasing the efficient employment of fuel dates from about the commencement of the nineteenth century.

About 1841 Ebelmen and others designed gas producers on the lines of the blast furnace, using a forced draught of pre-heated air and superheated steam. The ash of the fuel was fluxed and drawn off in a liquid state, while the fuel was admitted to the fire chamber by means of the hopper and bell.

The gas in this case was not for power purposes, but for heating puddling furnaces. Ebelmen's producer also had an extension of the iron hopper down into the furnace, thus providing a space between it and the wall of the producer for the free evolution of the gas, an arrangement which has also been applied to the Mond and other producers of the present day.

In a recent lecture on "Coal Gas and Its Rivals,"* Mr. Dugald Clerk explained that three years ago he had discussed the production of cheap coal gas. He thought that even now the trend of events pointed more strongly towards the necessity for such a cheap gas, pointing out that there was no better fuel for the gas engine than coal gas, and that if it could be supplied cheaply enough gas engines of every power would use it. While gas engines did not exceed 50 horse power the higher heat efficiency compensated for the "expensive" fuel, as compared with small steam engines, which not unusually cost 4d. per horse power per hour; while, with gas at from 2s. 6d. to 3s. per 1,000 cubic feet, the gas engine only cost 1d. per indicated horse power hour. The increase in the size of gas engines, however, brought them into competition with very much more efficient steam plants capable of developing 1 horse power hour at about one-fifth of a penny for fuel, and gave a further instance in which the cost was only one-tenth of a penny; going on to show that it would be necessary for gas of 600 British thermal units to be produced at about 1s. per 1,000 cubic feet to enable coal gas to cover the whole field of power supply economically up to at least 150 horse power. The lecturer then went on to explain that a high intrinsic illuminating power in coal gas was no longer the necessity it used to be, now that the mantle has come into common use; and given liberty on the part of gas manufacturers to discard the intrinsic illuminating power, they would soon succeed in producing a cheap gas at from 1s. to 1s. 6d. per 1,000 feet for heat purposes, such as stoves, gas engines, etc. As another instance of the necessity for a cheap supply of good coal gas, Mr. Dugald Clerk referred to the fact that within recent years the steam engine, reciprocating and turbine, had considerably increased in economy, so that large power gas engines had now to compete with a fuel cost of below ·1d. per horse power hour, and small gas engines driven by coal gas had a further competition in electric motors supplied with current

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* Lecture given to the North of England Gas Managers' Association, April 29th, at Newcastle-upon-Tyne.

from economical power stations. The number of electric motors now at work in six districts totals roughly to about 7,000, varying from 20 horse power to 1 horse power. In these districts the price charged for power per unit ranges from 0·55d. to 3d., the most usual charge, however, being about 1½d. per unit; but the lecturer thought that in a few years the general price would be reduced to 1·0d., or even under, for even at the present time the Charing Cross and Strand Electricity Company are quoting $^{15}/_{16}$d. per unit for large powers. The present price for coal gas for power in the principal districts of Britain are given in Table V. Taking the average prices, and assuming the thermal value at 600 British thermal units per cubic foot, and allowing for interest, depreciation, attendance, the corresponding fuel and total costs are given per brake horse power hour for brake efficiencies of 25 and 30 per cent respectively, the latter figure more nearly representing the average gas engine in general use:

TABLE V.—PRICES OF COAL GAS FOR POWER.

	Price per 1,000 cub. ft.	Average.	Fuel cost.		Fuel cost.	
			Per B.H.P. hour.	Total cost.	Per B.H.P. hour.	Total cost.
	s. d. s. d.	s. d.	30 per cent brake eff.		25 per cent brake eff.	
Leeds	1 6 to 2 3	1 10½	0·32d.	0·42d.	0·35d.	0·48d.
Birmingham..	1 8 ,, 2 6	2 1	0·36d.	0·46d	0·43d.	0·53d.
Glasgow	2 0 ,, 3 0	2 6	0·43d.	0·53d.	0·52d.	0·62d.
Liverpool.....	1 1 ,, 2 8	1 10½	0·32d.	0·42d.	0·38d.	0·48d.
Nottingham..	1 6 ,, 2 6	2 0	0·34d.	0·44d.	0·41d.	0·51d.
Bristol	1 9 ,, 2 0	1 10½	0·32d.	0·42d.	0·38d.	0·48d.
Newcastle....	1 6 ,, 3 3	2 4½	0·40d.	0·50d.	0·48d.	0·58d.
London........	2 0 ,, 2 11	2 5½	0·42d.	0·52d.	0·50d.	0·60d.
Sheffield	1 2 ,, 1 6	1 4	0·23d.	0·33d.	0·27d.	0·37d.
Widnes	1 0 ,, 1 4	1 2	0·20d.	0·30d.	0·24d.	0·34d.

In regard to competing with electricity, while even with London gas the gas engine can give its power for rather over half the cost for electricity, the electric motor has certain advantages over the gas engine; starting only requiring the turning of a switch, the electric motor occupies less space, and requires less attention, while in many cases counter-shafting can be dispensed with. Undoubtedly the electric motor has a certain field for very small powers from which it will not be displaced. Of course, in towns where current exceeds 1d. per unit the gas engine position is proportionately strengthened, and the lecturer instanced cases where electricity at 2d. per unit has been replaced by gas at 1s. 9d. per 1,000 cubic feet, with the result that the cost for power was reduced to about one-sixth.

Ekman, later, by causing the heated air to enter the fuel at about half of its height, and drawing off the gas at the bottom, was able to employ a solid hearth while not fusing the ash, which was removed through a door provided for this purpose. Many modern patents have included this arrangement to a certain extent.

The successful production of gaseous fuel from solid materials having been accomplished, the further improvements required were the production of gas continuously, of constant quality, and as free from deleterious matter as the purpose to which it is to be applied renders necessary.

As we are dealing with gas for power purposes principally, it may be said that the Dowson gas producer found most favour in regard to the increase in the proportion of gas engines to be worked with cheaper fuel than retort or illuminating gas.

To show graphically the increased efficiency to be obtained from the gasification of fuel over the method of burning it in its crude state, Mr. J. E. Dowson* prepared the diagrams, figs. 8, 9, and 10, to which the writer has added the results in per cent of the heat of the fuel.

Fig. 9 shows the various losses occurring in the ordinary type of Dowson power gas producer, where it will be noticed that a boiler forms part of the installation, and that about 8 per cent of the total heat of the fuel is

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* Transactions of the Institution of Electrical Engineers, vol. xxxiii., Part 165.

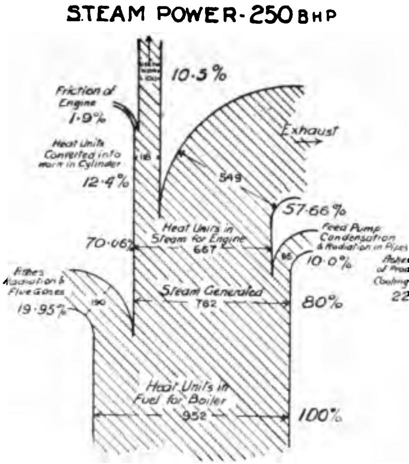

FIG. 8.—Heat Diagram based on Boiler efficiency 80% and Engine efficiency 15%.

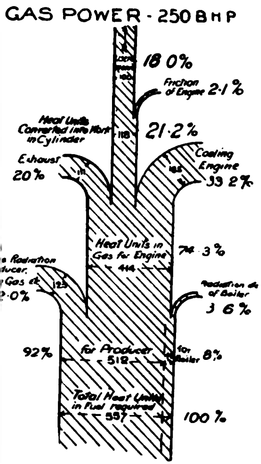

FIG. 9.—Heat Diagram based on Trials at Small Heath.

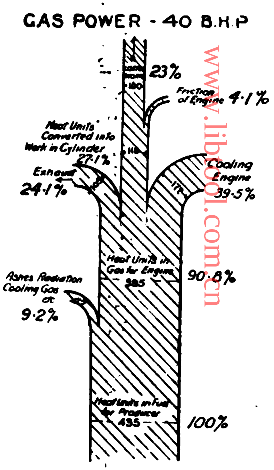

FIG. 10.—Heat Diagram based on Trials of Suction Type Plant and Engine.

required to provide the steam employed for the process of gas making; while the gas passing to the engine to perform useful work is about 74·3 per cent. This compares favourably with the steam boiler diagram, where the heat units passing to the engine only amount to 70 per cent, but in the suction producer a considerable increase is noticeable, viz., 90·8 per cent.

For power from 50 horse power to 500 horse power the system invented by Mr. J. E. Dowson was until quite recently the most favoured power gas generator. The producer chamber was fitted with grate bars, and air was induced below these bars by means of a steam jet, thus preserving them from becoming too greatly heated, and increasing the thermal value of the gas by the decomposition of the steam.

To show the difference between air gas, or that resulting from the partial combustion of carbonaceous matter such as coke or anthracite, by air alone, and by air and steam, the following typical analyses may be quoted:

	Air gas.		Air and steam gas.
Carbonic acid	1·6	...	5·25
Carbonic oxide	32·3	...	25·25
Hydrogen	4·0	...	18·50
Marsh gas	0·8	...	2·00
Nitrogen	61·3	...	49·00
	100·0		100·00
Thermal value per cub. ft. at 32° Fah. and 30″ Bar.	132·69 B.Th.U.		171·31 B.Th.U.

The thermal efficiency of these systems, however, are considerably different, and the writer has worked them out to be—

	Air gas.		Air and steam gas.
Thermal efficiency per cent.	69·3	...	80·9

The above figures show that by the Dowson system not only is the thermal value of the gas considerably increased over that of gasification by air alone, but the efficiency is also greatly increased, the heat value of the gas being raised 29 per cent, and the efficiency at the same time is increased 16·7 per cent.

The explanation of this improvement has already been given, showing that in the case of air gas the gaseous products contain a high amount of sensible heat, while in the Dowson system the gases are much cooler and also richer in combustible.

However, the system does not permit of the employment of bituminous coal, but requires anthracite or coke, both of which are of considerably higher cost.

CHAPTER VIII.

GAS PRODUCERS, PRESSURE TYPE DOWSON GAS PRODUCERS.

THE Dowson system of power-gas production consists of passing superheated steam, mixed with air, through red-hot fuel in a vertical gas generator. The original type included a small steam boiler. For gas engine work, or where cocks and burners are used, the gas is cooled and passed into a small gasholder.

The fuel employed consists either of anthracite or ordinary gas coke; the fuel must be small, either anthracite peas or nuts, or crushed coke.

For 200 brake horse power and upwards, where it is not desirable to use anthracite or coke, non-caking or semi-bituminous coal can be employed, but then it is necessary to increase the number of scrubbers so as to remove the tarry vapour, etc. The cost of the gas depends upon the price of the fuel and wages and the capacity of the installation, and is usually from 2d. to 3d. per 1,000 cubic feet, inclusive of fuel, wages, and repairs.

As the quantity of Dowson gas necessary to obtain the same engine power as ordinary town gas is about four times that of the illuminating gas, the cost of the equivalent quantity to 1,000 cubic feet of town gas is from 8d. to 12d.

The cost of repairs varies according to circumstances, but may be approximately stated as:

For	100	H.P. plant,	about	£4	per annum.
,,	200	,,	,,	6	,,
,,	300	,,	,,	9	,,
,,	400	,,	,,	12	,,
,,	500	,,	,,	15	,,

As the rate of production of gas is dependent upon the volume of air and steam employed, the efficiency of the method adopted to pass the air into the producer has its influence upon the total efficiency of the producer.

The Dowson producer is usually in the original type equipped with a boiler to provide the steam and induce the air by means of a steam jet blower; the steam is superheated, and the air is heated previous to its entering the blower.

The boiler consumes a certain amount of fuel, and under the most favourable conditions is only capable of giving an efficiency of about 70·0 per cent, while neglect and want of proper precautions may considerably reduce this. The steam from the boiler is connected by pipes to steam jet blowers, the following particulars comprising details of two types of steam blowers: A jet of steam is blown into a larger conical tube, and the air is drawn in by friction. As the amount of air induced is dependent upon the surface of contact between the air and the steam, and not upon the volume of the jet, an annular jet in which air can be admitted, both outside and inside, has many advantages. The area of the ring should be adjustable, so that the quantity of steam may be varied. In the Körting blower a solid jet and a series of short conical tubes are used.

The amount of steam required is given as 10 per cent by volume, or 6 per cent by weight of the air, which will be about 6 lb. of steam for each 20 lb. of carbon consumed, or ·3 lb. for each pound of carbon. With coal of 60 per cent of fixed carbon the amount of steam required for each pound of coal is ·6 × ·3 = ·18 lb.

The mixture of air and steam enters the producer below the grate bars, the presence of the steam reducing the temperature of the fire sufficiently to allow of the use of firebars of the usual type. The fuel is fed into the top of the producer centrally, and occupies the whole interior of the generating chamber, forming a bed of sufficient depth to ensure a constant quality of gas.

STEAM JET BLOWERS.

Size of bore of steam pipe.	Pressure of steam.	Thwaite's jet. Cubic feet of air per minute at atmospheric pressure.	Körting's jet. Cubic feet of air per minute at a pressure of 5 in. or 6 in. of water.	Diameter of air condenser.
Ins.	Lbs.			Ins.
⅜	60	60	..	..
½	45	..	150	4
9/16	60	250	..	..
¾	45	..	400	8
	60	350	..	..
1	45	..	650	9
	60	1,200	..	..
1⅛	60	2,000	..	..
1½	45	..	1,500	12
2	45	..	3,000	16
2½	45	..	4,000	18

The gas is led off from the upper part of the generating chamber through a pipe of considerable sectional area and length, which acts as a primary condenser, and then passes through coke and sawdust scrubbers; the capacity of these purifying vessels depends upon the quality of the fuel.

Although Dowson gas producers have been largely installed for several years for power and heating purposes, the capacity of the gas generator was generally from 10 to 250 horse power. However, this system found

FIG. 11. Dowson Producer Plant, Birmingham Small Arms Company.

such favour at three important works in this country that the capacity was increased to 1,000, and up to 1,650 horse power.

The Birmingham Small Arms Company was one of the first to adopt gas power in place of steam, and nine years ago put down a large installation of Dowson gas plant and gas engines of about 90 horse power each. The gas was also employed for hardening, tempering, and other furnaces. They have now a central gas-driven station for the supply of electric current for driving motors in their various shops, including three vertical pattern three-cylinder gas engines, driving Westinghouse dynamos of 150 kilowatts capacity each.

There are four producers of 250 brake horse power each, as will be seen in fig. 11. The illustration shows the charging stage nearly level with the top of the producers, with the condenser pipes of ∩ shape close to the wall of the building, while the boiler for providing the steam is seen on the left. The gas passes out of the generator room through sets of scrubbers. Above the second scrubber there is a small washer of special design, recently introduced by Mr. Dowson, and which forms a considerable improvement on previous methods of cleaning large volumes of gas. From the scrubbers the gas passes to a gasholder, and thence to the engines.

During a test made by Messrs. Henry Lea and Son, the consulting engineers,* extending over the regular working hours for one week, the quality of the gas was found to be very uniform. The coal consumption, including all losses and providing steam and banking fires during nights and noon hours, was 1·93 lb. per Board of Trade unit.

A notable power-gas installation is that at the electric light and power station of the Urban District Council at Walthamstow, where the capacity has been brought up to 1,650 brake horse power since it was originally laid down in 1901, and is to be increased

Fig. 12 shows the interior of the producer house, and fig. 13 the exterior, with the gas scrubbing apparatus. The producers have a capacity of 375 brake horse power each,

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* The *Birmingham Magazine.*

FIG. 12.—Interior View of Producer House, Urban District Council, Walthamstow.

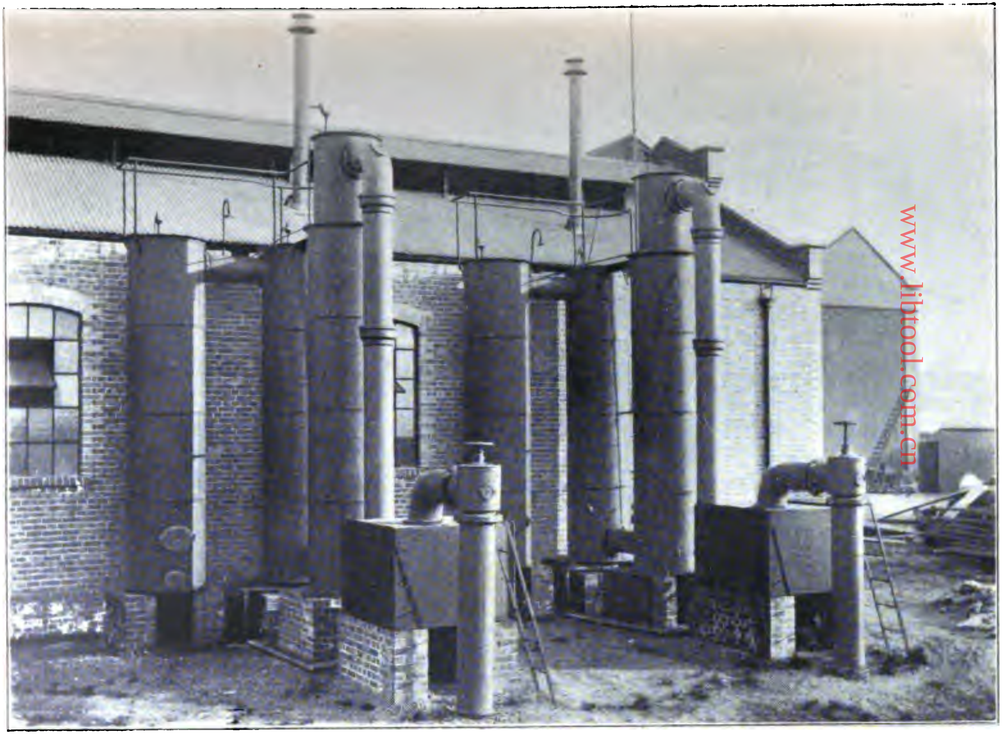


FIG. 13.—Exterior View of Producer Plant, Urban District Council, Walthamstow.

and are arranged in two houses 50 ft. long and 25 ft. wide each, and the two gasholders, through which all the gas is passed, are 25 ft. in diameter. As shown by the illustration, fig. 11, the level of the producers is so arranged that the feeding hoppers only stand a little above the charging floor, to facilitate hand stoking by the ordinary bell and hopper method.

To provide the steam required in the gas making, there are five small boilers of the vertical type, which deliver the steam directly to the steam jet blowers on the different producers. The hydraulic box, shown in fig. 11, for each set of producers and scrubbers, prevents a back flow of gas through any set that may be under examination or repairs at any time.

By volumetric analysis the following typical results have been obtained:

PERCENTAGE BY VOLUME.

Hydrogen, H	18·50
Carbonic oxide, CO	25·25
Marsh gas, CH_4	2·00
Carbonic acid, CO_2	5·25
Nitrogen, N	49·00
	100·00

Thermal value per cubic foot, about 160 B.Th.U.

To find the weight of carbon in the gas we have—

CO	·2525
CH_4	·02
CO_2	·0525

·3250 × ·0335 = ·0109 lb. per cubic foot.

And with anthracite containing 93·1 per cent of carbon 1 lb would give 85·4 cubic feet of gas at 32 deg. Fah., or per ton of fuel 191,296 cubic feet.

WORKING RESULTS OF DOWSON GAS PRODUCERS.

Mr. J. E. DOWSON, *Journal of the Institutute of Electrical Engineers.*

	Leicester.	Walthamstow.	Smallheath.	Limerick.
Make of engine	Crossley.	Westinghouse.	Westinghouse.	Westinghouse.
Power	300 B.H.P.	..	250 B.H.P.	3 sets of 75 kw.
Whether test or returns	Returns, January to May, 1903.	Returns, one year, to March 31, 1903.	Test, 5 days.	Test.
Total Board of Trade units generated	200,497	659,796	6,339	..
Average fuel consumption per unit generated, including "stand-by" and other losses	3 lb.	2 lb.	1·93 lb.	1·3 lb., exclusive of "stand-by" losses.
Kind of fuel used in producer	..	Small anthracite peas, $\frac{3}{8}$ to $\frac{3}{4}$ in. cube.	Small anthracite peas.	Anthracite peas.
Price of fuel per ton used in producer	15s., exclusive carriage on Mid. Rly.	26s. delivered.	20s. 6d. delivered.	..
Fuel consumed per standing hour	2·1 lb.	1·8 lb.	4·50 lb.	3·8 lb.
Works cost per unit generated:—				
Coal and other fuel	0·245d.	0·34d.	..	..
Oil, waste, water, etc.	0·039d.	0·19d.	..	..
Wages for generation—gas plant, 0·146; engine room, 0·437	0·583d.	0·33d.	..	..
Repairs and maintenance of gas plant, engines, and electrical plant	0·079d.	0·03d.	..	..
Total works cost per unit generated	0·946d.	0·89d.	..	..

Pressure Type Gas Producers made by Messrs. Crossley Brothers Ltd., Manchester.

Seeing that Messrs. Crossley were the developers of the Otto cycle gas engine, and are the principal manufacturers with a world-wide reputation, it is only to be expected that their work in connection with power-gas production should be of extreme interest. About four years ago this firm introduced a producer for gasifying anthracite, which is known as the type “A” pressure plant. As will be seen from the diagrammatic illustration, fig. 14, the air supply

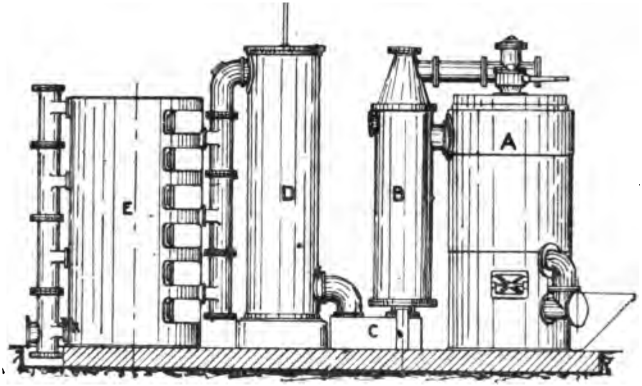


Fig. 14.—Elevation of the Crossley Type “A” Pressure Gas Plant.

is provided by a blower fan, driven from one of the gas engines supplied by the gas. The air from the blower enters a concentric tubular apparatus, styled a saturator, and marked B in the diagram, where it passes over the surface of water and becomes saturated with steam given off from the water, and enters the gas-generating chamber A through a superheating jacket, and thence through a pipe leading into the firegrate. The gas produced passes through the saturator, where it gives up its heat to the water contained therein. Coke and sawdust scrubbers, D and E, are provided for cleansing the gas, which passes away to be consumed under pressure. No gas holder is required, as with the Dowson system, as it is found not to be necessary.

A sectional view of this producer is given in fig. 15, where it will be noticed that the grate bars G are carried by a rotating table K, which enables the clinker and ashes to be removed without interrupting the continuous working of the producer. The uncombustible portion of the fuel falls into the water lute N, from which it can be removed at convenient intervals. From the illustrations it will be seen that the gas is drawn off centrally through

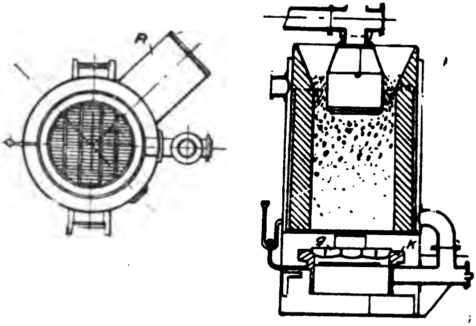


Fig. 15.—Sectional View of the Crossley Type "A" Pressure Producer.

an annular casting extending some way down into the generating chamber, the fuel being charged round the exterior of this inner vessel.

The firegrate is supported at a short distance below the vertical annular firebrick chamber, where gasification is effected, so that when the grate is revolved the ash and clinker is free to fall into the water lute. This producer is designed to obviate the necessity for having a second generator as a standby, to allow of cleaning and clinkering, and is capable of continuous running without any standby.

Several installations of the "A" type pressure producer are at work for generating gas for various purposes, including heating as well as power, using both coke and anthracite. Single producers of this type have been constructed of a capacity up to 330 brake horse power, and larger ones can be provided as required. They are capable of giving an efficiency of 88 per cent of the thermal value of the fuel converted into gas. An important point is that poking holes are provided to enable the fuel to be distributed where arching or hanging occurs, and for removing clinker. A great advantage is the dispensing with the usual gas holder; while all the steam required is provided by the heat of the evolved gases, thus increasing the efficiency of the apparatus. The saturator is separate from the generator, and is formed of two concentric cylinders, with water to a certain level contained in the internal space between the two. The gas passes down a central pipe provided with radial ribs, fitted to its internal surface by means of which the heat is transferred to the water. By this arrangement steam is raised in the top part of the annular space, across which the air is driven by the fan. The hydraulic box through which the gas passes from the saturator acts also as a seal, preventing any return draught through the generator.

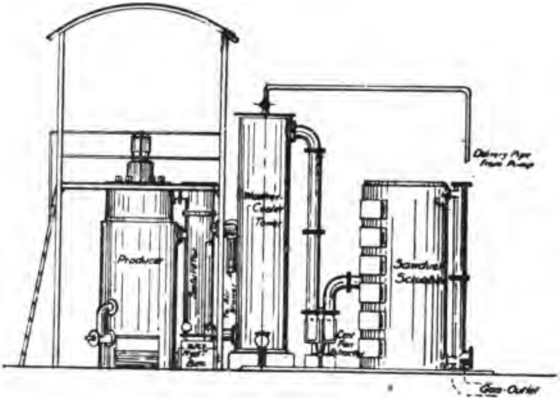


FIG. 16.—Side Elevation of the Crossley Type "B" Pressure Gas Plant.

In the "B" type, for powers of 80 horse power and upwards, any non-coking bituminous slack can be used. It is a more elaborate type of apparatus, and is provided with special means for removing tar and other impurities, thus permitting of the employment of cheap fuel of any non-caking class; figs. 16 and 17. As has already been explained, the various methods adopted for passing the gas through the hottest part of the fire before it leaves the producer to decompose or "fix" the tarry matter have only been partially successful, and has considerably increased the first cost. The tar products evolved by the distillation of bituminous coals vary considerably in composition, and it is found that only those portions become "fixed" or decomposed by being passed through fuel at high temperature which can be most readily removed in the ordinary type of cleaning apparatus, while the others which escape undecomposed are the source of serious trouble if allowed to enter the cylinder of a gas engine.

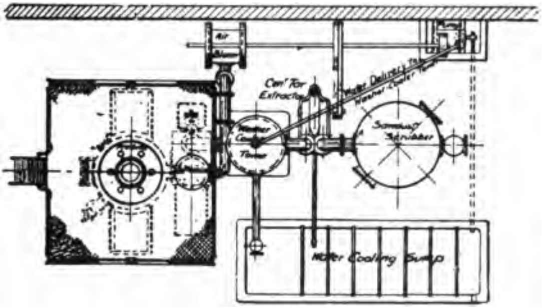


FIG. 17.—Plan of the Crossley Type "B" Pressure Producer Gas Plant.

For this reason Messrs. Crossley do not attempt to fix the tar, it being more simple to employ a rotary tar extractor after the gas has passed from the saturator and washing apparatus, and before it passed into the sawdust scrubbers, where the final removal of the last traces of tar and water vapour are extracted. The tar extractor consists of a rotary fan divided by a central rotary diaphragm. The gas enters in one side and passes through the blades on one side of the diaphragm, round the edge and back by the other blades on the other side. On the entering side the velocity of the gas is accelerated, and re-acts upon the diaphragm on its return passage, the net result being almost the same as if the fan was revolved in a vacuum. The acceleration causes the tar to separate in globules along with the water vapour, and to pass into the sump together with the water from the washer tower. This water passes through a vessel having a series of baffle

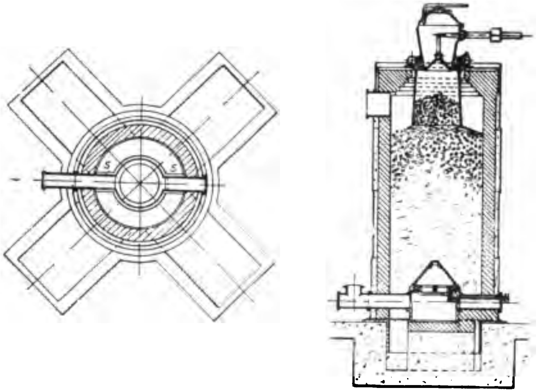


Fig. 18.—Plan and Section of the Crossley Type "B" Producer.

plates, which it passes over and under, during which time the tar is collected and finally skimmed off. The tar by-product is not of much value, being only worth a few shillings a ton, so the recovery of this material is not attempted in plants under 2,000 horse power. For larger installations, when the ammonia can be recovered as well as the tar, these by-products form an economical and commercial asset; in these plants, as it is not found practicable to generate all the steam required from the heat of the gases, a small boiler has to be provided to supply the surplus steam needed. A sectional view and plan of this type of producer is shown in fig. 18, where it will be seen that a special form of rotary grate is provided. Water lutes are provided for the removal of the ash and clinker, and the fuel is admitted to the generator by means of a bell and hopper. The saturator is somewhat similar to some classes of vertical steam condenser, having a number of tubes contained in a cylindrical vessel, with water round the outer surface of the tubes. The water from the tar sump is circulated through the washer tower usually by means of a centrifugal pump, so that the quantity used for all purposes does not exceed half a gallon per horse power per hour.

The space occupied by the "A" and "B" types of pressure producers is given for the following power capacities:

PRESSURE (A TYPE).

Maximum B.H.P.	Total space occupied for working plant. Ground space and height.									Net weights.	Gross weights.
	Ft.	in.		Ft.	in.		Ft.	in.		Cwts.	Cwts.
60	17	0	×	13	6	×	17	0		85	94
80	17	6	×	14	3	×	17	9		140	155
100	18	0	×	14	6	×	18	0		145	161
150	21	6	×	15	0	×	18	6		222	240
200	26	0	×	15	0	×	20	0		300	325
250	32	0	×	15	0	×	22	0		390	422
330	33	0	×	15	0	×	23	0		450	500

BITUMINOUS (B TYPE).

Maximum B.H.P.	Total space occupied for working plant.					Net weights.	Gross weights.
	Ft.		Ft.		Ft.	Cwts.	Cwts.
80	18	×	18	×	17	176	196
100	20	×	18	×	20	180	200
150	26	×	23	×	22	280	314
200	28	×	24	×	23	350	394
250	34	×	25	×	23	435	500
300	34	×	34	×	25	522	600
400	40	×	32	×	26	680	761
500	44	×	32	×	29	840	940
600	46	×	34	×	29	940	1030
750	47	×	36	×	32	1120	1240
1000	50	×	40	×	37	1500	1600
1500	57	×	51	×	40	2240	2480
2000	64	×	60	×	40	3022	3260

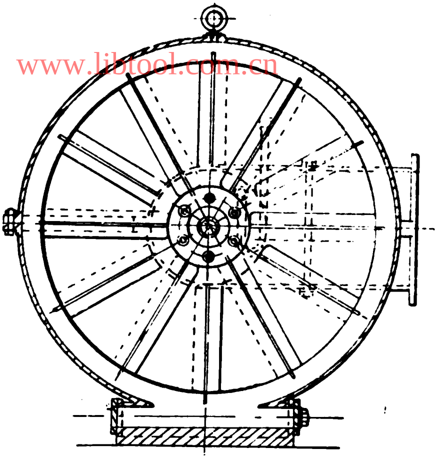


FIG. 19.

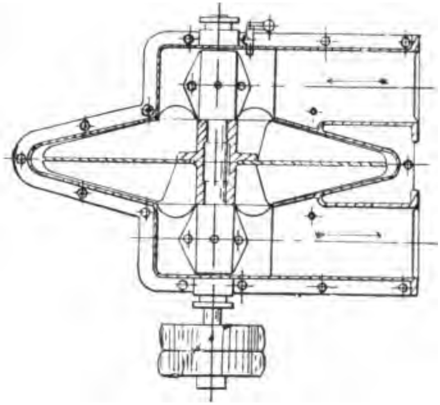


FIG. 20.

Centrifugal Tar Extractor (Crossley).

The Crossley centrifugal tar extractor is shown in figs. 19 and 20, and requires little explanation. The central shaft, fitted with fast and loose pulleys, carries a disc fan, having straight vanes, which is made to rotate

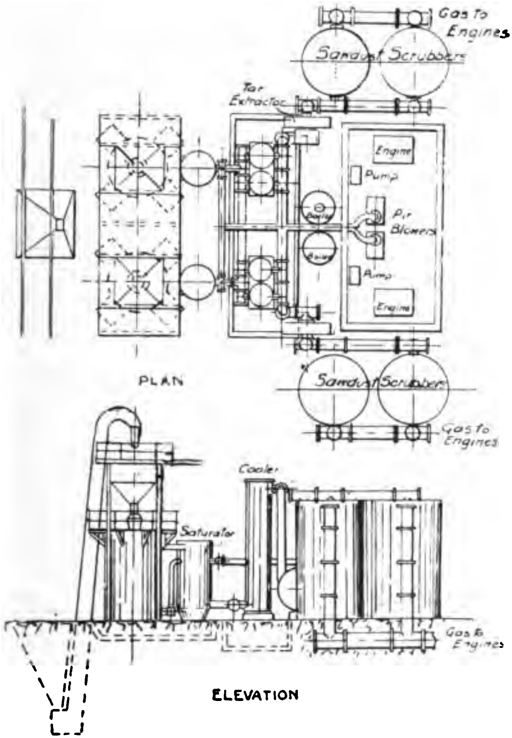


FIG. 21.—Typical Arrangement of Crossley Producers for a Central Station.

at a high speed. Unlike an ordinary propelling fan, the gas enters centrally at one side, and instead of being driven out through a passage connected to the outer circumference of the revolving disc, is returned through the vanes on the other side of the disc, and thence leaves by another central passage at about the same velocity at which it entered. The space between the periphery of the rotary disc and the casing is in connection with the sump, where the tar and other deleterious matter passes away to the drain. Fig. 21 shows in plan and elevation the gas-producer plant for a central station abroad, arranged for continuous running. It will be noticed that the coal supply is discharged into a hopper, from which an elevator delivers it to the two large capacity gas producers. The plant is in duplicate, and has no gas holder. Boilers are provided to supply the steam for enriching the gas, and engines for driving the air blowers and tar extractors. All the cleaning vessels are of large capacity, and provision is made so that either of the producers can be disconnected for cleaning and repairs. Also, either producer can deliver its gas through one or other of the sets of coolers and scrubbers.

WILSON'S POWER GAS PLANT.

The Wilson gas producer is by no means new, as it has been in use for several years for making gas suitable for various heating purposes, such as furnaces, kilns, boilers, etc. These producers are made of different rated capacity, starting from the smallest, which is capable of gasifying under normal conditions 2 cwt. of coal slack per hour; the sizes range 4 cwt., 8 cwt., etc., and up to 20 cwt. per hour.

A diagrammatic view, partly in section, of the Wilson producer is shown in figs. 22 and 23, as originally designed. The absence of a firegrate will be noticed, the fuel resting on a solid hearth to a depth of 6 to 10 ft. The mixture of air and steam is admitted centrally at the surface of the hearth, by means of a transverse tuyere box having openings in the sides in the form of pigeon holes. By this means the air and steam are delivered to the fuel close to the hearth. Owing to the outlets from the central box being horizontal, there is maintained a mass of fuel in the centre of the producer not in active combustion.

With this design the removal of clinker was found to be somewhat difficult. The earliest designs included a cleaning door, to enable the withdrawal of the clinker periodically, but later improvements include worm, or screw, automatic ash and clinker removers.

The early Wilson producer may be taken as typical of the solid-hearth type, as distinct from the water-tube bottom class. The employment of a continuation of the feeding hopper, as mentioned earlier, is represented in this producer by the brick cone in the upper part of the generator, which is penetrated by holes or passages, to allow of the evolved gases escaping to the gas outlet tube, and maintains the effective depth of fuel at a constant level. The coal is charged at regular intervals by a bell and hopper arrangement, the volatile gases are distilled off, and pass out with the carbon gases resulting from the partial oxidation of the fixed carbon of the fuel. Later types of the Wilson producer include a solid hearth without grate bars, but are provided with a water basin, into which the lower edge of the casing dips sufficiently to form a lute to prevent the escape of gas, while openings are so arranged as to allow of the removal of the ash and clinker which accumulates. This arrangement permits of the producer being kept continuously at work, but with this type there is rather more unconsumed fuel removed with the ash than

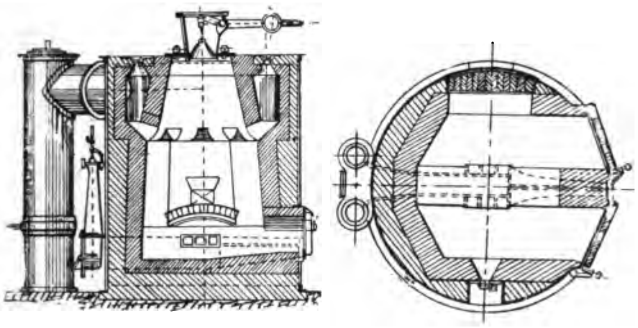


FIG. 22. FIG. 23.

Power Gas Producer, Pressure Type (Wilson).

in the early class. The gas, as it leaves the generating chamber, has a temperature of about 1,000 deg. Fah., and to recover the greater part of this sensible heat the gas is made to pass through a regenerator. This apparatus takes somewhat the form of the well-known economiser, the pipes being contained in an air-tight iron case provided with doors to facilitate cleaning. The hot gases circulate round the exterior of the pipes, and the air for the producer passes internally. Sometimes part of the regenerator pipes contain water, and communicate with a drum in which steam collects. The cold air, from the blower, and steam enters the pipes and traverses in an opposite direction to that of the gases, so that they leave the regenerator at its hottest end. A hydraulic box is provided between the regenerator and the producer, which prevents any return of gas upon the pressure in the producer becoming reduced from any cause. Owing to the weight of air being less than that of the gases, it is not possible to sufficiently cool the gas for use in gas-engine cylinders, so that it must be further passed through a cooler, consisting of a range of tubes air cooled; by this means the gas is reduced to the temperature of the atmosphere. It is claimed that by preventing the gases from coming into contact with water before they have become thoroughly cooled steam is prevented from mixing with them, so that the vapour of water does not become coated with tar, resulting in a mixture difficult to condense. From the cooler the gases are passed through a washer, which finally removes the last traces of tar without generating water vapour; this arrangement permits of the supply of water being kept small, and with plants of considerable capacity the water becomes highly charged with ammonia, which may be turned to profitable account if of sufficient strength and quantity to warrant its storage, handling, etc. Previous to the gas being admitted to a holder, or used directly in gas engines, it is passed through a sawdust scrubber. The employment of a pressure-regulating holder admits of an arrangement by means of which the rise and fall of the bell can be made to regulate the supply of air to the producer, and thereby the rate of gas production, to suit the requirements.

A typical arrangement of a Wilson producer plant of 500 I.H.P. capacity is given in fig. 24.

It will be obvious that the disposition of the various parts of the plant can be modified to accommodate the available space, and as there is no necessity for the gas plant being situatel close to the gas-engine house, there being only frictional loss to consider in the matter of conveying the gas to more or less considerable distances between the gas generator and the engine, no loss by condensation occurs as in the case of steam plant. It is an advantage to so arrange the level of the charging stage of the producer and the railway siding that the labour of discharging coal and feeding the plant is reduced to a minimum; where a suitable height of railway siding can be arranged to allow of the producer being on the general level, the coal can be discharged directly upon a stage on a level with the charging hopper, but where the installation is of large capacity it is best to provide storage bins for the coal directly above the producer, with elevators and conveyers, to be mechanically operated.

As before stated, the producer can be placed in the most convenient position for the delivery of the coal; the regenerator must be situated as close to the producer as possible; but all the other items, such as coolers, washers, purifiers, and gas holder can be arranged in almost any relative position.

As the production of gas is dependent upon the action of the blower employed to drive the air through the regenerator, it is important that an efficient type, well installed, should be provided; generally a mechanically-operated—either by gas or steam engine—blower of the Roots type is adopted, while a system of gauges, conveniently situated where the attendant can see them, indicate the pressure existing in the various parts of the apparatus. The highest pressure registered in the system will be that of the outlet from the blower, which may vary from a few inches of water up to 24 in., according to the size of the installation and the class and size of the fuel employed. The valuable assistance of these gauges is somewhat discounted by the fact that when the production of gas is being

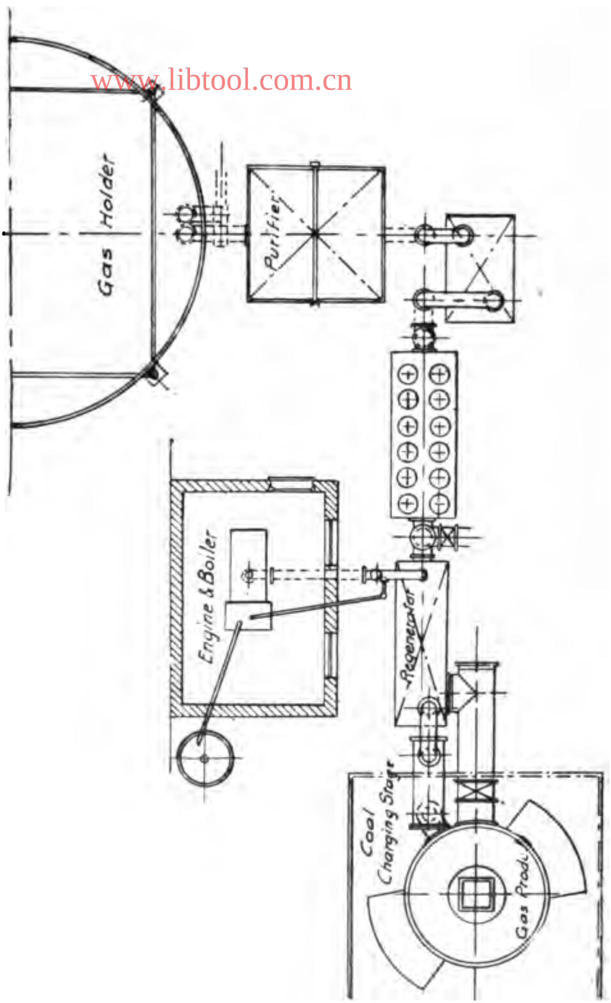


FIG. 24.—Typical 500 I.H.P. Power Gas Plant (Wilson).

satisfactorily performed the gauges are not examined, and when anything goes wrong it is more than probable that the attendant would fail to properly consider the readings, or that one or more of the pipes and connections might be clogged and give unreliable results.

In regard to the refuse from the plant, these consist of—(1) clinker and ashes, (2) soot from the regenerator, (3) tar and water from the purifying apparatus. The regenerator is provided with doors by means of which the soot can be removed periodically, every fortnight or three weeks; the tar is drained off into a well, to which pipes from the purifying vessels are led. A central diaphragm, vertically arranged, separates the tar from the water; thus permitting of the water being constantly drained off, while the tar is pumped out at suitable intervals into tanks or barrels.

An important feature relating to all types of gas producers, and influencing both the design and effective working, is the fact of the passage of the air and gases through the apparatus following the least line of resistance. An instructive illustration, which may be roughly applied in this connection, and one within the reach of any thoughtful observer, is the action of the fire in a blacksmith's hearth. In this, when the air blast is turned very low, so as to just keep the fire alight, small blue flames may be observed over nearly the whole surface of the heap of fuel, indicating the production of carbonic oxide, of which the blue flame is a characteristic property. During this period the heat developed in the region of the blast entrance is slowly transferred to the surrounding fuel. When the blast pipe is opened the heat is concentrated in a central zone. and the evolution of carbonic oxide on the surface of the fuel ceases. At an installation of Siemens gas producers of the rectangular type, with closed hearth and steam jet blower, and delivering the gas into a main flue, the writer has at times found as much as 16 per cent of carbonic acid in the gases. To ascertain the conditions of working of the producers, it was the practice of the writer to take samples of gas from the main gas flue at any convenient time, and without acquainting the men in charge of his intention to do so. That the men in charge were quite aware that by attention to poking, etc., the quality of the gas could be improved, was evidenced by the fact that when they found that the gas was being tested they immediately applied pokers, and levelled the fuel in the generating chambers, and confirmation of the improved quality was found on taking further samples for analysis; the reduction in the proportion of carbonic acid was almost instantaneous.

In the pressure type of producer, although the gases take the line of least resistance, the back pressure set up by the purifying apparatus, etc., causes the velocity of the gases through the generating chamber to be so reduced as to more or less traverse the whole mass of the fuel; but, in the case of the suction type, as will be more particularly described later, the tendency of the gases to take a direct course from the inlet to the point of suction is not in any way reduced by the capacity of the generating and purifying chambers. So that while with the pressure producer the generator and cleaning apparatus may with advantage have considerable cross-sectional area, with the suction type the sectional area should be kept as low as possible, and contact of the gas with the fuel and with the cleansing material must be obtained by increasing the length of the vessels, as against doing so by increasing sectional area.

In regard to the depth of fuel required to be maintained in any producer to ensure the most efficient supply of gas, this varies somewhat with the size of the grate and other conditions, for while in some types a depth of 2 ft. is found to give good results, in suction gas plants from 6 to 8 in. is not too low under certain circumstances. Much depends upon the class of fuel employed, whether bituminous or non-bituminous, caking or non-caking, and the average size of the pieces of the fuel charged; the fuel most usually employed is that styled slack, nuts, peas, etc.

When starting up a new or repaired Wilson producer two or three hours are required to get the fire properly into condition. After lighting up a little air is admitted, while the smoke is allowed to pass off through a small chimney, provided on the top of the producer for the purpose. When the depth of fuel, by gradual additions, becomes sufficiently deep to ensure a regular quality of gas, that issuing from the chimney may be lighted. At first the flame does not remain continuous, but keeps going out; but after a short time the gas ignites, and smoke ceases to issue; the flame continues to burn clearly with characteristic bluish colour, combined with a slight illuminating power, due to the small proportion of hydrocarbons present in the gases. The chimney valve can then be closed, and the valve leading to the holder opened. Fuel additions are made at intervals in quantity proportional to the gas requirement.

In all types of producers the provision of poking holes is an advantage. In the case of producers having a considerable area, it is a difficult matter to ensure the gradual even descent of the fuel, and an even level surface through which the gas is to make its exit; while if the fuel becomes heaped up in places and low in others, the gas will make its way out of the place of least depth, and concentration of heat and gas making will result, with the evolution of an excessive proportion of carbonic acid.

The proportion of carbonic acid in producer gases is an indication of the efficiency of the apparatus, for while it is found impossible in practice to produce gas free from CO_2, as has already been pointed out, an excessive proportion is an indication that too much carbon is being fully oxidised in the generator, the effect being that heat is developed in the producer where it is detrimental, and the proportion of combustible in the evolved gases becomes reduced below normal.

Though working a producer with an excessive proportion of steam results in a low temperature and a rather high proportion of carbonic acid, the fire becomes localised into small channels through the fuel, and a considerable proportion of carbonic acid may pass out undecomposed, thus indicating a direct loss of thermal efficiency. When gas is not required, as at meal times, nights, or at the end of the week, from Saturday to Monday, it is only necessary to close the gas valve and slightly open the chimney valve, so as to allow of a vent, the blower, of course, not being in action. The fire will continue smouldering for periods of considerable length, after which the producer can be brought up to its full capacity when the blower has been applied for a short time.

The solid hearth class of producer requires cleaning at intervals of from 12 hours to 48 hours, according to the class of fuel and the power required; this can usually be accomplished by shutting off the air supply, opening the cleaning door, and raking out the clinker and ash which has accumulated at the base of the fuel. With the water lute arrangement the incombustible refuse can be withdrawn at any suitable time by simply raking it from the bottom of the hearth out through the water at the place provided for that purpose. That sufficient removal of ash has been effected is shown by the presence of unconsumed fuel amongst the refuse. The steam caused by the hot ashes falling into the water in the base of the producer mixes with the air supply entering the fuel, and becomes decomposed.

In regard to the class of fuel suitable for use in the Wilson producer, or, in fact, any gas producer, any free burning small coal can be employed, but all coals having considerable caking qualities are not capable of giving good results when power gas is required. The presence of ash and moisture, even to the extent of 25 or 30 per cent, are not as detrimental in fuel as high proportion of of bituminous matter and caking qualities. However, when the installation is sufficiently large to permit of the by-products being an available asset, then the proportion of nitrogen in the fuel comes into consideration. As from 60 to 65 per cent of the nitrogen can be recovered, and as coal usually contains 1·2 to 1·4 per cent, the yield of sulphate of ammonia varies from 70 to 90 lb. per ton of coal consumed, but in this connection the installation should have a capacity of at least 50 tons of coal a day, while the proportion of steam used in the gasification should be from two to two and a half times the weight of the fuel. The gas from a Wilson producer, under conditions for recovering the nitrogen as ammonia, averages in volumetric composition:

Carbonic oxide, CO	10·0	per cent	Combustible.
Hydrogen, H	26·0	,,	
Hydrocarbons, CH_4, C_2H_4, etc.	2·5	,,	
Carbonic acid, CO_2	16·0	,,	Incombustible.
Water, H_2O	1·7	,,	
Nitrogen, N	43·8	,,	

The attention required for even a 300 horse power producer is only that capable of being given by one man, including the charging of the fuel, cleaning out the ashes and clinker, and all the other duties, and even then the man does not require to be a skilled artisan, only an intelligent labourer.

It is a pretty well established fact that the labour in connection with a gas-producer and gas-engine installation is of an entirely different nature to that of steam engine and boiler installations; this may partly be accounted for by the fact that the former have to be so designed that all conditions relating to laws of gases and gas making are fulfilled by the apparatus under normal conditions continuously. In the case of a steam boiler, even of the highest class, a very considerable difference results from good or bad stoking, while the losses from leakage, condensation, etc., may easily be increased by careless attention. The higher the pressure the more serious are the effects of leaky joints, unprotected pipes, etc., not to speak of the greater danger resulting from want of skill, etc.

In gas producer installations it is only necessary that certain routine conditions are fulfilled, most of which, outside the charging of the fuel and occasional poking, are automatically effected. The pressures in the different parts of the apparatus being low, there is seldom a joint to be made, or any work done which could not be readily accomplished by a handy man of the careful labouring class.

Given a well-designed gas producer and gas-engine installation, the amount of skill required in the attendant is remarkably small; he has no glands to pack, gauge glasses to replace, drain cocks to see to, but has only to charge the fuel in proportion to the power requirements of the engine, remove the clinker and ashes at suitable intervals, look after the lubrication, regulate the flow of water through the purifiers, and keep all parts clean.

The general arrangement of a Wilson power gas plant of 1,000 horse power capacity is shown in fig. 25, but it is obvious that the different items can be differently arranged to suit the exigencies of the available site.

The writer is indebted for much of the information relating to the Wilson power producer to a concise pamphlet on "Power Gas Plant," by Alfred Wilson. The makers of the plant are the Horsehay Company Limited, Horsehay, Shropshire.

THE DUFF AND WHITFIELD PATENT GAS PRODUCERS.

In regard to the theoretical production of power gas by producers employing steam and air, Mr. Dugald Clerk has given the composition of the best possible gas capable of being generated from carbon by air and steam as having the following composition:—

Carbon monoxide (CO)	38·7	per cent.
Hydrogen (H)	16·4	,,
Nitrogen (N)	44·9	,,
	100·0	

This gas could only be obtained in an apparatus in which there were no thermal losses, and if the practical construction of a gas producer could be carried out on the lines of a calorimeter it would be possible to obtain an efficiency nearly approximating to the above.

As already pointed out, though frequently overlooked by even experts, the thermal value of combustibles is determined in an apparatus which does not account for the amount of heat required to accomplish the gasification, only the net heat value being given, so that a perfect gas producer should give an efficiency of 100 per cent. In the calorimeter a given weight of fuel is burned in such a manner that the heat evolved is transferred to a given

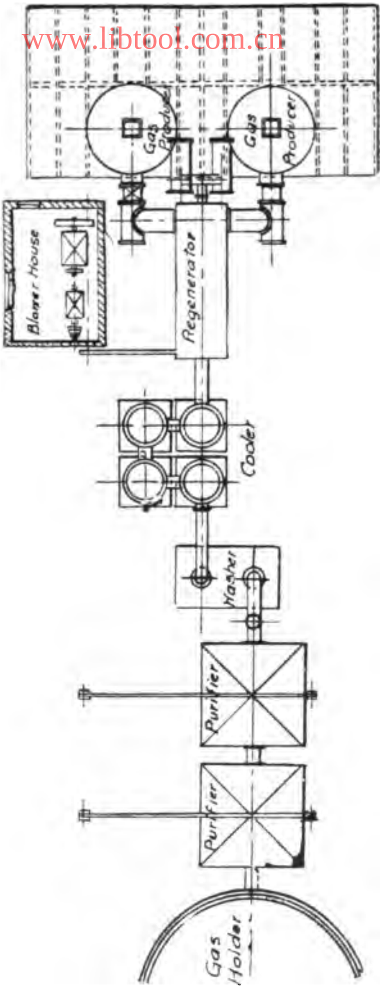


FIG. 25.—Typical 1,000 I.H.P. Power Gas Plant (Wilson).

weight of water without recording the amount of heat absorbed in releasing the volatile portion, or that necessary to bring about the combination of carbon with oxygen. This results in an unfair comparison between gas produced by the retort system and producer gas.

In the manufacture of retort gas there is required a certain amount of heat outwardly applied to cause the evolution of the volatile gases from the fuel. While there is certainly a loss of heat due to radiation and other causes, it must be evident that when calculating the efficiency of the process on a basis of the thermal value of the fuel as determined by the calorimeter, due allowance should be made for the gross thermal value and that of the requirements of the method adopted.

In the gasification of fuel by means of air, or air and steam, there enters the question as to which is the most efficient method of bringing these constituents into working contact.

Having a chamber filled with fuel and provided with the necessary charging apparatus and passages for the outlet of the gas, the best means of applying the air and steam requires consideration. The sectional plan of the generating chamber may be either circular or rectangular, with the interior surface composed of firebrick, and though in the upper part the gases travel in a vertical direction, there are considerations in regard to the direction in which the air, under pressure, should be admitted at the lower part of the chamber, for this controls, to some extent, the zone of highest temperature. It will be obvious that when steam is employed in conjunction with the air the working temperature of the gasification zone must be above that necessary to decompose steam; or, at any rate, the temperature must be somewhat above that necessary to bring about the combination of the oxygen of the steam with the carbon, the hydrogen being rendered free, say, about 3,450 deg. Fah. The location of this high temperature zone has considerable importance in regard to radiation losses and the softening of the firebrick lining.

When the air and steam are admitted by pipes or passages radially around the generating chamber, converging to the centre, as in the blast-furnace types, the zone of greatest heat will be central.

With centrally-arranged air inlets, if the direction of admission is horizontal, the tendency is for the highest temperature to be in the neighbourhood of the sides of the chamber, where the lining may be softened and fluxed into a semi-fluid state by the ash of the fuel, forming clinker.

The Duff-Whitfield producer is rectangular in plan, and is provided with a central box for the entrance of the air, etc., the important feature of which is that the air enters the mass of fuel vertically. Views of vertical and cross sections of the Duff-Whitfield gas producer are given in figs. 26 to 29.

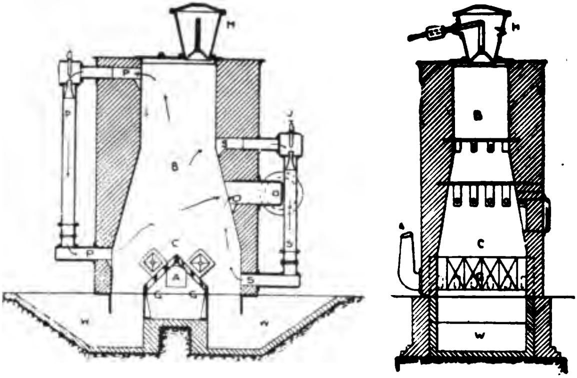


Fig. 26. **Fig. 27**

The Duff-Whitfield Gas Producer. Vertical Sections.

Figs. 26 and 27 represent vertical sections taken at right angles to one another through the producer, while figs. 28 and 29 show cross-sections at different levels. The charging hopper H is of the cup-and-cone type, by means of which the fuel is charged into the generating chamber B; the grid G admits the air and steam for the gasification of the fuel. It will be observed that the inlet A for the saturated air is placed as close as possible to the upper point of the grid G. As the grid G has openings arranged vertically, it is obvious that ash and small particles of fuel may fall through, so it is supported upon a framework, the lower part of which stands below the level of the water in the trough W, and the refuse which passes through the grid falls directly into water, where it is quenched, and finds its way into the trough W, from which it can be removed by rakes applied from the back or front of the producer.

The main gas outlet O is arranged more than halfway down the producer, and therefore this constitutes one of the special features of the system. Other specialties consist of the provision of circulators for the volatile gases, the higher one being indicated by the letter P, while the lower one, on the opposite side, is indicated at S. By means of these circulators a jet of steam causes the withdrawal of the evolved gases from the top and upper portions of the mass of fuel, and their delivery into the lower part of the generator, from whence they are obliged to pass towards the main outlet O through the hottest part of the fire.

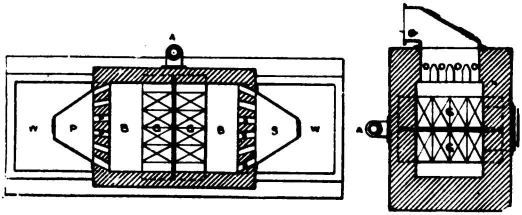


Fig. 28. **Fig. 29.**

The Duff-Whitfield Gas Producer. Cross Sections.

The water in the trough W is maintained at such a level as to form an effective seal, while all the refuse formed in the producer can readily be removed without the slightest stoppage of gas making.

When working on bituminous coal the body of the producer is kept as full of fuel as possible, and the volatile gases are forced through the hottest zone; the upper circulator draws off the volatile gases most readily given off upon the heating up of the fuel, while the lower one on the opposite side draws off those escaping at the higher temperature, somewhat lower down the chamber. The fixed carbon portion of the fuel is gasified by the saturated air passing through the grid, and the circulators so deliver the hydrocarbon gases that they pass along with a certain amount of steam, but without any additional admixture of air through the incandescent body of fuel with decomposition and enrichment by carbonic oxide through the combination of the oxygen from the steam and carbon.

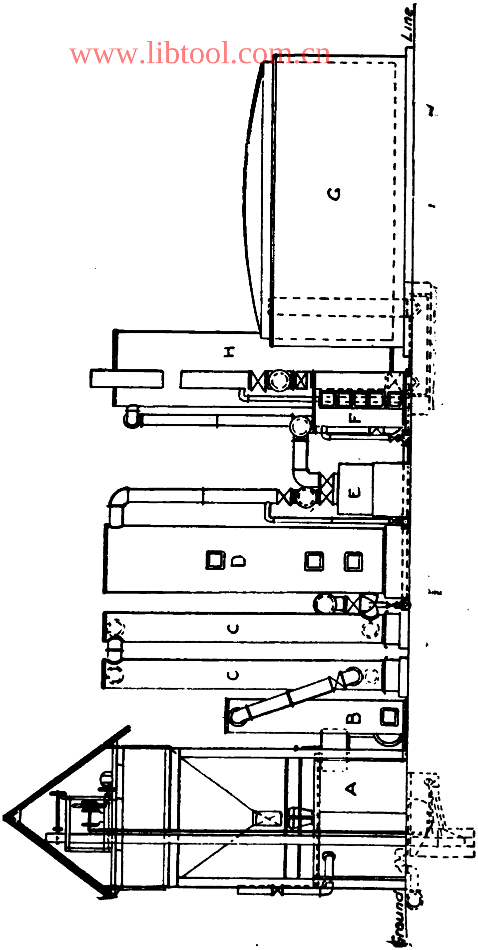
An important installation of the Duff-Whitfield producer plant for developing power gas from bituminous coal is that of the Reading Electric Supply Co. Ltd., Reading. The capacity of the installation is 1,800 horse power, and the gas is for use in gas engines for driving dynamos. This plant consists of two rectangular gas producers, having steel casings lined with firebricks, and arranged in such a manner that the gas from either one or both of the generators can be passed through the purifying apparatus. Each producer is provided with an overhead bunker, from which coal can be admitted to the ordinary charging hopper in quantities as required. The hoppers are filled with coal by means of an electrically-driven elevator in conjunction with a push-plate conveyor. The gas from the producer first passes through a vertical dust arrester fitted with baffle plates, which removes all the heavier particles of dust from the gas before it enters the atmospheric condensers. There are twelve condensers arranged in two rows, six being coupled to each producer. The gas enters the lower part of the first condenser, and slowly traverses the series, during which time it becomes greatly reduced in temperature, and freed from the remaining portions of dust. A large capacity coke scrubber is provided for each producer, and the gas, after leaving the scrubber, passes through Livesey washers, where any remaining physical impurity is removed, while the sawdust scrubbers remove excess of moisture previous to the gas entering the gas holder. The general arrangement of the installation is shown in elevation in fig. 30, and in plan in fig. 31, where it will be noticed that the Livesey washers and sawdust scrubbers are divided into units of three for the two producers. The gas holder is designed to act as a pressure governor rather than for storage purposes, as its capacity is only equivalent to about a quarter of an hour supply of gas for the engines.

In a separate house there are a couple of Root's blowers, driven by electric motors, which provide the air supply for the producers. The water, which has been employed in the purifying apparatus, becomes heated, and is conveyed to a water-cooling tower through which the air from the blower is passed; the water is thus cooled down, and the air becomes charged with vapour, which enriches the gas, and less live steam is therefore required under the grate of the producer than when blowing with air direct from a blower.

After being pumped through the cooling tower the water is conducted to a tank beneath the blower house, from which it is re-pumped to the purifying apparatus, so that the process is continuous.

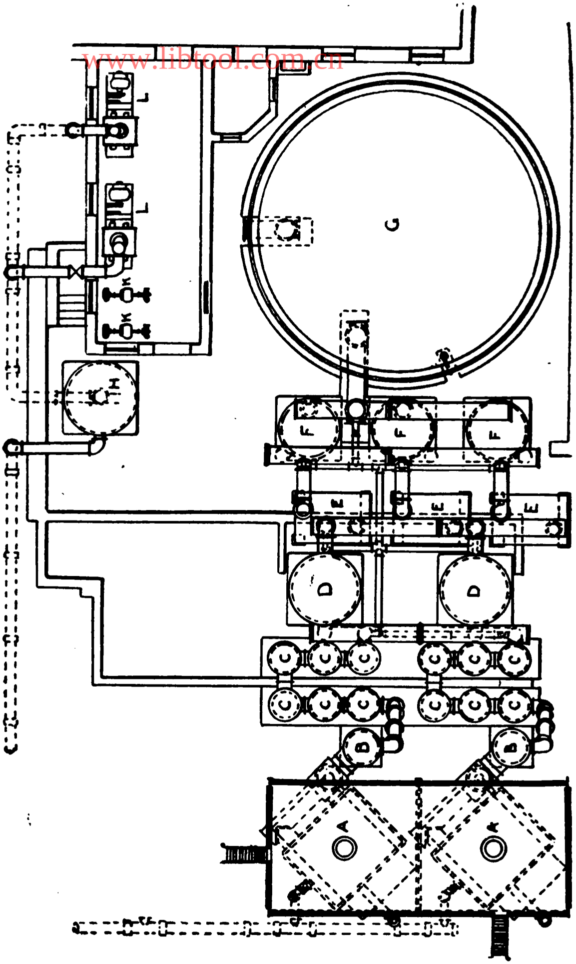
TEST OF 1,800 HORSE POWER DUFF-WHITFIELD GAS POWER PLANT AT THE READING ELECTRIC SUPPLY CO. LTD., READING, FEBRUARY 7TH, 1906.

Test started 8-15 a.m., finished 8-15 p.m.; depth of fire measured and finished same depth as started; height of gas holder marked and finished same mark; total hours, 12; fuel used, Ellistown breeze, cost 12s. 8d. per ton delivered; fuel charged per hour, lbs., 967·5; total fuel charged, lbs., 11,610; average B.Th.U. in gas (average of 23 calorimeter tests), 162 per cubic foot; thermal value of coal per lb., 12,000 B.Th.U.; total kilowatts generated, 5,400; average kilowatt load, 450; coal per kilowatt hour, 2·14 lb.; cost of coal per kilowatt hour,



ELEVATION.

FIG. 39.—1,800 H.P. Duff-Whitfield Gas Producer Plant for the Reading Electric Supply Co., Ltd.



PLAN.

FIG. 31.—1,800 H.P. Duff-Whitfield Gas Producer Plant for the Reading Electric Supply Co. Ltd.

0·14 pence; thermal efficiency of gas plant, 74·5 per cent; gas consumption per kilowatt, 122·3 cubic feet.

REMARKS.—The gas plant consists of two units of 800 horse power, each supplying gas to two sets of Willans-Siemens gas generators, each of 500 kilowatt capacity. During the test only one unit was in operation. The steam was measured from a separate boiler, and the total weight of steam used in the producer during the test was 12,473 lb. During the whole of the test the gas kept very regular in quality, and no difficulties were experienced with any part of the plant, which was worked by the gasman in the employ of the Reading Co., under the supervision of the contractors.

For the Reading Electric Supply Co. Ltd.,
(Signed) GEO. PHILLIPS, Elec. Super.

For Mason's Gas Power Co. Ltd.,
(Signed) G. H. BENTLEY.

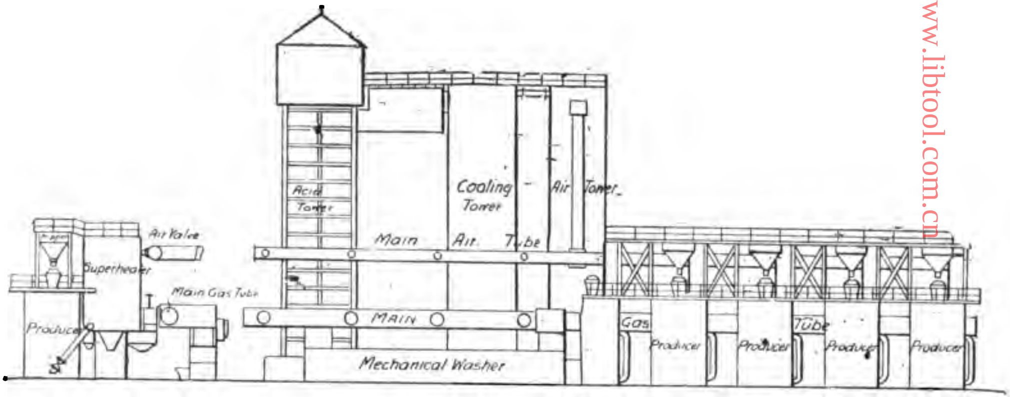
THE DUFF PRODUCER.

When the proportions of the installation are sufficiently large to warrant the recovery of the ammonia in the gases, the Duff producer system can be arranged as shown in the sketch plan given in figs. 32 and 33.

An ammonia recovery plant of this type has been in continuous use at the works of the United Alkali Company Limited since 1899, which is capable of gasifying 500 tons of slack coal per week, only requiring a slight overhaul during a period of twelve months. Continuous running is effected without the necessity of a spare producer, or a stand-by blower, showing the simplicity and efficiency of the plant; the only stoppage necessary during a year's continuous work being a few days at holiday time.

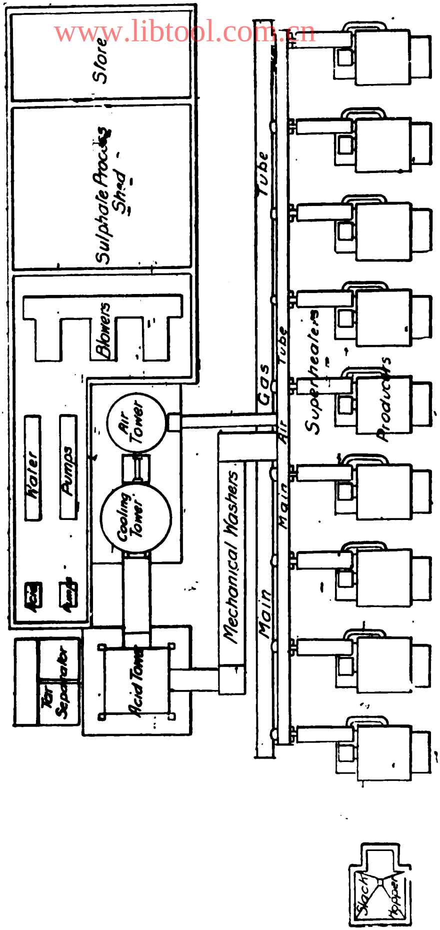
Coal slack is the fuel employed, and this is delivered by elevators and conveyers to the hoppers over each of the producers.

From the storage hoppers the fuel is admitted to the different producers by means of the smaller charging hoppers fitted with cone valves, and by this arrangement there is a minimum of labour in handling of the coal.



ELEVATION.

FIG. 32.—Power Gas Producers and Ammonia Recovery Plant, Duff Patents, at Messrs. Armstrong and Whitworth's Works, Manchester.



PLAN.

FIG. 33.—Power Gas Producers and Ammonia Recovery Plant, Duff Patents, at Messrs. Armstrong and Whitworth's Works, Manchester.

The producers themselves are of the usual Duff rectangular pattern, having steel shells lined with a sufficiently thick coating of firebrick to keep down radiation losses. The patent system of admitting the air and steam to rise vertically from the special grid not only has the effect of causing the zone of greatest heat to be confined within the body of the fuel, but owing to its ample area the flow of the gas is kept down to a low rate over the whole area of the chamber, thus not requiring a great depth of fire to ensure the fullest proportion of the carbonic acid gas becoming transformed to carbonic oxide.

Mr. Duff has stated, in reference to the different proportions of different producers, that the blowing area of a Duff producer grate was 1,720 square inches, as against 160 square inches in the tuyere of the Wilson producer of similar capacity.*

Immediately after leaving the producers the gases pass into recuperators, or superheaters, so that the sensible heat of the gases is recovered and transferred to the air and steam entering the generating chambers; gas and air mains run along the range of producers, to which they communicate by means of the recuperators.

As shown in the sketch plan, the gases are led through a mechanical washer into an acid tower, while the air for the producers is primarily heated by being caused to pass through a tower, where it comes into contact with the hot water from the cooling tower, becoming heated and saturated with water vapour, while the water is cooled sufficiently to allow of its further employment in the cooling tower.

For every ton of slack coal consumed there is recovered from 85 lb. to 100 lb. of sulphate of ammonia.

A large installation of the Duff system, consisting of 10 producers, capable of gasifying 1,400 to 1,500 tons of coal per week, and provided with ammonia recovery apparatus, has been erected near Manchester. The peculiar arrangement of the Duff producer, having vertical sides and large area of grate for distributing the

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*** Discussion of a paper by Mr. Wilson, at the West of Scotland Iron and Steel Institute.**

air over the whole sectional area, reduces the troubles due to the caking of the fuel and its uneven descent.

The influence of the completeness of combustion brought about by the Duff grid arrangement of air distribution is evidenced by the perfectly burned ash and minimum of hard clinker,* an important matter to be considered when comparing the various types, as in some cases a considerable amount of unburnt, or only partially burnt, fuel escapes with the ash and clinker into the base of the producer.

A comparison of the way in which the gas connections are arranged in this system with that adopted for the Mond installations, which will be fully described later, will repay careful consideration as to advantages and capital outlay.

For instance, while in the Mond system the water has to be pumped to the top of the gas-cooling tower, and also to the top of the air-heating tower, in the Duff system the towers and gas connections are so arranged that only one pumping is required.

For many of the foregoing particulars relating to the Duff patent gas producer the writer is indebted to a series of articles by Mr. F. J. Rowan, A.M.I.C.E., which appeared in the *Iron and Coal Trades Review.*

The average analysis of the gas from a Duff producer is given by Mr. F. J. Rowan as follows:—

	Percentage composition by volume.
Carbonic oxide (CO)	26·8
Hydrogen (H)	13·4
Marsh gas (CH_4)	4·4
Carbonic acid (CO_2)	4·0
Nitrogen (N)	51·4
	100·0

The thermal value of this gas at 32 deg. Fah. per cubic foot = 183·7 B.Th.U. gross.

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* Mr. F. J. Rowan, A.M.Inst.C.E., in the *Engineering Times.*

When being worked with ammonia recovery apparatus, in large installations, and with an excess of steam, the chemical composition of the Duff gas becomes:—

	Percentage composition by volume.
Carbonic oxide	11·0
Hydrogen	28·0
Marsh gas	2·5
Carbonic acid	15·5
Nitrogen	43·0
	100·0

Thermal value per cubic foot at 32 deg. Fah., 160·69 B.Th.U. gross.

In Madrid, Spain, the Societad de Gasificacion Industrial, formed in 1903, have put down a Duff producer plant with ammonia-recovery apparatus, by Duff Brothers and Company, Liverpool, which is the largest central power-gas station in the world. This plant was started in June, 1905, and has been running continuously since; there are six Nürnberg gas engines, direct-coupled to alternators of the three-phase type, generating current at 3,000 volts, and which run in parallel. There are six producers of 2,009 H.P. capacity, and the fuel employed is Spanish bituminous coal slack, having 17—25 per cent of ash; it is in a very fine state of division, most part being dust.

THE MOND POWER GAS PRODUCER.

The gas producer system invented by Dr. Mond to a certain extent accomplishes the result which has been the ambition of gas engineers; that is to say, it successfully gasifies ordinary bituminous slack coal.

The first application of the system was made at the works of Messrs. Brunner, Mond, and Co., Northwich, and included the necessary apparatus for the recovery of sulphate of ammonia as a profitable by-product.

Though in the first instance the producer was only designed to gasify a few hundredweights of coal per hour, it was rapidly enlarged until the capacity reached 250 tons per day of slack converted into gas.

As each ton of fuel gasified gave 148,000 cubic feet of gas, the output reached 37,000,000 cubic feet per day, and at the same time there were recovered more than 10 tons of sulphate of ammonia.

It is about twenty-seven years ago since Dr. Ludwig Mond commenced to experiment upon the ultilisation of cheap fuel, associated with the recovery of ammonia as a by-product, and now there are a number of very large installations of the system which have been at work for a sufficiently long time to demonstrate the advantages to be obtained from combining the gasification of the fuel and the turning of the by-products to profitable account.

Although the presence of nitrogen in coal and ammonia in the gases evolved in producers has been common knowledge for many years, it was discovered later, by Dr. Mond, that the amount of ammonia depended to some extent upon the temperature conditions maintained during the gasification; and, further, that by selecting classes of coal having the higher proportions of nitrogen it was possible to so increase the proportion of sulphate of ammonia recoverable as to render the by-product a considerable and valuable commercial asset.

The results of the early experiments, and the later practical applications of the system, demonstrated that (1) the installation must be of very considerable capacity, (2) the fuel should be of that class which contains the highest proportion of nitrogen, and (3) that the temperature of the zone of ammonia recovery must be kept as low as possible.

When these conditions are fulfilled the gas resulting is of excellent quality for the development of power in internal-combustion engines, while the quality of the gas is maintained very constant.

A peculiar feature of the Mond system is the amount of steam which is employed in the manufacture of the gas. It has already been pointed out that in the production of semi-water gas, or producer gas made with a mixture of steam and air in theoretical proportions to reduce the loss of heat in the process to the lowest possible point, the weight of steam amounts to about the weight of the fuel. In the Mond producer the proportion of steam is raised to two and a half times the weight of slack coal consumed.

Taking the thermal value of coal slack at 14,000 British thermal units per pound, we would have, if the steam employed entered completely into chemical combination:

		B. Th. U.
Heat units capable of being developed by 1 lb. of coal......	+	14,000
Heat units required to decompose 2½ lb. of water...........	−	17,231
Less heat units contained in the water at 212 deg. Fah. from 32 deg. Fah..........	+	2,867·5
Heat units to decompose steam................................ ..	−	14,363·5

So that the net result would be that theoretically the process could not be practically applied, owing to the heat requirements to carry out the process being in excess of that capable of being supplied by the fuel employed.

However, it will be obvious, in the first place, that the reaction between the steam and the fuel can only be maintained by the fuel in the generating zone of the producer being in a state of incandescence, and the proportion of carbonic acid in the evolved gases accounts for this development of heat for the successful continuous production of gas; it follows that some of the steam must pass through the gasification zone without decomposition, and this is proved to be the case.

If 2½ lb. of steam were decomposed in the generator for each pound of coal, the result would be that the fire would be quenched; but, as this is not the case, it follows that the reactions taking place must be different in different parts of the generating chamber.

While in certain localities the steam reacts upon incandescent portions of the fuel, in other places the temperature must be so reduced as to permit of steam passing up through the producer without being reacted upon by the carbon.

These conditions result in the proportion of hydrogen in the gases being higher than in producer gas made with considerably less steam mixed with the air, while the amount of carbonic acid is considerably increased at the expense of the carbonic oxide.

Typical Analysis of Mond Gas (Dry).*

	Percentage composition by volume.
Carbonic oxide (CO)	11·0
Hydrogen (H)	29·0
Marsh gas (CH_4)	2·0
Carbonic acid (CO_2)	16·0
Nitrogen (N)	42·0
	100·0

When steam alone is passed through a mass of incandescent fuel, as in the manufacture of water gas, chemical action between the carbon and the steam only continues during the interval which elapses between the commencement of the reaction and that at which the temperature falls too low to bring about the decomposition of the steam by the carbon, for in this process there is an absorption of heat. The supply of heat is usually provided by turning off the steam and blowing air through the fuel, so that the production of water gas is an intermittent process.

The chemical composition of the gas resulting from passing steam through incandescent carbon not only varies slightly during the period of water-gas making, but is also slightly different from the various classes of fuel and systems employed.

Typical Analysis of Water Gas.

	Percentage composition by volume.
Hydrogen (H)	49·65
Carbonic oxide (CO)	42·89
Oxygen (O)	·75
Carbonic acid (CO_2)	2·97
Nitrogen (N)	3·74
	100·00

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* "Humphrey on Power Gas and Large Gas Engines," Minutes of Proceedings of Institution of Mechanical Engineers.

It will be noticed that this gas consists chiefly of hydrogen and carbonic oxide, but contains some carbonic acid and nitrogen; but the fact that it can only be intermittently made prevents this method of power gas production being applied in a practical and commercial manner.

The Mond system of power gas production from coal slack and using an excess of steam provides a practical and economical compromise, capable of being worked continuously.

The effect of mixing air with the steam results in oxidation of carbon with development of heat taking place whenever the temperature falls too low for the decomposition of the steam, thus bringing about a balancing effect, which permits of a considerable amount of steam passing through and becoming mixed with the evolved gases.

It will be obvious that under the above conditions the active temperature of the fire in the generator never falls very low, while the evolved gases, having a large proportion of steam present, are kept sufficiently low in temperature to prevent the decomposition of the ammonia liberated from the coal.

The Power Gas Corporation Limited, having the control in the United Kingdom of both the patents of Dr. Ludwig Mond, F.R.S., and Mr. Edward James Duff, Assoc. M.Inst.C.E., M.I.M.E., are the proprietors of the most advanced systems for the production of power gas from bituminous coal. These processes were developed at the works of Messrs. Brunner, Mond, and Co., at Northwich, and the United Alkali Co., at Fleetwood, where 700,000 tons of slack have been gasified.

The standard sizes of gas plant made by the Power Gas Corporation Limited are:

WITHOUT AMMONIA RECOVERY APPARATUS.

		Approximate equivalent in horse power.
Daily fuel consumption (24 hours)...	2½ tons	250
" " " ...	5 "	500
" " " ...	7½ "	750
" " " ...	10 "	1,000
" " " ...	15 "	1,500
" " " ...	20 "	2,000
" " " ...	30 "	3,000

WITH AMMONIA RECOVERY APPARATUS.

Daily fuel consumption (24 hours)...	30 tons	3,000
" " " ...	40 "	4,000
" " " ...	60 "	6,000
" " " ...	80 "	8,000
" " " ...	100 "	10,000

The power requirements of the Corporation's large works are chiefly provided by power gas used in engines made by the following firms: The Premier Gas Engine Company, the National Gas Engine Company, and by Messrs. Crossley Brothers, direct-coupled to dynamos by the British Thomson-Houston Company. Besides being used for power purposes, the following heating operations are carried on: Evaporation, heating, heating the offices, cooking the workmen's dinners, etc.

To give some idea of the rapid appreciation of the system, the writer has before him the names of 56 firms provided with installations by the Power Gas Corporation, ranging from a capacity of 2½ tons per day to 250 tons; the aggregate equivalent in horse power being no less than 262,150.

The Power Gas Corporation claim the following advantages from the use of gas produced by their system:

The gas is produced from the *cheapest quality of coal*, namely, slack or dross, which is much cheaper than the steam coal required usually for the power generation in works.

The amount of labour is small when compared with steam power.

The heating power of the gas amounts to from 81 to 86 per cent of the thermal value of the fuel employed.

When produced on a large scale the gas costs less than ½d. per thousand cubic feet.

The volume of gas produced from 1 ton of rough slack is about 150,000 cubic feet, having a thermal value of 140 British thermal units per cubic foot.

In large gas engines about 60 cubic feet of this gas will develop an indicated horse power, 1 ton of slack gasified providing 2,500 horse power per hour in large gas engines, or about four times the power obtainable from the same amount of fuel with ordinary steam engines.

With fuel at 6s. per ton, gasified by the Mond system, an indicated horse power can be obtained for a cost of one-fortieth of a penny for fuel.

As showing the efficiency of the apparatus in regard to the important point of providing *clean* gas, a 150 horse power gas engine has been kept running on Mond gas day and night for a period of six months without stoppage.

It is well known in steam practice that when the load is variable and intermittent there is a considerable loss of fuel in keeping the plant ready to meet the calls for power, but in the case of power gas and gas engines this loss is reduced to a very small figure.

The stand-by losses for a 1,000 horse power plant are given at about 2 cwt. per night of 14 hours.

A 1,000 horse power plant when standing for eight days only consumed about 7½ lb. per hour, and could have been re-started any time in a few minutes. After standing over the end of the week only three minutes were required for the starting of a generating plant of 1,000 horse power. There is an entire absence of the smoke nuisance, the exhaust being delivered clear and clean and can be carried to any convenient point.

The constant quality of the gas, as well as its freedom from dust and tar, is a very important feature of the system, while the quantity can be regulated exactly to the load on the machinery.

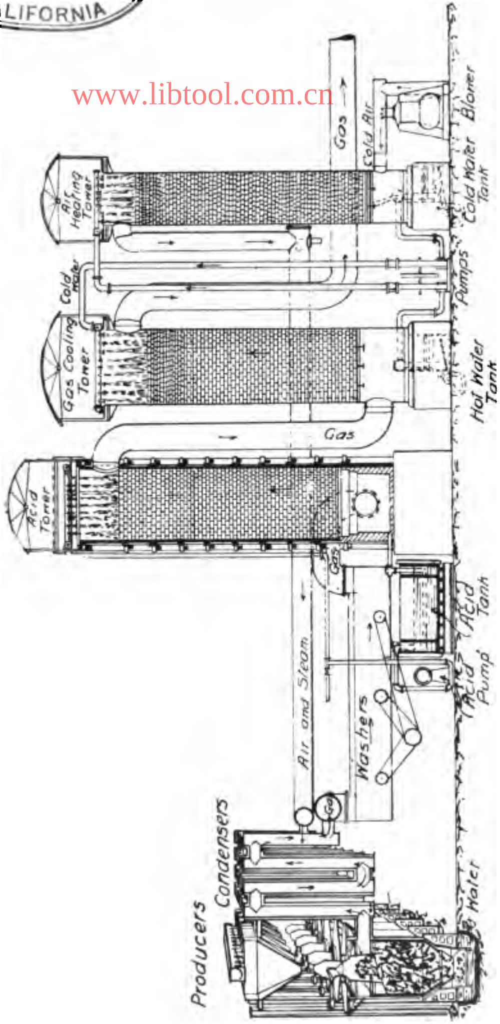

FIG. 34.—Diagram of Mond Gas Plant.

The recovery of the ammonia, as sulphate of ammonia, to the amount of about 90 lb. per ton of fuel gasified, not only compensates for the extensive outlay on the recovery apparatus, but is also a set off against the cost of the fuel.

Besides its high efficiency for power development in internal-combustion engines, the gas from Mond producers is of excellent quality for metallurgical purposes; its use ensures a perfectly-even temperature; while when used on the regenerative principle very high temperatures can be maintained, and either an oxidising or reducing flame is obtainable.

Fig. 35.—Power Gas Producer at London Paper Mill Co.'s Works.

A typical diagram of the Mond system is clearly shown in fig. 34.

Wherever possible, the fuel is received in bulk in railway wagons and discharged into an elevator boot, from which it is raised by an elevator and delivered to the storage hoppers, over each producer, by a conveyer.

The coal storage hoppers are shown in figs. 35 and 36, where fig. 35 illustrates a couple of producers, having a combined capacity of 1,000 horse power, recently erected at the London Paper Mill Company's works, Dartford, Kent; while fig. 36 is from a photograph of a single producer of 1,000 horse power erected at the works of Messrs. Brooks and Doxey Limited, Manchester.

FIG. 36.—Power Gas Producer at Messrs. Brooks and Doxey Ltd., Manchester.

From the hoppers the fuel is fed into each producer in proportion to the power requirements, and gasification is carried on continuously. Of the $2\frac{1}{2}$ tons of steam passed through the producer with the air, per ton of slack gasified, about 1 ton is automatically recovered and used over and over again. On leaving the producer the gas is passed through a regenerator, or condenser, where part of the heat of the gas and steam is communicated to the blast of steam and air passing to the producer; the gas then traverses the mechanical washer, being there thoroughly washed with water thrown up into spray by a series of revolving splashers. In this vessel the temperature of the gas is further reduced, while dust and particles of soot are removed; the washers being provided with lutes at the side, the accumulation of dust, etc., can readily be removed at any time without interrupting the process in any way. After being washed, the gas is passed into the acid tower, where its content of ammonia is recovered almost completely. It will be observed that there is a pump provided to lift the acid liquor to the top of the tower, while a tank at the bottom for it to drain into communicates with the pump; the liquor is, therefore, continuously circulated until it becomes sufficiently charged with sulphate of ammonia, when it is drawn off, and replaced by a fresh supply of a weak solution of sulphuric acid. When the acid liquor becomes charged with from 36 to 38 per cent of sulphate of ammonia it is withdrawn and evaporated, yielding solid sulphate of ammonia.

In the gas-cooling tower a downward flow of cold water meets the gas as it rises through the tower, so that when the gas leaves the top of this vessel it is ready for passing into the gas holder, or direct into gas engines, or mains for heating purposes.

All the steam which the gas carried is removed in the cooling tower, and leaves, with the cold water which entered at the top, as hot water, and this is again pumped to the top of the air-heating tower, where it heats the air supply.

The heating of the air in the air-heating tower by hot water results in the air becoming saturated with water vapour, which is carried into the producer, while the water which was delivered hot to the top of the tower leaves at the bottom in a sufficiently cooled state, having given up most of its heat to the air, to be returned to the top of the gas-cooling tower.

This system of employing the circulating water as the heat-carrying agent between the hot gas and the cold air, and the recovery of a large portion of the steam employed, forms a distinctive feature in the Mond process in regard to economy.

Typical Figures relating to a Mond Gas Installation of 20,000 Horse Power with Ammonia Recovery.

	Average percentage composition of fuel (by weight).	
	Slack, as received.	Calculated on dry slack.
Moisture, at 212 deg. Fah.	8·60	nil.
Volatile matter (excluding carbon)	18·29	20·01
Total carbon	62·69	68·59
Ash	10·42	11·40
	100·00	100·00

Analysis of Ashes leaving the Producer.

	Per cent.
Ash on dry sample, by weight	87·0
Carbon	13·0
Carbon lost in ashes, calculated on the fuel	1·56

Thermal Value of the Fuel (Tested on Dry Sample) Determined in a Bomb Calorimeter.

British thermal units per pound of dry fuel	12,213

Average Volumetric Analysis of Gas.

	Per cent.
Carbonic oxide (CO)	11·0
Hydrogen (H)	27·5
Marsh gas (CH_4)	2·0
Carbonic acid (CO_2)	16·5
Nitrogen (N)	41·3
Water vapour (H_2O)	1·7
Total volume	100·0
Total combustible gases	40·5

Thermal Value of Mond Gas.

British thermal units per cubic foot (saturated, at 60 deg. Fah.)	145·6
British thermal units per cubic foot (dry, at 32 deg. Fah.)	156·3
Weight per cubic foot, lbs.	·06472
Cubic feet of gas as above (saturated at 60 deg. Fah.) yielded by 1 ton of (moist) fuel	137,349

Note.—Coals having a higher percentage of carbon than the sample above, of which the analysis is given, would yield a proportionately larger volume of gas per ton.

Typical Figures Relating to a Mond Gas Installation of 1,000 Horse Power, without Ammonia Recovery.

	Average analysis of fuel (by weight). Slack as received. Per cent.		Average analysis of fuel (by weight). Calculated on dry slack. Per cent.
Moisture at 212 deg. Fah.	8·60	...	nil.
Volatile matter (excluding carbon)	18·29	...	20·01
Total carbon	62·69	...	68·59
Ash	10·42	...	11·40
	100·00		100·00

Thermal Value of Fuel (Tested on Dry Sample) Determined in a Bomb Calorimeter.

British thermal units per lb. of dry fuel	12,213

Average Analysis of Ashes from Producer.

	Per cent.
Ash on dried sample (by weight	86·1
Carbon	13·9
Carbon lost in ashes, calculated on the fuel	1·68

Average Analysis of Gas, Tested when Saturated at 60 Deg. Fah.

	Per cent.
Carbonic oxide (CO)	13·8
Hydrogen (H)	24·3
Marsh gas (CH_4)	2·0
Carbonic acid (CO_2)	13·9
Nitrogen + Moisture ($N + H_2O$)	46·0
Total volume	100·0
Total combustible gases	40·1

Thermal Value of Gas.

British thermal units per cubic foot (saturated, at 60 deg. Fah.)	144·2
British thermal units per cubic foot (dry, at 32 deg. Fah.)	154·8

When a plentiful supply of small coke and breeze from gas works or coke ovens is available the following figures will show the results obtainable in a non-recovery Mond gas pant from this fuel:—

Average Analysis of Mixed Coke and Breeze.

	Per cent.
Moisture	12·5
Ash	16·3
Volatile matter	3·9
Carbon	65·5

Analysis of Gas Made.

	Per cent.
Carbonic oxide (CO)	10·8
Hydrogen (H)	25·2
Marsh gas (CH_4)	0·4
Carbonic acid (CO_2)	16·8
Nitrogen (N)	46·8
Total volume	100·0
Total combustible gases	36·4

Thermal Value per Cubic Foot.

British thermal units	127·9

With the object of gaining the fullest advantages to be derived from the gasification of large quantities of cheap fuel, the recovery of by-products, and the transmission of gas to areas where it can be utilised for power and heating purposes, the South Staffordshire Mond Gas (Power and Heating) Company obtained an Act of Parliament in 1901 to enable them to manufacture and distribute Mond gas over the area included in the map given in fig. 37.

Lands Scheduled for Gas Generating Stations shown thus ⊙
Towns or Villages shown thus ●
Railways and Canals shown thus ~~~~~~
Parish and other boundaries shown thus ....

FIG. 37.—Plan of the Area over which Power Gas is distributed by the South Staffordshire Mond Gas Co.

The scheme includes the building of gas-producer stations in the most favourable positions in the district, situated so as to be available for distributing the gas, by pipes, to the surrounding works.

The first station erected has a capacity of 160 tons of coal per day, equal to approximately 16,000 H.P.

The area included by the Act covers about 123 square miles, the population of which is about 640,000. Works, including 140 different trades, to the number of 2,350, require both power and heat; the estimated H.P. required is 300,000. In the district about 4,000,000 tons of coal are raised each year, along with 340,000 tons of fireclay and limestone. The average price for illuminating gas is 2s. 5d. per 1,000 cubic feet.

One of the principal advantages in connection with the employment of ordinary illuminating gas in gas engines for power purposes is the convenience and economy due to the fact that by simply turning on a valve the power is available, and the instant the power requirement ceases the valve can be turned off, so that there are no stand-by losses, and no labour or other charges in connection with the power supply other than with the engine itself. These advantages apply equally to the supply of the much cheaper Mond gas, either for heating or power purposes; the absence of dust and dirt, the carting of coal and removal of ashes, is an advantage in any works, and must be set off against the cost of the gas.

The *Iron and Coal Trades Review* recently gave the following particulars of the first section of the works at Dudley Port, Tipton. The installation includes eight producers, each of which has a capacity for gasifying 20 tons of coal slack per day (24 hours), sufficient for gas engines of 2,000 H.P. running continuously. A specially-constructed basin in the canal allows of the coal being delivered by barges directly into coal bunkers, by hand; while "Hunt" conveyers, capable of dealing with 40 tons of fuel per hour, distribute the coal to the storage bunkers situated over each set of producers, each of which will hold 40 tons. Electric motors of about 5 H.P. are employed to operate the conveyers. The temperature of the gas as it leaves the producer is about 840 deg. Fah.; it is mechanically washed before passing to the ammonia-recovery apparatus and gas-cooling towers. Further purification is effected by means of two large centrifugal fans running in series at 850 revolutions per minute and requiring 45 H.P. each.

The gas from these fans passes through scrubbers before entering the compressors for distribution to the mains.

The air supply for the producers is provided by Root's blowers, there being three of these, requiring 35 H.P. each. Lee Howl pumps supply 160 tons of water per hour.

Electric motors are used to drive the fans, washers, etc.. the current being supplied at 220 volts from two Westinghouse three-cylinder vertical gas engines, each of 250 H.P., one only being in use at a time, the other being kept for stand-by purposes.

For forcing the gas into the distributing mains three Fraser and Chalmer compressors are provided, each requiring 450 H.P. to compress half a million cubic feet of gas per hour. Steam for the producers is generated in four Climax boilers, each of 500 H.P., and capable of evaporating 1,500 gallons of water per hour at a pressure of 160 lb. per square inch. Special stills are provided for evaporating the sulphate of ammonia, and the crystallised sulphate is dried in a hydro-extractor. Gas meters of the rotary type, capable of passing half a million cubic feet per hour, are employed for measuring the gas.. The gas mains vary in size from 35 in. diameter at the works to 21 in. at the end of the circuitor, and are filled with gas through Toll End to Ocker Hill, where the main divides, one leg passing through Bilston into Wolverhampton, and the other passing through Leabrook and Wednesbury into Walsall. The pressure of the gas as distributed is 5 lb. per square inch, but this is reduced, to suit customers' requirements, by reducing valves, which have been specially designed. At the time of writing the length of the trunk mains laid reached about 13 miles, of the Ferguson locking-bar type.

At the present time there are about 30 gas engines, of powers from 500 H.P. to 1,500 H.P., installed or in course of erection in this country to work on gas produced on the Power Gas Corporation Company's system.

Another large plant is being supplied to Hong Kong, which provides gas for two 1,400 H.P. and two 600 H.P. gas engines of the Cockerill type, made by Richardsons, Westgarth, and Company, of Middlesbrough; in addition, the producers will supply gas for furnaces and other heating operations.

On February 15th, 1905, Mr. W. Hartnell referred to an installation of 2,000 H.P. capacity Mond gas plant, only half of which was in use.*

There were 250 I.H.P. gas engines coupled direct to 150 kilowatt dynamos, gas also being used for heating purposes. The electricity was for power and lighting. The cost per unit, including operating expenses and allowance for interest and depreciation, was 0·62d.

A return for an installation of 1,000 H.P., taken under ordinary working conditions, over a period of nine weeks, showed the cost per unit to be 0·51d., including interest and depreciation (10 per cent) and all other expenses.

In another large plant, where by-products are recovered, the operating costs, including superintendence but not including interest and depreciation, were as low as 0·1d. per unit.

In an installation of 300 kilowatt capacity the works cost, excluding interest and depreciation, was 0·344d.

The costs vary with the locality and price of fuel, of course.

LIST OF LARGE GAS ENGINES USING MOND GAS—500 H.P. AND UPWARDS.

	B.H.P.
PREMIER :—	
Brunner, Mond, and Co.	650, 500.
Farnley Iron Co.	700.
Albright and Wilson	650, 650.
Monks, Hall, and Co	650.
Turkey Red Co	650, 650, 650.
J. Brown and Co.	500, 500.
KORTING :—	
Castner Kellner	900, 900.
J. and H. Robinson Ltd.	500.
Wm. Beardmore and Co.	1000, 500, 500.

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* Paper read before the Leeds Section of the Institute of Electrical Engineers.

	B.H.P.
Crossley :—	
Albright and Wilson	650, 650, 650.
Crossley Bros.	500.
Deutz :—	
Albright and Wilson	1200.
Westinghouse :—	
Hollins Mill	800.
Castner Kellner	750, 750, 750, 750.
Nurnberg :—	
Societe de Gasification	2500, 2500, 2500.
Central Station, Madrid	2500, 2500, 2500, I.H.P.
Cockerill :—	
Kosmoid Ltd.	1500, 1500, I.H.P.
Hong Kong Docks (J. Swire & Sons).	1100, 1100, 500, 500 B.H.P.

Oechelhauser :—

Wm. Beadmore have two 500 B.H.P. at work, and are manufacturing larger size.

Description of Mond Power-gas Plant at the Midland Railway Works, Heysham Harbour.

This gas plant is installed in conjunction with an electric generating outfit for supplying current for lighting and to motors driving the various cranes, winches, elevators, pumps, etc., which are in use about the dock. The electric generating plant consists of three 3-cylinder Westinghouse gas engines, direct-coupled to 150 kilowatt continuous-current Westinghouse dynamos. The gas plant consists of the following main parts: Root's blower, for delivering air blast; air tower, in which the descending hot water heats incoming air and saturates it with moisture; superheater, for bringing about an economical exchange of heat between the incoming air and the outgoing gas; two producers, consisting of external and internal shells: the air is further heated in the external shell before passing into the internal-combustion chamber; mechanical washer, for removing the dust and partially cooling the gas: also some of the tar is extracted in the water; gas tower, where the gas is completely cooled by descending water, and more tar is removed; gasholder governor, which does not serve in any way as a reserve supply, but merely as an automatic regulator of gas production; specially-designed fan, to throw out tar, and deliver gas under slight pressure;

sawdust scrubber, for removing last traces of tar. The same water is circulated through the gas and air towers, taking in heat from the gas in the former and giving it out to the air in the latter. Thus a continuous regeneration of steam is secured. The features of this gas plant are its high efficiency, positiveness of operation, and the compact arrangement of its various parts. Only two men are required to look after the whole gas plant.

Official Tests of Heysham Harbour Mond Gas Plant.

Gas plant capacity, 1,000 I.H.P.; engines capacity, 250 B.H.P. each; fuel used, small bituminous coal. N.B.—Only one producer was used throughout these tests.

TESTS.	A	B	C	D
Duration in hours	4	4	4	4
Conditions	1 Engine at ½ load.	1 Engine at full load.	2 Engines at ½ load.	2 Engines at full load.
Average calorific of gas during test in B.T.U,	185·6	171·2	160 6	158·3
Average I.H.P. produced	152·5	256	299	509
Average B.H.P. produced	114·2	217·4	224	432·3
Average kilowatts generated	77·5	150·1	152	298·3
Total fuel gasified in lbs.	831	1120	1232	2213
Fuel gasified per I.H.P. hour in lbs.	1·36	1·09	1·04	1·09
Fuel gasified per B.H.P. hour in lbs.	1·82	1·29	1·37	1·28
Fuel gasified per kw. hour in lbs.	2·68	1·87	2·03	1·85

Note.—In this particular plant the fuel figures given do not cover the power required for driving auxiliary apparatus. In our latest practice, however, no extra fuel is needed for this purpose as ample steam can be provided by means of special boilers heated by the exhaust gases from the gas engines, several plants being already successfully at work with this arrangement.

Taking the results of all four tests together—5,535 lb. of fuel produced gas containing 53,801,722 B.Th.U., or 10 per cent above the guarantee.

Tests of a Mond Gas-driven Electric Generating Installation at Messrs. Blair and Co.'s Works, Stockton-on-Tees.

The four generating sets are made up as follows:—

No. 1 Set.—250 I.H.P. Premier Engine direct-coupled to a 140 kw. Scott and Mountain dynamo.

No. 2 Set.—250 I.H.P. Premier engine direct-coupled to a 140 kw. Westinghouse dynamo.

No. 3 Set.—250 I.H.P. Premier engine rope driving a 140 kw. Scott and Mountain dynamo.

No. 4 Set.—Same as No. 3.

Date (1904 and 1905).	Dec. 20.	Dec. 21.	April 4.	April 5.
Conditions and duration.	(A) Sets 1 and 2 on ¾ load for 6 hours, then slightly overload 1 hour.	(B) Sets 1 and 2 on full load for 6 hours.	(C) Sets 3 and 4 on full load for 6 hours.	(D) Sets 1, 2, 3, and 4 and 60 h.p. gas engine driving shafting. All on full load for 12 hours.
Average calorific value of gas during test, B.Th.U., per cubic feet (higher value).	149·4	153	155·2	153·8
Average I.H.P. during the 7 hours.	424·8	496·2	482	1 000
Average kw. during the 7 hours.	220·9	237·5	224	470·7
Fuel	Auckland Park Colliery Durham.	Same as in last test (A).	Very poor slack from Black Bay Colliery, Durham.	Same as last test (C).
Size	1½ in. pieces to dust.	....	1 in. to dust.	....
Total gasified during test.	2,272 lb.	2,352 lb.	2,688 lb.	11,200 lb.
Fuel gasified per I.H.P. hour.	0·76 lb.	0·79 lb.	0·93 lb.	0·93 lb.
Fuel gasified per kw. hour.	1·47 lb.	1·43 lb.	2·00 lb.	1·86 lb.

Notes on the above Tests.—The fuel used in the Tests A and B was of a much higher quality and calorific value than that used in C and D. The former cost 9s. 6d. per ton, while the latter cost only 6s. 6d. It should be noted that throughout Tests A, B, and C the gas-producing plant was on less than half load. It should also be *specially* noted that the dynamos of sets 3 and 4 were rope driven, the combined mechanical efficiency being about 12 per cent below that of the direct-coupled sets 1 and 2.

Copy of Report on Producer Plant at Messrs. Blair and Co.'s Engineering Works, Stockton-on-Tees, by William A. Bone, D.Sc., Ph.D., F.R.S., Lecturer in Fuel and Metallurgy, the Victoria University of Manchester:—

"May 31st, 1905.

To the Power-gas Corporation Limited, London, S.W.

Sirs,—In accordance with your instructions, I made an inspection of the 1,000 horse power Mond producer at the engineering works of Messrs. Blair and Co. Ltd., Stockton-on-Tees, on Monday, February 27th, 1905, and beg to submit the following report on the same. The plant, so I was informed, had been erected in October, 1904, to supply gas for power purposes (gas engines). On the day of my visit the load was 630 horse power.

1. *Character and Calorific Value of Coal used.*—A very good quality of Auckland Park coal, containing only 1·94 per cent of moisture, was being used in the producer. The dry coal contained—carbon, 83·6; hydrogen, 5; ash, 6 per cent. It yielded 27 per cent of volatile matter at 1,000 deg. Cen. (1,832 deg. Fah.), leaving a porous cake or coke. The calorific value of the dry coal, as determined in a bomb calorimeter, was—

$$\left.\begin{array}{l}\text{Gross value} \ldots\ldots\ldots\ldots\ 3{,}723\\ \text{Net value}\ \ \ldots\ldots\ldots\ldots\ 3{,}600\end{array}\right\}\ \text{Kilogram Centigrade units per}$$

$$\text{pound}\left\{\begin{array}{c}14{,}773\\ 14{,}285\end{array}\right\}\ \text{British thermal units.}$$

2. *Character, Composition, and Calorific Value of the Gas.*—Samples of the gas as it left the scrubber were taken at intervals of two hours during the afternoon. It was

found to be remarkably clean and free from tarry products, having an average temperature of 17 deg. Cen. (63 deg. Fah.), and an average pressure of 16 cms. (6¼ in.) of water. On subsequent analysis the samples were found to have the following percentage composition:—

	1 p.m.	3 p.m.	5 p.m,	Mean.
CO_2	12·75	13·65	13·20	13·20
CO	15·50	15·00	15·40	15·30
H	18 50	19·70	19·80	19·35
CH_4	4·05	3·75	3·70	3·85
N	49·20	47·90	47·90	48·30
	100·00	100·00	100·00	100 00
Per cent of combustible	38·05	38·45	38·90	38·50

The gas was of good quality, and of very uniform composition, a matter of great importance when it is being used in gas engines for power purposes.

During the course of the day two separate determinations were made of the calorific value of the gas as it left the scrubber, by means of the Junker gas calorimeter, the one at 12-40 p.m., and the other at 3-30 p.m. The results obtained for *dry* gas per cubic foot, measured at 0 deg. Cen. (32 deg. Fah.) and 760 mm. (30 in.), were as follows:—

At 12-40 p.m.	Kilogram Centigrade units.	British thermal units.
Gross value	40·37	160·2
Nett value	35·70	141·7
At 3-30 p.m.		
Gross value	41·0	162·7
Net value	35·7	141·7

The *gross* value, calculated from the above analyses, would average 40·2 kilogram Centigrade units per cubic foot of *dry* gas at 0 deg. Cen. (32 deg. Fah.) and 760 mm. (30 in.), a result which is practically identical with that obtained in the calorimeter.

3. *Ratio of the Calorific Value of Gas to that of the Fuel.*—I was not able to make any direct measurement of the volume of gas yielded per lb. of coal gasified in the producer, but from a comparison of the compositions of the coal and gas, respectively, I estimate it to be approximately 72 cubic feet, measured *dry* and at 0 deg. Cen. (32 deg. Fah.) and 760 mm. (30 in.), thus:—

Carbon in 1 lb. *dry* coal = 453·6 × 0·836 = 379·3 grams.
Carbon in 72 cubic feet of *dry* gas at 0 deg. Cen. (32 deg. Fah.) and 760 mm (30 in.) = 353·0 grams.

The estimate of 72 cubic feet of gas per lb. of coal would, therefore, allow for a loss of 7 per cent of the carbon in the coal as condensable tarry products and in the ash. The factor of 0·783, based on *gross* calorific values of gas and coal respectively, does not include the fuel required to raise the steam for the producer. Since, however, in most complete installations all the steam can be raised from a boiler heated by means of the exhaust gases from the cylinder of the gas engine, the ratio of 0·714, based on the *net* calorific values of the gas and coal respectively, represents the fraction of the energy of the coal actually *available* at the gas engine.

	Kilogram Centigrade units.		British thermal units.	
Calorific value.	**Gross.**	**Net.**	**Gross.**	**Net.**
72 cubic feet *dry* gas at 0 deg. Cen. (32 deg. Fah.) and 760 mm. (30 in.) ..	**2,916·0**	**2,570·4**	**11,570**	**10·199**
1 lb. of *dry* coal	**3,723·0**	**3,600·0**	**14,772**	**14.285**
Ratio	**0·783***	**0·714**	..	..

*** Ratio ·783 respresents 78·3 per cent efficiency.**

In conclusion, I desire to say that in respect of the quality, cleanliness, and uniformity of composition of the gas, this plant left nothing to be desired. In all other respects, also, it was working very satisfactorily.

(Signed) William A. Bone,
Lecturer in Fuel and Metallurgy.

May 31st, 1905."

THE TRANSMISSION OF POWER GAS THROUGH PIPES.

Up to the present there is not much published information in regard to the transmission of power gas to considerable distances, as this system is still in its infancy; however, as the proportion of nitrogen in producer gas is high, the specific gravity of dry Mond gas being 0·7882 (air = 1), its transmission losses will be in the neighbourhood of those occurring in the transmission of air through pipes. In the United States, where in some localities there are available large volumes of natural gas, this is conveyed by pipes to cities situated up to 200 miles distant from the gas wells, while the pressure of the gas in the wells varies from 800 lbs. to 200 lbs. per square inch. The compressors used for forcing the gas to Chicago are capable of compressing up to 2,000 lbs. per square inch, but work normally at 300 lbs., the pipe lines being from 16 in. to 20 in. diameter. The average price of the gas supplied to consumers was in 1903 about 15 cents, say 7½d., per 1,000 cubic feet. Assuming that the price of the gas at the wells was 3 cents, say 1½d., the cost of transmission would be 12 cents, or 6d.*

As natural gas has a thermal value per cubic foot of 900 to 1,150 B.Th.U., this high cost of transmission would still render it economical for power and heating purposes, but when this method is adopted for producer gas, such as Mond gas, having a thermal value of 150 B.Th.U., the poorer gas is not so well able to carry such a cost for transmission as that given above, but is still available for piping to shorter distances.

In regard to loss through leakage, the class of pipes and joints employed for the distribution of illuminating gas is not suitable for the higher pressures required to economically distribute producer gas. The system of distributing illuminating gas through cast-iron pipes with open lead joints, associated with the numerous off-takes, results in a leakage loss of about 6 per cent. In this case the pressure is very low compared with that required to

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* "A Comprehensive Scheme for Gas Distribution," by Arthur J. Martin, A.M.I.C.E.

economically distribute producer gas, but with an improved pipe system the amount of leakage can be brought to a lower figure than that given above, even though the pressure is greatly increased, for the compressed-air mains in Paris give the lowest loss per mile as 0·38 per cent of the amount delivered. Mr. W. E. Dean* describes a turbine plant of 10 horse power driving a Sturtevant fan at 2,300 revolutions per minute, which, with an inlet pressure of 7 in. of water, maintained a pressure of 13 in. of water when dealing with 420,000 cubic feet of gas per hour through an outlet main of 36 in. diameter; the velocity of the gas being in this case about 16·66 cubic feet per second.

In the discussion on the same paper Mr. C. S. Carpenter said that, starting with an initial pressure of 10 in., they got 3½ in. pressure at a distance of three miles from the works; the main for 1¼ miles being 12 in. diameter, and for the remainder 10 in. diameter.

Mr. Arthur J. Martin, in further dealing with the economy of transmission of illuminating gas, considers, by way of example, the generation of gas in the coalfields of Yorkshire and transmitting it to London, a distance of about 173 miles, estimating that for a volume of gas of 1,946,000 cubic feet per hour to be forced through a 6 ft. diameter main would require an initial pressure of about 480 lb. per square inch; the power necessary for dealing with this volume of gas would, at 77 per cent efficiency, be about 575,710 I.H.P., while if the whole of the gas was employed for power purposes in gas engines it would develop over 9,000,000 I.H.P., the power expended in transmission would therefore amount to about 6 per cent. In this case the velocity of the gas through the main would be 1,147 ft. per second, while in air-transmission schemes a velocity of about 40 ft. per second is advised as a maximum, on account of friction.

With four mains, ranging from 36 in. diameter at the coalfield to 72 in. at the London end, it is estimated that 700,000,000 cubic feet per day, at an initial pressure of

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* "Boosting and its Application to the Distribution of Gas," London and Southern District Junior Gas Association.

510 lb. per square inch, would require 594,840 horse power; this would give a velocity of 289 ft. per second at the origin.

Such high velocities as have been referred to above have not yet been applied to producer gas.

Mr. Dugald Clerk, in his Cantor Lectures,* said that Mr. Humphrey told him that in a test made with air along a main five miles long an initial pressure of 10 lb. per square iinch at the central station would be fully equal to a gas supply to engines of 15,000 horse power; the main being 35 in. diameter, the velocity in this case would be about 63 ft. per second, which is within the range of economical practice.

As the South Staffordshire Mond Gas (Power and Heating) Company undertake to supply gas to customers at 2d. per 1,000 cubic feet through mains extending seven or more miles from the generating station, with, at present, an initial pressure of 5 lb. per square inch, it will be obvious, from the particulars already given, that the system of distribution must have been very carefully considered. At the generating station compressors capable of delivering 500,000 cubic feet of gas per hour require 450 horse power, equivalent to about 6 per cent on the power capable of being developed by the gas, so that for each 1,000 cubic feet there is expended about 1 indicated horse power, which for fuel alone, using Mond gas, will cost about 0·028d. The fact of the fuel being gasified in the neighbourhood of the colliery has the advantage of saving the cost of carriage by rail or boat, and this cost amounts to about 6s. 8d. per ton for gas-making coal delivered to London. As one ton of coal gives off 142,000 cubic feet of gas if gasified in a producer, the 6s. 8d. cost for railway carriage would be epuivalent to 0·56d. per 1,000 cubic feet for the transmission of the gas to an equal distance.

Outside the question of the cost of power required to force the gas through the pipes, there are many advantages in this method of fuel supply. For one thing, the gas

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* "Internal Combustion Engines," Society of Arts, 1905.

does not become reduced in quality; storage can be cheaply effected, and the user has not to deal with the handling of fuel or removal of ashes.

All interested in the transmission of gas for power purposes will eagerly await the publication of statistics relating to the South Staffordshire Mond Gas Company's project to enable them to more fully apply this method of economically providing a source of power to small and large power users all over the country. and at the same time increase the amount of heat turned into effective work from a given weight of coal.

CHAPTER IX.

RECENT IMPROVEMENTS IN GAS PRODUCERS.

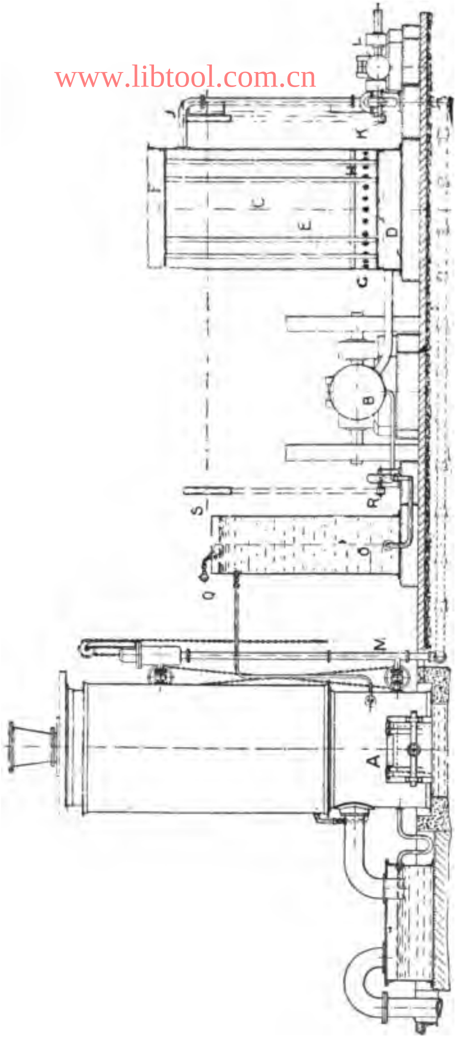
AN EXAMINATION OF THE DETAILS ADOPTED BY VARIOUS WORKERS IN THEIR ENDEAVOURS TO IMPROVE THE METHODS OF GASIFICATION OF FUEL.

A STUDY of the different designs exploited by gas engineers and the claims included in patent specifications will show that finality has not been reached in regard to the most efficient apparatus for the gasification of fuel, and that the different classes of fuel require special treatment.

A well-known name in connection with power gas engineering is that of Mr. B. H. Thwaite. Besides being the inventor and pioneer of the application of blast-furnace gas for the economical development of power on a large scale, Mr. Thwaite has designed and constructed a number of gas producers which have done good work, both with anthracite, coke, and bituminous coal; in fact, some of his patented designs of producers were so far in advance of the development of the gas engine that they failed to become generally used.

The spurt given to the development and enlargement of the gas engine by the successful application of blast-furnace gas to internal combustion engines, as was instanced by the 600 horse power single-cylinder gas engine developed by the Cockerill (Belgium) Company after experimenting with blast-furnace gas, the cylinder of which was 51 in. diameter, and which proved to the world that in 1895 the gas engine was in advance of the gas producer. The rapid advance in gas engine engineering naturally brought about competition in the direction of bringing the producer into line with the modern requirements.

A gas producer designed by Mr. Thwaite, and which has been doing good work since 1889, is illustrated in figs. 38 and 39. The general arrangement of the plant shows how provision has been made to conserve the heat and increase the efficiency. The gasification of the fuel is effected in twin vessels A, the gas produced passing out through the water seal shown on the left; this seal prevents any air from entering the producer during stoppage, or when the pressure is reduced from any cause. The system being of the pressure type, a gas holder is necessary, but not shown in the views. The main gas engine is lettered B, the exhaust gases from which pass through the chamber C, by the tubes E connecting the entrance chamber D with the exit chamber F. At G a series of holes permits the air supply to enter the air heating and exhaust cooling vessel C, through the perforated plate H, and thence through the pipe J to the exhauster K, which forces the heated air by way of the pipes M to the generating vessels. An auxiliary gas engine L drives the exhausting and blowing fan K, and by a counter shaft and pulley S the water circulating pump R. The cooling water tank O is provided with a ball valve supply pipe Q, and while cold water is drawn off at the bottom for cylinder cooling purposes, it has an outlet at the top P to permit hot water to flow into the chamber below the grate of the primary generating vessel to provide the necessary quantity of steam for keeping the firebars cool and free from clinker. The circulating water, after passing through the cylinder jackets, is led in a heated state to the tank O by pipes not shown. The generating vessels stand over a water seal, and the overflow from the hydraulic seal is conducted into the lower



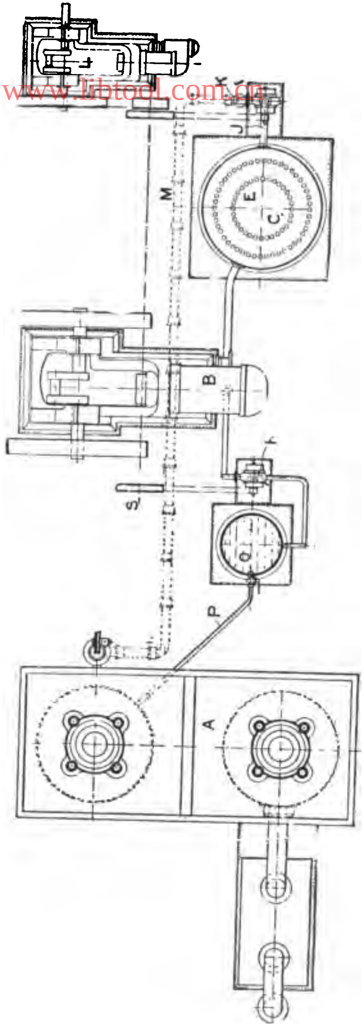
ELEVATION.

FIG. 38.—Twin Producer Power Gas Installation (Thwaite)

part of the secondary generating chamber. A special feature of this producer will be noticed in the air supply being admitted above as well as below the fuel in the primary vessel by valves coupled together by a chain; however, the supply of air admitted above the fuel is further controlled by a valve actuated from the gas holder by the chain passing over the pulley. The admission of air above the fuel in the primary chamber has for its object the raising of the fuel in the secondary chamber to incandescence by the combustion of a portion of the gas evolved, so as to bring about the complete gasification of volatile tarry vapours.

As long as the temperature of the gases evolved in the primary chamber is above 1,200 deg. Fah. any air admitted above the fuel will enter into combustion, and by so doing will raise the temperature of the top part of the fuel in the secondary chamber to incandescence. The advantage of this system is that the volatile hydrocarbon gases, including the tar, are burnt to carbonic acid and steam, and as these products of combustion pass down through the heated fuel in the secondary chamber they become transformed into carbonic oxide and hydrogen.

Mr. Thwaite further designed three different cycles of operation for the gasification of bituminous fuel, two of which were continuous, and one reversible. In each case twin generators were employed, connected together by a conduit at the upper part; for two of the cycles reversible valve connections are provided also. The water bottom was employed in each type, so that clinkers could be removed without interrupting the production of gas. The secondary chamber, in one of the continuous cycles, only acts as a scrubber, arresting tarry matter and dust, as well as a proportion of the sensible heat of the gases; further, sensible heat is recovered by causing the gas to pass through the water in the baths before it escapes into the mains. As both the water baths are connected, and the radiated heat from the grate highly heats the water in the bottom of the first generator, the passage of the air through it, on its way to the fire, causes it to become saturated with vapour, which is introduced into the fire and becomes dissociated.



PLAN.

FIG. 39.—Twin Producer Power Gas Installation (Thwaite).

In the second continuous cycle the combustion of the tarry products is effected as already described. In the reversible cycle both vessels are made to act alternately by means of a special valve arrangement, which both

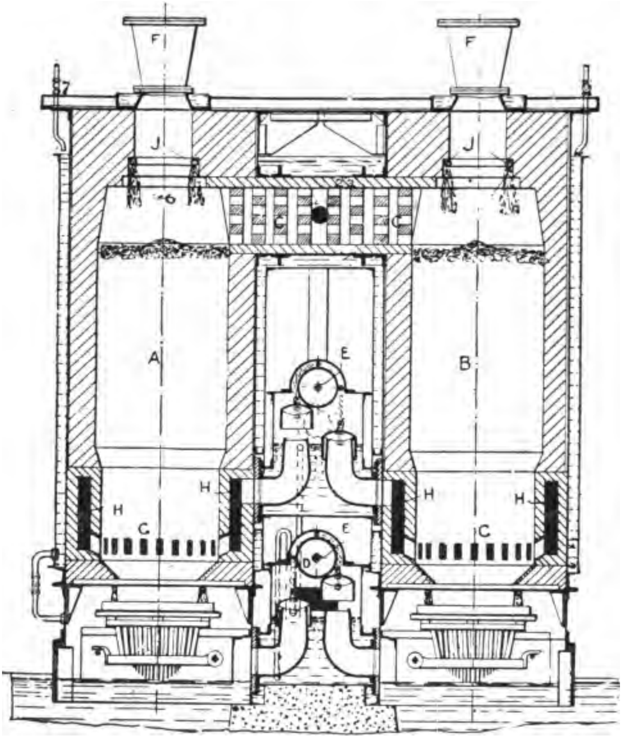


FIG. 40.—Reversible Type Duplex Gas Producer for Bituminous Coal (Thwaite).

regulates the admission of air to the grates and the outlet of the evolved gas to the main. However, the gas produced in one vessel can only reach the mains by passing downwards through the incandescent fuel in the second chamber. The arrangement of the generators is shown in fig. 40, being a sectional view showing the generators A and B with the connecting conduit C, and the reversal valves for the air D and gas E. It will be observed that the generators are water jacketed, and each vessel is provided with a charging hopper F. The outlets for the gas G and H are situated at the lower part of the producers. When hydrocarbon oil is to be employed it is admitted by the pipes J. The apparatus employed for automatically reversing the air and gas valve is shown in fig. 41, where water tanks are alternately filled, and, after over-balancing and reversing the valves, discharged.

The quality of the gas when steam coal is gasified with unmoistened air, and with steam-moistened air, is shown by the following analysis:

PERCENTAGE COMPOSITION OF GAS FROM A THWAITE DUPLEX REVERSIBLE PRODUCER AT STOKE NEWINGTON, 1894.

	Steam coal and unmoistened air.	Steam coal and moistened air.
Analysis by..............	Horace Allen	Prof. Vivian B. Lewes
Carbonic acid (CO_2) ...	5·0	11·83
Saturated hydrocarbons	—	4·10
Carbon-monoxide (CO)..	24·0	17·16
Hydrogen	3·3	7·33
Nitrogen	67·7	59·58
	100·0	100·00

The writer examined the exhaust gases from the gas engine while working on the first class of gas given above, and found from 13 to 14 per cent of CO_2 present, while when the same engine was working on illuminating gas the proportion of CO_2 was from 4·5 to 7·5 per cent.

The gas was very uniform in quality, and no poking was required during running, clinkers being cleaned out once a day. For small powers an indicated horse power can be developed with an expenditure of from 1 to 1½ lb. of common slack per hour.

The following particulars relate to a Thwaite power gas plant applied to a textile factory,* replacing a steam

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* Partly from the *Electrical Review*, November 5, 1906

plant, at Birstall. The gas engine was of the two-cylinder side-by-side type, having 16 in. diameter cylinders and 24 in. stroke. The normal speed was 140 revolutions per minute, and at full load there would be the same number of explosions.

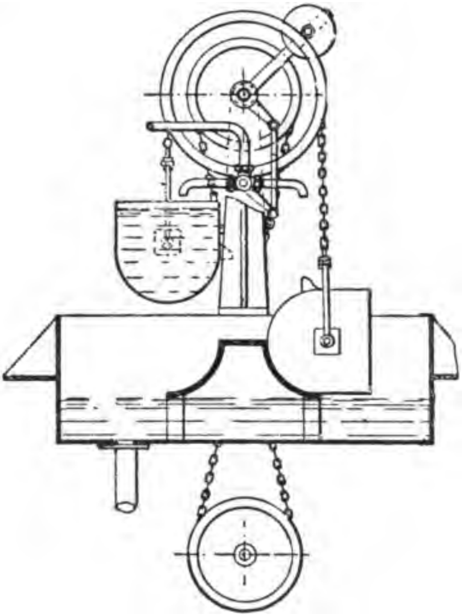

FIG. 41.—Thwaite Automatic Reversing Apparatus.

The average initial maximum pressure was about 297 lb., and the mean effective pressure 78 lb. per square inch, giving at 140 revolutions per minute 133 indicated horse power. Consumption of gas per hour 10,640 cubic feet, gas per indicated horse power per hour 80 cubic feet, and coke per indicated horse power per hour ·99 lb. The producer was of the twin-generator type, continuous cycle, with air blast from a fan driven by the main engine; the air is heated by the effluent gas, and steam is derived from the evaporation of the water in the seal below the grate, in which each vessel stands.

PERCENTAGE COMPOSITION OF THE GAS BY VOLUME.

	Average of 7 analyses. Coke fuel only.	Average of 8 analyses. Coke and bituminous coal.
Carbonic acid, CO_2	3·4	5·1
Carbonic oxide, CO	27·8	24·0
Hydrogen, H	5·5	7·4
Marsh gas, CH_4	1·9	1·3
Nitrogen, N	61·4	62·2
	100·0	100·0

Thermal value per cubic foot at 32 deg. Fah. down to 212 deg. Fah. .... } 128·6 B.Th.U., 115·6 B.Th.U.

The load on the plant was extremely variable, changing at times from no load to maximum load almost instantly.

A week's test of the fuel consumption, made by the proprietor of the factory, Mr. Arthur Porritt, including standing over Sunday, the nights, and the afternoon of Saturday, when the load averaged between 70 and 80 indicated horse power, was 1 cwt. per working hour.

A special feature of economy in this installation is that the circulating water, after being heated in the cylinder jackets, is employed for dyeing purposes, so that practically the whole of the heat given off in cooling the cylinders is turned to effective account, and any excess of heated air over that required by the producer is used for drying purposes.

EFFICIENCY ACCOUNT FOR THE INSTALLATION.

Total heat value of the coke, 100.

Heat used in gasification and radiation	10	per cent.
Heat returned by the recuperator	9	„
Heat value of the gas	81	„
	100	

Efficiency of the gas generator, 90 per cent.

Heat converted into work	18·5 per cent.
Heat rejected in circulating water available for dyeing, etc.	44·5 ,,
Heat rejected in exhaust available for drying and other purposes	18·0 ,,
Efficiency of gas engine	81·0 ,,

The quantity of heat turned into work by the gas engine 22·8 per cent of the heat value of the gas—

thus $$\frac{18·5 \times 100}{81·0} = 22·8 \text{ per cent.}$$

Abstract of Report on Experiments made at the Motor Gas Plant Syndicate's Demonstration Station at Stoke Newington on their Thwaite "Simplex" and "Duplex" Motor Gas Producers, with various kinds of Fuel. By Mr. Geo. Cawley, M.I.M.E.*

"The comparative efficiency of the gas plant is most conveniently expressed by stating the required *weight* of any given fuel to produce one *indicated* horse power per hour in the gas engine. The fuels used are anthracite, steam coal, slack, and coke.

"In the Simplex producer the fan blast is introduced above the grate level, and it passes up through the body of the fuel to form 'producer gas.' In the Duplex producer, instead of the gas passing off direct from the top, it is made, after being first formed in one cupola, to pass down through the incandescent fuel in the other, the object aimed at being the conversion and utilisation of the crude tarry hydrocarbon vapours evolved in the first cupola into a permanent gas. In order that this action may go on continuously, it is arranged that the direction of flow of blast and gas may be reversed at frequent intervals. This is effected automatically by means of a hydraulic tumbler. In this way a gas is made suitable for gas engines from bituminous coal, or even from slack

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* "Practical Treatise on the Otto Cycle Gas Engine," by W. Norris.

of indifferent quality. In the Simplex producer the fan blast is introduced above the grate level, and it passes up through the body of the fuel to form *producer gas.*

"In the Duplex producer, instead of the gas passing off direct from the top, it is made, after being first formed in one cupola, to pass down through the incandescent fuel in the other, the object aimed at being the conversion and utilisation of the crude tarry hydrocarbon vapours evolved in the first cupola into a permanent gas. In order that this action may go on continuously, it is arranged that the direction of flow of blast and gas may be reversed at frequent intervals. This is effected automatically by means of a hydraulic tumbler."

TESTS OF THWAITE GAS PLANT.

Type of producer	Duplex.	Duplex.	Simplex.	Simplex.
Class of fuel	Steam coal.	Slack.	Coke.	Coke
Air supply	Fan blast.	Fan blast.	Steam blast.	Fan blast.
GAS VOLUME TEST.				
Date of trial	April 2, 1905	April 3, 1905	April 1, 1905	April 4, 1905
Time of trial	10 a.m. to 6 p.m.	11 a.m. to 7 p.m.	10-45 a.m. to 9-45 p.m.	10-15 a.m. to 4·15 p.m.
Duration of trial	8 hours.	8 hours.	6 hours.	6 hours.
Condition of weather	Fine, but cloudy.	Fine, but cloudy.	Cloudy with occasional showers.	Dull, but fine.
Aver. temperature of outside air, deg. Fah.	46	47	47	46
Aver. temperature of gas entering holder, deg. Fah	62	50·5	81·9	59·25
Pressure of gas in holder, ins. of water	1·5	--	1·5	1·5
Aver. pres. of gas in producer delivery pipe, ins. of water	3·57	3·25	4·41	4·21
Density of fuel per cub. ft., lb.	47·18	48·18	27·25	27·25
Weight of fuel per in. depth, both cupolas lb	13·88	—	—	5·59
Total volume of gas produced, cub. ft.	34,020	23,312·5	37,485	31,150
Aver. vol. of gas produced per hour	4,252·5	2,976·56	6,247·5	5,191·6
Volume of gas produced per lb. of fuel, cub. ft.	54·04	43·91	84·57	82·24
Total net weight of fuel charged lb	—	542·25	—	378·75
Average net weight of fuel charged per hour lb.	—	67·78	73·87	63·125
Weight of steam for blower, lb.	—	—	450	—
Weight of steam for blower per hour lb.	—	—	75	—

TESTS OF THWAITE GAS PLANT—*continued.*

Type of producer ...... Class of fuel .... Air supply	Duplex. Steam coal. Fan blast.	Duplex. Slack. Fan blast.	Simplex. Coke. Steam blast	Simplex. Coke. Fan blast.
GAS QUALITY TEST.				
Time of trial	7 p.m. to 7-15 p.m.	7-15 p.m. to 7-30 p.m.	5-30 p.m. to 5-45 p.m.	5 p m. to 5-15 p.m.
Duration of trial	15 min.	15 min.	15 min.	15 min.
Dia. of gas engine cylinder. in.	$13\frac{1}{8}$	$13\frac{1}{8}$	$13\frac{1}{8}$	$13\frac{1}{8}$
Length of stroke .... in.	22	22	22	22
Length of working stroke per revolution, ins	11	11	11	11
Nature of load on engine....	Friction brake.	Friction brake.	Friction brake.	Friction brake.
Power	Gas inlet valve full open.	Gas valve full open.	Gas valve full open.	Gas valve full open.
Total revolutions of engine in 15 minutes	2,625	2,466	2,572	2,703
Average revolutions of engine per minute	175	164·4	171·5	180·2
Brake horse power	21·77	19·48	20·14	19·06
Number of indicator cards taken	10	10	10	10
Scale of indicator spring, ins..	$\frac{1}{80}$	$\frac{1}{80}$	$\frac{1}{80}$	$\frac{1}{80}$
Average mean pressure, neglecting pump stroke, lbs per square inch	46·35	46·53	46·2	41·44
Net mean effective pressure after allowing for work done in pumping stroke lbs. per square inch	44·92	45·08	44·63	40·7
Average maximum initial pressure	156·8	164	182	130·73
Maximum possible explosions in 15 minutes	1312·5	1,233	1,286	1351·5
Maximum possible explosions per minute	87·5	82·2	85·73	90·1
Total actual explosions in 15 minutes, as shown by recorder	1,312	1,233	1,284	1,333
Average number of actual explosions per minute	87·46	82·2	85·6	88·85
Average indicated horse power.	29·54	27·69	28·71	27·18
I.H.P. capacity of producer, as deduced from gas production test	54·10	33·77	64·52	52·2
Gas used by engine in 15 minutes, cubic feet	555	580	695	642
Gas to drive fan, cubic feet per hour, estimated	—	—	—	135
Gas per I.H.P. (including fan), cubic feet	78·6	88·12	96·83	99·45
Fuel per I.H.P. per hour (neglecting fan), lbs.	1·39	1·91	1·14	1·15
Fuel per I.H.P. per hour to drive fan, lbs.	0·07	0·10	0·52	0·06
Fuel per I.H.P. per hour, raising steam for blower....	—	—	—	—
Total per I.H.P. per hour (including fan). lbs.	1·46	2·01	1·66	1·21

A more recent invention of Mr. Thwaite's, which includes some novel points, is that of March 28th, 1904, No. 7347.

Fig. 42 shows a sectional view, in which the main features are clearly indicated.

The claims are as follow:—

1. The provision of both a primary and a secondary air supply at two levels in a vertical gas generator.

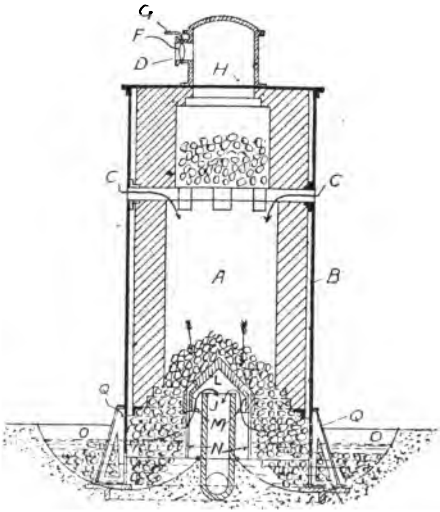

Fig. 42.

2. The arrangement of a centrally-located gas outlet apparatus with its vertical fire bars.

3. A suction generator combined with a fan exhauster and purifying elements.

4. Method of regulating the suction effect on the gas generator by the rise and fall of the governor.

The generator A is contained in a sheet-steel casing B, the lining consisting of refractory material.

At C, about two-thirds of the height of the producer, secondary air supply inlets are provided, while the primary air supply is admitted at D and regulated by the valve F, which is arranged on the side of the charging hopper H.

The gas outlet J is situated at the base and in the centre of the gas-generating chamber, and consists of a pipe provided with a special headpiece, which prevents ashes and fuel from falling into the pipe.

A number of vertical bars are suspended from the braket M, which also carries the headpiece. The lower ends of the bars dip into the water in the trough at the base of the producer, and are thus maintained cool, while their object is to ensure an unobstructed passage for the gas.

The producer is designed to use bituminous and other solid fuels, while the special feature is to maintain a column of fuel in state of graduated and inverted combustion, the combustion being initiated at the upper level, and at this part the hydrocarbons are evolved.

By admitting a further supply of air through the passages C a higher state of combustion is established, and also increased temperature of incandescence, through which, by the inverted direction of the flow, the evolved hydrocarbons are obliged to pass.

The object of the duplex air supply and the establishment of the two zones of combustion, one low temperature and the other high temperature, is as follows:—

"If the fuel introduced into the generator contains moisture, whether physically or chemically combined, or contains dense hydrocarbons that are liable to re-condense after being volatilised into tar, etc., the moisture is evaporated in the upper zone of combustion, and the hydrocarbons evolved. Both products are compelled to flow downwards into and through the secondary high-temperature zone of combustion, and in passing through this zone the hydrocarbon vapours are made more or less permanent, and the evaporated moisture is dissociated, the hydrogen being set free, and the oxygen combining with the carbon to form carbon-monoxide. Besides this chemical action, the gases are partially scrubbed in their passage through the incandescent fuel."

As the outer shell Q of the generator dips into the water bath the ashes and clinker can be withdrawn without escape of gas or inrush of air, while the steam generated by the hot material and radiation passes with the gas through the coke scrubber, and assists in the separation of tarry matter.

An exhauster-blower fan placed behind the cooling apparatus draws in the air, by suction, through the passages provided in the generating apparatus, and the gas resulting from the partial combustion of the fuel, through the purifying and cooling apparatus, and passes it on to the gasholder.

Another interesting patented design of power gas producer of Mr. Thwaite's is that of No. 16986, 1902.

The object in this case is the production of power gas having no greater portion of hydrogen than 8 per cent, and hydrocarbons not more than 2 per cent, so as to permit of compression in gas engine cylinders, when mixed with its proper proportion of air, to 75 lb. per square inch, without the risk of premature explosion.

The fuel employed is coke, or any equivalent carbonaceous fuel, either naturally free or preliminarily denuded from hydrocarbons or moisture.

The type of producer adopted is based on the iron-making blast furnace, using an air supply under pressure with a closed hearth, in which the earthy matter of the fuel is converted into liquid slag, which can be run off without interrupting the process of gas making.

The main differences between this producer and an iron melting foundry cupola furnace are: (1) The fuel can be fed continuously without interrupting the generation of gas; (2) the height of fuel in the generator is greater in proportion to the diameter, the height of the fuel being seven or eight times the net internal diameter of the cupola; (3) the pressure of the blast being greater than in foundry practice, special blowers are employed to provide pressure from ¾ lb. to 1½ lb. per square inch; (4) owing to the high temperature of combustion the air inlets, or tuyeres, are water-cooled, as may also be the hearth and slag hole; (5) a special heat recuperative tubular apparatus is employed.

The special claims for this invention are as follow:—

1. The method described of generating a combustible power gas having a limited proportion of hydrocarbon and hydrogen.

2. The gas generating apparatus, in which heated air under considerable pressure is introduced by means of tuyeres, and for establishing a temperature that will effect the melting of the earthy matter as slag.

3. The introduction of flux for liquifying the earthy matter.

The writer has already pointed out that in gas producing apparatus where steam or water vapour is not employed to conserve the heat developed by the partial combustion of carbon there can be little benefit, if any, from causing the incoming air to absorb the sensible heat of the gas, there being continuously an excess of heat generated in the reaction between carbon and oxygen to form carbonic-oxide.

Tangye's Improved Gas Producer.

Messrs. Tangyes Limited, Birmingham, are the makers of a pressure type of gas producer, to use either anthracite or gas coke. A sectional diagrammatic view of this producer installation is given in fig. 43. A charging hopper, centrally placed on the top of the generator, is fitted on the top, with an air-tight cover which can readily be swung aside by means of the handle provided for the purpose.

The bottom of the hopper is closed by a valve, which opens upwards and allows the charge of fuel to fall directly into the gas-making chamber. The gasifying chamber enlarges conically from the bottom of the charging hopper to a plain cylindrical chamber, provided at the bottom with a set of fire bars, a firebrick lining extending from the top to the bottom.

By means of a steam jet blower air and steam are forced through the fire, entering below the grate bars, while a gas off-take conducts the gas from above the fuel to a cooler. There is a blow-off pipe in connection with gas off-take, fitted with a valve, to allow of the escape of the gas generated while the fire is being blown up. In the gas pipe, just outside the generator, a steam superheating coil is inserted.

The cooler consists of a cylindrical water tank arranged vertically, with a central pipe, through which the gas is caused to descend. The central pipe is continued below the bottom of the tank into a dust-arresting chamber.

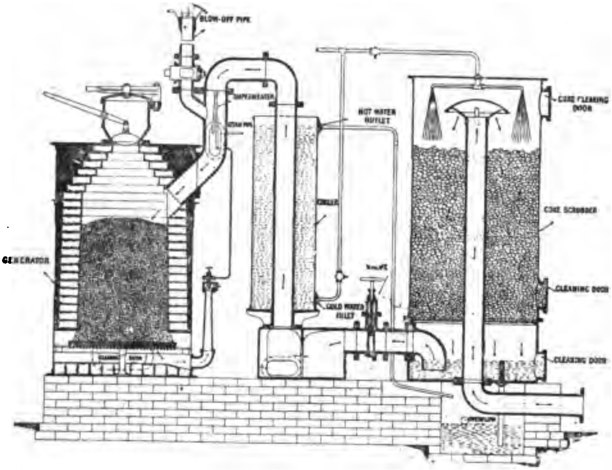

FIG. 43.—Improved Power Gas Producer (Tangye).

From the cooler the gas passes through a valve and a pipe with a curved end, which dips below water in the lower part of the coke scrubber, being thus sealed against any return of air and gas into the generator.

The coke scrubber consists also of a cylindrical vessel of large area, and is provided at the junction of the steel shell with the cast-iron seal box, with a perforated plate upon which the coke rests.

The gas passes upwards from the seal box through the deep bed of coke, and thence downwards through the centrally-arranged gas outlet pipe.

A cold water supply connects to the top of the scrubber, where jets are arranged for distributing a spray of water over the coke, and also to the lower part of the cooler tank.

Below the scrubber there is a sump, into which overflow pipes from the top of the cooler and the seal box discharge the surplus water

Being of the pressure type, this plant includes a small vertical boiler and a gas holder.

With Welsh anthracite coal, at full load, from ¾ lb. per indicated horse power per hour for the larger size of gas engines to 1¼ lb. for the smaller engines is required. With washed gas coke the consumption is, at full load, from 1 lb. for larger to 1½ lb. per indicated horse power per hour for small class gas engines.

While these plants give their best efficiency at full load, they can be run at a reduced load of 75 per cent without blowing gas to waste. When required for varying and intermittent loads it is advisable to have two generators of equal or different sizes, according to the class of duty, etc., and by a little care the attendant can work these so as to meet the variations in load without wasting gas.

The gas-holder bell consists of thin sheet steel, but the tank can either be of brick built into the ground or a steel tank standing above ground.

The following approximate dimensions show the space occupied by anthracite producer installations, but not including the gas engines:

Capacity of plant, H.P.	25 to 40	45 to 70	90 to 105	110 to 135
Ground space, feet	10 × 24	12 × 28	14 × 32	18 × 38
Holder, diameter, feet	6	8	8	10
Holder, depth, feet	6	8	8	8
Vertical boiler, nominal H.P.	3	3	3	3

For gas coke a rather larger generator is required.

The rate of gas generation is controlled by the admission of steam to the jet blower, and the valve for this purpose can either be regulated by hand, or automatically by gear connecting it with the gas holder. The holder, when lifted to nearly its highest position, closes the steam valve and reduces the volume of air and steam entering the producer.

As is usual with all steam boilers, the small vertical boiler must be efficiently stoked, so as to maintain a uniform pressure of steam.

When the requirement for gas ceases, as at the close of the day's run, the steam valve is closed and the vent pipe opened; also the doors leading to the under side of the grate are opened. Combustion then almost ceases, but gas production can again be restored in a short time on the following morning. The amount of fuel burnt under stand-by conditions is very much less for this type of producer than steam boilers.

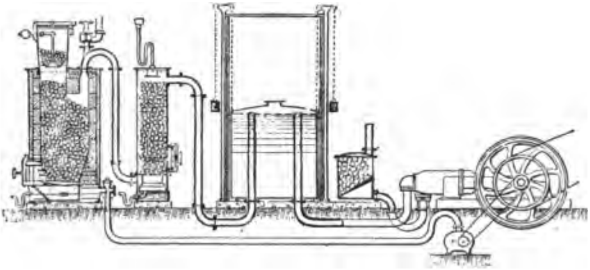

FIG. 44.—Power Gas Producer (Lencauchez).

Lencauchez's Power Gas Producer.*

A somewhat similar gas plant to that just described is the Lencauchez, a sectional diagrammatic view being given in fig. 44. A comparison with the Tangye producer will show that in place of a boiler and steam jet, air is supplied to the generator by a pressure blower driven by

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* *Revue Industrielle,* July 8th, 1905.

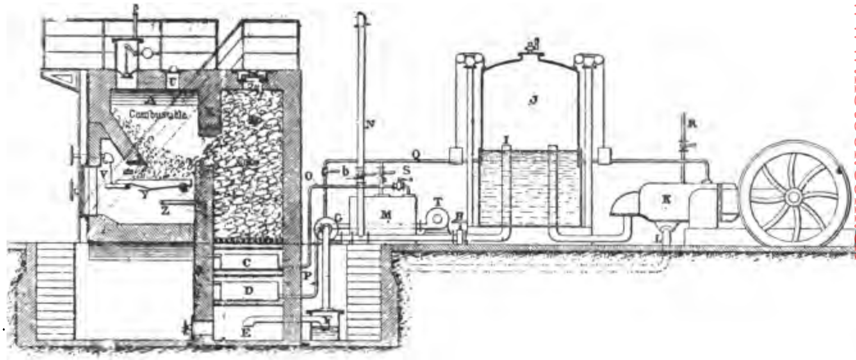
the main gas engine, steam for gasification being obtained from the evaporation of water in the lower part of the producer, below the grate. The details do not greatly differ in the two types of producers, except that in the Lencauchez producer there is no special dust-arresting chamber, or gas pipe dipping into a water seal.

Hovine-Brenille Power Gas Producer.

Another type of producer in which the gasification chambers differ considerably from those we have been examining is shown sectionally in fig. 45.

Reference to the different parts of the apparatus by letters:

A. Generating chamber.
B. Gas-regulating chamber.
C. Water vaporiser.
D. Air heater.
E. Gas outlet.
F. Hydraulic seal.
G. Aspirating fan.
H. Gas valve.
I. Gas inlet pipe to gas holder.
J. Gas holder bell.
K. Gas engine.
L. Gas pipe to gas engine.
M. Boiler.
N. Vent pipe.
O. Steam pipe.
P. Air pipe.
Q. Hot water from gas engine.
R. Cold water supply to gas engine.
S. Steam pipe from boiler.
T. Blowing fan.
U. Poking hole.
V. Grate bar agitator.
W. Conduit between the generating chambers.
X. Firebrick arch.
Y. Fire-bars.
Z. Steam pipe underneath the fire-bars.
a. Cold air inlet below the grate.
b. Air valve in vent pipe.



SECTIONAL VIEW.

FIG. 45.—Power Gas Plant (Hovine-Brenille).

A general plan of an installation is shown in fig. 46, which represents a 100 H.P. electric power station :

a. Gas producer.

b. Fan blower for the gas.
c. Aspirating fan.
d. Gas holder.
e. Gas engine.
g. Air blowing fan.
h. Motor for fans.
i. Water vaporiser for exhaust gas from engine.
j. Water regulator to vaporiser.
k. Exhaust gas pipe.
l. Water circulating pump.
m. Water supply to silencer.
n. Air inlet to gas engine.
p. Fuel storage hoppers.
q. Pipe conducting circulating water to the drain.

A test made at Creusot on a 74 H.P. plant, of six hours' duration, gave the following results—

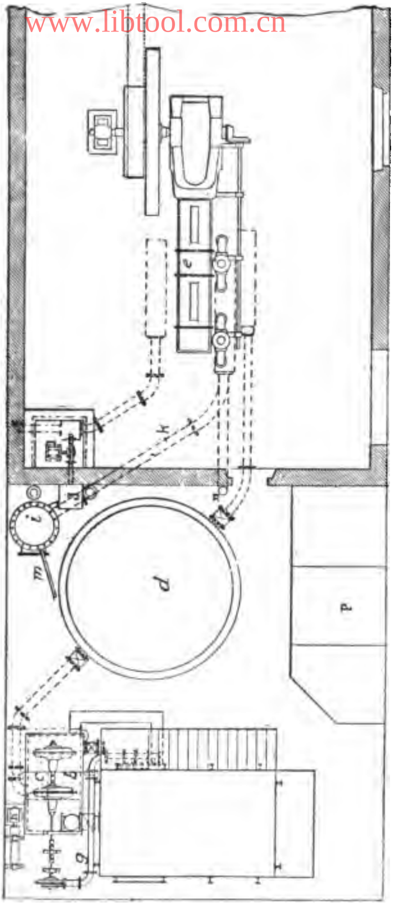
Effective work per hour	79 H.P.
Weight of fuel per horse power hour...	1·86 lb.
Thermal value of the gas per cub. ft...	129 B.Th.U.

Another test made with coke fuel gave—

Effective work per hour	103 H.P.
Weight of coke per horse power hour...	1·3 lb.
Thermal value of the gas per cub. ft...	126 B.Th.U.

From a number of analyses of the gas made in this producer using coke, the proportions of the different constituents were found to vary between—

Carbonic acid, CO_2............	3·50	to	9·40
Oxygen, O	0·50	,,	0·00
Carbonic oxide, CO............	27·00	,,	21·20
Hydrogen, H	8·00	,,	14·64
Marsh gas, CH_4...............	0·50	,,	0·36
Nitrogen, N	60·50	,,	54·40



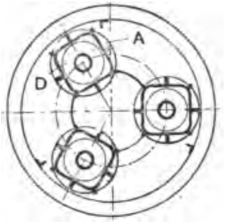
PLAN.

FIG. 46.—100 H.P. Power Gas Installation (Hovine-Brenille).

CROSSLEY'S GAS PRODUCER FOR BITUMINOUS COAL.

A novel type of bituminous coal gas producer has been designed by Messrs. W. J. Crossley and T. Rigby, of Messrs. Crossley Brothers Limited, Openshaw. This is illustrated by the views in figs. 47, 48, and 49.

FIG. 48.



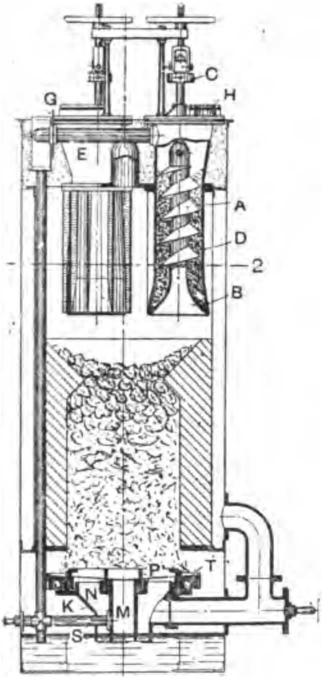


FIG. 47.

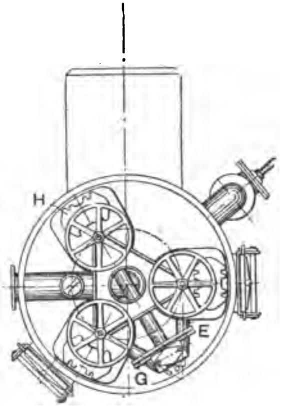


FIG. 49.

Crossley's and Rigby's Bituminous Coal Gas Producer.

It will be noticed that above the generating chamber proper there are arranged a series of three closed retorts, into which the coal fuel is successively charged; they are situated in such a position that the surrounding heated gases cause distillation of the volatile matter, which is made to mix with air and steam and pass through the lower and highly-heated fuel bed, with the object of fixing the vapours and tarry matter given off in the retorts. When the fuel in the retorts is sufficiently freed from volatile matter the resultant coke is discharged into the generating chamber by means of the screw gear provided.

In this and other recent inventions the idea of causing the volatile matter given off by bituminous coal to pass through an intermediary stage of combustion has been followed, and would appear to be the best system of preventing condensible vapours from entering and intermingling with the gases to be introduced into the cylinders of internal-combustion engines.

FICHET-HEURTET POWER GAS SYSTEM.

This type of gas producer has been installed in some French works. Fig. 50 is a diagrammatic illustration of the gas power plant on this system adopted for the Orleans tramways, and fig. 51 is a sectional view of the Fichet-Heurtet gas producer. It will be observed that the grate can be rotated by the handle and gearing shown, and a combined gas down-comer and air heater forms part of the generator plant, while in the upper part an arrangement of "Perkins" or "Field" tubes, situated in the flow of the hot gases, generate the steam for the jet blower; the arrows indicate the direction of flow of the air and gases; the generated gases passing out at the top of the producer and traversing down through the air heater, and the steam and air mixture entering the fuel bed centrally. This producer is not provided with a water trough at the base, but the ash and clinker, as they are discharged by the rotating grate, fall into the chamber below the grate, from which they can be removed by the cleaning door provided. Further, it will be observed that the air and steam for gasification only come into contact with the fuel at a considerable height above the grate bars, so that the most highly heated part of the fuel is situated centrally, and

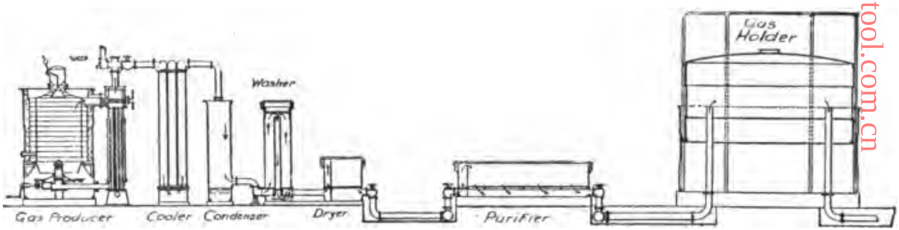


Fig. 50.—Power Gas-driven Plant for Orleans Tramways. Fichet-Heurtet System.

not in contact with either the grate bars or the surrounding firebrick casing, thus preventing the accumulation of clinker upon the sides of the generator.

In fig. 50 the various cleaning vessels are shown. After leaving the air heater, the gas traverses a series of cooling pipes and a condenser, and thence through a washer and drier. A purifier then finally prepares the gas for its admission to the gas holder.

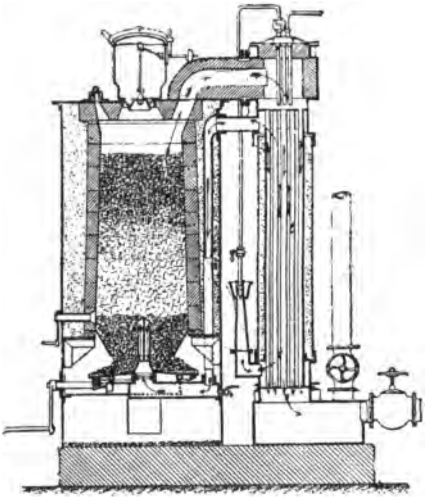


Fig. 51.—Gas-driven Plant for Orleans Tramways. Fichet-Heurtet System.

A more recent device by Messrs. A. Fichet and R. Heurtet, of Paris, for gasifying coal, lignite, and combustibles having a greater proportion of volatile ingredients than poor coal, in which it is desirable to produce gas free from tarry products, is shown in fig. 52. The invention is No. 10706, May 22nd, 1905, and the illustration is a sectional view of the producer. The raw fuel is fed into the chamber A at the top of the producer, and the distilled gases enter into combustion with air entering the chamber B, to be reduced on their passing down through the incandescent body of fuel; air is also supplied to the central chamber A for the partial combustion of the raw fuel. The walls of the internal concentric chambers are protected from destruction by water cooling, pipes for the inlet and outlet of the cooling water being shown in the illustration. As the fuel is denuded of its volatile constituents it falls into the lower chamber, where it is gasified by air entering below the grate bars. This design, therefore, combines the functions of a coke oven and a coke gas generator; the admission of air at three different points, as shown, bringing about distillation, combustion of the hydrocarbons distilled, and the reduction of the carbonic acid and water formed by this combustion during the passage of the gases formed through the mass of incandescent fuel. At the same time the combustion of the fixed carbon by the lower air supply results in ordinary coke generator gas, which mixes with

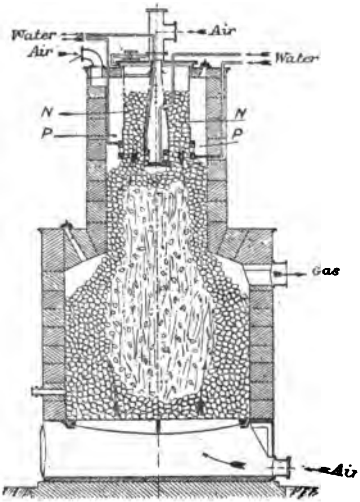


FIG. 52.—Lignite Power Gas Producer (Fichet-Heurtet).

the other gases on passing out at the single gas outlet. The upper and lower parts of the producer are proportioned in capacity to the rate at which the different functions of each are effected.

In an early article it was pointed out that the distillation of the volatile matter from coal proceeded at a much more rapid rate than the oxidation of the fixed carbon; also that the rate of distillation was entirely dependent upon temperature conditions, while the gasification of the fixed carbon involves the exposure of the surface of the particles to air. The construction of the producer as shown is suitable for fuels in which the ash is but little fusible and liable to form large clinkers, but when there is a large proportion of fusible earthy matter the hearth can be made somewhat similar to a blast-furnace hearth, closed, with a well for the fluid ash to collect and a tapping hole for its removal at suitable intervals. Poking holes are provided in three different positions, so that the descent of the fuel can be regulated. Theoretically, this system has many points in its favour; but, besides the necessity of careful adjustment of the different air supplies, the complicated arrangement of concentric chambers inside the upper part of the generator may not be found free from trouble from corrosion, etc.

Loomis-Pettibone Gas Producers.

The Loomis-Pettibone gas producer is of the duplex generator type, and is available for gasifying almost any class of fuel, ranging from bituminous coal to wood, etc.

A novel feature of the system is that the generators, when making power gas, work under a down draught, there being an exhauster for drawing the air, steam, and gas through the fire; either water gas, producer gas, or a mixture of these can be made as desired. Two similar cylindrical firebrick-lined vessels of considerable diameter, and with vertical linings, are connected with each other near the top, while a passage from the bottom of each, leading from the chamber below the grate bars; connects with a chamber at the bottom of a vertical boiler. Owing to the employment of the suction principle, only a simple charging door is required centrally at the top of each generator, through which both fuel and air are admitted. A cover is provided, however, for use when water gas is required. The intermittent method of working is employed generally, so that when the gas is for power purposes the water gas and producer gas are mixed in a single holder in the proportions generated.

The method of procedure is as follows: A deep body of incandescent fuel is first established in each of the generators by the exhauster creating a downward draught; during these conditions producer gas only is drawn off and passed to the holder.

When the fuel has reached a certain point of incandescence the covers are placed over the charging doors, the passage leading from the bottom of one of the generators is closed, and steam is admitted into the chamber below the grate. This steam passes upwards through the highly-heated fuel, forming water gas, which then passes through the upper connecting passage into the top of the other generator, and thence downwards through its fuel and up through the boiler to the gas holder.

As heat is rapidly absorbed during the making of water gas, this process is only carried on for a few minutes; the intervals of making water gas and producer gas alternating about every five minutes. The operation of the system may, however, be varied, so that instead of working intermittently at intervals of five minutes or so, producer gas alone can be produced with steam admitted at different points.

In some instances very little steam is admitted with the air, and when the fuel becomes excessively heated, steam only is admitted, and in this way the intervals of making water gas can be made to suit the requirements of the plant.

With bituminous coal of 13,500 British thermal units thermal value, and containing 35 per cent of volatile matter, there is only a trace of tar in the gas after passing through the second chamber. By passing the highly-heated gases directly from the generators through a boiler the whole of the steam for gasification is provided by the cooling of the gas, thus accomplishing a considerable thermal economy; but on light loads this has to be assisted by an auxiliary boiler.

With a fair grade of soft coal averaging 13,500 British thermal units per pound, and running the producer on air gas for ten to fifteen minutes, and on water gas from ½ to ¾ of a minute, a gas having a thermal value per cubic foot of slightly above 100 British thermal units results.

The depth of coal is maintained between 5 ft. and 6 ft., and as the most intense combustion occurs on the surface of the fuel, clinker forms at this point instead of on the grate, and when the proportion of ash is excessive it is necessary to clean out the generators weekly. The system when applied to gasifying wood permits of a large charging door being provided to allow of the admission of large pieces of wood, and permits of the attendant so disposing the fuel that cavities can be prevented; when using green wood the water contained provides the steam for gasification, so that the injection of steam is unnecessary.

The following particulars relating to the quality of the gas from different fuels and the variations of range are taken from results obtained by A. Sandberg, Ph.D., of London :—*

GAS FROM MIXED ANTHRACITE AND SOFT COAL, NACOZARI GAS PLANT.

	Per cent.	
CO	24·40—	18·40
H	14·43—	9·90
CH_4	3·01—	1·10
C_mH_{2m}	0·20—	0·10
CO_2	8·80—	5·10
O	0·50—	50·00
N	59·17—	4·59
B.Th.U. at 62 deg. Fah. and sea level	141·70—	122·4

---

* Paper by Mr. James Douglas, LL.D., Iron and Steel Institute, 1902.

GAS FROM WOOD, NACOZARI GAS PLANT: VOLUMETRIC PERCENTAGE.

	Mixed gas.		Water gas.
CO	15·50—	11·00	10·30
H	22·35—	13·50	51·38
CH_4	3·10—	1·67	2·38
C_mH_{2m}	0·60—	0·20	0·80
CO_2	17·90—	14·40	20·20
O	0·40—	40·00	0·00
N	55·20—	5·19	14·94
B.Th.U. at 60 deg. Fah. and sea level	146·9 —	113·2	233·97

THERMAL TESTS OF WOOD GAS FROM 30 DIFFERENT TESTS OF MIXED GAS.

	B.Th.U. Actual.	B.Th.U. at 62 deg. Fah. and sea level.
Maximum	123·9	146·5
Minimum	104·8	122·4

The relative consumption of fuel required to develop 1 horse power per brake hour was—

Coal containing about 20 per cent ash	1·5 lb.
Wood	3·0 lb.

with a load factor of 54 per cent.

The thermal efficiency of these producers when working on coal of 13,500 B.Th.U. was from 70 to 71·5 per cent.

MEININGHAUS GAS PRODUCER.

A novel type of gas producer was devised by E. Meininghaus in 1903 for the simultaneous production of heating and lighting gas. A sectional view of the apparatus is shown in fig. 53, where it will be seen that a coal retort is arranged to pass downwards through the gasification chamber of a coke-gas producer. Two charging hoppers are provided, C being used for the introduction of raw coal into the vertical retort tube, and at the same time forms a gas outlet for the illuminating gas products of distillation. The lower end of the retort is provided with a sliding shutter, through which the coked fuel is removed at suitable intervals. The coke from the retort is charged into the hopper B, and is gasified in the ordinary manner.

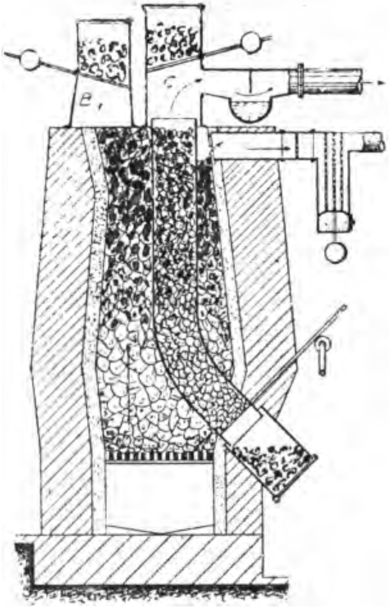


Fig. 53.—Power and Lighting Gas Producer (Meininghaus).

Provided that a satisfactory retort tube can be maintained without involving undue stoppages for renewals or repairs, this system should be economical.

TOWN'S GAS PRODUCER.

Mr. William Town, of Liverpool, has recently designed gas producers of somewhat novel construction.

The sectional view fig. 54 shows a producer in which the special features are a central conical grate, and a roof which is so carried by brackets on the casing that the lining walls of the gas-generating chamber are relieved from this weight. The casing, lined with firebrick, is carried on girders over a trough of water, into which the lower part of the producer dips. The water forms a seal for the gas and a receptacle for the ash and clinker.

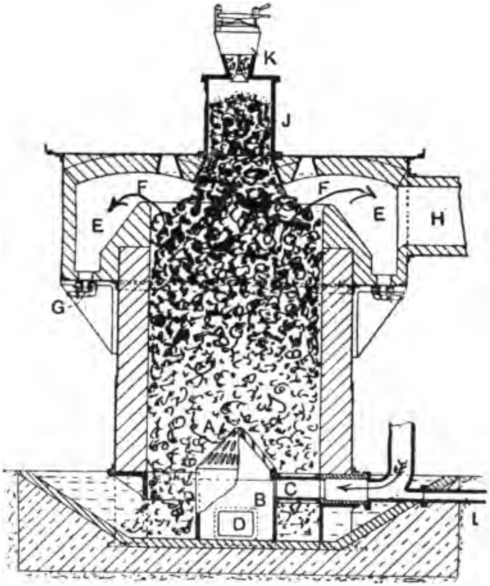


Fig. 54.—Power Gas Producer (Town).

A cast-iron box B, having a conical perforated top, is situated in the water trough centrally, and the air supply enters this box by way of the pipe C. By this arrangement the air is delivered directly into the body of the fuel in the generating chamber, and in such a manner that intense combustion does not take place close to the lining of the chamber. Any ash that may fall through the perforations in the blast box can be removed at intervals through the door D. As the gas is produced it passes into the annular chamber E, and thence to the gas outlet pipe H.

Poking holes are provided for regulating the descent of the fuel; doors G are for the removal of any dust that may deposit from the gas; and a drain pipe L permits of any water that may get into the air box B to pass away to the drain.

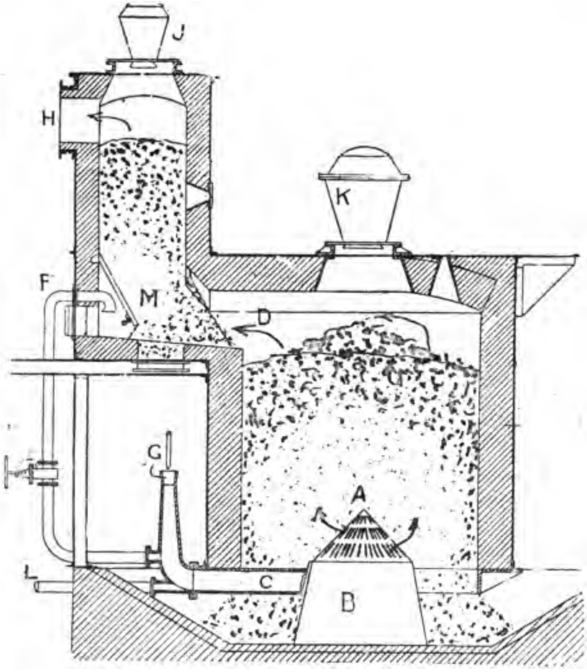


FIG. 55.—Bituminous Power Gas Producer (Town).

Another arrangement of this producer is shown in fig. 55, to which a second chamber M is applied in such a manner as to cause the gas generated in the main producer A, and containing the volatile hydrocarbons distilled from the bituminous fuel, to pass through a body of incandescent non-bituminous fuel on its way to the gas outlet H. The steam jet G induces air into the pipe C leading to the air box B for the gasification of the bituminous fuel in the main generator.

A branch pipe F admits air to the chamber M in such a manner as to gasify the non-bituminous or coke fuel and keep it in a state of incandescence, while the hydrocarbon gases distilled from the fuel in the main chamber become transformed into fixed gases, whereby tarry matter is entirely removed.

This system constitutes a modification of the previously described twin type, and the regulation of the supply of air to the secondary chamber must be so effected as to prevent its contact with the gases from the primary chamber, as then carbonic acid would be formed in too high a proportion and escape reduction to CO.

HALL-BROWN'S GAS PRODUCER.

Mr. E. Hall-Brown, Glasgow, has devised a producer for gasifying bituminous coal, and in which the volatile distillates are collected in the upper part of the generating chamber A, and, by means of a steam jet, delivered to the lower and hottest part of the fire, to fix the tarry matters. The inclined grate bars C are provided with a rocking arrangement, so that clogging of the fuel and clinker is prevented and the descent of the fuel assisted.

Fig. 56 is a longitudinal section, and fig. 57 a cross-section through the producer. The air and steam for the gasification of the fuel enter below the grate by the pipes E_1, E_2. The steam jet G_1 draws off the distilled gases through the passage G, and thence through the breeches pipes G_2, G_3, fitted with valves and leading to the chambers H_1, H_2. It will be observed that the off-takes K for the fixed gas are situated at a low level, or midway down the fuel bed, and, with the inlets for the volatile gas and steam, are disposed in such a manner as to prevent local action occurring.

LANE'S GAS PRODUCER.

An intermittent type of gas producer has lately been devised by Mr. H. Lane, Gravelly Hill, near Birmingham, and a sectional view is given in fig. 58.

The producer works under suction, the gas outlet pipe being R_3, which is in connection with the annular collecting passage R, having apertures O leading to the generating chamber. Air for combustion is admitted below the fuel by passages E and above by passages F, these being provided with self-acting valves E_2 and F_2 respectively.

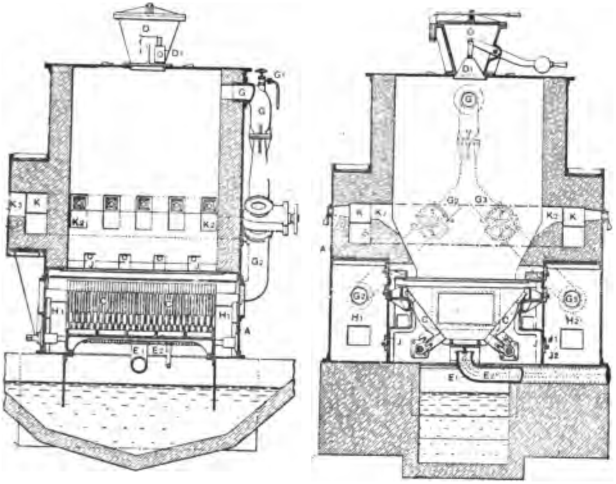


FIG. 56. FIG. 57.

Bituminous Coal Gas Producer (Hall-Brown).

When the producer is working on air the products are withdrawn through the pipe G, and during this period the fuel becomes raised to incandescence, while the regenerative chamber formed at the top of the producer, above the stoking door, also becomes heated.

When the valve of the pipe G is closed, and steam is admitted both below the fuel and above the regenerative chamber, water gas is produced, and during this period the air-inlet valves close automatically.

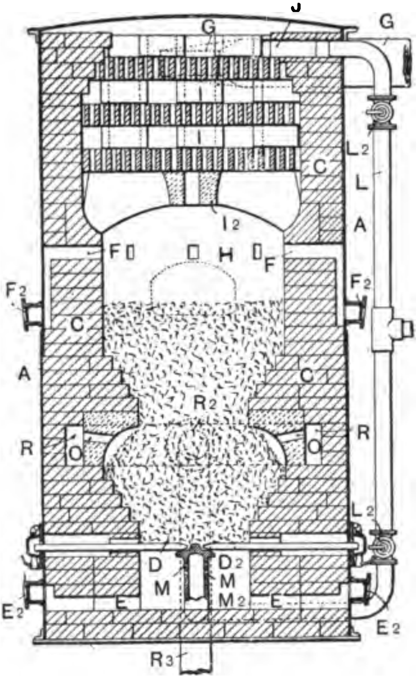


FIG. 58 —Intermittent Gas Producer (Lane).

There have been several other gas producers designed recently, but from those selected the methods of attacking the subject of gasifying fuel by different workers has been clearly shown. While the principle is much the same in most of the types, the details of the generating chamber and accessories to accomplish the end in view have formed the subject of numerous inventions.

CHAPTER X.

SUCTION GAS PRODUCERS.

THE advent of the suction gas producer dates from 1891, when M. Bernier, Paris, took out a patent for a producer in which the air and steam for the gasification of the fuel in the generator was drawn in by the suction action of the gas-engine piston on its charging stroke. In the chapter on pressure gas producers reference has been made to systems in which an exhauster blower has been employed to draw the gas from the producer, induce the air, or air and steam supply, and deliver the gas to a pressure governor holder, but the so-called suction gas producer differs from these in that there is no auxiliary apparatus employed, as a fan or aspirator, the gas-engine piston directly establishing the necessary draught. The system, therefore, dispenses with such accessories as a boiler or fan, and a gas holder. A gas holder has always formed an important item of cost in power gas installations, while, besides the cost of an auxiliary boiler, or fan, forming an item in the first cost, they also reduced the total efficiency of the installation.

Another important advantage of the suction gas producer system is that, owing to the fact that no gas holder or auxiliary boiler is required, even units down to 4 horse power could be brought into competition with any other system of power development.

The low proportion of first cost, simplicity, and direct transformation of the heat of fuel into mechanical work of the suction power gas producer has been the means of bringing the producer gas engine into use for power requirements ranging from 4 brake horse power up to 2,000 horse power in a single unit.

During the sixteen years which have elapsed since Bernier invented the suction gas producer, the success of the system has so appealed to gas-engine makers and users that a large number of installations have been put to work, and as each maker has endeavoured to introduce some improvement, there are already a bewildering number of designs to select from.

In the pressure type of gas producer it is the rule to deliver the gas from the holder to the gas engine under a slight pressure, from 1 in. to 2 in. water gauge; but in the suction system, owing to the resistance offered by the fuel, cleaning apparatus, and friction, the gas enters the cylinder of the engine at a pressure of a few inches of water gauge below that of the atmosphere.

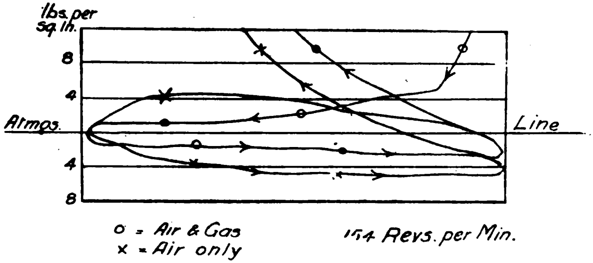


FIG. 59.

In this connection it will be of advantage to refer to the development of the draught through the gasifying chamber and the suction action set up by the charging stroke of the engine piston.

The most usual type of gas engine employed with suction gas producers works on the Otto cycle, in which one charging stroke occurs in four strokes, or two revolutions; and fig. 59 is an indicator diagram, taken with a weak spring, showing the variations in pressure during the charging stroke, both when an explosive mixture of gas and air, and a charge of air only, as occurs when the charge of gas is cut out.

When the engine air valve, communicating with the atmosphere, only is open, the reduction of pressure during the suction stroke averages about 4 lb. per square inch, as shown by the lines marked ×, but when the gas valve, leading from the producer, is also open, the mean pressure amounts to about 2 lb. per square inch below the atmosphere, lines marked O. The relative velocities for these pressures are—

	Velocity. Feet per second.
4 lb. per square inch...	715
2 lb. „	500

and this reduction in pressure is due to the resistance offered to the passage of the charge into the cylinder by friction in apparatus and valves, to fill the space travelled by the piston at its high rate of travel. However, the reduction of pressure at any part of the producer seldom reaches more than 12 in. of water gauge, and this almost instantaneously, which is equivalent to about 7 oz. per square inch, or a velocity of 220 ft. per second. Owing to the draught through the producer, when coupled to a single engine, being intermittent, and the velocity set up, almost suddenly, so high, renders it necessary that all parts of the apparatus should have small sectional area.

From the official report of the judges at the Highland Show trials of suction gas producers in 1905, Mr. W. A. Tookey* has made the following calculations for seven different producers:—

P = piston displacement in cubic feet;
E = average explosions per minute;
G = generator capacity in cubic feet;

R = ratio of $\frac{PE}{G}$	Full load		Half load.
= maximum	31·5	......	18·1
= minimum	10·9	......	7·0
average	16·3	......	10·3

C = consumption of anthracite† per I.H.P. pounds per hour—full load ·65 to 1·05, half load ·65 to 0·9.

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* "Recent Developments in the Construction of Suction Gas Producers," by William A. Tookey. The Junior Institution of Engineers, April 20th, 1906.

† Anthracite, 58 lb. per cubic foot.

The consumption of fuel per square foot of cross-section of furnace, from 11 suction producers tested:—[*]

ELEVEN SUCTION GAS PLANTS AND GAS ENGINES FROM 15 TO 20 B.H.P.

		Anthracite. Lbs.		Coke Lbs.
Consumption per square foot of cross-section of furnace	Average	23·9	...	26·2
	Maximum	39·2	...	45·7
	Minimum	16·5	...	17·0

In this comparison the cross-sectional area of the furnace has been taken in preference to that of the grate area, because it is the most usual practice to make the sides of the gasifying chamber vertical, while there are considerable variations in the arrangement of the grate, some being larger in area, others the full area, and still others of less area than the furnace proper. The depth of the furnace, measured from the grate to the gas outlet, varies from once to twice the diameter of the furnace.

At the Derby trials indicator diagrams showed that the gas from the producers was suitable for compression up to 210 lb. per square inch, although most of the engines worked at lower compressions, down to 110 lb. The maximum initial pressures ranged up to a maximum of 510 lb., but the minimum was as low as 150 lb. when coke was the fuel. In this connection it is worthy of notice that while one of the engines working on a compression of 110 lb. gave an initial pressure ranging from 280 lb. to 330 lb. when firing every time, gave a maximum pressure of 490 lb. after there had been a *cut-out* of gas; this shows the effect of the complete removal of products of combustion, coupled with the increase in explosive mixture introduced into the cylinder owing to the cooling effect of the blank charge of air only, during the cut-out stroke.

The consumption of fuel per brake horse power per hour, as found in 11 plants tested at Derby, of powers ranging from 15 to 20 brake horse power:—

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[*] "Trials of Suction Gas Plants," by the Royal Agricultural Society of England, Derby, 1906.

	Full load. Lbs.	Half load. Lbs.
Anthracite......	1·0 to 1·48	1·38 to 1·98
Average (11)...	1·21	1·65
Coke	1·21 to 1·65	—
Average (11)...	1·42	—

From the figures so far given it is a fairly easy matter to arrive at the capacity of any producer, and compare this with the actual power requirements, for with this system there is no necessity to provide for any more power than the actual maximum load that may be put upon the engine. It will make this clearer if it is pointed out that where the load may be, say, 50 brake horse power as a maximum, it would not be an advantage to apply a 75 brake horse power suction gas producer; it is much more satisfactory for the plant to be working from half load to full load (producer and gas-engine capacity) than from light load to half load.

Having considered the proportions of the gasification chamber and the consumption of fuel, it is next necessary to examine the quantity of water required by the producer.

The consumption of water comes under two heads:—

1. Water for the efficient gasification of the fuel, and
2. Water employed for the cooling and purification of the gas.

From careful measurement at the Derby trials, the total consumption of water per brake horse power per hour ranged as follows:—

	Anthracite.		Coke.
	Full load.	Half load.	Full load.
Gallons per B.H.P. per hour.........	·73 to 3·61	·52 to 3·61	1·40 to 5·76
Average	1·88	1·85	2·99

Most of this water was employed in the purifying apparatus, and a test of the amount of water used in the vaporisers of four of the plants while running on coke fuel showed that it varied from 0·08 gallon to 0·5 gallon per brake horse power per hour; the average being 0·25 gallons. This is equivalent to about 1·7 lb. of water per pound of coke on average during full-load trial.

It must be borne in mind that the more water there is consumed in the scrubbers, etc., the cleaner will be the gas, and the less the trouble in cleaning the valves, pipes, combustion chamber of the engine, and all other parts with which the gas comes into contact, providing the apparatus is well designed; for this reason, and in the absence of tests to show the cleanliness of the gas, it is not an easy matter to compare different types of producers in regard to the amount of water used, but it is the endeavour of designers to reduce the quantity of water to a minimum.

The amount of clinker resulting from a day's run, at the Derby trials, was found to vary as follows:—

	Weight of clinker.		
	Minimum. Lb.	Maximum. Lbs.	Average. Lbs.
Anthracite (11 plants).....,	1·0	7·3	3·15
Coke (11 plants)	0·2	6·0	1·53

A notable point of difference between the plants by various makers is the situation of the vaporiser; out of 53 different plants 23 had the vaporiser situated inside the generator casing, 20 had a separate external vaporising apparatus, while in the remaining 10 particulars are not to hand. As has before been mentioned, if the producer could be designed on the lines of a calorimeter, it would have a thermal efficiency of nearly 100 per cent; therefore it would appear that, all things being equal, when the vaporiser forms part of the gasifying apparatus the conservation of heat loss due to radiation would probably be lower than when the heat of the gas is employed to vaporise water in a vessel separate from the producer.

At the Derby trials of suction gas producers fourteen competitors entered plants, and after careful consideration the gold medal was awarded to that of the National Gas Engine Company Limited.

A diagrammatic sectional view of this producer was given in *Engineering*, June 22nd, 1906, and is reproduced in fig. 60. The rated capacity of this producer was 20 brake horse power, and during the trials the average brake horse power when running on anthracite was 20·6, and with coke 20·5 brake horse power, on full load. The grate area was 0·72 square feet, and the cross-sectional area 1·31 square feet, the furnace volume being 2·37 cubic feet.

The producer casing is of cast iron throughout, and this has the advantage over steel in the matter of corrosion in the parts subject to heat, moisture, and carbonic acid gas; while the method of building up the fire-brick lining prevents the ingress of air through any imperfect joints. Although the vaporiser is internal, consisting of an inner cylindrical vessel fitted with ribs over which the water flows, it is not of the open-boiler type adopted by many other makers.

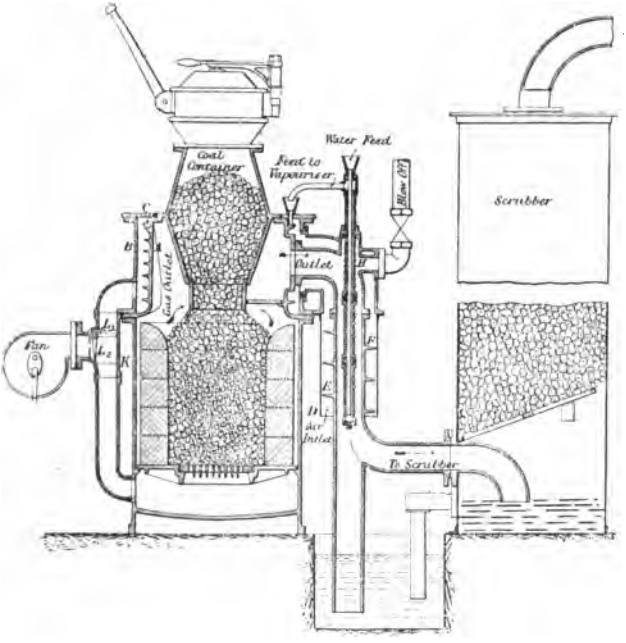

FIG. 60.—20 B.H.P. Suction Gas Producer.—National Gas Engine Co.

Also, it will be noticed that previous to entering the vaporising chamber the water is heated in a combined external water heater, air heater, and gas cooler. A combined fuel storage chamber and distilling bell forms the upper part of this producer, which not only provides a considerable supply of fuel, but allows the volatile matter to be gradually distilled off as the heat increases. In normal work the surface of the fuel at that part where the gas escapes is maintained constant, so that the resistance offered to the passage of the gas maintains an even velocity and quality of gas. The fan for blowing up the fire at starting, and the valve for controlling the passage of the air, are shown on the left; when the fan is in use the valve closes the pipe leading from the vaporiser, but when the quality of gas is satisfactory this valve shuts off the pipe leading from the fan. When the engine is drawing gas the air supply enters the heating chamber D, and traverses the spiral passage, formed by a spiral rib on the gas outlet pipe, and enters the vaporiser in a heated condition. In connection with the gas outlet pipe leading from the producer to the scrubber there is a blow-off outlet for use when starting the fire by means of the hand fan, and the valve on this branch pipe is practically the only one which requires attention at starting and stopping. The lower end of the gas pipe is formed of two branches: one leading directly to a water seal, and the other to a further seal in the bottom of the scrubber. The advantages of this arrangement are that any heavy particles of dust carried out of the producer fall directly into the seal pot, while, as the other branch dips into water contained in the bottom of the scrubber, there can be no return of air when the blow-off pipe is open, or explosions take place inside the scrubber through gas becoming ignited in the gas pipe.

An important feature of the producer which we have been considering is the construction of the vaporising chamber in such a manner that by removal of the outer casing the interior of the chamber is readily inspected and cleaned. The regulation of the water suppy to the vaporiser is by hand, and it is usually found unnecessary to reduce the supply when working on low loads.

The silver medal of the Royal Agricultural Society (Derby, 1906) was awarded to the 15 horse power suction gas plant exhibited by Messrs. Crossley Bros., Openshaw, Manchester, a sectional diagrammatical view of which is given in fig. 61.

It will be observed that while the general principle is not much different from the "National" plant, previously described, the vaporiser is internally situated, the charging hopper is situated more externally, and the gas pipe entering the scrubber does not dip into the water to form a water seal. The method of heating the air is also different. In this case the vaporiser surrounds the fuel inlet between the top of the producer and the point at which the gas escapes from the fireplace, so that the high temperature of the gases cannot be directly applied to the distillation of the volatile matter of the fuel entering into the gasifying chamber, owing to the intervention of

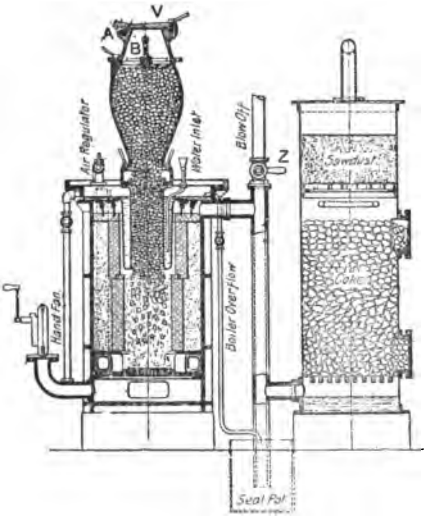

Fig. 61.—Crossley's Suction Producer.

the boiler. The manner in which the air, saturated with steam, is conducted to the grate forms a feature, as the lower part of the gasifying chamber is surrounded by an annular box, through which the moist air has to pass on its way to the grate. This method reduces the tendency for clinker to form on the surface of the firebrick lining, owing to the refractory lining not extending down to the hottest part of the fire, and in the trials it was found that no clinker had formed on the firebrick. For use when the plant is running on light load there is provided a "secondary dry air" supply, which reduces the supply of steam, and by so doing provides a poorer quality of gas, thus enabling the engine to keep the fire in good condition by drawing more charges of poorer gas than would be the case if the gas was of the richest quality.

During the full-load trials, when running at 15·3 brake horse power, the consumption of anthracite was 1·15 lb. per brake horse power per hour, and the water consumption was 2·45 gallons. At half load the consumption of fuel was 1·52 lb. and water 0·89 lb. per brake horse power per hour. With coke fuel, at full load the consumption was 1·36 lb. coke and 5·76 gallons of water per brake horse power per hour.

In the sectional view of the scrubber it will be noticed that the purifying materials are coke in the lower portion and a bed of sawdust in the upper part; a water-spraying tube is fixed just below the grid holding the sawdust, from which water is sprayed over the coke.

Professor W. E. Dalby, M.A., B.Sc., in a paper read before Section G, August 7th, 1906, describes the action of the suction gas producer in a way somewhat as follows: "The gas current through the plant is put on the rack, as it were, and stretched out, as shown in the diagram, fig. 62. The gas-engine cylinder acts as a pulse to the system, and is shown on the right. The piston moving out on the charging stroke, reduces the pressure all through the apparatus, and air enters at the points A and B. Referring to the air entering at A, it traverses the passage, and receives heat in the region H, thereby increasing its capacity for absorbing moisture. At this point water enters, and the heated air becomes saturated, and then passes through the fire in the gasifying chamber, where for each pound of carbon 4½ lb. of air and about 0·084 lb. of water enter into combination, and on leaving the producer each 100 lb. of gas contains about—

	Lbs.
Carbonic oxide	29
Hydrogen	1½
Marsh gas	½
Nitrogen	57
Carbonic acid	12
	100

This gas, being in a highly-heated condition, is very low in density, and must be cooled to the lowest extent practicable to permit of the engine cylinder being filled with the highest possible weight of gas. The gas is therefore cooled down to somewhere about the temperature of the atmosphere in the region C_1, C_2. The gas from the producer enters the cylinder through the valve G, but the air for its combustion is admitted through the air pipe B, which is controlled by a valve, so as to cause sufficient suction to be set up in the producer to provide the requisite proportion of gas; the air valve on the engine in some, if not all, cases requires adjustment to suit the changes in the load when the power requirement is liable to alterations lasting over considerable periods."

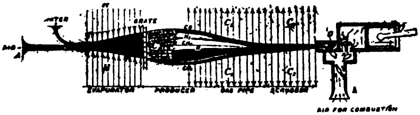

FIG. 62.

In the same paper Professor Dalby says that at the present time there does not appear to be a definite relation between the proportions of the producer and the power required to be produced, but that in producers of 15 to 20 horse power the height from the grate to the gas outlet is generally about 2 ft. The area of the cross-section of the furnace averages about 0·065 to 0·075 square foot per brake horse power, and the cubical capacity is 2·37 cubic feet in the case of a 20 horse power National producer, and 1·58 cubic feet in a Crossley 15 brake horse power producer, or 0·118 and 0·105 cubic foot per brake horse power respectively; the furnace area being 1·31 and 0·785 square feet respectively, or an area of 0·065 and 0·075 square foot per brake horse power.

Of the suction gas plants and gas engines, made by the Gas Motoren Fabrik Deutz-Cologne, M. Mathot has given descriptions of tests on plants made by the Deutz Company,* from which the following particulars have been extracted:—

60 B.H.P. SUCTION PRODUCER PLANT AND ENGINE, CYLINDER DIAMETER 16·5 IN., STROKE 18·9 IN. FUEL USED, ANTHRACITE, 0·4″ TO 0·8″.

	Percentage composition.
Carbon	83·22
Nitrogen and oxygen	3·01
Hydrogen	3·31
Sulphur	0·44
Ash	7·33
Moisture	2·69
	100·00

Thermal value per pound 13,650 B.Th.U.

GAS PRODUCED.

	Percentage composition.
Carbonic acid, CO_2	6·60
Oxygen, O	0·30
Hydrogen, H	18·90
Marsh gas, CH_4	0·57
Carbonic oxide, CO	24·30
Nitrogen, N	49·33
	100 00

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* "Large Gas Engines," by M. R. E. Mathot, Inst.M.E., &c.

Thermal value of gas, combination water at 59 deg. Fah., constant volume reduced to 32 deg. Fah., and atmospheric pressure, per cubic foot, 140 B.Th.U.

	Lbs. per sq. in.
Average final expansion pressure	25
Vacuum at suction	4·4
Compression.................	176
Average maximum explosion pressure	397
Average mean effective pressure..................	81
Average I.H.P. with 85 per cent explosions....	77·0
Average B.H.P. with 85 per cent explosions...	65·11
Average revolutions per minute	188·66

$$\text{Mechanical efficiency } \frac{\text{B.H.P.}}{\text{I.H.P.}} = 84{\cdot}5 \text{ per cent.}$$

TEMPERATURES.

Engine cooling water at inlet	55·4	deg.	Fah.
Engine cooling water at outlet	109·5	,,	,,
Engine cooling water at cylinder outlet	127·5	,,	,,
Water in producer vaporiser	158·3	,,	,,
Consumption of coal, gross per B.H.P. per hour	0·86 lb.		
Thermal efficiency in proportion to effective work and gross consumption of coal in the generator	24·3 per cent.		

Calculating on the composition of the dry gas, we have, in 1 cubic foot—

CO_2	·0660
O_2	·0030
H_2	·1890
CH_4	·0057
CO	·2430
N_2	·4933
	1·0000

To find the weight of carbon :—

CO_2 .... ·0660
CH_4 .... ·0057
CO .... ·2430

·3147 × ·0335 = 010542 lb.

To find the weight of oxygen :—

CO_2 .... ·0660 × 2 = ·1320
O_2 .... ·0030 × 2 = ·0060
CO .... ·2430

·3810 × ·0447 = 017031 lb.

To find the weight of hydrogen :—

H_2 .... ·1890 × 2 = ·3780
CH_4 .... ·0057 × 4 = ·0228

·4008 × ·00279 = ·001118 lb.

To find the weight of nitrogen :—

N_2 ·4933 × 2 = ·9866 × ·0391 = ·038576 lb.

Weight of 1 cubic foot of dry gas at 32 deg. Fah. :—

	Lb.
Carbon	·010542
Oxygen	·017031
Hydrogen	·001118
Nitrogen.....................	·038576
	·067267

The anthracite contained (dry) 85·52 per cent carbon, so

$$\frac{\cdot 0105}{\cdot 8552} = \cdot 0123 \text{ lb. of anthracite per cubic foot of gas.}$$

The fuel contained 3·31 per cent of hydrogen = ·000407 lb., and ·001118 − ·000407 = 000711 lb. hydrogen due to added water; ·000711 × 9 = ·0064 lb. of water per cubic foot of gas.

Taking atmospheric air as containing by weight nitrogen 77 and oxygen 22 per cent, and weighing ·0807 lb. per cubic foot at 32 deg. Fah., we have for 1 cubic foot of gas—

	Lb.		Per B.H.P. per hour. Lbs.
Anthracite.........	·012327	....	·860
Water	·006399	....	·446
Air.................	·048541	....	3·386
	·067267		4·692

which by volume becomes per B.H.P. per hour—

	Cubic feet.
Fuel at 53 lb. per cubic foot...............	·0162
Water at 62·25 lb. per cubic foot.........	·0071
Air at ·0807 lb. per cubic foot	42·5277
Volume of gas	69·79

Thermal efficiency of the producer—

$$\begin{matrix}\text{Gas } 69\cdot79 \text{ at } \quad 140 = \\ \text{Fuel } \quad \cdot86 \text{ at } 13650 = \end{matrix} \frac{9770\cdot60}{11739} = 83\cdot2 \text{ per cent.}$$

At the temperature of the water in the vaporiser of 158·3 deg. Fah., the air, if saturated, would increase in volume 1 to 1·8137, and could carry per cubic foot ·0219 lb. of water vapour. The cylinder being 16·5 in. diameter by 18·9 in. stroke, developing 65·11 brake horse power when firing 85 per cent of explosions at 188·66 revolutions per minute, gives a capacity of ·104 cubic feet per brake horse power, and the volume swept by the piston on the charging stroke, compared with the volume of gas per brake horse power hour (measured at 32 deg. Fah.), is 2·91 to 1.

M. R. Mathot gives the following particulars of a test made on a 200 horse power suction gas installation at the works of the Gas Motoren Fabrik Deutz-Cologne, on March 14th and 15th, 1904:—*

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* "Large Gas Engines," Institution of Mechanical Engineers, Liège Meeting, 1905.

ENGINE, FOUR-CYCLE DOUBLE-ACTING. DIAMETER, $21\frac{3}{4}$ INS. × STROKE $27\frac{9}{16}$. PISTON RODS, FRONT, $4\frac{3}{4}$ IN. DIAMETER; REAR, $4\frac{5}{16}$ IN.

FULL-LOAD TESTS.

	Date.	
Engine.	March 14.	March 15.
Average number of revolutions	151·29	150·20
Corresponding effective load, B.H.P.	214·22	222·83
Duration of tests, hours	3	10
Average temperature of water after cooling the piston, degs. Fah.	117·5	...
Average temperature of water after cooling the cylinder and valve seats, degs. Fah.	135	...
Water consumption for cooling the piston, per hour, gallons	39	...
Producer.		
Fuel, anthracite coal. "Bonne Esperance et Batterie," Herstal-Belgium :—		
Heating value of fuel, B.Th.U.	14,650	...
Consumption of fuel per hour (plus 53 lb. during the night of 14th inst. for keeping the generator fired during the 14 hours, the engine being stopped), pounds	199	160
Water consumption per hour in the vaporiser, gallons	...	14·2
Water consumption per hour in the scrubbers, gallons	...	318
Average temperature of gas at the outlet of the generator, degs. Fah.	...	558
Average temperature of gas at the outlet of the scrubbers, degs. Fah.	...	62·5
Efficiencies.		
Gross consumption of coal per B.H.P. and per hour, pounds	0·927	0 720
Consumption of coal per B.H.P. after deducting the moisture	0·907	0·704
Thermal efficiency relating to the effective horse power, and to the dry coal consumed in the generator, per cent	19	24·4
Water consumption per B.H.P per hour :—		
For cylinder, stuffing boxes, valve seats, and jackets, gallons	...	4·65
For the piston and piston rods, gallons	...	1·75
For the vaporiser, gallons	...	0·0655
For washing the gas in the scrubbers, gallons	...	1·42
Water converted into steam per pound of fuel in the generator, gallons	...	·093

In figs. 63 and 64 is shown a section and elevation of a suction producer patented by Messrs Tangyes Limited, Soho, and J. Robson, jun., Handsworth, April 20th, 1905, and it has been selected to compare with the earlier type of suction producer made by Messrs. Tangyes, fig. 65.

The newer type of producer is intended for using fuel containing considerable tarry matter, and in which gas practically free from tar is to be produced. It will be observed that the water vaporiser is situated around the hottest part of the generator, while in the older pattern it was placed at the top of the producer, surrounding and forming the fuel inlet.

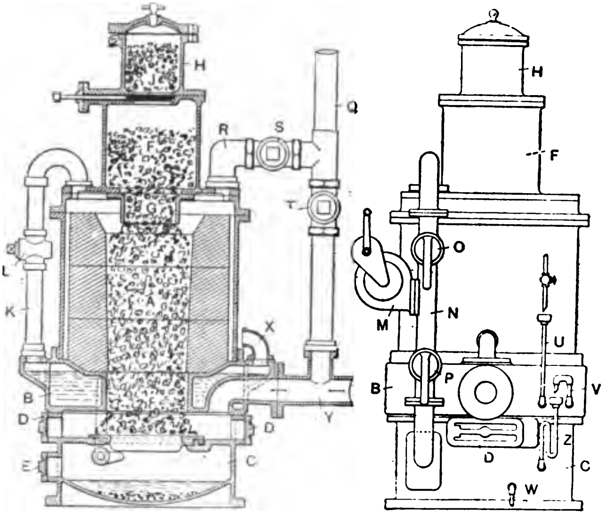

FIG. 63. FIG. 64.

Tangye and Robson's Gas Producer.

The different parts are indicated by letters, as follows: A, firebrick-lined generator chamber; B, vaporiser; C, ash chamber; D, fire door; E, ash door; F, fuel chamber; G, fuel inlet; H, fuel hopper; J, slide for admitting fuel from hopper; K, water vapour and air pipe; L, valve;

M, hand fan on pipe; N, air pipe; O, air valve; P, air valve; Q, blow-off pipe; R, branch pipe leading to Q; S, valve; T, valve; U, water supply to vaporiser; V overflow from vaporiser; W, overflow from ash chamber, leading to drain; X, air inlet; Y, producer gas outlet; Z, water-seal pipe leading to chamber C.

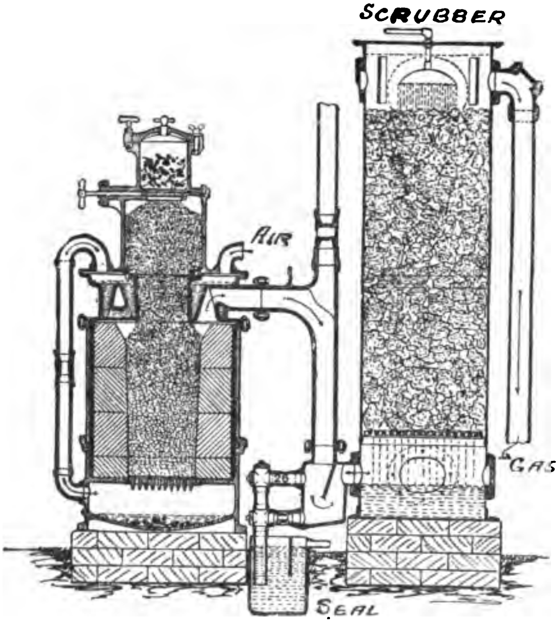

FIG. 65.—The Tangye Producer.

At starting a fire is made upon the grate, and the hand fan is operated with the valve O closed and valve P open, so that air is forced in below the grate through the pipe N; fuel is fed in through the hopper H and chamber F until sufficient has been admitted to give a considerable depth. Blowing is continued until incandescence is established for a good distance up the chamber, and during this period the valve S is open and valve T closed, to allow of the products of combustion passing away into the atmosphere. The arrangement of pipes, it will be observed, allows of the air from the hand fan being delivered either above or below the fuel, and also permits of the products of combustion being led off from the top or bottom of the producer as desired.

When the condition of the fuel is suitable for the admission of air saturated with water vapour, the valves S and T are closed, and the suction of the engine draws air into the producer by the inlet X and through the space above the water in the vaporiser, and by the pipe K (the valve L being open and valve S closed), and passes down through the incandescent fuel, forming producer gas, and thence to the pipe Y leading to the engine, after passing through the cooler and scrubber. This arrangement differs considerably from that of the earlier producer, which required fuel such as anthracite or coke, in that as the volatile gases slowly distil from the fuel at its upper part they are carried by the air and steam down through the hottest part of the fire, thereby fixing the tarry matter.

Owing to the admission of air above the fuel the zone of highest temperature will be raised from the grate to the central part of the chamber, whereas in the older type the gasification of the fuel was in an upward direction.

To give an idea of the space occupied by a suction gas plant and gas engine installation there is reproduced, in figs. 66 and 67, a plan and elevation of a 20 horse power gas engine and Dowson suction gas producer.*

The gas engine shown works on the Otto cycle, and is manufactured by the Railway and General Engineering Company Limited, of the Midland Engine Works, Nottingham. The gas producer is situated in one corner of the building, which measures 20 ft. long by 13 ft. wide; the scrubber is placed close to the producer, and from this the gas passes under the floor to an expansion box near the cylinder of the engine. The cooling water for the cylinder jacket is provided by three tanks, 2 ft. 9 in. diameter by 5 ft. 6 in. high, coupled together in such a manner that the

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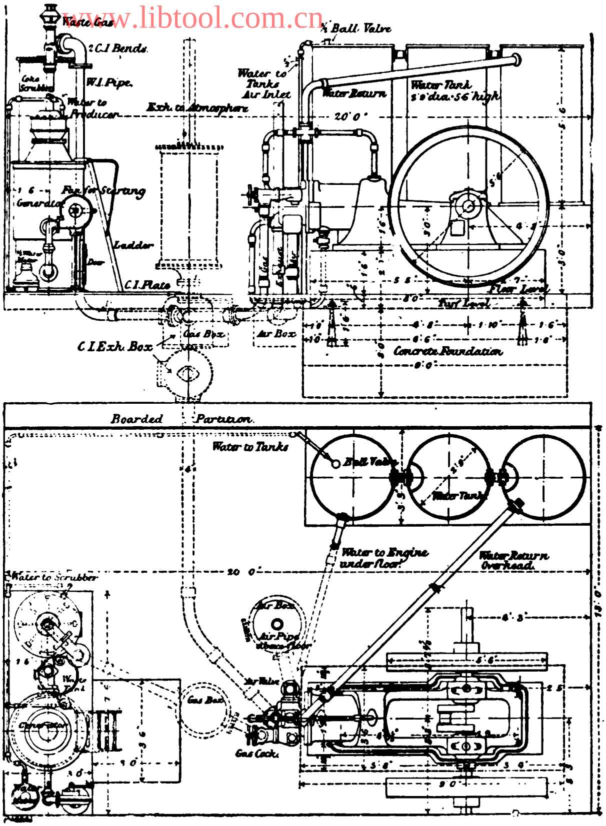
*_Engineering_, June 15th, 1906.

water heated by the engine has to circulate through each of the tanks. An air box is placed below the floor, while



Figs. 66 and 67.
Suction Gas Installation, 20 H.P.

the exhaust is conducted by a 4 in. pipe to a silencer placed outside the building. The leading dimensions are given for all the parts, and the different items are clearly shown.

The arrangement of the installation can, of course, be modified to suit any available space, but generally indicates the room occupied by the most important items for any type of producer or engine.

An important point in this connection is the elevation of the cooling tanks in regard to the engine cylinder, to allow of proper circulation through the cylinder and tanks.

DOWSON SUCTION GAS PRODUCER.

Suction producer gas is a semi-water gas differing only slightly from gas as generated under the original Dowson principle, as will be seen from the following typical analyses of gas from Dowson pressure and suction producers:—

	H.	CO.	CH_4.	CO_2.	N.	Thermal value, B. Th. U.
Pressure	18·50	25·25	2·00	5·25	49·00	160
Suction	17·00	23·00	2·00	6·00	52·00	150

As Mr. J. E. Dowson developed the system of semi-water gas from such fuels as anthracite and coke, it would naturally be expected that his firm would take a leading position in the manufacture of suction gas plants. At the Derby trials a Dowson suction plant was entered for competition, and a description of the producer was given in *Engineering*, June 15th, 1906, from which the sectional view, fig. 68, is reproduced. The extreme simplicity of the apparatus is a noticeable feature, there being practically only one valve for the attendant to control at starting and stopping the generation of gas, while the vaporiser is neither a separate vessel nor a boiler in which scale troubles can occur. The generator chamber is surrounded by an outer jacket, and the space provided is filled with broken coke or other suitable material, and the air supply is made to traverse this chamber on its way to the firegrate. A specially-designed water sprinkler supplies water to this outer chamber, so as to moisten the material with which it is packed, while the heat of the gases and the generating chamber causes the air to become saturated with moisture. The water-feeding device is so

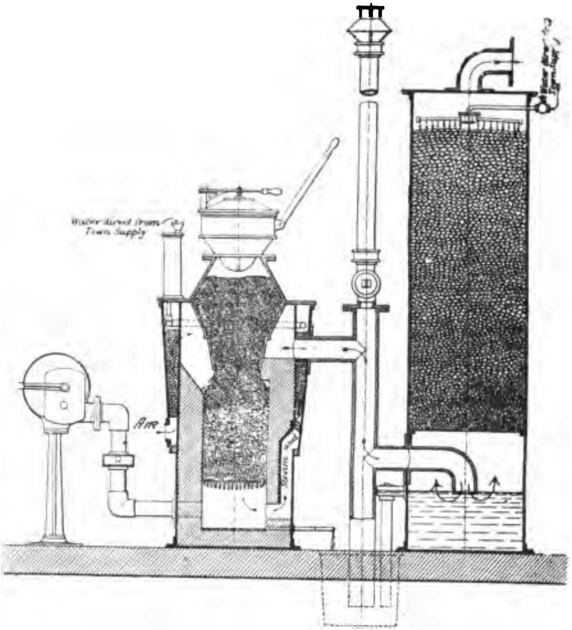


Fig. 68.—Dowson Gas Producer.

arranged that the supply of water admitted is regulated by the suction set up by the charging stroke of the engine, and therefore the amount of water entering the fire is in proportion to the load. At full load the suction of the engine strokes maintains such a vaccuum in the water regulator as to keep up a continual supply of water, but at light loads the water supply diminishes, and a poorer quality of gas is provided, which enables the engine to take more frequent charges than would be possible with a full water supply.

Dowson Suction Gas Plant at Derby Trials. Rated Capacity 20 B.H.P.

	With anthracite fuel.	
	Full load.	Half load.
Total hours running	14·08	6·00
Average B.H.P.	20·4	10·3
Coal per B.H.P. per hour, lbs.	1·09	1·49
Water per B.H.P. per hour, gallons.	0·98	0·66

Grate area, 0·66 square feet; cross-section of furnace, 1·22 square feet; volume of furnace, 2·44 cubic feet. Ratio of volume swept by the piston to—

1. Grate area, 118.
2. Cross-section of furnace, 64.

Brake horse power obtained per square foot of grate area—coke or anthracite, full load, 30·9.

Brake horse power obtained per cubic foot of furnace volume—coke or anthracite, full load, 8·4.

Brake horse power that would be obtained per cubic foot of volume swept by piston, if firing every time—anthracite, full load, 0·142; coke, full load, 0·147.

The fuel container, at the top of the generator, holds sufficient fuel for several hours' run, and the gas outlet pipe enters the scrubber by a bend which dips below the level of the water in the lower part of the scrubber, and prevents the return of either gas or air when the generation of gas is interrupted. The temperature of the gas on entering the scrubber is about 550 deg. Fah., and is partly cooled and freed from dust by bubbling through the water. The time required for starting and getting on full load only amounts to from 16 to 18 minutes, which is very much less than would be the case with any steam plant. The mean effective pressure in the gas-engine cylinder usually amounts to from 80 lb. to 90 lb. per square inch, and it may be noted that two or more gas engines can be run from a single producer, if properly arranged.

In a paper read by Mr. Ernest A. Dowson before the Birmingham Association of Mechanical Engineers, April 27th, 1905, the following comparison of running cost was given:—

Installations of 25 and 100 brake horse power respectively, working for 54 hours per week, and 50 weeks per annum, taking those items which may be called variables.

ANNUAL COST OF RUNNING POWER PLANTS.

	25 B.H.P.			100 B.H.P.		
	£	s.	d.	£	s.	d.
(*a*) Electric motor, taking current at 1d. per Board of Trade unit.						
Current, allowing ¾ unit to develop each B.H.P.	205	0	0	820	0	0
Interest, depreciation, etc., at 7½ per cent.	4	10	0	11	5	0
Total	£209	10	0	£831	5	0
(*b*) High-speed steam engine, with Lancashire boiler.						
Coal, 5 lb. and 4 lb. per B.H.P. per hour, respectively, at 12s. per ton	90	8	0	289	5	0
Water, 4 gallons per B.H.P. per hour, at 9d. per 1,000 gallons	10	2	0	40	0	0
Labour, at 15s. and 27s. per week, respectively	37	10	0	67	10	0
Interest, depreciation, etc., at 10 per cent.	35	0	0	100	0	0
Total	£173	0	0	£496	15	0
(*c*) Gas engine, on coal gas at 2s. per 1,000 cubic feet.						
Gas, at 17 c.f. and 15 c.f. per B.H.P. respectively	114	15	0	405	0	0
Labour, 1 hour per day, at 6d.	7	10	0	7	10	0
Interest, depreciation, etc., at 10 per cent.	16	0	0	50	0	0
Total	£138	5	0	£462	10	0
(*d*) Gas engine, on semi-water gas.						
Coal, 1 lb. per B.H.P. per hour, at 20s. per ton	30	0	0	120	0	0
Water, ¾ gallon per B.H.P. per hour, at 9d. per 1,000 gallons	2	0	0	8	0	0
Labour, at one-third of case (*b*)	12	10	0	22	10	0
Interest, depreciation, etc., at 10 per cent.	25	0	0	65	0	0
Total	£69	10	0	£215	10	0

BUTLER SUCTION PRODUCER.

This producer in some details departs from usual practice, the principal difference being in the facility afforded for starting, for which purpose a carburetter is connected by a three-way cock to the gas supply pipe of the engine cylinder, by which means the engine can be started without delay, either on town gas, if available, or on petrol. The engine, as soon as started, can be utilised for blowing up the producer by an exhaust fan, connection with which and the producer is made on putting the engine in communication with the starting oil or gas supplies. The producer is fitted with a water-feed aspirator, which automatically adjusts the supply of water in a fine spray to a vaporising chamber around the hottest part of the producer furnace. Other improvements are introduced in this producer, such as a circular grid grate, capable of being rocked or rotated by a star wheel, which at the same time moves the grate in a vertical direction for a short distance, just sufficient to dislodge any accumulated ash or clinker deposit.

Referring to the illustration, fig. 69, B is the fuel hopper fitted with a sliding gastight door in the usual way, D is a hollow cylindrical feed valve, and E a renewable neck for supplying fuel to the furnace F. Around the top of the producer is a casting forming a cistern R, for the supply of water to the aspirator P; air enters the cistern at A, and is drawn through the aspirator by the action of the engine, and thence into the vaporising jacket V, where the water spray, drawn from the cistern R, is vaporised. Communication from the vaporiser to the ashpit is by the side jacketed passages J; overflow of water from R passes to H, where it absorbs waste heat from ash and grate radiation. The gases produced pass away around the fuel-feed neck E to the outlet G, and thence to a trough forming the base for two scrubber chambers S; on this base is fixed the three-way cock K, by which the engine cylinder may be put into communication with the carburetter T at starting, when either petrol by the feed-screw L or town gas by the feed-screw Z can

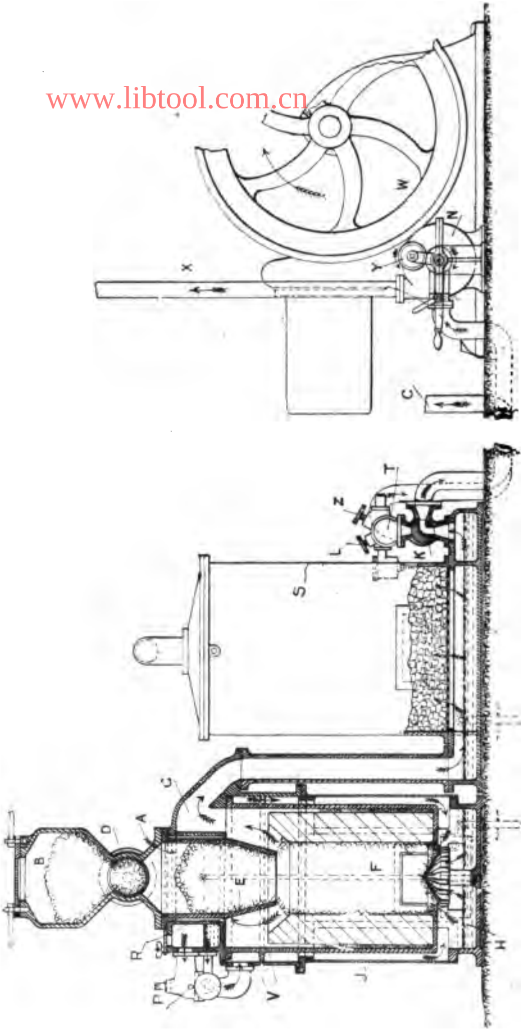


Fig. 69.—The "Butler" Suction Producer

be turned on, either fuel being drawn in and mixed with air in a proportion for forming a volume of about the equivalent of the producer gas, and supplied to the engine cylinder by the pipe C. During the time of running the engine at starting the exhausting fan N is put into motion by the paper or leather faced jockey pulley Y; by this means an artificial draught is formed in the producer, which is convenient for lighting up at starting, as it enables the side doors of the producer to be removed for placing the fuel in position, and for such other attention as required during the time necessary to get the furnace into proper working order. One advantage of this method, apart from dispensing with the somewhat arduous task of blowing up by a hand-driven pressure fan, is the total absence of smoke during this process, also all bad gas is exhausted from the scrubber chambers, thus avoiding delay occasionally experienced from this cause. The exhaust pipe X can be taken to a point conveniently distant from the engineroom, and forms a vent to the producer furnace when closed down. Obviously, this method does not lend itself to the use of a test-cock for determining the quality of the gas at starting, as, however, the engine can be switched over from starting to running gas, or *vice versâ*, by one instantaneous operation, no inconvenience from this cause is experienced.

Mr. Edward Butler's successful work in connection with internal combustion engines, both for oil, petrol, and gas, including not only the design of carburetters, vaporisers for liquid fuel, and oil measures, but the "compounding" of petrol motors and gas engines, is sufficient warranty that all the features and details of his latest suction gas producer will prove effective. If in some of his designs of details for petrol oil and gas engines extreme simplicity has been sacrificed with the object of attaining the highest efficiency, an examination of the diagrammatic illustration of his suction producer will show that each part has been designed to be effective, while simplicity has been adhered to as far as practicable.

PINTSCH SUCTION GAS PRODUCER.

A more elaborate type of suction producer plant is shown in fig. 70, made by M. Julius Pintsch, Berlin.

The producer shell is supported upon columns, while a chamber is provided below the grate, which is closed at the bottom by a water seal; to this chamber a pipe connection admits air from the hand fan for starting purposes. The generating chamber consists of a plain cylinder, lined with refractory material, and provided with a fuel-charging hopper. A gas outlet passage is provided about one-third down the chamber, and the gas passes out through a vaporiser, which forms a separate vessel; the passage of the hot gas through the tubes vaporises water which is carried along with the air supply to below the grate. On leaving the vaporiser the somewhat cooled gas passes in an upward direction through a coke scrubber of the usual type, but before entering the gas engine cylinder it has to pass through a second purifier of horizontal pattern, which contains trays of shavings or sawdust. A gas governor, or pressure regulator, is connected to the gas pipe between the sawdust scrubber and the engine. The peculiar shape of the generating chamber and feeding apparatus, associated

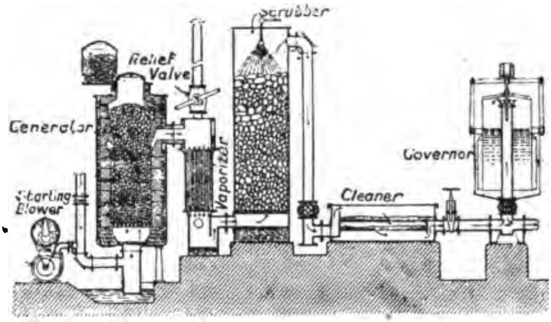


FIG. 70.—The Pintsch Producer.

with the addition of a sawdust scrubber, permits of semi-bituminous fuel, wood shavings, etc., being employed for gasification, as well as anthracite or coke. An automatic adjustment regulates the amount of water vapour mingling with the air for gasification in proportion to the load upon the engine. Upon each charging stroke made by the engine a reduction of pressure is set up by the resistance of the fuel, etc., in the passage of the air through the generator, and this draws down the bell of the governor against the resistance of a spring; at the end of the stroke the closing of the gas valve stops the flow of gas, and the reaction of the spring-controlled bell draws a further supply of air into the generating chamber.

CHAPTER XI.

THE SUCCESSFUL OPERATION OF SUCTION GAS PRODUCERS.

IT has already been indicated that there are on the market a large number of suction gas producers, in which, while the main principles differ only slightly, each design generally has some special detail which identifies the firm by which it has been manufactured.

An attempt to describe every make of this type of power gas producer would occupy considerable space, without serving any special purpose; but, owing to its so recent introduction, the suction producer has in some cases proved unsatisfactory through a want of knowledge of the sequence of conditions necessary for successful running. It will, therefore, form an instructive study if each separate detail is considered in regard to its contribution towards a complete efficient gas generator. We have seen that the area and cubic volume of the generating chamber do not differ greatly in modern plants, which is proof that the velocity at which the air and steam should pass through the fuel has been fairly fixed by practical experiments.

If the area of the gasifying chamber is made larger than that given the velocity of the steam and air through the fire will either be so low as not to keep the base of the fuel in an even state of incandescence, or else the fire will work into patches; in either case the quality of the gas would be irregular.

In regard to the depth of the fuel bed necessary to ensure good gas of regular quality, it is found that in a well-designed producer, after the generating chamber has become heated and generation of a constant quality of gas established, can be run without a falling off in gas or quality until the depth of fuel on the grate falls to about 9 in. or less, provided that no further additions of fuel are made after the fuel has sunk below the bottom of the fuel bell, or the level of the normal gas outlet, as this would cause a cooling of the generator chamber and change in the quality of the gas.

The fuel-charging arrangement should be gastight, as well as all joints, because during the blowing-up period gas would escape, and when the fire was working under suction air would be drawn in and impoverish the gas.

The firebrick lining must be so set that no air can enter the generator at any point other than that for which the producer is designed.

Although in normal working the whole of the apparatus is under a pressure less than that of the atmosphere, and there is no possibility of the escape of gas, the gas-tightness of all joints must be assured, as otherwise leaks of poisonous gas may occur when blowing up at starting, which has no sufficiently distinctive odour to indicate the presence of carbonic oxide gas in dangerous quantities, and "gassing" may result in insufficiently ventilated places.

Unless the hand fan provided for starting purposes is provided with a gastight valve it sometimes occurs that gas escapes through the fan air inlet. An important point to be guarded against in *all* parts of the apparatus is that all spaces in which an explosive mixture may accidentally collect shall be constructed of sufficient strength to resist the force of any explosion that may occur.

Owing to the different physical properties of anthracite and coke, and the amount of ash, it is an advantage to have poking holes provided, the formation of clinker interrupting the steady downflow of the fuel and the obstruction of the grate when this kind of fuel is employed. A sight-hole, allowing of the condition of the fire being observed from time to time, is of considerable service to the man in charge, as in many suction producers it is not an easy matter to judge the rate of consumption of fuel: in the absence of a sight-hole, when in doubt, the attendant has to resort to adding fresh fuel until he is satisfied that there is no shortage, but in this case he may overfill the fuel chamber, and obstruct the action of the charging valve.

Clinker and ash removal has received a great deal of consideration, and various devices have been adopted. In many producers at the bottom of the gasifying chamber there is provided an ordinary grate-bar arrangement; while others have gear for rotating or rocking the grate.

Another type dispenses with grate bars altogether, and allows the fuel, ash, and clinker to rest upon a solid base.

As it is almost, if not quite, impossible to prevent some ash from becoming fused and forming clinker, the aim is to so arrange the zone of high temperature that a minimum of clinker shall be formed; a further object is to prevent the clinker from accumulating in such a manner as to obstruct the descent of the fuel and the passage of the air and steam. Where the highest temperature zone is in contact with the firebrick lining the clinker becomes fused to the brickwork, and its removal brings away portions, and destroys the lining in time. A door is usually provided for removing accumulations of ash and clinker, and this should be so arranged that the whole surface of the lining of the part of the chamber where clinker can form is conveniently accessible for examination and the careful removal of any adhering particles.

To reduce the temperature of the fire, and therefore the proportion of fused ash, as well as to increase the efficiency of the apparatus, steam or water vapour is introduced with the necessary proportion of air; with only dry air supply the temperature of the fire would be high, and with steam only there would be such an absorption of heat as to quench the fire, so that the adjusting of the proportion of water vapour is one of the most important points in the design of a suction gas producer.

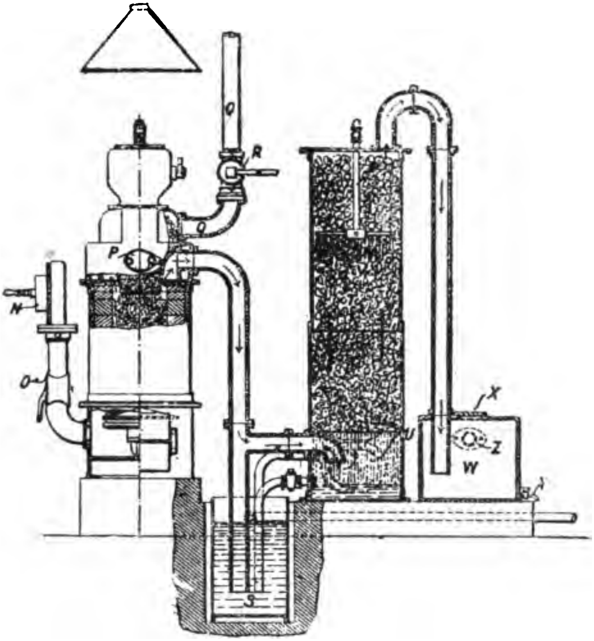


FIG. 71.—Section of the "Fielding" Producer.

The regulation of the amount of water for gas making is, in some types of producers, effected by a separate piece of apparatus, while in others it is associated with the vaporiser; still other makers combine the latter method with a hand adjusting valve.

When the producer is being worked at normal load the necessary water supply is higher than is suitable at reduced load, while at light load it is an advantage to use only dry air.

Where the air supply is simply made to pass over the surface of water contained in a vaporising vessel internally situated in close proximity with the gas generating chamber (see fig. 63 *ante*), unless an auxiliary dry-air

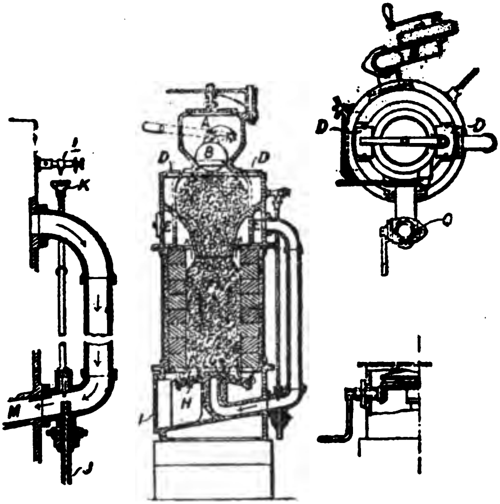


Fig. 75.

Fig. 73. Fig. 72. Fig. 74.

Details of the "Fielding" Producer.

inlet is provided for use at light load, the gas generated when the engine is running light will be so rich that the engine will have to *cut out* more charges than would be the case if the water supply was shut off.

The special feature of the "Fielding" suction producer, described and illustrated in *Engineering*, June 15th, 1906, from which figs. 71 to 75 are reproduced, is the arrangement of the water supply and its vaporisation.

The air supply enters an annular passage formed round the hopper casting by the openings O, where it is heated by the evolved gases, previous to its passage to the grate by the pipe M.

The method of introducing the water supply is shown in fig. 73, where, by a valve L and drip nozzle, a succession of drops fall into the funnel K and pass down the pipe opening into the air pipe; immediately below the inlet there is provided an outlet for the water, but, according to the amount of suction set up by the gas engine on its charging stroke, more or less water is carried along by the hot air, to be converted into gas at the grate.

The method adopted for the adjustment of the water supply in the Dowson producer has been described and illustrated in fig. 68 *ante*. Various other methods have been applied, which give more or less successful results, and these form an interesting particular for comparing the different types offered to intending purchasers.

An example of the separate, or external, vaporisr is shown in fig. 76, as adopted by Kynoch Limited, Birmingham.

In this case the vaporiser forms an entirely separate piece of apparatus, situated between the producer and the scrubber. Air enters the vaporiser by the inlet X, and thence to the ashpit by the pipe K; the close proximity of the inlet X to the shell of ,the producer causes the air to become slightly warmed before entry. The supply of water is regulated by the device shown in fig. 77. The small chamber A is in connection, by a pipe, with the scrubber, or some pipe in which the pressure is reduced when the engine is making a charging stroke. The base of the chamber A is formed of a rubber diaphragm, to which is attached the spindle carrying the double valve seats D and E; the chamber B contains water, maintained at a constant level by an inlet and overflow. Upon the engine making a charging stroke the pressure is reduced above the diaphragm, and it raises the valve D from its seat and brings valve E on to its seat, water flowing at the same time into the space provided. At the completion of the stroke, as the reduction of pressure ceases, the diaphragm falls and valve D closes, when the small quantity of water flows to the vaporiser by the passage C; adjusting screws F are provided for regulating the volume of water passing at each stroke. By this arrangement water only passes to the vaporiser on the engine taking a charge of gas, so that the charges becoming less frequent when the load is reduced,

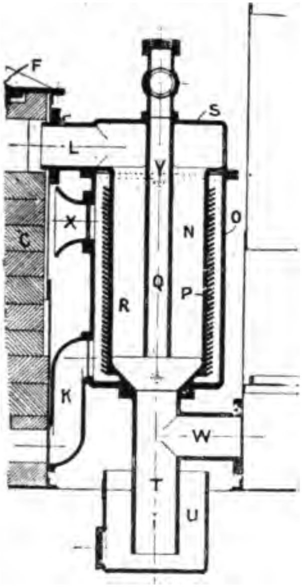


Fig. 76.—Vaporiser (Kynoch).

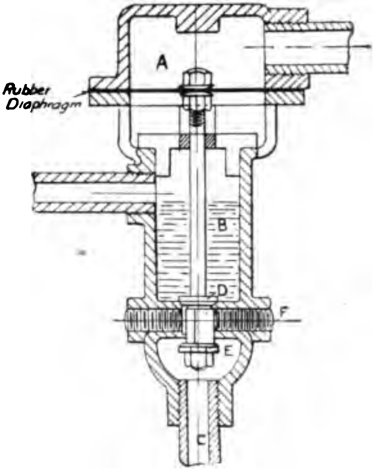


Fig. 77.—Water Regulator (Kynoch).

there is a less quantity of water delivered, and an excess of water cannot enter the fire and cause too rich a gas to be evolved, or cool the fire.

Referring again to fig. 76, the vaporiser consists of an outer casing O and an inner one P, having on its outer surface a rib in the form of a coarse screw thread, along which the water travels in a downward direction, in close contact with the surface of the casing, through the interior of which the hot gases from the producer pass on their way to the scrubber by the pipe N. An inner pipe Q is provided for use when the fire is being blown up, for the escape of the early products of poor gas and smoke, through the valve V.

The lower part of the vaporiser connects to the pipe T and branch W, the former leading directly to the water seal U, where any particles of dust are arrested in the usual manner.

As pointed out by M. Mathot,* the practice of some suction producer makers, of allowing the accumulation of water in the ash chamber, from the overflow of the vaporiser, brings about the possibility of the quality of the gas being disturbed through the steam generated when hot ashes are caused to fall into the water when the grate is cleared, by rocking the grate or poking the fire.

The necessity for providing means for regulating the water supply for the producer, as has been explained, is to ensure the generation of gas being satisfactory either when the gas engine is running at full load or light, or with a load that varies from full to light over more or less long periods.

For an engine which runs almost continuously on full load the regulation of the water supply is a fairly simple matter, and may be effected by providing a tank with a ball valve, from which water at a constant head can be admitted to the vaporiser by hand adjustment.

However, when the installation is required to deal with considerable variations in the load, and which may be running light for one or more hours, the producer should have a smaller grate area than when the variations from full load are only of short duration. When a gas engine is running light the number of strokes during which air is being drawn into the producer are so decreased that the temperature of the fire may fall so low as not to keep the fire in a condition to produce good gas when an increase in the load takes place. Therefore, it is necessary to reduce the volume of water vapour admitted with

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* *Engineering Magazine*, May, 1905.

the air, for in this case, through the quality of gas being poorer when made by air alone, the engine takes more gas strokes, and thus keeps up the heat of the fire.

One way of dealing with this difficulty is to provide a by-pass between the gas pipe and the gas-engine mixing chamber, so that at every suction stroke of the engine a small quantity of air is drawn through the fire, and though a small quantity of gas is made, this is not sufficient to produce an explosive mixture, and passes out in the exhaust pipe. Though this entails a small loss of combustible gas during the period of running light, the producer is ready to respond to an increase in the load without requiring further adjustment.

An examination of the various types of suction gas plants upon the market will show that makers' opinions differ in regard to whether the vaporiser should be situated internally or externally, the claims being:—

External Vaporiser.	Internal Vaporiser.
By making the vaporiser a separate vessel heat is extracted from the gas between the generator and the scrubber, heat is retained in the generator, and the gas cooled before entering the scrubber. Also the cooling effect of fresh charges of fuel is not transmitted to the engine.	Though the addition of fresh charges of fuel may be found to affect the quality of the gas, the generation of steam responds more readily to the engine requirements. By placing the vaporiser inside the producer casing there is less loss of heat by radiation. When the vaporiser is situated internally the excess of steam can escape to the atmosphere when no suction stroke is taking place.

It has already been shown that one of the necessities of a modern suction gas plant is the supply of a considerable amount of water; most of this is utilised for the cooling and purification of the gas previous to its employment in the gas engine cylinder, but the purity of the water is not so important as in the case of steam plants. With hard and impure water for use in the producer, it is necessary that the vaporiser shall be of a class which has facilities for cleaning out scale, which is a special feature in some designs.

In this connection it must be borne in mind that it is a matter of importance and economy for the gas to be both as cool and as free from impurity as possible, so that it is no advantage to stint the quantity of water applied to the cooling and scrubbing apparatus, as otherwise the power developed in the engine will be low if the gas is not sufficiently cooled; and if dust and fume, or tarry matter, is permitted to enter the engine there will be more frequent cleaning of the valves and combustion chamber. In regard to the provision of special water regulation devices for gasification purposes, Mr. Hugh Campbell, of the well-known firm of gas engine and producer makers, has stated it to be a fact that, though their suction producers are all provided with means for regulating the proportions of air and water, he questioned whether they were ever made use of, as he had never found a suction gas plant, which was properly worked, to fail in regard to dealing with a varying load or running light; even for such work as driving wood-working machinery a suction gas plant was satisfactorily capable of maintaining regularity of speed under the varying conditions of load, and developing full power whenever required.*

In suction producer gas installations it is not necessary that each gas engine shall have its own producer. Several engines can take their gas from a single producer if properly arranged, and multi-cylinder engines of the petrol-motor class can be run satisfactorily. When two or more engines are arranged to take gas from a single producer it is essential that the gas pipes are to be so disposed that they shall not rob each other of gas during the charging stroke. Mr. George Stevenson has pointed out that the successful development of the suction producer has already considerably affected the employment of retort gas, and caused gas companies to lower their charges, as the only means by which the competition could be met. It is probable that the large profits previously made by gas undertakings, which were applied to relieve the rates, will have to be reduced to all of the

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* Discussion upon a paper recently read before the Institution of Engineers and Shipbuilders at Glasgow.

gas being charged at a low enough rate to compete with suction gas.†

Mr. W. Watmough (Heywood) has said that if gas companies would make it easy for consumers to put in gas engines, and supply gas at 1s. 6d. per 1,000 cubic feet, they would not be bothered with the worry and inconvenience of suction plants.‡

The following particulars, which will be of service to prospective users of suction gas plants of small units of power, have been culled from the reports of the suction gas plant trials of the Agricultural Society:

HIGHLAND AND DERBY SUCTION GAS TRIALS, 1905 AND 1906.

PARTICULARS OF SUCTION GAS PLANTS BY DIFFERENT MANUFACTURERS.

Declared capacity, B.H.P.	Price of producer plant.	Weight of producer plant.	Space occupied by complete plant, producer, engine, &c.	Price of plant declared.
	£	Cwt.	Square feet.	£
8	80	25	160	160
10	60	15	288	135
10	65	20	225	145
12	58	17	160	148
15	..	..	..	180
15½	..	..	..	210
17	..	..	..	198
17	..	..	..	200
18	..	..	..	180
18	105	25	225	230
20	80	25	225	200
20	..	..	..	233
20	..	..	..	190
20	..	..	..	200
20	..	..	..	225
20	..	..	..	193
20	..	..	..	176·5
20	..	..	..	*280
20	..	..	..	*210
20	..	..	..	200
20	80	25	225	200
21	90	28	225	221
24	80	45	240	190
25	94·5	35	144	224·5
25	72	25	288	202

* Vertical gas engines; all others Otto cycle engines.

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† Paper by Mr. George Stevenson, presented to the Manchester District Institution of Gas Engineers on "Town Gas *versus* Suction Gas."

‡ Discussion on Mr. George Stevenson's paper.

As a further example of the space occupied by suction plants, and the approximate weight, the following table relates to suction gas producing plant (Fielding's patent), as made by Messrs. Fielding and Platt Ltd., Gloucester:

SPECIFICATION.—The plant consists of suction generator with fuel-charging arrangement; heat interchanger; cake scrubbers, or purifiers, complete with water sprinklers, etc.; expansion box; C.I. connecting pipes, syphons, and bends; and blow-off cock. Water-service pipes and foundations not included.

SIZES OFFERED.

Engine power, B.H.P.	Approximate space occupied.					Approximate weight.
	Ft.	in.		Ft.	in.	Cwt.
6·5	4	0	by	2	6	19
11	4	0	,,	2	6	19
13·5	4	6	,,	3	0	20
20	4	6	,,	3	0	20
24	5	6	,,	3	9	23
29	5	8	,,	3	10	24
32	6	9	,,	4	0	32
35	6	9	,,	4	0	32
50	6	9	,,	4	0	35
60	6	11	,,	4	2	35
84	12	3	,,	5	6	66
90	13	3	,,	5	9	70
104	13	3	,,	5	9	70
120	14	6	,,	6	9	88
150	12	0	,,	10	6	95
200	12	9	,,	11	0	120

From the special supplement of the *Electrical Review*, June 7th, 1907, giving a list of electricity supply works of the United Kingdom, comprising 428 installations, the following particulars of those driven by gas power show their encroachment in the field originally held by steam power:

Place.	Supply authority.	Year of opening.	Total capacity.	Total capital.	Remarks.
			K.W.	£	
Brighouse	Corporation	1898	70	4,674	Gas power.
Buckingham	B. E. L. Co.	1889	70	..	Part gas power.
Burgess Hill	B. H. and D. E. S. Co. Ltd.	1906	64	4,000	Suction gas power
Church Stretton....	C. S. E. S. Co. Ltd.	1904	100	..	Suction gas power
Faversham	Corporation	1904	270	21,186	Gas power.
Frinton-on-Sea	F.-on-S. and D. E. L. and P. Co. Ltd.	1903	60	7,500	Gas power.
Guernsey	G. E. S............	1900	870	127,768	Part gas power.
Galway	G. E. C. Ltd.......	1889	130	14,000	Part gas power.
Kendal	Corporation........	1902	109·5	13,792	Part gas power.
King's Lynn	Corporation	1899	680	48,000	Part gas power.
Leek	L. U. D. C........	1904	255	15,747	Gas power.
Limerick	Corporation	1902	180	..	Gas power.
Melrose	E. S. Cn. Ltd. ..	1904	66	10,000	Gas power.
Milford-on-Sea	M. E. S. Co. Ltd...	1906	100	8,000	Suction gas power.
Minehead	M. E. S. Co.	1908	141	13,000	Suction gas power.
Newcastle-u.-Lyme.	Corporation......	1904	140	8,500	Gas power.
Norton and Malton..	N. C. E. S. Co Ltd.	1904	80	..	Town gas power.
Redditch	R. U. D. C........	1899	544	36,739	Part gas power.
Roundhay	R. & D. E. L. Co. Ld.	1903	160	14,000	Part gas power.
Rugby School	R. S. E. L. Co. Ltd.	1896	85	4,500	Part gas power.
Ryde and St. Helens	Isle-of-Wight E. L. and P. Co., etc.	1903	295	60,819	Part gas power.
St. Austell	St. A. and D. E. L. and P. Co. Ltd.	1886	100	8,000	*Suction gas power.
Saltburn	C. Trust Ltd.......	1899	170	14,000	Part gas power.
Stowmarket	S. E. S. Co. Ltd. ..	1896	78	..	Gas power.
Walthamstow	W. U. D. C........	1901	1,900	132,000	Gas power.
Witney	W. E. S. Co. Ltd...	1900	90	9,700	Gas power.
Wormit	T. E. & G. L. Co. Ld.	1899	21	..	†Suction gas power

* Substituted for steam, 1904. † Substituted for steam.

From the above table it will be observed that at this date gas power for electrical supply works amounts to 6·3 per cent of the total number, of which 18 per cent are of the suction type, dating only from 1904. The power units are not high when compared with the numerous gas engines working on blast-furnace and coke-oven gas, but the trend in this direction is positive.

Mr. W. B. Esson, M.Inst.C.E., M.I.E.E., in his address to the Civil and Mechanical Engineers' Society on "The Industrial Power Problem," made a careful comparison of the cost of producing power by different types of gas producers, steam, and oil, on the basis of so much paid for so much received. He took the case of a factory having to be furnished with power from power-producing plant located on the premises, assuming that an engine of 500 brake horse power would meet all requirements, with distribution by electricity throughout the works; the generator to give a maximum output of 470 electrical horse power, with a total output of one million electrical horse power hours per annum. Taking in all cases a mean consumption of fuel, as between full load and half load, the following figures show the comparative costs:

COST OF POWER PER ELECTRICAL H.P. HOUR.

	Mond gas (without ammonia recovery).	Suction gas.	Steam condensing.	Steam non-condensing.	Oil (Diesel).
Price of fuel.	7s. 6d. ton	24s. ton.	7s. 6d. ton.		45s. ton.
Lbs. of fuel............	1·26	1·00	2·25	3·00	0·52
Cost of fuel ....*d*.	·051	·129	·090	·120	·125
Oil, water, and stores.*d*.	·030	·030	·025	·024	·025
Wages................*d*.	·070	·070	·070	·070	·065
Maintenance & repairs.*d*.	·075	·070	·070	·070	·065
Works cost............	·226*d*.	·299*d*.	·255*d*.	·284*d*.	·280*d*.
Capital expenditure, including the electric generator and main switchboard.......£	6,710	5,150	5,400	4,900	6,850

Allowing 10 per cent for interest and depreciation, the charges are—

Works costs ....*d.*	·226	·299	·255	·284	·280
Capital charges ......*d.*	·161	·124	·130	·118	·164
Total cost ....*d.*	·387	·423	·385	·402	·444

CHAPTER XII.

THE APPLICATION OF THE SUCTION GAS PRODUCER.

THE dispensing with a gas holder, even of small size, the auxiliary boiler, etc., in the suction method of gasifying fuel, reducing the space occupied to such small proportions, opened up a new field where gas power could be applied with advantage—that is to say, to uses where the power has not only to be developed locally, but that the power generated can partly be utilised for transporting the apparatus. Besides reduction in space occupied, there is to be considered the weight of the installation in proportion to the power capacity. In this connection the *Commercial Motor* quotes an experiment where a suction gas producer, weighing only 15 lb., was coupled to a six to eight horse power petrol engine, in which it was found that the suction gas gave about the same power as petrol; and the inventor was confident that a producer, weighing 20 lb., will easily run a petrol engine of 20 horse power, which would make the suction system applicable to the propulsion of road vehicles.

In Germany the application of gas engines to canal boats has made more progress than in this country, and we find the following particulars given in the *Mechanical Engineer* of December, 1905: Canal boats, capable of carrying a dead-weight cargo of 240 tons, with a draught of 6½ ft., are fitted with horizontal four-cylinder gas engines and a gas producer. The cylinders are arranged in pairs on each side of a single crank shaft, and are capable of developing 80 to 100 horse power. The propeller is reversible, so that the boat can go ahead or astern without having to stop the engine. The consumption of anthracite coal is only 1·32 lb. per horse power hour, and, including interest on capital, insurance, depreciation, lubrication, fuel, wages, etc., the cost works out at about 0·125d. per ton per mile.

M. Capitaine has designed a suction producer especially for marine purposes, a sectional view of which is given in fig. 78, the principal object in this case being the reduction in weight.

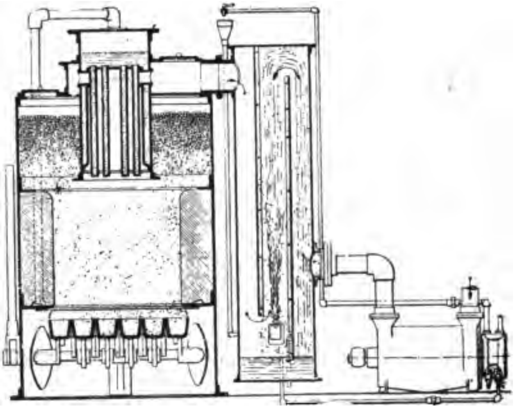

FIG. 78.—The Capitaine Suction Producer for Marine Use.

For marine purposes the question of weight is even of more importance, both as regards the power developing apparatus and that of the fuel for consumption during the period occupied by the voyage, than in the case of barges.

In the first place, power for power, the same weight of fuel would carry a vessel twice the distance that steam power could. In a test made with two motor launches, one fitted with gas engine and suction plant, and the other with a triple-expansion steam engine, on a run from Hamburg to Keil and back, during stormy weather, the consumption of fuel was:*

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* *Mechanical Engineer* Vol. 16 No 390

Name.	Type of engine.	Power.	Speed.	Coal used.
			Knots.	Lbs.
Gasschlepper, 44 ft. 8 in. × 10 ft. 6 in.	4-cylinder gas	50-70 h.p.	8¼	580 anthracite.
Elfriede, 47 ft. × 12 ft.	Triple-expansion steam	75 h.p.	8½	1,820 steam coal.

The agents in this country for the Capitaine gas producer and gas engine are Messrs. Thornycroft and Co. Ltd., who include in their lists plants up to 600 horse power.

Referring to fig. 78, the producer consists of a steel shell, lined above the grate with refractory material. A novel feature of this producer is the design and construction of the grate; the bars are of U section, forming channels in which ash may collect, and so preserve the metal from destruction by the heat of the fire. Mechanism is provided for rocking the bars, so as to discharge the ash and keep the air passages free. The upper part of the producer shell forms a fuel storage hopper of considerable capacity; charging is effected through doors provided on the top. The water vaporiser is centrally situated, and consists of a shell containing a number of "field" tubes connected to a water tank; the hot gases escaping from the generating chamber pass through the interior of the vaporiser surrounding the tubes, and give up a considerable amount of heat to the water. The vaporised water is carried along by the air to the space below the grate.

To minimise weight and space the ordinary coke scrubber is replaced by a purifier G, consisting of a shell, in which the passage for the gas is elongated by diaphragms, and a very fine water spray is caused to mingle with the gas at the jet D. Centrifugal pumps, operated from the gas engine, provide the spray of purifying water, and discharge the surplus overboard. To further purify the gas from tarry matter and remove the water vapour carried by the gas, it is caused to pass into a mechanically-operated centrifugal apparatus E, having a peripheral speed of 160 ft. per second, which, besides effectually purifying the gas, delivers it under a slight pressure to the engine, thereby increasing the efficiency of the installation, the grate area necessary being 0·05 square feet per horse power, as compared with a steam boiler under natural draught of 0·2 square feet. With the object of maintaining a suitable temperature in the generator during periods of low or light loads, provision is made for the excess of gas made owing to the suction effect of the centrifugal separator to be discharged into the atmosphere. In the gaspipe leading to the engine a gas outlet port and valve are provided, and a governor, driven from the engine automatically, allows the excess of gas to escape to a place where it can be burnt, and the heat of this gas can be applied to maintaining the temperature of the generator. Apparatus of a somewhat similar type to that just described has been employed to gasify low grade oils in place of anthracite, with promising results.

On the subject of "Marine Gas Propulsion in Relation to Imperial Commerce and Defence,"* the author, an experienced marine engineer, shows that while steam plants consume from 1·3 to 1·6 lb. of coal per indicated horse power, gas plants would only require from 0·65 to 0·8 lb. per indicated horse power, so that either the bunker capacity could be reduced 50 per cent, or the vessel's radius of action increased 100 per cent by the adoption of gas propulsion. The author of the paper also enumerates the following advantages in favour of the gas producer and gas engine: (1) The ship driven with half the amount of fuel, (2) stand-by losses reduced over 75 per cent, (3) working pressure confined to the engine cylinders, (4) no boiler tubes or steam pipes to burst or furnace crowns to collapse, (5) no priming in a heavy seaway or water-hammer in pipes or cylinders, (6) no more difficulties with the firing of boilers in a beam sea. Gas producers may be charged only twice in 24 hours, while the

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* A paper read before the Manchester Association of Engineers, January 26th, 1907. See *The Practical Engineer*, February 8th, 15th, 22nd, and March 1st, 1907.

rolling and pitching of the sea would be rather an advantage in assisting the descent of the fuel in the hoppers and generators.

In all the types of gas producer described by the writer they have only been found to be successful with certain classes of fuel. Where anthracite or coke are available there is little or no difficulty in obtaining producers of any convenient power unit to give clean gas of regular quality without any considerable cost or complication in purifying apparatus, so that for small craft making short voyages within a range of suitable fuel supply there is nothing to prevent the development of the application of gas-driven vessels as far as the producer is concerned.

For such vessels as constitute our mercantile marine service the question is complicated by the fact that for long voyages the available fuel at the different coaling stations would be of greatly varying quality, chiefly of the bituminous class, which would necessitate a producer so devised as to be capable of gasifying fuel of both caking and non-caking qualities, and containing high percentages of hydrocarbons. The purifying apparatus would have to be capable of rendering the gas clean and free from condensible hydrocarbons, whatever the class of fuel might be; mechanical separators would, therefore, most probably be preferred. However, as sea water is quite suitable for the purposes of the plant, the cooling and purification of the gas can readily be assured.

The author of the paper on "Marine Gas Propulsion in Relation to Imperial Commerce and Defence," already referred to, says that the prices for small marine suction plants and engines are about the same as for steam installations, and gives the following figures:

Engine.	B.H.P.	Cost of engine and producer.	Cost of stern-gear propeller reversing clutch.	Total.	If with reversing propeller. Total.
		£	£	£	£
Vertical, two-cylinder ..	25-30	450	126	576	530
Vertical, four-cylinder ..	50-70	650	165	815	760

Mr. James McKechnie has given the following figures, estimated, as a comparison between gas, steam, and oil propelled machinery applied to a battleship of 16,000 horse power:—

Comparison of Weights, Etc., of Steam, Gas, and Oil Machinery for 16,000 H.P. Battleship.*

	Steam engine.	Gas engine.	Oil engine.
Indicated horse power available for propelling the ship	16,000	16,000	16,000
Weight of machinery, including usual auxiliaries, but not deck machinery	1,585 tons.	1,105 tons.	750 tons.
Indicated horse power per ton of machinery	10·1	14·48	21·33
Area occupied by machinery, engines and boilers, or producers	7,250 sq. ft.	5,850 sq. ft.	4,110 sq. ft.
Area per indicated horse power	·453 sq. ft.	·366 sq. ft.	·257 sq. ft.
Fuel consumption in pounds per indicated horse power per hour :—			
At full power	1·6 lb.	1·0 lb.	·6 lb.
At about quarter full power ..	1·66 lb.	1·15 lb.	·75 lb.

In fig. 79 is shown a sectional view of the Boutillier suction gas producer, which is designed to use bituminous coal. To cause the volatile gases to become fixed by having to pass through the zone of highest temperature there is provided a mechanical apparatus for delivering the raw fuel upwards through the fire, so that tarry hydrocarbons become decomposed; in other respects this producer somewhat resembles the Capitaine producer.

The application of internal combustion engines, driven by gas, to marine purposes is not so much retarded by the gasification of fuel in producers as the difficulties associated with the engine, such as want of reversibility, non-suitability of this type of power developer to slow running, and with no load.

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* "The Influence of Machinery on the Gun Power of the Modern Warship," a paper read by Mr. James McKechnie, before the Institution of Naval Architects, 1907.

For land purposes installations of suction producer, in units of 350 horse power up to 2,000 horse power, have been put down, in which the floor space occupied by the gas apparatus comes out at about 2 square feet per horse power. Not only is gas plant economical in fuel, but the loss of fuel during stand-by periods is from $^{1}/_{11}$ to $^{1}/_{20}$ of that required in steam practice. While gas producers require only from 0·005 to 0·018 lb. of fuel per horse power hour on rated maximum capacity, steam boilers consume from 0·058 to 0·36 lb. per hour on maximum horse power*

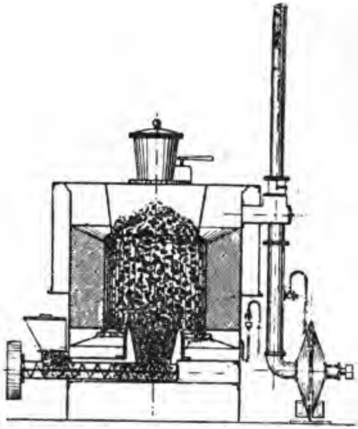

FIG. 79.—The Boutillier Suction Gas Producer.

Compared with steam boilers, the producer not only occupies less space; is of less weight, power for power, but it is not subject to troubles from internal pressure, etc.; the heat resulting from radiation is small, and the charging of the fuel is not an arduous operation in a heated atmosphere, and only occurs at periods of two or more hours.

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* "Gas Power," by J. Emerson Dawson, A.I.E.E., Proceedings of the Institute of Electrical Engineers, 1904.

CHAPTER XIII.

POWER GAS INSTALLATIONS GENERALLY CONSIDERED.

IN one of the workshops of Messrs. John Wallace and Sons, agricultural engineers, Graham Square, Glasgow, steam power used to be employed, of which the cost of working was as follows:—

Average weight of coal used per month, 13 tons 10 cwt.			
Cost of coal, at 6s. per ton delivered.........	£4	1	0
Carting ashes, five loads, at 1s. per load......	0	5	0
Attendant's wages, 20s. per week	4	0	0
Water, 12,000 gals., at 4d. per 1,000 gals...	0	4	0
Total....................	£8	10	0

The steam installation was replaced by a 30 I.H.P. Acme gas engine and suction gas producer, by the Acme Engine Company Limited, Shettleston, Glasgow. The fuel used was anthracite coal, costing 17s. per ton delivered; the daily ashes amounted to one shovelful, and the water used so little as to be practically negligable.

The total attention required did not exceed one hour per day, including charging the producer, starting the engine, and poking the fire two or three times a day. Starting at 6 a.m., the generator is filled with coal, and this suffices till between three and four o'clock, when a further bucketful is added; five to eight minutes in the morning and two to four minutes at meal hours are required for making preparations and starting. Compressed air is employed for starting the engine. The cost of working for a month, as compared with the previous steam power, was:—

Average coal used per month.........	1 ton	1 cwt.	3 qrs.
Cost of coal per month, at 17s. per ton......	£0	18	6
Attendance, labourer, 24 hours at 5d.	0	10	0
Overtime, cleaning producer and engine valves	0	6	0
Carting ashes		none	
	£1	14	6

The same engine was run on town's gas, and used 10,500 cubic feet per week, which works out per month as follows:—

Gas used per month....................	42,000 cubic feet.		
Cost of gas, at 2s. per 1,000 cubic feet	£4	4	0
Attendance	0	6	0
	£4	10	0

A recently installed pressure power gas plant is that of Messrs. Argyll Motors Limited, Alexandria, near Glasgow. The gas engines are used for direct driving, and for generating electric current for driving electric motors for driving machinery in the works and lighting. Eight producers of 200 brake horse power capacity are installed, with purifying apparatus, in complete sets, so arranged that any set may be disconnected for cleaning, repairs, etc., without interrupting the working of the other sets. Further provision is made for the "cutting out" of any single scrubber without necessitating the associated producer from being put out of action, an arrangement of pipes and valves allowing the gas to pass through other scrubbers.

A gas pressure governor holder regulates the pressure at which the gas is supplied to the engines, and its rise and fall automatically controls the air supply from the Roots blowers to the producers. Exhaust steam from an associated steam engine provides the air supply to the producers with the requisite proportion of moisture for regulating the gasification of the fuel; a mechanical elevator and conveyers transfer the coal from a hopper to each producer; a gas main of 24 in. diameter carries the gas to the power house, where eleven gas engines are installed up to the present.

Johannesburg Tramways Power Plant.—The history of this installation is of considerable interest to gas engineers, owing to the magnitude of the undertaking and the associated difficulties which had to be contended with.

In 1903 the Municipality of Johannesburg decided upon the erection of an electric power station to provide current for the tramways and lighting, of a capacity of about 12,500 brake horse power, and tenders were obtained for both steam and producer gas power.

According to the Johannesburg *Star*, April 9th, 1907, the Town Council selected the following tenders as the best:—

		Per kw.
Steam power driven installation	£195,495	£24·1
Gas power driven installation, including gas engines, producers, and generators.	204,920	25·3

and the cost of running the gas plant was estimated to be £15,277 per annum less than the steam plant.

The tender for the gas power scheme was accepted, and the first gas engine started early in 1906. About the end of that year practically the whole of the town and district were equipped for service. The power plant consisted of Poetter producers, Oechelhauser gas engines, and Siemens generators. Of the eight units, four were of 1,350 kw. and four of 675 kw. capacity. Continuous current was applied to the tramways and inner area lighting, and alternating current for lighting the outlying districts.

From the first troubles arose; the coal was not satisfactory for gas making, and a good deal of tarry matter was carried by the gas. The failure of a crosshead of one of the larger engines resulted in serious damage, and many other stoppages occurred.

Owing to the troubles with the installation, the Town Council arranged a contract with the contractors to supply current at 1·39d. per unit at the switchboard, not including depreciation, in November, 1906, for twelve months. In

March of this year a serious explosion took place in the producer plant, inside one of the air blowers, and this brought the whole of the service to a stand for a short time. While, in the absence of reliable particulars, it is evident that the installation was not a success, it is a difficult matter to arrive at the causes of the troubles. In this case the whole ground was clear for putting down a complete gas power installation based upon working results already proved satisfactory in continuous working.

In the case of an installation to use coal, the first consideration is the character of the fuel. The Mond system has shown that bituminous coal slack of poor quality can be successfully applied, if associated with by-product recovery, but, as has already been pointed out, the cost of recovery apparatus is only warranted when the installation is intended to gasify about 40 to 60 tons of coal per day, and in the case in question recovery was not attempted. As the contractors were running the plant, the numerous defects and stoppages could not well be attributed to want of skill in the operators. There appears to have been considerable leakage of gas, causing several cases of "gassing"; this is not easy to account for, as, knowing the poisonous nature of the gas, great care should have been taken to prevent leakage, and this danger is seldom found in well-arranged systems. Blast furnaces evolve enormous volumes of equally poisonous gas, which is conveyed to various points in brick flues and tubing, but cases of "gassing" are not frequent. It is alleged that most of the interruptions were due to troubles with the air and gas pumps. Pre-ignition troubles added to the unsatisfactory working of the installation, it is alleged, and this probably arose from the tarry matter in the gas, for the Oechelhauser gas engine works upon the scavenging principle, which should render pre-ignition a rare occurrence. This two-cycle large power gas engine has been in use since 1898, when the first 600 horse power engine was started.

Mr. E. J. Duff, in 1906, referred to 28 British-built Oechelhauser gas engines, designed for driving dynamos. rolling mills, air compressors, and cement mills, all of which were working on some form of Duff producer gas, the aggregate horse power being 32,600.*

M. Mathot, a couple of years ago, referred to 60 of these engines, aggregating 50,300 horse power, in different countries, so that no little experience has been gained by this of the suitability of this type of engine for running on blast-furnace and producer gas.

The reports from time to time have been rather conflicting, for, though interruptions were frequent, it was said that the producer plant was fairly satisfactory, though the gas was not altogether free from tar. Electric blowers were employed, and, of course, when the current failed, there was trouble at this point, and steam-driven blowers were recommended.

The sets were reported as not able to give their full output.

There appears to have been an accumulation of failures from different causes, such as pre-ignition, hot bearings, water supply, and troubles with the compressors, as previously stated.

The running costs of the installation, as estimated by the consulting engineers, and as obtained during three months by the contractors, were:—

	Estimated. d.	Actual. d.
Fuel	·37	·55
Water	·06	·10
Oil, waste, stores	·10	·46
Wages	·23	·86
Repairs	·10	·58
Total works cost per unit...	·86d.	2·55d.

An offset of ·4d. per unit was obtained by the sale of tar at 8d. per gallon.

Whatever the actual defects, if these are ever definitely published (?), it is, the writer understands, a regrettable fact that the gas installation is to be replaced by steam,

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* Discussion on a paper on "Large Gas Engines," by Mr. Tom Westgarth, Iron and Steel Inst. Meeting.

and even if it is not altogether shut down at the time of writing, orders have been placed for steam power generating sets.

The general conclusion, from experience gained up to date, is that there is no trouble in producing gas, for even the poorest quality of blast-furnace gas gives positive explosions in the cylinders of internal-explosion engines; while rich gas, such as town's gas, coke-oven gas, and natural gas can be equally well applied, provided that the gas is free from tarry matter or fume on entering the combustion chamber. Therefore, the purification of the gas must always form a serious consideration, and when this is efficiently effected proper cooling is also assured.

The deposition of tar and fume, at the explosion of the charge, upon the walls of the combustion chamber and valves of the engine are bound to necessitate stoppages for cleaning purposes, and when applied to vertical inverted cylinder engines these troubles are aggravated by the fouling of the piston causing pre-ignition. It is no doubt due to this cause that vertical gas engines are not found to give the satisfaction in continual work which is indicated over short-period trials; stations which have given considerable promise in the way of economy and reliability have been found to come short of the high expectations resulting from their initial results.

Lubrication, always an important matter in the case of internal-combustion engine pistons, has to be on the "forced" principle for continuous-running engines, and it is not an easy matter to lubricate vertical-running pistons; excessive lubrication, often a cause of trouble, is almost, if not quite, as bad as the employment of impure gas, as regards fouling the combustion chamber and causing pre-ignition, owing to the charring of the oil resulting in incandescent particles existing in the combustion chamber when the incoming charge is admitted. As compression proceeds the charge becomes ignited before the piston has completed its stroke, and the explosion causes excessive pressure upon the bearings.

The Blast Furnace as a Gas Producer.

It has already been noted that the iron-smelting blast furnace is an abundant power gas producer, and instructive details of the researches of Messrs. Bunsen and Playfair have appeared in the early pages.

In the year 1906 the world's output of pig iron aggregated 59,000,000 tons, and as it requires at least one ton of coal per ton of pig, usually in the form of coke, it will be clear that this amounts to an hourly consumption of 7,506 tons of coal. Of the heat capable of being developed by this amount of coal only about one half is turned to account in the smelting and production of the iron, the rest appearing in the sensible heat and combustible power of the gases evolved.

The partial combustion or gasification of each ton of coke in a blast furnace produces about six tons of gas, the combustible property of which renders it a very suitable fuel for driving gas engines.

The average output of blast furnaces in the United States per hour is about 9½ tons of pig iron, so that the weight of gas given off amounts to 57 tons per hour.

In English practice the average weight of iron produced is not so great as this; but then in many districts the iron ore is not of so rich a quality, and requires a greater proportion of coke, owing to the larger proportion of slag. The rate of driving, for the same reason, is not so high as in the American practice. A notable feature of blast-furnace practice in this respect is that this large weight of poisonous gas is carried in tubing and flues to different parts of the works (not to speak of that which escapes during the charging of the fuel at intervals) continuously day and night, with an extremely small number of serious accidents, although there are about 300 blast furnaces continuously at work in this country.

Each ton of coke consumed in blast-furnace work results in the evolution of about 170,000 cubic feet of gas when measured under atmospheric temperature and pressure, while at the high temperature at which it leaves the furnace top this volume is doubled or trebled, according to the working conditions.

All the moisture contained in the ore and coke charged into the furnace is carried by the escaping gas, as well as a considerable weight of dusty particles of ore, coke, and a persistent exceedingly fine fume, which deposits at all parts traversed by the gas.

Previous to this gas being applied to gas engines it must be cooled and freed from any material which would become deposited in the pipes, valves, and combustion chamber. A notable feature in this connection is that at every point in the apparatus where eddying can occur the fine particles of dust accumulate, even after the gas has passed through washers and scrubbers. It is not a difficult matter to arrest the heavier dusty matter by dust catchers, etc., but the finest impurities can only be removed by high centrifugal action or fine physical filtration. When raw coal, impure qualities of coke, or a mixture of coal and coke constitute the fuel, tarry matter has also to be dealt with.

Efficient cooling of the gas is accompanied by a condensation of the moisture in the form of fog, which also acts as a medium for carrying down fine dust.

The blast furnace resembles the gas producer in that it comprises a cylindrical chamber lined with refractory material, into which the fuel is charged at intervals at the top, and air is forced in at the bottom, there being maintained, during the life of the furnace, a large volume of incandescent fuel; but the depth of the materials constituting the stock is from 40 to 60 ft., and the earthy matter of the iron ore and ash of the fuel are removed in a molten state, while there is no addition of water or steam employed with the air blast.

Previous to the introduction of coke for smelting iron by Abraham Darby, 1735, charcoal and coke were the only available fuels, and the air blast was used at ordinary temperature until Neilson and Condie applied heated air in 1828. The furnace tops were open to the atmosphere, and the combustible gases wasted up to the year 1832, when Mr. J. P. Budd first attempted the utilisation of the gas for heating purposes. It was not until 1894 that Mr. B. H. Thwaite first applied the gas to the development of power directly in the cylinders of internal-combustion engines.

For each ton of coke carbonised there is required 4·36 tons of air, and 5·92 tons of gas are evolved, measuring about 172,210 cubic feet under atmospheric conditions. The air is heated previous to its introduction into the furnace through the tuyeres to about 1,200 deg. Fah.

In furnaces smelting hematite ores, with Durham coke and limestone flux, a blast pressure of 3·3 lb. at the tuyeres gives a pressure inside the furnace of 1·66 lb., and the evolved gases at the top of the furnace have from 1·7 to 2·7 in. of water pressure above the atmosphere, at an average temperature of about 700 deg. Fah.

Fig. 80 is a sectional view of a blast furnace designed by the late John L. Stevenson, 65 ft. high and 12 ft. diameter in the widest part, and is capable of producing from 80 to 85 tons of pig iron per day, if provided with sufficient air blast and heating stoves.

In regard to the quality of the gas produced in blast furnaces, there is not a considerable difference between that given off when the furnace is working under normal conditions or when coke only is employed, either in composition or heat value, so that in the case of a considerable power installation being applied to a furnace plant, should any cause arise, other than the failure of the furnaces themselves, to render it advisable to cease iron smelting, one or more furnace could be run on coke only to supply the power requirements during a reasonable period.

The determination of the weight and composition of the dust carried out of the furnace is a somewhat difficult matter; while a number of conditions, such as class of materials employed, velocity at which the gas is discharged, etc., etc., contributed to the variation in the weight of dust carried by the gas from furnaces in different districts.

In a number of different furnaces the weight of dust has been computed, and it would appear that ·1875 lb. per 1,000 cubic feet is only obtained in some few cases, while

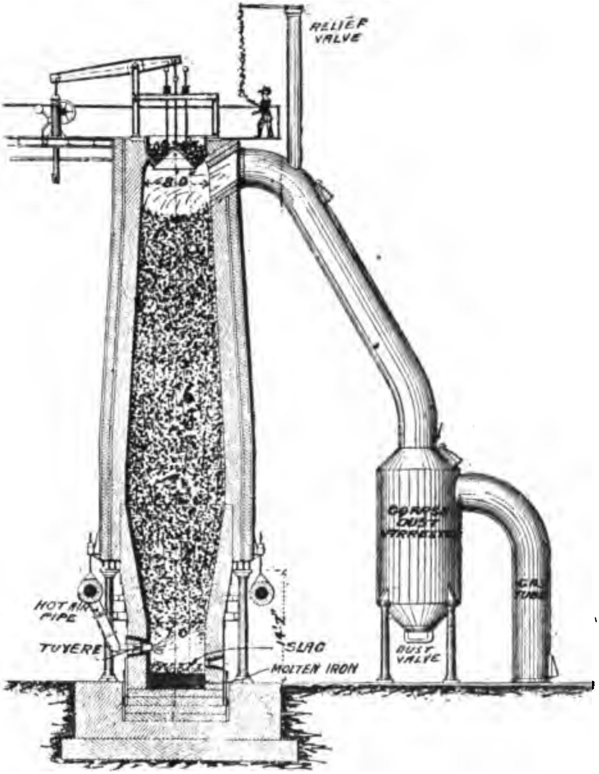

FIG. 80.—Iron Smelting Blast Furnace (Modern Type).

the more usual weight is nearly 1 lb. per 1,000 cubic feet when the furnace product is ordinary pig iron; but in furnaces making manganiferous iron, such as spiegeleisen, the amount of dust is much higher, approaching

2 lb. per 1,000 cubic feet of gas. The coarse dust arrester is capable of dealing with the heaviest particles, but the most troublesome portion is the light persistent fume.

Although the stack of the blast furnace is maintained full of fuel and ore, and in an incandescent condition for the most part, for the whole life of the furnace lining, year in and year out, the production of gas is interrupted every time the air-blast is shut off, and usually a proportion of gas is wasted every time the materials constituting the charge are admitted to the furnace.

At some Middlesbrough furnaces the blast was off 25 times in 76½ hours, during the periods of running the metal and slag, and for fettling, etc. ; these periods varied in length from 5 minutes to 1¾ hours, and aggregated 19 per cent of the working time.

To quote a second case, the blast was "off" 14 times in 43½ hours, for from 5 minutes to 1 hour, equivalent to 10 per cent.

In a third instance the blast was "off" eight times in 24 hours, for average periods of 40 minutes, equal to 27 per cent, and in three days (24 hours) the interruptions were 24, and the percentage was 22.

During these periods there is no available gas whatever for power purposes, unless there are two or more furnaces in the installation.

Another point is that the exigencies of smelting may require the closing of the blast valve at any time and for uncertain periods.

Also it must be particularly borne in mind that the costly installation is intended for the regular production of pig iron, and only under exceptional circumstances can it be rendered subject to any requirements of an application of its bye-products.

However, while the blast in "on" the furnace the amount of gas evolved is greatly in excess, in regard to its heating power, of the requirements of the furnace itself, and also that when the blast is shut off the furnace does not require any considerable development of power for its own purposes, so that as long as the gases are only applied to providing steam and heating the air, the above considerations do not amount to anything.

Though blast furnace gas is of low thermal value, the provision of a gas storage holder is not so costly as might at first appear, for a gas holder having a capacity of 15,000 cubic feet, and costing about £700 would allow a 1,500 H.P. gas engine to run for six minutes, costing, with 10 per cent for interest and depreciation, 11s. 2d. per H.P. year; while such a large gas holder as 7,750,000 cubic feet capacity, costing say £53,000, with interest and depreciation, would only cost £1 15s. 4d. per H.P. year, and provide a 3,000 H.P. gas engine installation for periods of 26 hours.

These are two extreme instances; for the necessary capacity and cost would depend upon the number of furnaces from which the gas was available, as the largest holder quoted would be capable of providing gas for engines of 77,500 H.P., for periods of one hour, at a cost of 1s. 5d. per H.P., and such a holder could be applied to deal with the gas from a number of furnaces; in fact, the larger the number of furnaces, the less the necessity for the provision of storage, and the less the cost per unit of power.

In regard to chemical composition of the gases evolved, this varies with conditions of driving, purity of the ore, and class of fuel; but, for given materials, etc., there is not as great a variation in the gas as is common in many producer plants.

At a number of furnaces using hematite ore, limestone and Durham coke, taking samples each day for 38 days from 13 furnaces, the greatest difference as shown by the content of carbonic acid gas, was found to be as follows:—

PERCENTAGE BY VOLUME.

	CO_2.	CO.	H.	N.	Total.	B.Th.U. per cubic foot.*
I.	7·1	30·1	2·9	59·9	100	104·2
II.	10·3	29·7	0·9	59·1	100	97·3

* At 60 deg. Fah. and 30 in. bar., H_2O passing off at 212 deg. Fah.

Mr. Gayley, New York, has given particulars of the composition of the gases from the Isabella furnaces, where rapid driving with high-class ores gives a high proportion of carbonic acid gas.

While the writer has seldom found the furnace gases in this country, as well as some districts in Germany and France, to contain less than 25 per cent, by volume, of carbonic oxide, in the dry gas, Mr. Gayley quotes some results where much lower percentages have been obtained, of which the following are examples:—

PERCENTAGE BY VOLUME.

CO_2.	C O.	N. & H.	B.Th.U. per cubic foot, neglecting H.
16·0	23·2	60·8	74·70
13·0	20·6	66·4	66·33
12·6	25·8	61·6	83·07

* At 60 deg. Fah. and 30 in. bar.

At Seraing, Belgium, when experimenting with the first 200 H.P. gas engine, in 1895, the quantity of water employed for cleaning the gas was 6·6 gallons per B.H.P. per hour in the scrubbers, but then it must be borne in mind that the weight of dust carried by the gas at the point of application was lower than is usually found. This first engine was designed to work at a compression of 115 lb. per square inch, but later, with engines of 600 H.P., this was raised to 152 lb., which considerably increased the efficiency; the maximum pressure developed in the cylinder was about 218 lb., and the thermal value of the quantity of gas required to develop 1 I.H.P. per hour was 13,135 B.Th.U.

At Differdingen (1901), where a value of 0·51d. per 1,000 cubic feet was assumed, the total cost per H.P. hour, including labour, oil, gas, etc., amounted to 0·166d.; while at the same works a 60 H.P. gas engine was found to develop 80 H.P. on retort gas and 67 H.P. on blast furnace gas.

An approximate rule for ascertaining the weight of gases, at 32 deg. Fah. and 30 in. bar., is:—

$$\frac{\text{Molecular weight}}{4} = \text{cwts. per 10,000 cubic feet.}$$

In regard to the consumption of fuel in blast furnaces, air blast having a pressure of 3¼ lb. per square inch, gasified coal equivalent to 265 H.P. per square foot of combustion area.

With coke from Derbyshire coal and lean ores the gases had a thermal value per cubic foot of 121·66 per B.Th.U., and 88·7 cubic feet developed 1 I.H.P. in a gas engine in which the compression was 115 lb. per square inch.

The maximum initial pressure on the piston was 192·5 lb., and the m.e.p. 53·7 lb. per square inch

An example of the gases from furnaces using Cleveland ores and Durham coke is as follows:—

PERCENTAGE COMPOSITION BY VOLUME.

Carbonic acid, CO_2......	10·94	carbon per cub. ft. ·0116 lb.
Carbonic oxide, CO ...	23·84	
Hydrogen, H	2·34	
Nitrogen, N	57·33	
Water vapour, H_2O ...	5·55	
	100·00	

Weight per cubic foot, ·0796 lb. 1 ton of coke at 90 per cent carbon, and 1 ton of iron at 3½ per cent carbon, give 167.034 cubic feet of gas.

In the above analysis it will be observed that the water vapour has been determined; this is frequently omitted, owing to the more usual practice of analysing the gas in a dry state.

Cleveland gas, having a value of 98 B.Th.U. per cubic foot, when applied to a 742 H.P. gas engine, gave 1 H.P. for 109·7 cubic feet.

Mr. Greiner, Seraing, has given the cost of electrical power by blast furnace gas as £7 per k.w. year, or 0·21d. per B.O.T. unit.

From a large number of indicator diagrams taken from gas engines of various sizes, in five different districts, it was found that the maximum initial pressure ranged from 337 lb. to 238 lb. per square inch, and the mean effective pressure, maximum 58·4 to 75 lb., and minimum 31·5 to 49·5 lb. per square inch.

These figures show the very considerable range of mixture of air and gas which is capable of being effectively exploded when a high compression is employed.

According to calculations made by Mr. Scott, the heat value of Cleveland blast furnace gas, at a temperature of 600 deg. Fah., amounts to 19,592,536 B.Th.U. per ton of pig iron, and after providing for the heating of the furnace air blast in Cowper stoves, and raising steam for the blowing engines, there would be available for profitable power development 33·4 per cent of the total heat value given.

If gas blowing engines were installed in place of steam, then the available heat would be 47·7 per cent.

The sensible heat of the gas amounts to 9 per cent of the total.

The works cost per B.O.T. unit of electricity generated by blast furnace gas has been estimated as:—

	d.
Fuel	·042*
Oil, waste, water, &c.	·050
Wages	·011
Repairs and maintenance	·018
	·121

= £4 0s. 8d. per year of 8,000 hours.

* The value of cleaned gas was in this case taken at ¼d. per 1,000 cubic feet.

Refering again to the weight of dust carried by blast furnace gas, it was found at Seraing that *heavy dust* amounted to 0·81 per cent of the weight of the gas, and *light dust* 0·17 per cent, while in the case of Cleveland furnaces the weight of dust is about 0·1 per cent. In some German furnaces, where the gas was *washed*, it was found that it still carried 0·125 lb. to 0·182 lb. per 1,000 cubic feet, which clearly indicates the value of fine physical filtration, or other means of purification, before the gas is in a fit state to be used in an internal combustion engine.

In regard to the comparison between the cost of gas producer plant and a blast furnace capable of producing a similar quantity of gas, a producer plant of 12,500 B.H.P. capacity would cost about £43,000, while a blast furnace plant of about the same capacity would cost from

£28,000 to £38,000. The above costs do not include buildings and other such requirements, as these would to a certain extent, be common to both.

A moderate sized blast furnace is capable of an output of 500 tons of pig iron per week (modern furnaces are designed for an output of double and treble this amount), and usually the weight of coke consumed is about the same as that of the iron produced.

Reducing this to hours, we have approximately:—

Coke consumed per hour	3 tons.
Volume of gases evolved per hour...	510,000 cubic feet.
Gas used in stoves and boilers	266,730 ,,
Loss during charging, &c............	51,000 ,,
Gas available	192,270 ,,
Gross horse power at 100 cubic feet, at full load........................	1,922 horse power.

The figure 1,922 H.P. represents the power which could be developed by gas engines working at maximum load, but while this would be the maximum power of the engines, the actual output of a power station would be nearer half load, and calculations in regard to renumerative application should be based upon 960 H.P. An approximate calculation, by the writer, gives the maximum horse power available from a blast furnace equipped with firebrick air-heating stoves and steam-driven blowing engines, etc., as 3·3 times the weekly output of pig iron in tons of the furnace.

The purification of blast-furnace gas preparatory to its application to gas-engine driving was first attempted by Mr. B. H. Thwaite in 1894, and the Thwaite-Gardner patented system included the following treatment of the gas as it was delivered from the furnace gas flues in a heated and dusty condition:—

1. Washing the gas in an apparatus arranged to cause the hot gas to come into contact with water by passing under and over diaphragms, the lower edge of each alternate one being slightly below the level of the water, and provided with a framework with wire netting stretched over it, and through which the gas was broken up into streams and mingled with the water.

In this apparatus the gas becomes somewhat cooled, and the heavier particles of dust intercepted, falling to the bottom of the tank in the form of mud.

The wirework frames were hinged and arranged to be agitated, by hand, at intervals, as they become coated with sludge, and a water-sealed trough at the side permits of the withdrawal of the settled deposit at convenient intervals without interrupting the flow of the gas.

2. Cooling the gas is effected, in the next stage by causing it to traverse pipes which are exposed to the atmosphere, while the base is so arranged that condensed water and mud can flow away continuously through a seal pipe.

3. To draw the gas through the washer and cooler an exhauster blower is introduced at this stage, as owing to the preliminary washing and cooling of the gas it would be more efficient than if applied to the gas while in a highly heated condition, and as the gas has to be further treated in apparatus which would offer frictional resistance, the operation of suction and propelling would be about equally divided.

As, at this stage, the gas still carries more or less dust in suspension, which the centrifugal action of the fan separates, water jets are applied to keep the fan flushed and clean; the water passes out through sealed pipes carrying a high proportion of the fine fume and water accompanying the gas.

4. The gas is next propelled by the fan through coke scrubbers of the usual type, the gas travelling upwards through broken coke, or other available material, which is kept moist with a spray of water. As the gas enters at the bottom and the water passes in the reverse direction, the fine dust deposits in the lower layers of the coke; doors are provided so that at intervals the lowest portion of the coke can be extracted and a similar proportion added through a manhole at the top, thus minimising the handling of the cleaning material.

5. To further remove any traces of tar or fumes and to dry the gas from any supersaturating moisture, it is next passed through a fine physical filtering apparatus,

containing sawdust, wood shavings, or other available material.

6. After passing the above-described purifiers the gas now enters a gas governor holder, in which the pressure is not only regulated so that the gas engine is not subjected to the variations in pressure which take place in the furnace flues, but also a further cooling and condensation takes place, with the result that the gas delivered to the engine is free from supersaturation and at a temperature below that of the surrounding atmosphere.

Fig. 81 shows a typical arrangement of a Thwaite-Gardner purification plant applied to a gas-driven blowing engine.

The inlet valve to the washer is connected by a pipe to the furnace flue, and the scrubbers are provided in duplicate to permit of the purifying material being renewed as required without causing any interruption to the running of the engine.

In the engine-house the supplementary small gas engine is for starting purposes, while the fan is driven by a belt and countershaft from the main engine.

Several plants of this system have been put down in this country, which have given very satisfactory results.

Shortly after the publication of Mr. Thwaite's invention, the Cockerill Company, of Seraing, Belgium, commenced experiments in the same direction, and applied the gas from their furnaces to an engine of 200 horse power; the cleaning of the gas was not attempted for reasons which will be given later, and the results obtained with the 200 horse power engine were so satisfactory that single-cylinder 600 horse power engines were designed and put to work.

It so happened, at this particular works, that the proportion of dust in the gas leaving the furnaces was considerably lower than is usual in many other ironmaking districts, but, besides this, the arrangement of the works made it necessary for the gas-engine station to be situated at a considerable distance from the furnaces, the gas having to be conveyed through a long system of tubing. This tubing to some extent fulfilled the require-

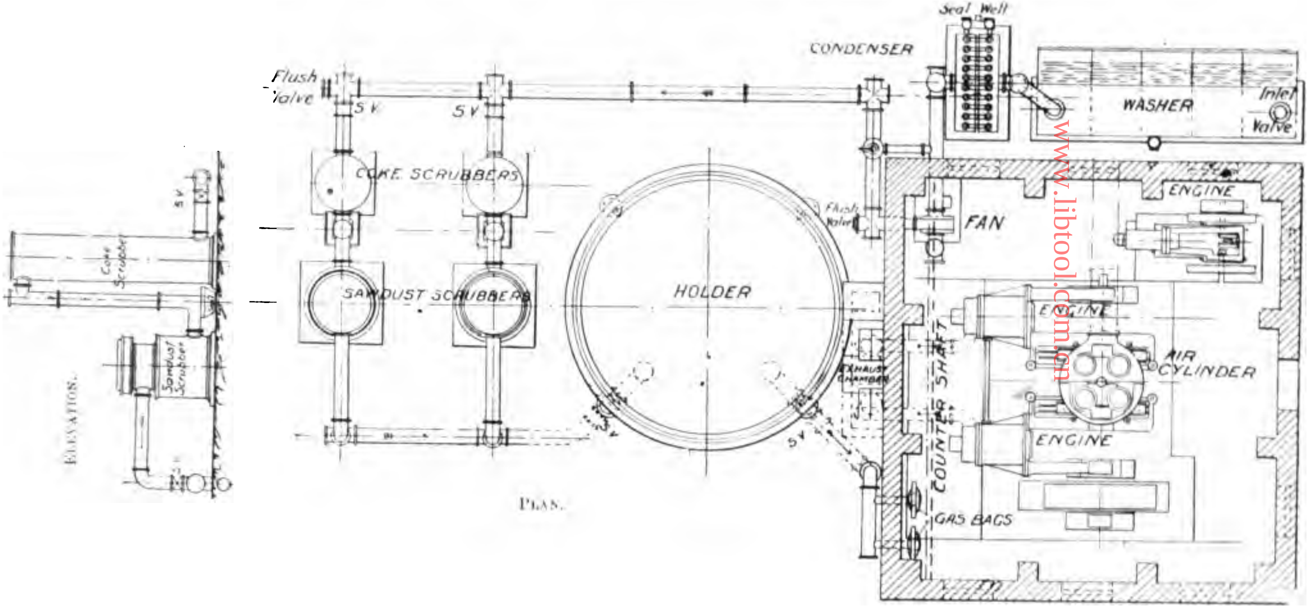

FIG. 81.—Blast Furnace Gas Purification Plant (Thwaite-Gardner Patents).

ments as proved necessary, for the gas became cooled in transmission to the engines, and the condensation of the water vapour deposited the dust to a considerable extent.

Besides the usual dry-dust arresters there was about 220 yards of tubing, and water sprinkling was applied close to the engine. The Cockerill Company therefore devoted themselves to developing gas engines of large power units, and neglected the perfection of cleaning apparatus. The published results of the success obtained in this direction, at Seraing, considerably misled many ironmasters, and several gas engines were installed not provided with cleaning plant, or only very inefficient ones. It was shortly found that satisfactory running could not be obtained unless the gas was cleaned, and the problem was attacked in different ways.

Mr. Cecil A. Cochrane, of Messrs. Cochrane and Company Limited,* and Mr. H. G. Scott, engineer to the firm,† have given their experience of the application of Cleveland blast-furnace gas to 600 horse power Simplex gas engine.

In the first place, they carefully ascertained that the engine would work on gas such as was given off from their furnaces; then, in regard to the gas, they decided that the following two conditions must be satisfied:—

1. The gas must be cooled to about 68 deg. Fah.
2. The gas entering the engine must not contain more than 0·0156 lb. of dust per 1,000 cubic feet.

After due consideration in regard to the best method of cooling, it was decided to "erect a new main the whole length of our works, and to use an old hot-blast stove to increase the travel of the gas and act as a cooling reservoir."

In some experiments in this connection it was ascertained that if gas with an initial temperature of 500 deg. Fah. was passed through a tube 5 ft. 6 in. diameter at a velocity equal to that required to provide the volume of gas to the

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* "The Use of Blast Furnace Gas in Gas Engines." A paper by Mr. Cecil A. Cochrane read before the Cleveland Institution of Engineers, December, 1902.

† "Blast Furnace Gas Engines and Steam Engines," by Mr. H. G. Scott, *Engineering*, May, 1903.

engine, the loss in temperature per square foot of surface would be 0·08 deg. Fah., so, as the amount of water otherwise necessary to effect the cooling of the gas was not available, this method of cooling was adopted, the gas being made to travel through 1,120 ft. of tubing. In the absence of a pressure governor gas holder, while the engine was only drawing gas from one furnace the fluctuations of pressure were felt by the engine, so a connection was made to two other furnaces.

Starting with the gas at the bottom of the furnace downcomer, where the temperature ranged from 510 deg. Fah. to 710 deg. Fah., the average loss in temperature was found to be as follows: Before entering the stove, 286 deg. Fah.; after leaving the stove, 211 deg. Fah.; before entering fan, 70 deg. Fah.; after leaving fan, 6 deg. Fah.; in engine-house, 0 deg. Fah.

Mr. Cochrane, in referring to the cleaning of the gas, said: "In approaching the problem of how to clean the gas . . . we never had any hesitation in adopting the 'dynamic' method of cleansing, as it is called, in preference to the static method; the former being cheaply applied, very efficient, and occupying little space, this being of great importance at our works."

However, in this connection, it will probably be allowed that the 1,000 ft. of tubing would *statically* cleanse the gas to a considerable extent, so that the gas-treatment plant employed can hardly be included under the term dynamic.

Further cleaning being necessary centrifugal fans were adopted. With one fan, running at 1,100 to 1,150 revolutions per minute, the amount of dust was reduced to between 0·002 lb. to 0·0046 lb. per 1,000 cubic feet, while with two fans the dust was brought down to 0·0015 lb. in some instances, water being applied at the rate of 420 to 500 gallons per hour.

The first fan with water required 16 horse power; the second fan with water required 10 horse power; total for the two fans, 26 horse power; pressure of gas in mains, 3 in. of water; pressure of gas at engines, 10 in. of water.

Although the centrifugal fan enters into most systems of gas purification, as it is generally necessary to employ some such apparatus to withdraw the gas from the furnace flues and deliver it through the other apparatus under pressure, and the centrifugal action causes the deposition of a considerable proportion of dust, it has not been found sufficiently effective to dispense with filtering methods.

Also, it is not advisable to apply a centrifugal fan to gas of very high temperature owing to low density of the gas under these conditions, and the removal of dust by means of this apparatus while the gas is in a heated state would necessitate the employment of a considerable volume of water.

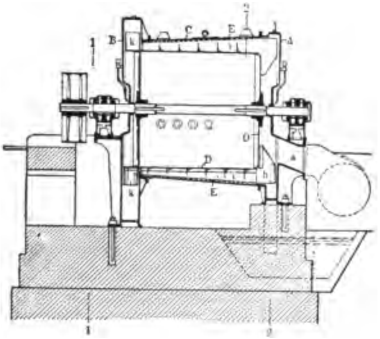

Fig. 82.—Thiesen Gas Washer.

M. Thiesen, of Munich, has patented a centrifugal apparatus for purifying blast-furnace and other gases, the arrangement of which is shown in figs. 82, 83, 84, and 85. The essential parts consist of—

A, the suction chamber;
B, the pressure chamber;
C, the middle chamber;
D, the drum shaft and bearings;
E, the grating.

Water jets are provided at F, and the pipe G conducts the used water away.

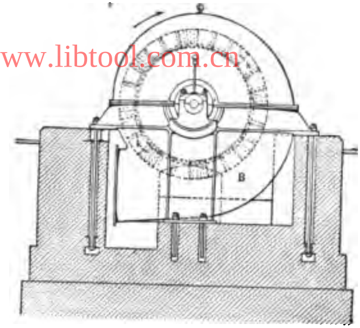

FIG. 83.—Thiesen Gas Washer.

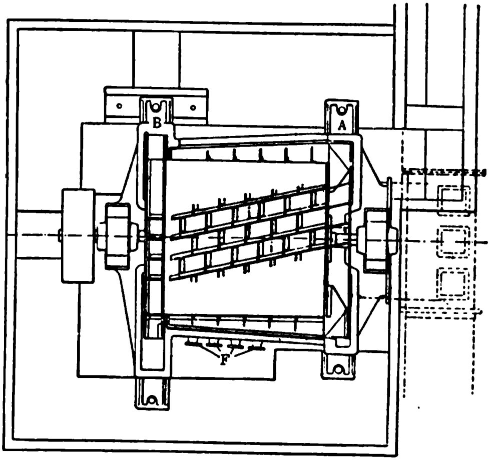

FIG. 84.—Thiesen Gas Washer.

The gas, in a *cooled* and *water-charged condition*, is drawn by the suction set up by the vanes into the suction chamber A, where coarse dust is arrested, and the gas is caused to traverse the space between the drum and the casing by the action of the vanes at each end, while the number of inclined spiral vanes on the circumference of the drum cause the travel of the gas to be prolonged; the injection of water at the points indicated condenses the water vapour and deposits the dust, which is precipitated against the coarse grating E fixed to the interior of the casing. The centrifugal action causes the water to cleanse the grating and prevent its becoming clogged with deposited dust.

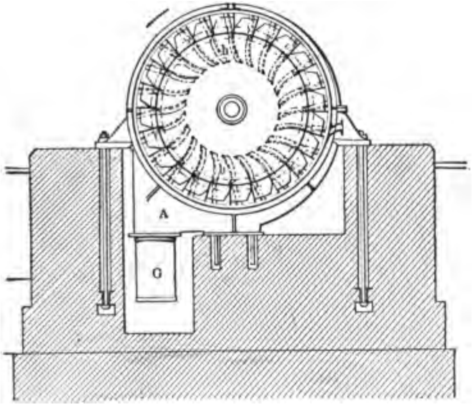

Fig. 85.—Thiesen Gas Washer.

The speed of revolution of the apparatus ranges from 300 to 450 per minute, and a consumption of water per 1,000 cubic feet of 40 to 74 pints is said to reduce the dust from 0·1875 lb. to 0·25 lb. per 1,000 cubic feet to 0·00125 lb. to 0·001875 lb.

The capacity of the sizes generally used ranges from 211,800 to 1,164,900 cubic feet per hour, and the power from 0·236 to 0·129 electrical horse power per 1,000 cubic feet.

Another type of centrifugal fan purifier (R. W. Dinnendahl, Steete) is shown in fig. 86, which consists of a strongly-constructed fan provided with water injection at the suction side, and an arrangement for pulverising the water to form a curtain through which the gas is caused to pass, and the deposited dust is carried by the water into the tank A, from which the sludge flows away.

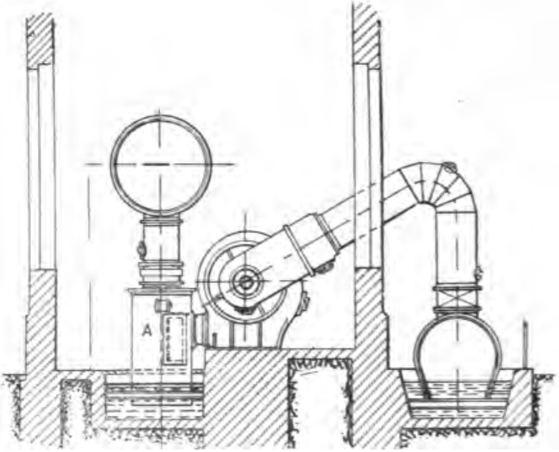

FIG. 86.—Dinnendahl Gas Washer.

These fans are made to deal with 519,500 to 2,471,000 cubic feet of gas per hour, and the power required ranges from 0·077 to 0·0445 horse power per 1,000 cubic feet. The tip speed is about 183 ft. per second, and the diameter from 3·6 ft. to 5·7 ft.; the water required per 1,000 cubic feet is from 9·43 gallons to 12·57 gallons, and the dust is reduced to 0·0125 lb. per 1,000 cubic feet usually.

The discovery that almost any type of centrifugal fan employed to draw the gas from the furnace flues and transmit it to the engines, through the tubing, scrubbers, etc., arrested a very considerable amount of fine dust, which, if not washed out with water, rapidly clogged up the machine, induced many engineers to devise fans specially suited for depositing the accumulated dust and provided with special flushing apparatus to carry away the dust-laden water and allow of continuous running.

However, the fan (of either high or low purifying efficiency) only forms an item in the complete gas-cleaning plant, for previous to the gas entering the fan it must be cooled somewhat, denuded of the greater part of the mechanically carried heavier earthy particles of dust, as well as being, by preference, saturated with water. Further, the gas, on leaving the fan, usually carries too much fine fume to allow of its direct application to gas engines, so the provision of some type of scrubbers is usually adopted. Each blast furnace requires the special local considerations, including the class of ore, fuel, and flux, together with the dust-catching apparatus associated with the furnace, and the distance between the furnace and the site of the gas-engine power house. The amount of dust varies so considerably that while in some cases, as at Seraing, Belgium, the ordinary dust catchers, water-spraying apparatus, and the length of tubing required to convey the gas to the engine site, so reduced the dust content that the engines were able to run for reasonable periods between cleaning stoppages; in other cases fans in duplicate were not sufficient alone, and had to be supplemented with about one-fifth of a mile of tubing and an old stove casing fitted with deflecting diaphragms, as was the case at the Middlesbrough furnaces of Messrs. Cochrane and Company.

To illustrate this point, the gas-treatment plant at some Belgian furnaces is shown in fig. 87,* where for a power installation of 4,600 horse power three Lencauchez fans E draw the gas from the main gas through a set of scrubbers D, and forces it through drying apparatus G and regulator K. Three auxiliary gas producers A provide gas during periods when the supply from the furnaces should be interrupted from any cause.

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* *The Iron and Coal Trade Review*, February 20th, 1903.

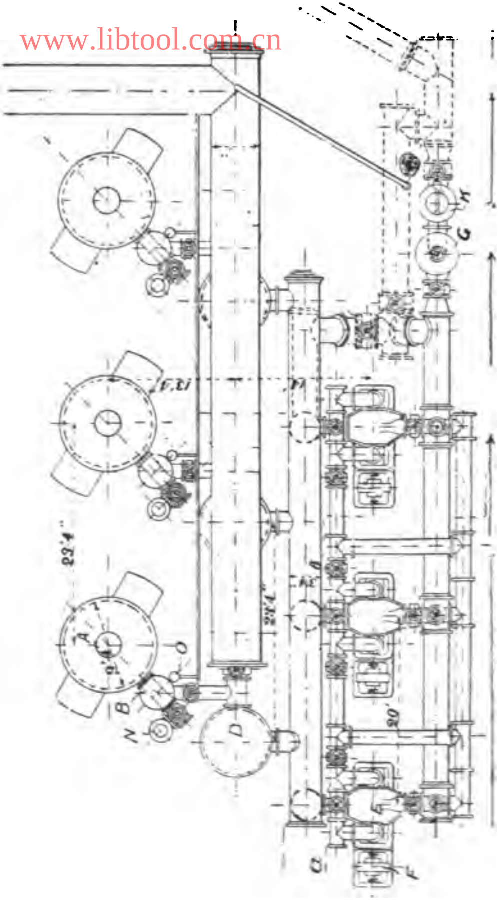

FIG. 57.—Plan of Gas Producers, Scrubbers, and Cleaning Fans of 4,600 H.P. Plant.

While troubles in the gas engine, from the deposition of dust, are reduced to a minimum if the content of dust is reduced to 0·0015 lb. per 1,000 cubic feet, the cost of the purification plant required to accomplish this will depend upon various contributing conditions, and must be estimated separately for each application.

It has been estimated in one case that a plant of a capacity to deal with 1,000,000 cubic feet per hour would cost £6,700, while in another instance the estimate was as high as £20,000 for the same capacity.

Coke Oven Gas.

Although the coke oven can hardly be brought into line for comparison as a gas producer, the large volumes of rich gas evolved in the coking of coal for employment in blast furnaces, and which is suitable for employment in gas engines, renders a treatise upon producer gas and its applications hardly complete without a reference to this source of power.

The coke oven, as a gas producer, occupies a position between the retort system adopted for making coal (or town's) gas, and the system of partial combustion of the fuel.

The 60,000,000 tons of coal yearly treated in coke ovens preparatory to its application to the smelting of iron for the world's requirements release a highly combustible rich gas, amounting to over 11,000 cubic feet of gas for each ton of coal coked, having a thermal value per cubic foot of 483 B.Th.U., and 29·31 cubic feet is capable of developing 1 horse power.

Mr. F. Schmewind, Ph.D., of New York, in 1901, gave the following figures for the heat efficiency of gas-making processes:—

	Energy wasted. Per cent.		Energy utilised. Per cent.
1. Carburetted water-gas process………	30·0	…	70·0
2. Gas benches, average ………………	24·8	…	75·2
3. Otto-Hoffmann ovens, Dominion coal	10·9	…	89·1

Taking the case of a range of coke ovens capable of an output of 1,050 tons of coke per week, the hourly products would be :—

Coke at 70 per cent yield 6 tons = 8·57 tons coal; at 9,535 cubic feet of gas per ton the total gas per hour would be 81,700 cubic feet, and allowing 60 per cent for heating the ovens, the available volume would be 32,680 cubic feet.

At a thermal value of 540 B.Th.U. per cubic foot, and allowing 25 cubic feet per effective horse power per hour, the equivalent effective horse power = 1,307. In coke oven practice the old method of providing the heat required for the distillation of the volatile gases from the coal was by the combustion of a portion of the coal itself; this was followed by an improved type of oven in which some of the distilled gas was arranged to be ignited in flues surrounding the oven proper. Further, the value of the by-products tar and ammonia attracted attention, but still there was found to be a considerable amount of gas not utilised, and which could be employed for raising steam in boilers, and later, by the more economical applisation to gas engines to develop power. As the modern type of oven includes a regenerative method of heating the air employed to burn the gas in the flues to carry out the distillation process, this increases the thermal efficiency of the system.

Most instructive information in connection with the coking of coal in by-product ovens has been furnished by tests made by Dr. Schmewind, at Glassport, Pa., which appeared in *Power*, March, 1905.

Coal having an average composition of :—

	Per cent.
Volatile hydro-carbons	34·6
Fixed carbon	59·56
Ash	5·84
	100·00

took 34 hours and 54 minutes to coke a charge of 6½ tons. The chemical composition of the distilled gas was found to vary from start to finish, marsh gas being rapidly evolved at first, and in diminishing proportion as the time of coking proceeds, falling very rapidly after 20 hours. Hydrogen gas, on the contrary, gradually increases up to about the same period, when it increases in about the same ratio that the CH_4 falls off. The total volume of gas distilled per long ton of dry coal was 10,390 cubic feet, and the volume and thermal value of this gas is given in the diagram, fig. 88, reproduced from *Power*.

The heat value of the coking operation is shown in the following table:—

100 lb. of dry coal yields	B. Th. U. per lb.	Total thermal power.	Per cent of thermal power of dry coal.
71·13 lb. coke	12,645	899,456	72·3
3·38 lb. tar	12,210	51,410	4·1
229·6 cubic feet surplus gas ..	Per cub. ft. 686	157,504	12·7
234·2 cubic feet heating gas ..	567	132,835	10·7
Ammonia liquor, sulphur in purifier, and loss	....	2,496	0·2
Total = 100 lb. dry coal	....	1,243,700	100·0

The recovery of the by-products necessitates the cooling and scrubbing of the gas, but though it is necessary to remove the tar and ammonia previous to the application of the gas to driving gas engines, the commercial value of these by-products more than pays for this purification, so that the surplus gas, when applied to gas engines, is free of charges. Taking coal at 12s. 6d. per ton, the coke at 16s. 8d., and 1s. 5½d. per 1,000 cubic feet for the surplus gas, the figures given above show that the coke value would be 12s. 0½d., and the gas 6s. 8d., so that the value of these two items alone amounts to 18s. 8½d., as against the cost of the coal of 12s. 6d., and to this would have to be added the value of the tar, etc., from which it will be seen that coking coal in by-product ovens is in itself a profitable trade. Ovens 43 ft. long can coke a charge of 8 tons in 24 hours, and the average output of surplus gas per hour would amount to 1,530 cubic feet, which at 686 B.Th.U. = 1,049,580 B.Th.U.

With a gas engine of 25 per cent efficiency, 10,180 B.Th.U. would represent 1 horse power hour, so that each oven would supply gas equivalent to 103 horse power, or about 13 horse power per ton of coal coked, and this is based only upon the gas in excess of any requirements of the oven itself. Even with this rich gas a compression of 120 lb. per square inch can be applied, and the initial explosive pressure is about 350 lb.

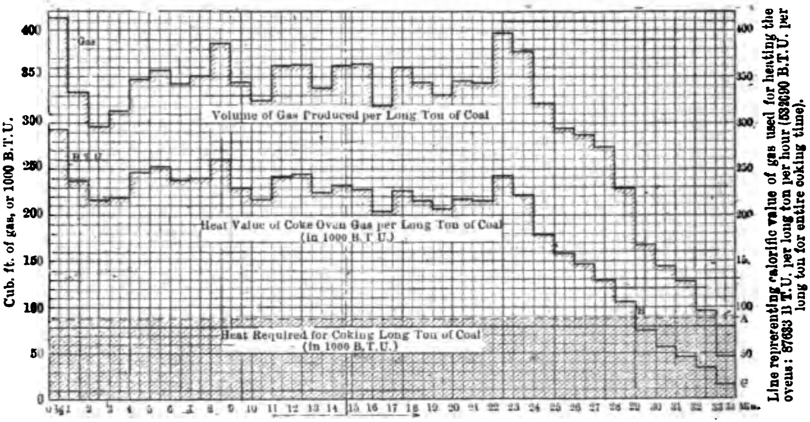

FIG. 88.—Volume and Thermal Power of Coke-oven Gas.

According to Mr. George Beilby, the amount of bituminous coal coked in the year 1898 was: In bee-hive ovens, without recovery of by-products, 12,500,000 long tons; in ovens, with recovery of gas, 3,250,000 long tons; of which 1,250,000 tons was coked in by-product ovens.

In fig. 89 is shown a sketch plan arrangement of gas treatment plant as employed in connection with coke ovens (United Coal and Gas Company, U.S.A.).*

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* F. Schmewind, Ph.D., Gas Section, Engineering Congress, Glasgow, and reproduced from the *Iron and Coal Trades Review*.

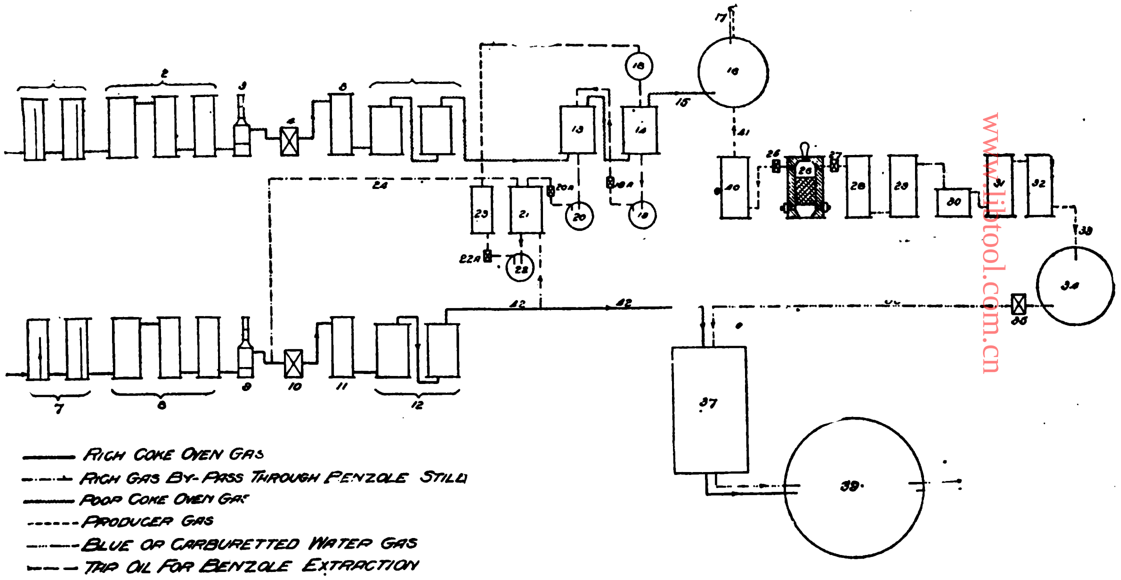

FIG. 89.—Arrangement of Gas Plant for Coke Ovens (United Coal and Gas Co.).

Description:—

1 and 7. Air coolers.
2 ,, 8. Multitubular water coolers.
3 ,, 9. Tar extractors.
4 ,, 10. Exhausters.
5 ,, 11. Second coolers, intended to remove the heat due to compression in exhausters.
6 ,, 12. Ammonia washers.
42. Pipe leading rich gas freed from tar and ammonia to purifying plant 37.
37. Purifying plant.
39. Holder for rich gas for illuminating purposes.
13 and 14. Benzol scrubbers for treating the poor gas after it has had the tar and ammonia removed in 6.
15. Pipe leading to gas holder 16.
16. Gas holder for poor gas for heating purposes.

The tar-oil by which the gas is washed runs first from tank 18, through the second benzol scrubber 14, into tank 19; from here it is delivered by pump 19A into the first benzol scrubber 13.

The tar-oil enters from tank 18 with about 5 per cent of benzol, and finally leaves washer 13 with about 15 per cent benzol; it is collected in tank 20. From tank 20 it is fed by pump 20A into still 21, in which the benzol is reduced again to about 5 per cent; 22 is a tank for exhausted oil, which pump 22A delivers into the oil cooler 23, from whence it passes to tank 18 for new absorption.

26. Auxiliary gas producer.
25 and 27. Valves.
28. Carburettor.
29. Superheater.
30. Washer.
31-32. Condensers.
34. Relief gas holder.
35. Exhauster for passing the carburetted water gas into the purifying plant 37. and thence to gas holder 39.

When the producer is being heated up valve 25 is opened, and the gas passes through the scrubber 40 into the oven-fuel gas holder 16.

When hot enough valve 25 is closed and valve 27 is opened while steam is blown through the generator; the resulting blue-water gas passes through the entire set of apparatus 28 to 32.

DOMINION COAL COKED IN OTTO-HOFFMANN OVENS.

	Average percentage composition by volume.	
	Rich gas produced in first 14 hours.	Heating gas produced in remaining 19 hours.
$C_m H_n$	5·2	2·4
CH_4	38·7	29·2
H_2	38·4	50·5
CO	6·1	6·3
CO_2	3·6	2·2
O_2	0·3	0.3
N_2	7·7	9·1
	1·000	100·0

CHAPTER XIV.

THE APPLICATION OF GASEOUS FUEL TO INTERNAL-COMBUSTION ENGINES.

A REFERENCE to the tables relating to the properties of gaseous fuels will show that, although there are a number of gases and compounds of combustible and incombustible gases which are available for use in gas engines, the heat of combustion of mixtures of these gases with air, in the proportion to form a perfect mixture, does not vary in anything like that of the initial richness of the gas. Not including acetylene gas, the heat power of perfect mixtures ranges from 58·2 B.Th.U. to 97·2 B.Th.U.

HEAT OF COMBUSTION OF GASES IN GAS ENGINES.*

Gas.	Average Volumetric Analysis.						Heat of combustion per cub. ft. at 60 deg. Fah. 14·7 lb. Lower.	Cubic feet of air per cubic foot of gas. Perfect mixture.	Heat of combustion per cub. ft. of perfect mixture. Lower.
	CO_2.	N_2.	CO.	H_2.	CH_4.	Unsaturated Hydro carbons as C_3H_6.			
							B.Th.U.		B.Th.U.
Illuminating gas	0·02	0·03	0·05	0·45	0·40	0·05	622·1	6·159	86·9
Coke oven gas	0·02	0·18	0·03	0·57	0·19	0·01	364·7	8·487	81·3
Siemens' producer air gas	0·04	0·62	0·23	0·08	..	0·03	165·4	1·406	68·7
Water gas	0·03	0·04	0·44	0·49	..	..	278·2	2·220	86·4
Producer gas, anthracite	0·07	0·47	0·27	0·18	..	0·01	160·3	1·296	69·8
Producer gas, vituminous	0·04	0·50	0·22	0·20	..	0·04	218·3	1·890	75·5
Natural gas	..	0·08	..	0·02	0·90	..	830·8	8·721	85·4
Blast furnace gas	0·10	0·58	0·30	0·02	..	..	102·7	0·764	58·2
Oil gas	..	0·07	..	0·31	0·46	0·16	874·1	8·727	89·9
Acetylene gas, pure	..	..	..	..	..	..	1483	12·250	111·9
Carburetted air, or gasolene gas, 2 gallons per 1,000 cub. ft.	..	..	..	..	..	..	214·2	1·203	97·2
Pure gasolene vapour	..	..	..	..	..	..	..	..	97·2
Pure kerosene vapour at 150 deg.	..	..	..	..	..	..	2526	31·11	78·7
Taylor anthracite, average	0·084	0·527	0·183	0·174	0·026	..	131·3	1·075	63·3
Taylor anthracite, minimum	0·091	0·569	0·160	0·152	0·023	..	115·0	0·943	59·2

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* Best obtainable average values, Sandford A. Moss in *American Machinist*.

GASES AND VAPOURS, ELEMENTARY AND COMPOUND.*

Name of gas.	Chemical formula.	Density and weight of 1 cubic foot. Density.	Weight of. 32 deg. Fah.	1 cub. ft. at 30 in. bar. 60 deg. Fah.	Heat of combustion per cub. ft. at 60 deg. Fah. and 14·7 lb. per square inch. Lower. B.Th.U.	Cubic feet of air for perfect combustion of 1 cub. ft. of gas.	Heat value of perfect mixture per cubic feet. B.Th.U.
Air, atmospheric	Molecular	14·422	0·0807	0·0761	*	*	*
Nitrogen	N_2	14·020	0·0786	0·0742	....	....	....
Oxygen	O_2	15·960	0·0894	0·0844	....	....	....
Hydrogen	H_2	1·000	0·0056	0·0053	277	2·389	81·7
Carbonic oxide	CO	13·965	0·0781	0·0739	324	2·386	95·7
Carbonic acid	CO_2	21·945	0·1234	0·1163	....	....	....
Marsh gas	CH_4	7·985	0·0447	0·0422	917	9·637	86·2
Acetylene gas	C_2H_2	12·970	0·0727	0·0703	1483	12·25	111·9
Olefiant gas	C_2H_4	13·970	0·0783	0·0740	1542	14·61	98·8
Ethane gas	C_2H_6	14·970	0·0837	0·0792	1611	17·35	91·1
Propylene gas	C_3H_6	20·955	0·1173	0·1111	2289	22·21	98·6
Propane gas	C_3H_8	21·955	0·1228	0·1161	....	....	....
Butelyne gas	C_4H_8	24·940	0·1562	0·1478	2968	29·59	97·0
Butane gas	C_4H_{10}	28·940	0·1651	0·1562	....	....	....
Amylene gas	C_5H_{10}	34·975	0·1946	0·1841	....	....	....
Pentane gas	C_5H_{12}	35·925	0·2011	0·1902	....	....	....
Hexane gas	C_6H_{14}	42·910	0·2406	0·2276	4525	45·40	97·5
Benzine gas	C_6H_6	38·910	0·2235	0·2115	3675	36·96	96·8
Carbon disulphide	CS_2	37·965	0·2131	0·2016	....	....	....
Water vapour	H_2O	8·980	0·0502	0·0476	....	....	....
Hydrogen sulphide	H_2S	16·990	0·0949	0·0899	....	....	....
Ammonia	NH_3	8·505	0·0476	0·0450	....	....	....
Cyanogen	CN	12·990	0·1453	0·1375	....	....	....
Chlorine	Cl_2	35·500	0·1983	0·1876	....	....	....
Sulphur dioxide	SO_2	31·950	0·1814	0·1716	....	....	....
Nitrous	N_2O	21·990	0·1232	0·1166	....	....	....
Nitric oxide	NO	14·985	0·0838	0·0793	....	....	....

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* Sandford A. Moss, *American Machinist*,

Thermal Value of Combustible Gas per Cubic Foot, at Atmospheric Pressure.

Temperature Fah.	32		60	
Name of Gas.	B.Th.U.		B.Th.U.	
	Gross.	Available.	Gross.	Available.
Hydrogen, H_2	344*	294*	330	282
Carbonic Oxide, CO	342*	342*	319	319
Marsh Gas, CH_4	1072*	964*	1010	908
Olefiant Gas, C_2H_4	1677*	1573*	1585	1490
Benzene, C_6H_6	4150	4000	3933	3790

* Julius Thomsen.

Whatever gas is to be employed for power development, there are a number of conditions tending to economy and efficiency which, though outside the range of the method of gas production, are associated with the practical application.

(1) The compression of the explosive mixture has an important effect upon the thermal efficiency, and should be carried as high as the quality of gas will permit without risk of premature ignition.

(2) Piston speed is one of the factors determining the power output of an engine of a given size, and as speed of rotation may be said to cost nothing, this method of reducing the cost of the motor is of great importance.

(3) Cost of gas engine and floor space required is influenced by the two foregoing factors, while for electrical generator driving the higher the speed of revolution the less the size and cost of the dynamo.

For marine purposes also the reduction of the proportions and weight of the engine are qualifications much to be desired.

To give an example illustrating the points above referred to, we may take the "Hindley" vertical high-speed gas engine, fig. 90. By adopting the vertical arrangement in place of the usual horizontal type of engine there is a direct economy in floor space. By carrying the compression up to about 156 lb. per square inch the thermal efficiency is brought up to a very high point; while the

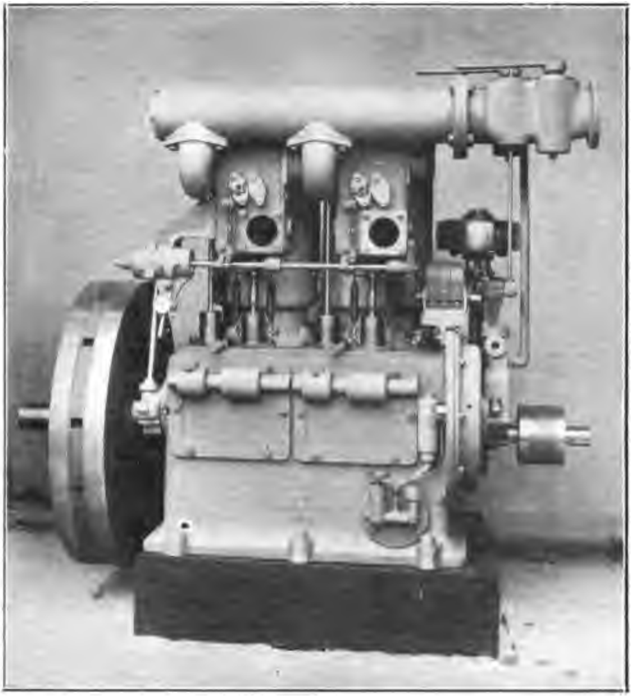

Fig. 90.—Hindley Vertical High-speed Gas Engine.

piston speed adopted of 700 ft. per minute renders the power of the engine high in proportion to its dimensions—the high compression bringing the maximum initial pressure to between 328 lb. and 406 lb. per square inch.

Increase of speed of rotation, further, reduces the weight of flywheel required to give any required cyclic regularity, and dispenses with the necessity for belt or rope connection for driving dynamos; while the combination of the engine and dynamo, direct coupled, upon one substantial bed plate, and the perfect balancing, are very serious advantages in all installations, and also in respect to the transportation by rail or ship.

Compared with slower-running horizontal types of gas engines, the floor area is only about one-fourth, while the silencing of the exhaust can be more readily effected for small cylinders.

There are certain mechanical details, upon the perfection of which the successful design of gas engines of the vertical type are dependent, which do not come within the scope of this work, but are receiving the attention of manufacturers, such as perfect lubrication, accessibility for cleaning, etc.

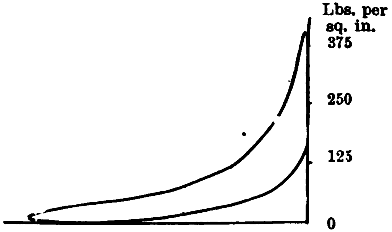

Fig. 91.—Diagram from Hindley Vertical Two-cylinder Gas Engine.

However, the type of vertical high-speed engine requires the gas to be delivered to it free from dust and condensable matter, and for high compression the combustible should consist of those gases which have the highest ignition point and least tendency to pre-ignition.

Fig. 91 shows an indicator diagram taken from a Hindley vertical two-cylinder gas engine, running at 600 revolutions per minute, cylinder diameter 7 in., stroke 7 in., and developing 15 indicated horse power. This engine is suitable for using gas made in the Hindley suction gas producer, a sectional view of which is given in fig. 92.

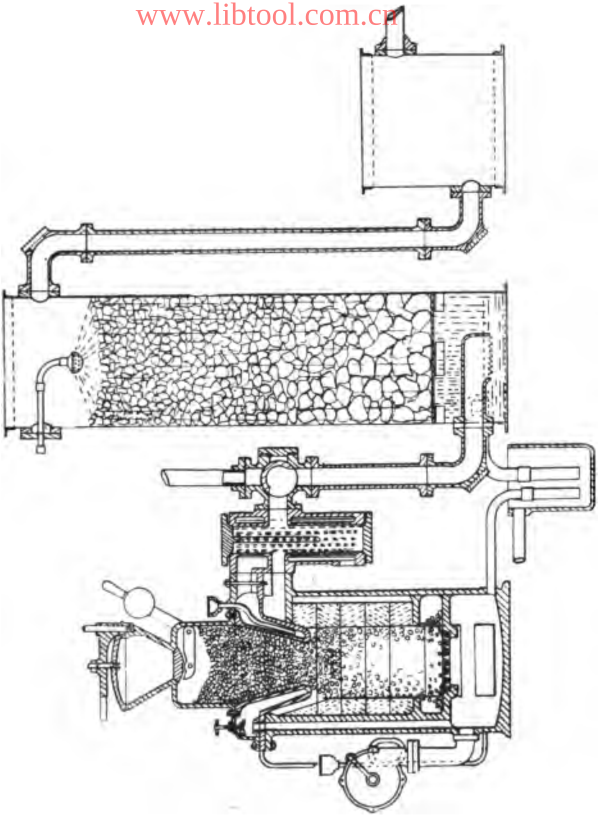

Fig. 92.—Section through the Hindley Suction Gas Producer.

IGNITION TEMPERATURES OF COMBUSTIBLE GAS WITH OXYGEN.

Average Results obtained by various Investigators :—

	Deg. Fah.
Propylene, C_3H_6	940
Propane, C_3H_8	1,017
Acetylene, C_2H_2	1,038
Hydrogen, H	1,077
Ethane, C_2H_6	1,141
Olefiant gas, C_2H_4	1,124
Marsh gas, CH_4	1,212
Carbonic oxide, CO	1,253

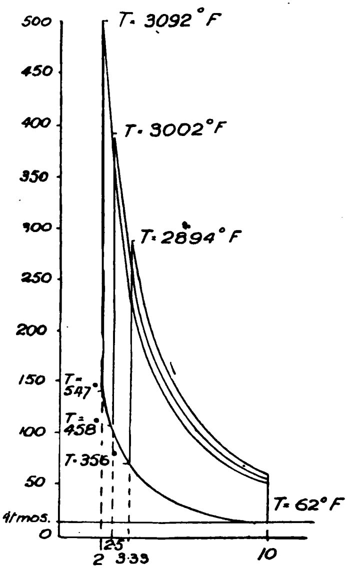

FIG. 93.—Diagram from Otto Cycle Air Engine at Different Compressions.

The effects of different compressions in the development of heat in constant volume engines working on the Otto cycle has been very clearly explained by Dugald Clerk,* and fig. 93 shows a range of three diagrams in which the heat additions are equal, but with different compressions.

The following particulars relate to results which would be obtained in an ideal engine, without heat losses of any kind, working with air of a constant specific heat:—

	Maximum pressure per sq. in.	Mean pressure per sq. in.	Efficiency.
$\frac{1}{r} = \frac{1}{5}$	500 lb.	105 lb.	·48
$\frac{1}{r} = \frac{1}{4}$	391 lb.	101 lb.	·43
$\frac{1}{r} = \frac{1}{3}$	287 lb.	97 lb.	·36

Calculating on the formula,

$$E = 1 - \left(\frac{1}{r}\right)^{\cdot 408}$$

the following efficiency values were obtained :—

$\frac{1}{r}$	E
$\frac{1}{2}$	·246
$\frac{1}{3}$	·36
$\frac{1}{4}$	·43
$\frac{1}{5}$	·48
$\frac{1}{7}$	·55
$\frac{1}{10}$	·61
$\frac{1}{20}$	·70
$\frac{1}{100}$	·85

The temperature due to compression rises rapidly as the clearance space is reduced, and in practice the increasing of compression carries with it the problem of prevention of premature ignition, and it is found that such gas as that which issues from blast furnaces, in which there is only a very low proportion of hydrogen and the combustible portion consists principally of carbonic oxide, compression can be carried much higher than is the case when combustible gases of low ignition points are present.

Further, the explosive properties of gases are influenced by the presence of dust, even if this is incombustible, and it has been found that fire damp (chiefly CH_4) is explosive in the presence of mineral dust, when only forming 2 per

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* "Internal Combustion Engines." By Dugald Clerk, M.Inst.C.E. Cantor Lectures, Society of Arts, 1905.

cent of the mixture, while Eithner has found the explosive limits of various gases with air to be by volume—

	Lower limit. Per cent.	Higher limit. Per cent.	Explosive range. Per cent.
Carbonic oxide, CO	16·5	74·95	58·45
Hydrogen, H	9·45	66·40	57·95
Water gas, $CO-H$	12·40	66·75	54·35
Acetylene, C_2H_2	3·35	52·30	48·95
Coal gas	7·9	19·10	11·20
Ethylene, C_2H_4	4·10	14·60	10·50
Methane, CH_4	6·10	12·80	6·70

Though the above figures are subject to variation according to the initial pressure and other conditions, such as the presence of dust, etc., etc., it will be noticed that carbonic-oxide gas not only has the highest lower limit of mixture to form an explosion, but also has the largest range, for while illuminating gas forms an explosive mixture with air when present in about 8 per cent of mixture, and ceases to explode above 20 per cent, carbonic oxide is explosive at 17 per cent, and ranges up to 75 per cent.

It is claimed by some that the large power gas engine was gradually developed through the improvements in gas producers, but this is not the case.

The wonderful advance in the power unit of the cylinder of gas engines was mainly, if not entirely, due to the application of blast-furnace gas in which the combustible element was carbonic-oxide gas, even though the thermal value of the gas derived from this source was so considerably below any used for developing power prior to 1894.

This class of fuel gas was found to give such satisfactory results that the Cockerill Company, of Seraing, ventured to increase the diameter of the cylinder to 51 in., and though a large number of single-cylinder engines of this size have been found to operate with great success for certain requirements, the trend has lately been to keep the cylinder diameter lower, and so reduce the effects of expansion and contraction, as well as the expenditure in metal and machining.

The Otto cycle engines, while giving the highest efficiency, are, of necessity, more costly to build than steam engines of equal power; the employment of the two-cycle system reduces the first cost somewhat, but not to a great extent, while the efficiency is lower.

CHAPTER XV.

THERMAL POWER, FLAME TEMPERATURE, AND EXPLOSION PRESSURES OF COMBUSTIBLE GASES.

THE thermal power and flame temperature of combustible gases, upon complete combustion in pure air, containing, by volume, $O^1/_5$th, $N^4/_5$ths, for different volumes of gas, and mixtures of combustible and incombustible gases, at 60 deg. Fah. and 30 in. Bar., and water vapour uncondensed, can be readily obtained by the following tables:—

TABLE I.—HEAT DEVELOPED, IN B.TH.U., BY DIFFERENT VOLUMES OF COMBUSTIBLE GAS

Cubic feet.	CO.	H.	CH_4.	C_2H_4.
1	319	282	908	1485
2	683	564	1816	2960
3	957	846	2724	4455
4	1276	1128	3632	5940
5	1595	1410	4540	7426
6	1914	1692	5448	8911
7	2233	1974	6356	10395
8	2552	2256	7264	11880
9	2871	2538	8172	13366

TABLE II.—SPECIFIC HEAT OF GASES AND VAPOUR AT 60 DEG. FAH. AND 30 IN. BAR.

	CO_2.	CH_4.	H_2O.	CO.	N.	H.	C_2H_4.
Per cub. ft.	·0252	·0250	·0226	·0183	·0181	·018	·0273

The flame temperature or theoretical temperature of a gas or mixture of combustivle gases is obtained by dividing the thermal power of the gas, as found in Table I., by the number of heat units carried away by the products of combustion (Table III.).

Example :—

	Suction producer gas. Percentage composition by volume.	1 cubic foot.
CO	24·30	·2430
H	18·90	·1890
CH_4	·57	·0057
O	·30	·0030
CO_2	6·60	·0660
N	49·33	·4933
	100·00	1·0000

Thermal value, or heat developed per 1 cub. ft. (Table I.):—

CO	·2	63·8	
	·04	12·76	
	·003	·957 —	77·517
H	·1	28·2	
	·08	22·56	
	·009	2·538 —	53·298
CH_4	·005	4·540	
	·0007	·6356—	5·1756
			125·9906 B.Th.U.

TABLE III.—HEAT UNITS CARRIED AWAY BY THE PRODUCTS OF COMBUSTION FOR EACH DEGREE OF TEMPERATURE, FOR DIFFERENT VOLUMES OF EACH GAS CONTAINED IN THE ORIGINAL MIXTURE, IN B.TH.U.'S AT 60 DEG. FAH.

Volume of gas in original mixture. Cub. feet.	CO_2 originally present.	N originally present.	CO_2 and N from combustion of CO originally present. 1 c. ft. CO = 1 c. ft. CO_2 + 2 c. ft. N.	CO_2, H_2O, and N from combustion of CH_4. 1 c. ft. CH_4 = 1 c. ft. CO_2 + 2 c. ft. H_2O + 8 c. ft. N.	H_2O and N from combustion of H. 1 c. ft. H = 1 c. ft. H_2O + 2 c. ft. N.	CO_2, H_2O, and N from combustion of C_2H_4. 1 c. ft. C_2H_4 = 2 c. ft. CO_2 + 2 c. ft. H_2O + 12 c. ft. N.
1	·0252	·0181	·0614	·2152	·0588	·3128
2	·0504	·0362	·1228	·4304	·1176	·6256
3	·0756	·0543	·1842	·6456	·1764	·9384
4	·1008	·0724	·2456	·8608	·2352	1·2512
5	·1260	·0905	·3070	1·0761	·2940	1·5640
6	·1512	·1086	·3684	1·2912	·3528	1·8768
7	·1761	·1267	·4298	1·6064	·4116	2·1896
8	·2016	·1448	·4912	1·7216	·4704	2·5024
9	·2268	·1629	·5526	1·9369	·5292	2·8152

Heat carried away by products of combustion (Table III.):

Products.			
CO_2 originally present	·06	·00151	
	·006	·00015—	·00166
N originally present	·4	·00724	
·4933 – ·012 to correct for O present = ·4813.........	·08	·00144	
	·001	·00002	
	·0003	·00000—	·00870
CO	·2	·01228	
	·04	·00245	
	·003	·00018—	·01491
CH_4	·005	·00107	
	·0007	·00016—	·00123
H	·1	·00588	
	·08	·00470	
	·009	·00053—	·01111
			0·03761

$$\text{Flame temperature} = \frac{125\cdot99}{\cdot0376} = 3349 \text{ deg. Fah.}$$

Applied to pure hydrogen burned in air, we have—

$$\begin{array}{l} 1 \text{ vol. (Table I.)} \\ 1 \text{ ,, (,, III.)} \end{array} \quad \frac{282}{\cdot0588} = 4796 \text{ deg Fah.}$$

And pure carbonic oxide

$$\begin{array}{l} 1 \text{ vol. (Table I.)} \\ 1 \text{ ,, (,, III.)} \end{array} \quad \frac{319}{\cdot0614} = 5195 \text{ deg. Fah.}$$

EXPLOSIVE PROPERTIES OF GASES.

The development of power by means of gaseous fuel in internal-combustion engines is dependent upon the expansive property of heated gases, and as air and gas are bad conductors of heat, the only practical method of raising the temperature of the working medium is to bring about a rapid chemical action within the body of the mixture of gas and air. All chemical reactions are accompanied by a disengagement or absorption of heat, and the combination of combustible gas with oxygen results in a rapid rise in temperature. Pre-compression of the explosive charge also raises the temperature, and if this heat of compression is conserved it increases the thermal efficiency of the system in a greater ratio than is represented by the increase in temperature, *per se.*

A contributor to *Power* has given the following formulæ and table for determining the temperature due to compression in gas-engine cylinders:—

1. For ordinary types of gas engines:—

$$\left(\frac{V}{Vc}\right)^{0·35} = \frac{Tc}{T}; \text{ or } Tc = T\left(\frac{V}{Vc}\right)^{0·35}$$

2. For engines working on the scavenging system—

$$\left(\frac{V}{Vc}\right)^{0·32} = \frac{Tc}{T}; \text{ or } Tc = T\left(\frac{V}{Vc}\right)^{0·3}$$

where V = total volume of clearance and cylinder;
Vc = volume of clearance space;
T = absolute initial temperature in deg. Fah.;
Tc = absolute temperature of the compression in deg. Fah.

$\left(\frac{V}{Vc}\right)$	3·0	3·1	3·2	3·3	3·4	3·5	3·6	3·7	3·8	3 9	4·0
$\left(\frac{V}{Vc}\right)^{0·35}$	1·4689	1·4858	1·5025	1·5187	1·5347	1·5503	1·5657	1·5808	1·5956	1·6102	1·6245
$\left(\frac{V}{Vc}\right)^{0·32}$	1·4213	1·4362	1·4510	1·4653	1·4793	1·4932	1·5066	1·5199	1·5330	1·5457	1·5583
$\left(\frac{V}{Vc}\right)$	4·1	4·2	4·3	4·4	4·5	4·6	4·7	4·8	4·9	5·0	5·1
$\left(\frac{V}{Vc}\right)^{0·35}$	1·6386	1 6525	1·6662	1·6796	1·6929	1·7059	1·7188	1·7315	1·7441	1·7564	1·7687
$\left(\frac{V}{Vc}\right)^{0·32}$											
$\left(\frac{V}{Vc}\right)$	5·2	5·3	5·4	5·5	5·6	5·7	5·8	5·9	6·0		
$\left(\frac{V}{Vc}\right)^{0·35}$	1·7807	1·7926	1·8044	1·8160	1·8275	1·8389	1·8501	1·8612	1·8722		
$\left(\frac{V}{Vc}\right)^{0·35}$	1·6948	1·7052	1·7154	1·7255	1·7355	1·7453	1·7550	1·7647	1·7742		

Applied to an ordinary gas engine having

$$\frac{V}{Vc} = 5·5,$$

and an absolute initial temperature of charge before compression of 159 deg. Fah., the temperature at the end of the compression would be

$$1{\cdot}816\ (159 + 461) = 1{\cdot}816 \times 620 = 1126 \text{ deg. Fah. absolute,}$$

$$\text{or} \qquad (1126 - 461) = 665 \text{ deg. Fah.}$$

The energy developed by heating air or gas can only be made to perform useful work by allowing expansion to take place, and in practice it is requisite that the heat should be developed with great rapidity, while any cooling, other than that due to expansion, should be minimised.

The material of which the commercial gas engine is constructed necessitates that some cooling medium shall be applied to enable the development of a high internal temperature within the combustion chamber, but the less heat that is extracted from the working medium during expansion the higher the mean pressure developed.

Dugald Clerk, and others, have found that a mixture of coal gas and air, in the proportion of 1 to 5, ignited in a closed vessel, reaches its maximum temperature in from 0·04 to 0·06 of a second, and a mixture of 1 to 10 in about 0·16 of a second.

Miller found that a mixture of 1 to 6, when compressed to 25 lb. per square inch, took about 0·08 of a second to reach maximum temperature, while a similar mixture compressed to about 1,135 lb. was found by Petavel to reach a maximum temperature in 0·06 of a second, and give a maximum pressure of nearly 10,000 lb. per square inch. Pure hydrogen with 2½ parts of air reached maximum explosive temperature in 0·015 second, and with 6 parts of air 0·18 second in Clerk's experiments.

Again, the size of the containing vessel has an effect upon the time of explosion; a mixture of oxygen and hydrogen in chemically combining proportions reached maximum temperature in 0·0017 second; in a larger vessel the period was extended to 0·0042 second. Carbonic oxide and oxygen took 0·0129 second to reach maximum temperature in a small vessel, while hydrogen, oxygen, and nitrogen only took 0·0027 second.

Compared with the latter, a mixture of carbonic oxide, oxygen, and nitrogen only reached complete explosion in 0·0265 second; and Berthelot found that carbonic oxide and oxygen gave about 9 per cent higher explosive pressure than a mixture of hydrogen and oxygen.

Petavel made experiments upon the explosion of gas under high compression in an enclosed vessel of 552 cc. capacity, and found that with a compression pressure of 77·3 atmospheres a maximum pressure of about 10,000 lb. per square inch was developed in 0·06 second, while cooling by transmission to the enclosing walls in 2·5 seconds reduced the pressure to 3,000 lb., the ratio of time being 1 to 40.

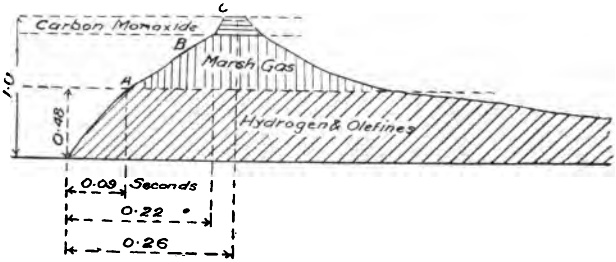

FIG. 94.—One Volume Coal Gas with 12 Volumes of Air.

Seeing that a gas-engine cylinder's working capacity is limited by the sectional area and the stroke of the piston, irrespective of the volume of the clearance, the controlling factors of the power to be obtained are the lowness of the temperature at which the charge can be got into the cylinder, whereby the density is increased, and the amount of compression into the clearance space the quality of the gas employed will permit.

Grover has obtained a very instructive diagram, fig. 94,* from the explosion of a mixture of coal gas and air in the proportion of 1 to 12 volumes, and similar diagrams were obtained from a small gas engine working with a

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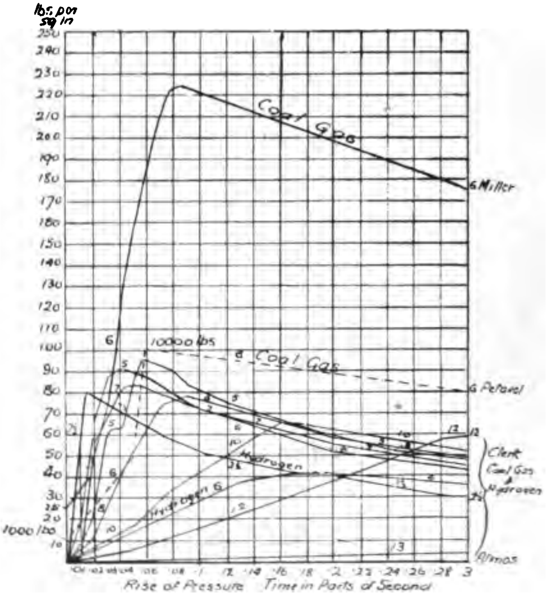
* Grover in "Modern Gas and Oil Engines." Similar diagrams were obtained by Grover from a small gas engine in which the compression was from 80 to 100 lb. per sq. in.

compression of 80 lb. to 100 lb. per square inch. The order in which the combustible gases become ignited is clearly shown.

The results of explosion of different gases with varying proportions of air, and under atmospheric pressure and



The numbers denote the proportions of Air

FIG. 95.

higher compression pressures, obtained by experimenters whose names are given, have been incorporated in a diagram, fig. 95: the period of time in reaching maximum temperature and the rate of cooling being indicated by curves.

CHAPTER XVI.

THE PROPORTIONS OF PIPES IN GAS PLANTS.

IN all gas-producer installations the passage of the gas through the purification apparatus is accompanied by a change of sectional area of the different pipes and scrubbing apparatus. All changes in sectional area of the gas passages should be suitably proportioned, so that the frictional resistance may not at any stage exceed that based upon the gas outlet from the producer.

In those installations where air cooling pipes are employed the number of pipes and diameter must correspond in frictional resistance to that of the main gas pipes.

The internal friction of air and gas is very slight compared with that due to the surface of the pipes or that offered by the purifying material, so that careful consideration must be given to the sectional area provided.

No general rule can be devised to cover both the sectional area and length of such passages, as the gas has to travel through in the coke and sawdust scrubbers, but in the case of pipes this has been approximately determined.

The accompanying table of the proportions of pipes to give equal frictional resistance is only applicable when similar lengths are compared, so that the proportions should be increased where the smaller pipes are of greater length than the main pipes.

For instance, if a pipe condenser is to be applied, and the gas enters through a 24 in. diameter inlet, there would be required not less than 35 pipes if of 6 in. diameter, or 12 pipes if of 9 in. diameter; while if the condensing pipes are made of considerable length, these numbers should be increased. The table can also be used to proportion the pipes in the case of gas distribution, for it will be seen that if a 24 in. main is to be divided into two branches, these, if about the same length as the main, should be 17 in. diameter, or, if there are to be four branches, they should have a diameter of 14 in.

PROPORTIONS OF PIPES FOR EQUAL FRICTIONAL RESISTANCE.

Dia. in inches.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3	3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.
4	7	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..
5	12	4	2	..	..	..	..	..	..	..	..	..	..	..	..	..
6	18	6	3	..	..	..	..	..	..	..	..	..	..	..	..	..
7	27	9	5	3	..	..	..	..	..	..	..	..	..	..	..	..
8	33	13	6	3	..	..	..	..	..	..	..	..	..	..	..	..
9	51	18	8	5	3	2	..	..	..	..	..	..	..	..	..	..
10	68	23	11	6	4	3	2	..	..	..	..	..	..	..	..	..
11	87	30	14	8	5	3	3	2	..	..	..	..	..	..	..	..
12	109	37	18	10	6	4	3	2	.	..	..	..	..	..	..	..
13	133	45	21	12	7	5	4	3	2	..	..	..	..	..	..	..
14	161	55	26	14	9	6	5	3	3	2	..	..	..	..	..	..
15	193	66	30	17	11	7	5	4	3	3	2	..	..	..	..	..
16	227	77	36	20	12	9	6	5	4	3	2	..	..	..	..	..
17	264	90	42	24	15	10	7	5	4	3	3	2	..	..	..	..
18	305	104	49	27	17	11	8	6	5	4	3	3	2	..	..	..
20	400	136	63	35	22	15	10	8	6	5	4	3	3	2	..	..
24	636	215	100	56	35	24	17	12	9	7	6	5	4	3	3	2
30	1121	379	178	99	62	41	30	21	16	13	10	8	7	6	5	4

Table showing the number of pipes of a diameter, as given in the horizontal line of equivalent delivery, for equal lengths and under similar conditions, of pipes of a diameter, as given in the vertical column on the left.

CHAPTER XVII.

Gas Analysis.

In all gas-producer work, as the quality of the fuel available differs according to the class adopted, and is not constant even when derived from a certain seam or district, it is a great advantage to be able to analyse the gas, so as to judge of the proper working of the plant.

Exact methods of analysis require laboratory apparatus and the services of an expert analytical chemist, but closely approximate analyses can be made of mixtures of gases by portable apparatus, which have been designed to give good working results in the hands of unskilled workers after a little practice.

The volumetric determination of carbon-dioxide CO_2, oxygen O, ethylene C_2H_4, carbonic oxide CO, hydrogen H, marsh gas CH_4, and nitrogen N, in mixtures of these gases can be made by means of the Bunte gas burettes and accessories. The necessary apparatus consists of: 2 gas analysis burettes (Dr. Bunte's pattern), 2 aspirating bottles, 1 tube for burning hydrogen, fitted with a small spiral of palladium wire, 1 stand with clamps, 1 air pump and bottle, 1 bunsen burner or spirit lamp, all of which are shown in the sketch, fig. 96.

The principal item is, of course, the burette, which may be described as follows: A small funnel, having a containing mark about half-way down—*i.e.*, 25 cc.—and which is connected by a capillary tube with the body of the burette; a three-way cock between the funnel and the burette controls the direction of either gas or water. The capacity of the burette is 100 cc., and to increase the delicacy of measurement a portion is reduced in diameter, so as to allow of clear marking into fifths of a cubic centimetre. A zero mark is made about 10 cc. above the lower tap, and corresponds with 100 cc. from the three-way cock at the top.

The iron stand, as will be seen, is fitted with two clamps for holding burettes, and a holder for the burner, or spirit lamp, while at the top is a tray for supporting the bottle for aspirating and levelling purposes.

The *modus operandi* may well be described in detail as follows:—

To take a sample of gas, an aspirating bottle with a tubulure at the bottom, connected by an indiarubber tube to the lower end of the burette, is filled with water, or, better, a strong solution of salt, which does not absorb carbonic acid gas to the extent which pure water does; the burette is filled with water by opening the bottom and top taps and allowing water to flow up into the top funnel, the taps being then closed. If now the three-way cock tubulure is connected by an indiarubber tube to another

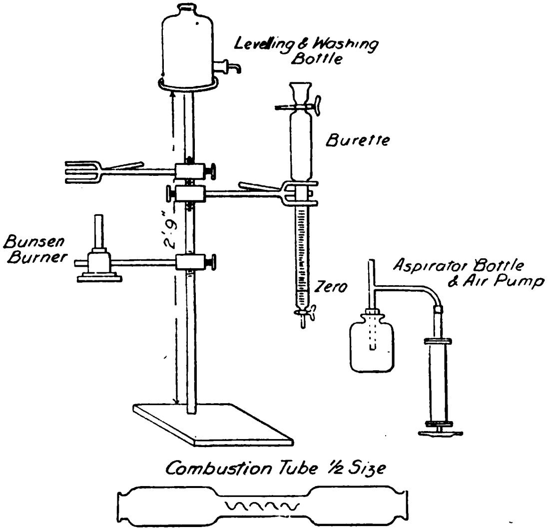


FIG. 96.

tube placed in connection with the place from which the sample of gas is extracted, and the three-way cock so turned that a connection is made from the sampling tube to the burette, on opening the bottom tap and lowering the water bottle gas will be sucked into the burette. To ensure that the sample of gas is freed from any air that might have been in the tubes, etc., the first few burettefuls of gas can be discharged into the air by turning the three-way cock into connection between the burette and the funnel and raising the water bottle, when the gas in the measuring tube is discharged and replaced by water, and another charge of gas can be drawn in. Thus, the taking of a sample of gas is very conveniently performed, for only the burette, detached from its stand, and the water bottle are required, and can readily be manipulated in almost any situation.

To permit of the analysis of the gas being carried out at a constant temperature, the burette can be obtained fitted with a water jacket.

Having obtained a sample of gas in the burette, this is now placed in the clip on the stand, and the water bottle, still connected to the lowest point of the burette by a tube, is placed upon the table on the top of the stand. If now, on opening the bottom tap, the water level does not rise to the zero mark, indicating that the volume of the gas is exactly 100 cc., a little of the gas may be allowed to escape through the top tap until the volume measures 100 cc. As all measurements of volume should be made under the same conditions—*i.e.*, with 25 cc. of water in the funnel (an indiarubber cap being fitted on the end of the three-way cock directly the sample has been obtained)—every reading of volume should only be made when the level of the water in the levelling bottle is made to correspond with the level of the water in burette, with water in the funnel up to the 25 cc. mark, and after the upper tap has been opened for an instant to allow any excess of gas to pass out through the water in the funnel.

Having now 100 cc. of gas in the burette, with 10 cc. of water below it, analysis can be proceeded with as follows: Having both taps of the burette closed, the levelling bottle tube is disconnected from the burette and the aspirating bottle tube put in its place. A few strokes of the air pump establishes sufficient vacuum to draw some of the water from the bottom of the burette when the bottom tap is opened, care being taken that *all* the water, and some gas, is not drawn out. The aspirating bottle is now disconnected, and a small dish containing a solution of caustic potash is brought under the burette, and on the bottom tap being opened the solution will enter the burette and replace the water previously withdrawn. The burette is then removed from the stand, and shaken in such a manner as to bring the gas into intimate contact with the potash solution.

The reagent can now be washed out, the burette having been replaced in its holder, by allowing water to flow into the funnel and opening the top and bottom taps, when water will flow right through the burette. The carbonic acid in the gas will have been absorbed, and to measure the amount the operation of levelling, as previously described, must be repeated; the reduction in volume would then represent the percentage of CO_2. The absorbing reagent for CO_2 consists of 16 grammes of potassium hydrate dissolved in 100 cc. of water, 4 cc. or 5 cc. being sufficient for each test.

If any oxygen is suspected of being present, the absorption is carried out in a similar manner to that described for CO_2, except that the reagent in this case consists of a solution of pyrogallic acid in water mixed with an equal quantity of the potassium hydrate solution—20 grammes of pyrogallic acid to 10 cc. water. Another mixture consists of—caustic potash, 48 grammes; pyrogallic acid, 29 grammes; and 160 cc. of water.

If ethylene, C_2H_4, is to be determined, the reagent is bromine water; 1 cc. of bromine water will absorb 20 cc. of C_2H_4.

The proportion of carbonic oxide, CO, may also be determined by employing one of the following solutions:

1. Cuprous chloride, 15 grammes. Hydrochloric acid (1·19 sp. gr.), 100 cc., 1 cc. of which will absorb 20 cc. of CO.

2. Ammonia-copper-chloride, 250 grammes. Water (distilled), 730 cc.; hydrochloric acid (1·1 sp. gr.), 20 cc. This solution should be kept in a stoppered bottle, with a copper wire spiral immersed, and before use 65 cc. ammonia (·905 sp. gr.) is to be mixed with 100 cc. of the colourless copper solution. It should smell of ammonia.

The determination of hydrogen, H, is not such a simple matter as the foregoing, but with a little practice is not difficult. In the first place, depending upon the proportion in which H is present, it is necessary to provide oxygen for its combustion, and for producer gas this is generally done by lowering the levelling bottle and drawing in air at the three-way cock until the water level in the burette and bottle stands at zero. In mixtures of gases in which the proportion of H is high, oxygen in place of air must be introduced into the burette.

A second burette is required, with suitable clip to hold it on the stand. This burette is held vertical alongside that containing the sample to be examined, and a tube containing a spiral of palladium wire, or asbestos with palladium black, is connected by short pieces of india-rubber tubing to the projecting end of each of the top three-way cocks of the burettes, and the second burette is entirely filled with water, while two levelling bottles are required, one connected to each burette at the bottom; that in connection with the burette containing the sample is to be raised to the table on the top of the stand, while the other must be at a level below the bottom outlet of the burette. If now the small bunsen burner, or spirit lamp, is brought under the *combustion tube*, and the bottom tap of the burette containing gas is opened, the three-way taps of both burettes being turned on so as to allow the gas to pass into the second burette, on opening the bottom tap of the burette containing water the gas will pass slowly through the heated combustion tube, and the hydrogen will combine with oxygen, forming water, which is condensed, causing a corresponding reduction of volume of gas in the burette after the two water bottles have been reversed in position and the gas returned to the measuring burette. When the contraction due to the combustion of H has been read off, the operation of absorbing CO_2 is repeated, and if the original sample measured exactly 100 cc., the readings obtained must be worked out as follows:—

$$
\begin{aligned}
CO_2 &- \text{reduction of volume} = CO_2 \text{ per cent} \\
O &- \text{reduction of volume} = O \text{ per cent} \\
C_2H_4 &- \text{reduction of volume} = C_2H_4 \text{ per cent} \\
CO &- \text{reduction of volume} = CO \text{ per cent} \\
H &= \tfrac{2}{3}\,[\text{total contraction of volume after combustion} \\
&\qquad - \text{volume of } CO_2 \text{ from combustion of } CH_4]
\end{aligned}
$$

$$\left(\frac{CH_4}{2\text{ vols.}} + \frac{4\,O}{4\text{ vols.}} = \frac{CO_2}{2\text{ vols.}} + \frac{2\,H_2O}{4\text{ vols.}}\right) = H \text{ per cent.}$$

$$CH_4 = \text{volume of } CO_2 \text{ after combustion} = CH_4 \text{ per cent.}$$

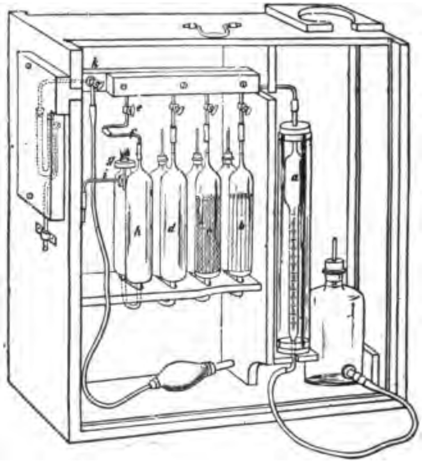


Fig. 97.—Lunge's Modification of the Orsat Apparatus.

The Bunte burette has been selected in this case, and its application so fully described, because it is both handy and inexpensive; burettes can be obtained for from 10s.

to 13s.; stands, 5s. to 8s.; while the reagents and accessories only amount to a few shillings.

Lunge's modification of Orsat's apparatus, fig. 97, though slightly more costly, is a very convenient arrangement of absorbing tubes, burette, levelling bottle, etc., which is both portable and also ready for immediate use when charged with reagents, while the charges of reagents in the absorbing tubes will last for a considerable period without deterioration. The whole apparatus is contained in a case fitted with removable sides, and a handle for carrying, and the reagents already described are all that is required; the price of the complete apparatus, without reagents, is about £4, and it is more economical in reagents than the Bunte burette.

Where more exact determinations are desired, there are different types of apparatus on the market, as Stead's, Macfarlane's, etc., in most of which mercury is employed in the place of water in the levelling bottles, thereby preventing the absorption of CO_2.

CHAPTER XVIII.

THE EXAMINATION OF VARIOUS CLASSES OF FUEL AND DETERMINATION OF THE THERMAL VALUE.

POWER gas can be made from a variety of fuels, such as coke, anthracite, semi-bituminous and bituminous coal, lignite, peat, wood, heavy oils, etc., and in all cases the value as fuel depends upon the thermal power of a given unit weight.

The most important preliminary operation in regard to the examination into the value of any fuel is the selection and preparation of a representative sample. It is essential that the portion taken for testing should be an exact representation of the bulk of the fuel available, as otherwise misleading results will be obtained.

In the case of coke, anthracite, wood, and oil the selection of a representative sample is a fairly easy matter, and only requires good judgment; but in the case of coals, which not only vary in quality according to the seam and district from which they are extracted, but are not of uniform quality throughout the seam, the sampling can only be properly effected by taking pieces from numerous lumps, and portions of the slack, in such a manner that the bulk of the sample shall form a representaton of the gross bulk under consideration.

To take, for example, the case of a quantity of coal delivered in railway wagons: it is not sufficient to take a basketful of coal from one wagon, but a small selection should be made from each wagon, pieces from the large lumps, with a proper proportion of the small and slack. The whole of the sample so taken should be laid on a large cast-iron plate, and crushed small, until a thorough mixture can be made, and permit of a portion being taken for further pulverisation until the sample is sufficiently small for performing the necessary tests.

By the aid of a fairly delicate chemical balance, a blowpipe burner or small muffle furnace, a few porcelain crucibles and a piece of platinum foil, it is possible to make some rough tests, which would be useful in judging the character of the fuel.

The first operation is to subject the sample to a temperature of 230 deg. Fah., so as to drive off any moisture.

If, now, 1 or 2 grammes of the coal be placed in a porcelain crucible and covered with a piece of platinum foil, the proportion of volatile matter can be ascertained by raising the crucible and contents to an incandescent temperature. After cooling, the crucible can be weighed (the tare having previously been taken, without the foil in each case), and the resulting coke remaining in the crucible represents the fixed portion of the coal.

The crucible is now again returned to the burner, or furnace, and heated until there is no trace of carbon remaining; the further weighing of the crucible and contents will give the amount of ash.

With the calculation of the weights obtained reduced to percentage on the weight of coal taken, the proximate results can be stated as:—

Volatile mattter	a	
Fixed carbon....................	b	Coke.
Ash	c	
	100·0	

During the above-described operation notice will have been taken of the character of the volatile matter, as to flame, soot, etc., given off; while the coking quality can be approximately judged before the carbon is burned off.

Where it is desirable to have more particulars of the fuel, especially in regard to the recovery of by-products, recourse may be had to the new apparatus for the analysis of coals and other combustibles, brought out by the Simplex Coke and Engineering Company Limited,* a sectional view of which is given in fig. 98.

In the laboratory the usual practice, in the analysis of fuel, is to employ very small weights of the substance, while, also, the conditions under which the various operations are performed, though nearly approaching those desired by theory, do not represent results which can be obtained in practical working.

The apparatus under review has been so devised and constructed that as much as 2·204 lb. of coal (1 kilogramme) can be employed in the determinations, which permits of results being obtained which approach more nearly those given by coke ovens, producers, gas works, etc.

The apparatus consists of: A vertical iron retort, which can be heated to a temperature of 1,470—1,650 deg. Fah.; a water condenser, for cooling gases and condensing heavy tar; a series of wash bottles, for collecting the light tar, ammonia, and benzol; a small experimental gas index, registering litres, for measuring the volume of gas liberated by the heated fuel.

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* Temple Bar House, London, E.C.

Detailed description, as indicated by numbers: (1) Inlet for air to oven, which is heated by a part of the waste heat, and meeting the heating gas, burns it at (2) the heating chamber; (3) Bunsen burner, or other heating burner; (4) Bunsen burners; (5) movable metal foot, permitting of the removal of the burners (4); (6) the

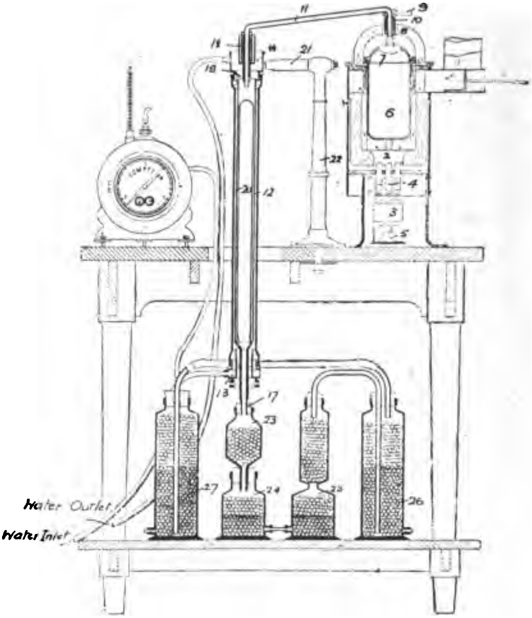

FIG. 98.

retort, made of iron plate; (7) cover for retort; (8) stirrup for fastening the cover (7); (9) pressure screw for cover (7); (10) bulb tube; (11) iron tube rising from bulb tube (10), fitted with mercury joint, for leading off the gas to the condenser; (12) condenser, of glass tube, supported between (13) and (14), metal parts by (15) connecting rods; (16) cooling tube, having admission and waste tubes for the cooling water fitted to (13) and (14); (17) indiarubber stopper, for supporting the lower end of (16); (18) bulb fitted to upper part of cooling tube (16) in the (19) indiarubber stopper, which is covered with water while working, to prevent heating; (20) deflector in the interior of the condenser, to give a larger cooling surface for the gases; (21) clamp; (22) stand. The gases evolved in the retort (6) pass by the tube (11) into the condenser (12), and are cooled, the condensible matter remaining on the walls. From the condenser the gas, tar, and liquor pass successively into (23) (24) (25) scrubbing bottles, filled with glass spheres, to offer a large surface for arresting the small particles of tar and liquor suspended in the gas; (26) and (27) washing bottles, for collecting the ammonia and benzol, (26) containing dilute sulphuric acid, and (27) heavy oil of tar freed from naphthalene.

The estimation of the ammonia can be directly effected by completing the neutralisation of the acid liquor, or by boiling with lime, baryta, soda, or potash, etc. The benzol can be estimated by distillation of the washing oil and weighing. The volume of gas evolved is measured by the gas meter.

In one single operation this apparatus gives all the results practically required, in almost the same conditions as actually obtaining on a large scale.

Example.—Coke: Nature—compact, metallic grey appearance. Coke yield, 71·605 per cent; sulphate of ammonia, 0·854 per cent; corresponding to ammonia, 0·220 per cent; tar, 6·050 per cent; benzol at 300 deg. Fah., 0·271 per cent; gas, volume reduced to 32 deg. Fah. and 30 in. bar., 828 cubic feet.

All information is supplied with the apparatus and complete directions for working.

The commercial value of all fuels should be based upon the heat it can be made to develop in practice by the apparatus in which the fuel is to be employed.

Not only does the amount of incombustible matter present in the fuel affect its heat value, but the character of the volatile constituents must also be taken into account. For this reason it is only possible to obtain approximate results as to the heat value by calculation from the figures obtained by analysis, though they agree pretty closely with direct determinations of the thermal value. Bituminous fuels give off, on heating, volatile constituents of varied composition; some of these hydrocarbons are not only condensible, but can only be made to enter into combustion with air under specially arranged conditions, frequently not obtainable in practice.

In open fires, boiler furnaces, metallurgical furnaces, and also in gas producers, the condensible hydrocarbons are the cause of smoke troubles, and the fouling of valves, combustion chambers, pipes, etc.; and though in thermal testing apparatus it is possible to develop a certain amount of heat and transfer it to water, the same conditions cannot, so far, be arranged in actual practice. Therefore, for any application, the true value of the fuel depends upon the heat it can be made to develop under the special circumstances, and not upon laboratory determinations made under special conditions. However, the usual practice is to define the thermal efficiency of all apparatus employed for the development of power by means of the combustion of fuel as the ratio of the thermal value of the fuel employed—as measured by means of calorimeters—to the heat equivalent of the power developed.

When the chemical analysis of any sample of fuel is available, the approximate thermal value can be calculated by M. Dulong's formula, or modifications:—

H = heat value in British thermal units per 1 lb. fuel.
C = total carbon weight in 1 lb. fuel.
H = hydrogen weight in 1 lb. fuel.
O = oxygen weight in 1 lb. fuel.
S = sulphur weight per 1 lb. fuel.

$$(1)\quad H = (14500 \times C) + \left\{ 62535 \times \left(H - \frac{O}{8}\right) \right\}.$$

$$(2)\quad H = 14544 \left\{ C + 3{\cdot}67 \left(H - \frac{O}{8}\right) \right\} \text{ water vapour, gaseous.}$$

$$(3)\ H = 14544\left\{C + 4{\cdot}265\left(H - \frac{O}{8}\right)\right\} \text{ water vapour, condensed.}$$

$$(4)\ H = 14544\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right) + {\cdot}28\ S\right\}.$$

Direct Determination of the Heat Value of Fuels by Means of a Calorimeter.

Before submitting a sample of fuel to a calorimeter test, the proportion of moisture should be determined by heating a weighed portion to a temperature of 230 deg. Fah. in an air oven. The calorimeter is an apparatus in which a small weighed portion of the dry sample of fuel is burned, by air, oxygen, or other oxidising elements, and the heat developed is absorbed by a weighed quantity of water; there are a number of types available.

Usually 1 or 2 grammes of the fuel are placed in a small crucible; if air or oxygen is to be the oxidising agent, a fuse is introduced; and when an oxidising element is employed, a mixture of nitre and potassium chlorate is mixed with the sample, as well as the fuse. The crucible is enclosed in a glass bell jar, the fuse ignited, and the bell jar lowered into a vessel containing the heat-absorbing water, in which a delicate thermometer is situated. The temperature of the water prior to the introduction of the bell jar having been noted, the combustion of the fuel is carried out either by the introduction of air or oxygen, or by means of the oxidising agent, and the evolved gases caused to pass through the water. Fig. 99 shows the Thomson calorimeter (Rosenhain's improved form), in which the determination can be performed in about half an hour; while fig. 100 is a sectional view of a calorimeter in which sodium peroxide is the oxidising agent, and in which the gas is absorbed by the sodium peroxide instead of passing up through the water in bubbles.

The different modifications of calorimeters require a certain amount of experimentation and care in manipulation on account of the difference in combustible properties of the various classes of fuel, and allowances have to be made for radiation losses, as well as the capacity for heat of the vesseds employed.

When the containing vessel consists of a glass jar, care must be taken that combustion is not carried on at such a rapid rate as to cause the jar to bump, and different expedients have to be resorted to to restrain the violence of combustion in some cases and promote combustion in others. With each type of calorimeter there is usually provided a pamphlet, giving full instructions for carrying out the determination.

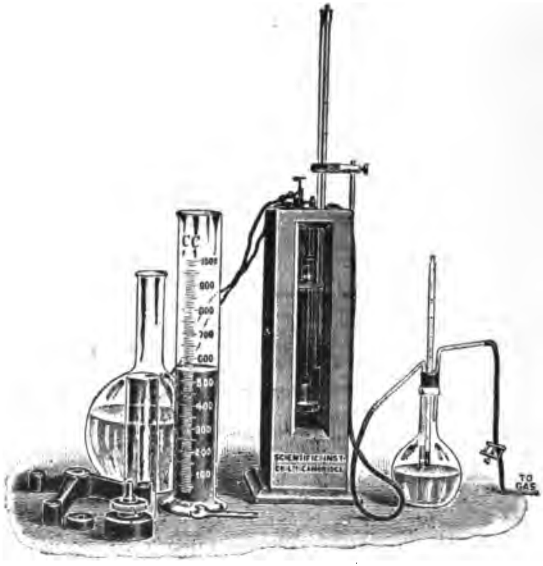

Fig. 99.—Thomson Calorimeter (Rosenhain's Improved Form).

THE BERTHELOT-MAHLER BOMB CALORIMETER.

Bomb calorimeters differ from those already described, in that the sample of fuel is burned in a strong enclosing vessel supplied with oxygen under pressure, and ignited by an electric spark. The products of combustion are allowed to escape through a small coiled tube, controlled by a tap; this permits of the gas being passed into a gas analysis apparatus if desired. A weighed sample of fuel is placed in a platinum crucible and introduced into the bomb, while platinum wires are so arranged that the passage of an electric current will ignite the coal. The bomb is closed and oxygen introduced under a pressure of about 21 atmospheres; after the oxygen cylinder has been

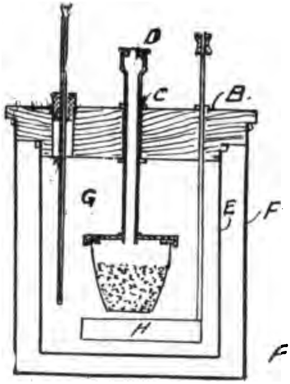

FIG. 100.—Calorimeter, designed by R. C. Wild.

A—crucible. B—cover. C—tube suspending crucible. D—valve.
E—water vessel. F—outer vessel G—thermometer. H—agitator.

disconnected the bomb is lowered into a copper vessel containing a known weight of water. The temperature of the water is measured by a thermometer, an agitator being used to circulate the water, and when the temperature is found to be constant the sample is ignited. The heat developed causes the temperature of the water to rise, and when this reaches a maximum it is registered. The increase in temperature of the water, when multiplied by the weight of the water in the calorimeter and the water equivalent of the apparatus, gives the quantity of heat evolved. If a Centigrade thermometer has been used and a weight of 1 gramme of the sample employed, the result will represent calories, which if multiplied by 1·8 will give British thermal units per 1 lb. of the fuel tested.

CHAPTER XIX.

THE DETERMINATION OF THE THERMAL VALUE OF COMBUSTIBLE GASES.

THE development of power by the combustion of gaseous fuel is dependent upon the quantity of heat which a given volume of a mixture of combustible gas and its oxidising agent are capable of giving out.

Commercial power gas seldom consists of a single pure elementary combustible gas, but of a mixture of two or more; while power gas obtained by the partial combustion of fuel by air in a gas producer not only contains varying proportions of combustible gases, but also incombustible inert gases. This being so, the only way in which the value of any given power gas can be arrived at is by a determination of the heat which a measured quantity will develop. It is possible to very closely approximate the heat value by calculation from the results of analysis, but a better way is to make a direct determination by means of a gas calorimeter, of which there are a number of available patterns. The determination of the heat value of gases, in which hydrocarbon compounds exist, can be better arrived at by direct combustion in a calorimeter than by calculation from the proportions of the constituents as found by analysis, because there are no means of determining the exact composition of those hydrocarbons which are absorbed by bromine water or fuming sulphuric acid.

There is a considerable variety in these compounds, and they have a high heat value, so that any small error in arriving at the exact proportion in which they exist in the gas may cause a very erroneous approximation.

Professor Junkers devised, some years ago, a calorimeter in which the direct determination of the heat value of any mixture of combustible and other gases could

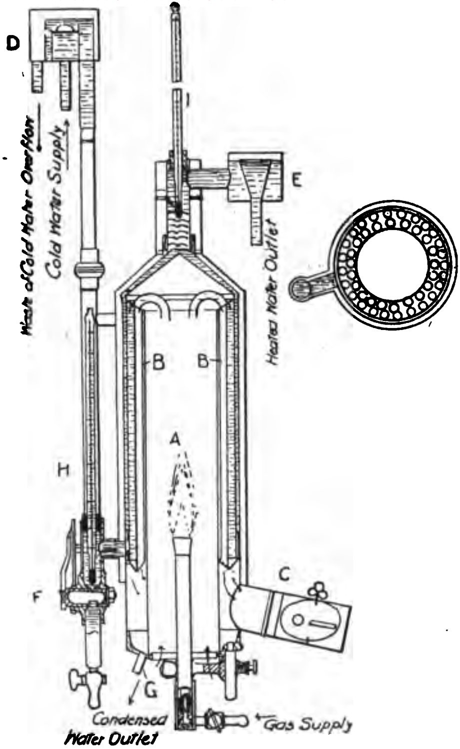

FIG. 101.—Junkers' Gas Calorimeter.

readily be effected, and other workers have from time to time confirmed the correctness of the results obtained by the apparatus.

A diagrammatic sectional view of Junkers' calorimeter is given in fig. 101, the various parts being indicated by letters, thus:—

A. The combustion chamber, formed of an angular copper vessel.

B. A number of copper tubes for conducting the products of combustion in a downward direction from the top of the combustion chamber to the lower part of the instrument. The space between the combustion chamber and the shell of the apparatus through which the tubes pass forms a water jacket, through which a current of water is made to flow in an opposite direction to the products of combustion.

C. The outlet for the waste products communicating with the atmosphere, after having become cooled to the temperature of the water.

D. and E. Two overflows to keep the pressure of the water constant; the water entering D at a greater rate than it passes through the water jacket of the calorimeter, the excess passing away by the waste pipe. In the overflow E the heated water has to run out over the edge of the funnel.

F. Cock for regulating the flow of water through the instrument.

G. Outlet for conducting any water that may have condensed in the apparatus into a measuring glass.

H. Thermometer for registering the temperature of the water entering the water jacket.

I. Thermometer for registering the rise of temperature of the water flowing through the instrument, with its bulb situated in close proximity to baffle plates, which ensure the thorough mixing of the water before it reaches the thermometer.

The water flowing from the outlet E is collected and measured.

The instrument is surrounded by an air jacket to prevent loss of heat by radiation.

The following particulars are required in a test:

1. The quantity of the gas burned.

2. The quantity of the water passed through the apparatus.

3. The difference in temperature between the water entering and leaving the instrument.

4. The amount of water condensed from the products of combustion.

Therefore the complete apparatus includes (1) a gas meter, (2) calorimeter, (3) water-measuring vessels.

The method of conducting a test is as follows: The gas to be tested is connected up to the gas-measuring meter and the burner in the calorimeter, and after the supply of water to the calorimeter has been turned on the gas is lighted at the burner, and the rate of flow of both gas and water are so regulated that the difference in temperature between the inlet and outlet thermometers is somewhere between 10 and 20 deg. Cen.

On the difference between the thermometers becoming about constant, and the water condensed in the apparatus is dripping from the outlet pipe G, the test may be commenced. When the meter indicates a certain definite measure this is noted, and measuring vessels are at once placed under the outlets from E and G.

Readings of the thermometers are taken at short intervals until about 1 cubic foot of gas has been passed through the meter; this may be judged by selecting a measuring vessel for the water flowing from E of such a capacity that when filled up to a mark it will be equivalent to the water passing through the apparatus during the combustion of 1 cubic foot of gas. When the water reaches the mark (as determined by trial) the gas is turned off, and the measuring vessels removed. As the thermometers associated with the calorimeter are usually divided to Centrigrade scale, and the measures in cubic centimetres and litres, the results are given in calories, thus: Heat power per cubic foot of gas in calories

$$= \frac{\text{vol. of water in litres} \times \text{diff. in temp. in deg. Cen.}}{\text{cubic centimetres of gas consumed.}}$$

The result in calories, multiplied by 3·97, gives British thermal units.

The gas meter is fitted with a thermometer which may be divided to give degrees Fah., and the volume of gas passed can be corrected to give the volume at 60 deg. Fah. and 30 in. barometer. When the test is being made the barometrical pressure should be noted, so that corrections can be made for pressure as well as temperature.

As an example the following results may be taken: Gas passing through the meter 62 deg. Fah., 29·8 in. bar. Water passed through the calorimeter, 8 litres. Difference in temperature between the incoming water and the outflowing water, 18·3 deg. Cen. Gas consumed, 0·935 cubic foot. Condensed water, 21 cc. The volume of gas passed, corrected to 60 deg. Fah. and 30 in., = 0·924 cubic foot.

The gross calorific power would therefore be:

$$\frac{8\cdot0 \times 18\cdot3}{0\cdot924} = 158\cdot4 \text{ calories per cubic foot,}$$

which, multiplied by 3·97, = 628·8 British thermal units. The gross value given is based on the water resulting from the combustion of the gas being condensed and giving up its latent heat, and corresponds with the *higher* or maximum heat value. This value compares with the heat value of fuels, as determined by a bomb calorimeter, and should be used for an equivalent comparison, but the *lower* value is now frequently adopted for reports on the thermal efficiency of gaseous fuel engines; therefore it is advisable that any statistics relating to thermal efficency should state whether the *higher* or *lower* heat value has been taken.

The *lower* value is based upon the fact that the latent heat of the water vapour in the products of combustion can seldom be rendered useful in either engines or boilers; so to obtain the net heat value, with all water vapour resulting from combustion passing away in an uncondensed state, the latent heat of the water vapour must be deducted from the gross value.

For each cubic centimetre of water condensed in the calorimeter 0·6 calorie must be deducted. In the example 21 cc. of water was condensed from the products of combustion; so

$$\frac{21 \times 0\cdot6}{0\cdot924} = 13\cdot6 \text{ calories, or } 13\cdot6 \times 3\cdot97 = 54 \text{ B.Th.U.,}$$

and the results may be stated as: Thermal value, water condensed, 628·8 British thermal units, *higher*; thermal value, water uncondensed, 574·8 British thermal units, *lower*.

Another form of gas calorimeter is shown in fig. 102,* and which can be obtained from Alex. Wright and Co.

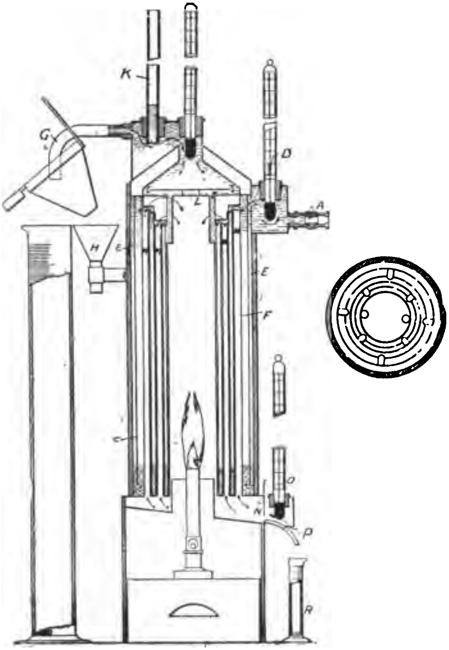

Fig. 102.

Ltd., Westminster; it only differs in details from that already described, and the calculations are the same.

To obtain results of a very accurate nature it is necessary to take a number of precautions, and in this connection

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* From an illustration in *Engineering*, January 13th, 1905, in connection with an article on Calorimetry, by John F. Simmance.

the user of a calorimeter would do well to consult the pamphlet on "Calorimetry of Producer and Illuminating Gases," by John F. Simmance, Assoc.M.Inst.C.E., M.Inst.Mech.E.

Dowson's improved gas calorimeter, to determine promptly and accurately the calorific value of heating or lighting gas, is another modification of those already described, and can be obtained from the Dowson Economic Gas and Power Co. Ltd., London.

CHAPTER XX.

Dangers in Connection with the Manufacture of Power Gas.

As most classes of power gas contain a considerable proportion of carbonic oxide gas, which is poisonous when inhaled, no work on the production of power gas would be complete if it did not refer to the principal sources of danger.

Owing to the increase in the manufacture of gases containing carbonic oxide, the Home Office has thought it advisable to issue a "Memorandum as to the Use of Water Gas and other Gases in Factories," which is signed by Dr. B. A. Whitelegge, Chief Inspector of Factories.

It is pointed out that the chief danger is from poisoning by carbonic oxide gas, which in ordinary illuminating gas varies from 4 to 12 per cent, is as much as 25 per cent in blast-furnace gas, and 50 per cent in water gas; the more usual proportions are from 10 to 25 per cent.

In 1899 a Departmental Committee recommended that the manufacture and distribution for lighting and heating purposes of any poisonous gas which did not have a distinct and pungent smell should be prohibited, and that regulations should be made limiting the proportion of carbonic oxide gas. More recent Acts, authorising companies and local authorities to manufacture power gas require that—(1) the gas shall be strongly scented; and (2) either the quantity of carbonic oxide in the gas shall be limited to 14 per cent, or, when not so limited, the Secretary of State may impose such regulations as may be deemed necessary to protect against the risk of poisoning. It is made the duty of H.M. Inspectors to enforce these provisions as regards factories and workshops to which the gas is distributed.

For commercial power purposes blast-furnace gas is now being extensively used in gas engines, and producer gas applications are extending daily; the former gas seldom has a less proportion of CO than 25 per cent, while the latter usually carry 10 to 12 per cent. The very enormous volumes of blast-furnace gas dealt with at the numerous ironworks, with so slight a number of cases of fatal poisoning, is a comforting fact, but at the same time cases of "gassing" of only a slight nature are more frequent than statistics would show, because they usually do not require medical treatment; notwithstanding this, considering the enormous volumes dealt with, the cases of "gassing" are exceedingly low.

However, as both blast-furnace gas and producer gas installations are at times subject to leakage, and the presence of poisonous CO cannot be detected by the smell, it is necessary that certain precautions should be taken. In many cases the first symptom is faintness, and when the sufferer is taken into fresh air this may pass off, or else it may be followed by sickness. Owing to the attack being usually of a sudden nature, no person should be allowed to be in suspected places alone.

While the principal remedies are fresh air, artificial respiration, the administration of oxygen, and the application of warmth, the following preventative measures should be generally adhered to:

1. Notices should be posted in conspicuous places describing the poisonous nature of the gas, the symptoms produced from its inhalation, and the best means of rendering aid to those who suffer from "gassing."

2. Persons in charge of any engine worked by the gas, or of any apparatus in which it is stored, or otherwise exposed to risk of inhaling carbonic oxide, should be free from any disease of the heart or lungs.

3. No person should be allowed single-handed to execute work in places where exposure to the gas is to be anticipated. This applies to the opening of such parts of producer plant as gas scrubbers, holders, etc.

4. No engine in which the gas is used should be in a confined space.

5. A competent responsible person should inspect all valves and connections for leakages from time to time.

6. The openings giving access to any part of the gas apparatus should be few, and in positions as safe as possible. This applies to such items as testing cocks and other valves in suction gas plants.

7. No workman should enter, or approach when opened, the holder or other part of the gas circuit until the gas has been well flushed out by air.

8. A cylinder of compressed oxygen, fitted with a suitable valve, tubing, and mouthpiece, should be kept in readiness.

In this connection the Power Gas Corporation Ltd., in consultation with the medical inspector of factories, has drawn up the following notice, to be posted in places where danger from poisonous gas is suspected:

Danger of "Gassing."—Breathing of producer gas should be avoided. It is dangerous when breathed in quantity. The first symptoms produced by breathing the gas are giddiness, weakness in the legs, and palpitation of the heart. If a man feels these symptoms, he should at once move into fresh warm air, when, in slight cases, they will quickly disappear. Exposure to cold should be avoided, as it aggravates the symptoms. A man should not walk home too soon after recovery, as muscular exertion after exposure to the gas should be avoided. If a man should be found insensible or seriously ill from the gas, he should at once be removed into fresh warm air, and immediate information be sent to the oxygen administrator, a medical man being sent for at the same time.

Should the nature of the work cause a man to enter a culvert or hole, he should have a rope tied securely round his waist, held at the other end by his mate, standing outside.

Use of the Oxygen Cylinder.—The cylinder should be provided with a lever key, nipple, and union, together with a rubber tube, at the end of which is a mouthpiece. It is also advisable to have a small pressure gauge attached to the cylinder, so that the loss of oxygen may be observed, and the cylinder kept in working order.

Open the valve gradually by tapping the lever key (fully extended) with the wrist until the oxygen flows in a gentle stream from the mouthpiece in the patient's mouth, and allow the oxygen to be breathed until relief is obtained. The lips should not be closed round the mouthpiece, as it is important to allow free egress for surplus oxygen. The nostrils should be closed during inspiration or inflation of the lungs, and opened during the expiration or deflation of the lungs, so that the oxygen may be inhaled as pure as possible through the mouth. If the teeth are set, close the lips and one nostril. Let the conical end of the mouthpiece slightly enter the other nostril during inspiration, and remove it for expiration.

Artificial Respiration.—Artificial respiration is sometimes necessary, in addition to the oxygen inhalation, if the oxygen does not appear to act quickly. Place the patient on his back, slightly raising the shoulders with a folded coat, remove everything tight about the chest and neck; draw the tongue forward, and maintain it in that position. Grasp the arms just above the elbows, and draw them steadily above the head, keeping them on the stretch for two seconds, and then folding them and pressing them against the chest for the same length of time. Repeat these movements about 15 times a minute for at least half an hour, or until natural breathing has been initiated, when the oxygen inhalation alone will suffice. After recovery, oxygen inhalation at intervals should be continued as desired.

Other dangers relate to the opening of the fire door when the generator contains only a small quantity of incandescent fuel, as on the entrance of air a strong flame may issue through the door, to the danger of the attendant. Also, the combustion chamber of a gas engine should never be opened unless a sufficient quantity of air has been made to pass through to remove all traces of gas, as the approach of a lighted candle, for the examination of the combustion chamber or valves, may cause an explosion which might be injurious to the workman.

CHAPTER XXI.

The Testing of Gas Producers.

As, up to the present time, it has not been found possible to design a gas producer which is capable of satisfactorily gasifying all classes of fuel, it follows that the first consideration in the design of any power-gas installation is the class of fuel it is desired to utilise. The variation in character of the different classes of carbonaceous fuels has already been dealt with at some length, and in the description of the numerous producers given it has been clearly shown that the general type of the gas generator is controlled by the class of fuel available.

Before attempting to apply a certain unknown class of fuel to a producer, it should be carefully tested, not only by a calorimeter to ascertain its heating value, but also as to the proportion of hydrocarbons present. Also it must be ascertained whether the fuel will properly descend, as the lower portions are gasified, for some classes of bituminous coals melt and run into a semi-liquid mass. The content of ash is also an important factor.

In tests of pressure types of producers where an auxiliary boiler is used to provide the steam required for the regulation of the gasification of the fuel, the fuel employed in the boiler should be carefully ascertained, and if it is of a different class to that used in the producer, its equivalent in thermal value should be added to the fuel gasified. The weight of water evaporated and passed into the producer should also be noted.

When the refuse material from the producer is removed in a wet state, it can be weighed and the proportion of water deduced by drying a representative portion and making a correction in the bulk.

Any unburnt fuel in the refuse should be sorted out, and its thermal value tested, so as to correct the gross for the net amount of fuel used.

It is important that too much reliance should not be placed upon a trial of short duration, as in this case the efficiency of the accessories, such as scrubbers, clinkering, etc., cannot be ascertained; while the condition of the pipes, valves, etc., can only be determined after a fairly extended period of running..

In starting up any installation there is, more or less, danger of an explosion occurring in the tubing and accessories, owing to their being filled with air; a good precaution is to fill the whole of the associated apparatus with steam before turning in the gas.

All joints, as far as possible, in gas-producer installations should be faced, and made perfectly gas-tight, as only those who have learnt by experience can understand how great danger there is from comparatively small leaks and badly-made joints; in all new apparatus tests for leakage should be made by a responsible person. Suction gas producers can be tested by the application of the auxiliary blower while a lighted candle is carefully passed over all points where a leakage might be suspected. Although the suction type of producer, in normal working, is under a less pressure than the atmosphere, and any leakage is into the system, during the blowing-up periods and standing-by poisonous gases may escape in sufficient quantity to cause trouble.

In all power-gas producers the grate area should be suitably proportioned to the rate of gasification of the fuel desired; suction producer installations have given dissatisfaction simply through this point having been neglected. The tendency, in designing installations, is to provide for *future requirements*, both as regards the capacity of the producer and the power of the gas engine; this generally results in the plant running at from light to half load, under which conditions both economy and satisfactory running are not attainable, instead of running between half load and full load, under which conditions the gasification of the fuel proceeds most economically and of regular quality, and the gas engine not only consumes a lower proportion of gas, but also gives best results as to responding to changes in load and regularity in power output.

In all installations which provide the proportion of water required to regulate combustion in the generating chamber by the saturation of the air supply, it is advisable to carefully test the efficiency of the water vaporiser. Various methods of heating the water for vaporising the air prior to its entering the producer have been adopted, especially in suction gas plants. An examination of the curve given in fig. 103, which shows the weight of water required to saturate air at different temperatures, will show that as the temperature increases, the weight of water which the air is capable of carrying, in a saturated state, rises very much more rapidly than the temperature rate. However, as in some cases the air supply is simply drawn suddenly, by the action of the piston during the charging stroke, over the surface of heated water contained in the vaporiser, it does not follow that when the engine is working at full load, when the fire requires the greatest proportion of water vapour, the air will be sufficiently long in contact with the water vapour to become saturated, while when the engine is *cutting-out* frequently, and requires less moisture in the generator fire, the longer interval between the charging strokes will allow of a higher proportion of water—up to saturation point—to be taken up.

If the air supply and vaporising apparatus is so arranged that saturation is ensured, the curve given shows that while the engine is working at full load the maximum amount of water is carried into the producer, because the fire works at the highest temperature; and when the load becomes lighter the temperature of the fire will fall, owing to the

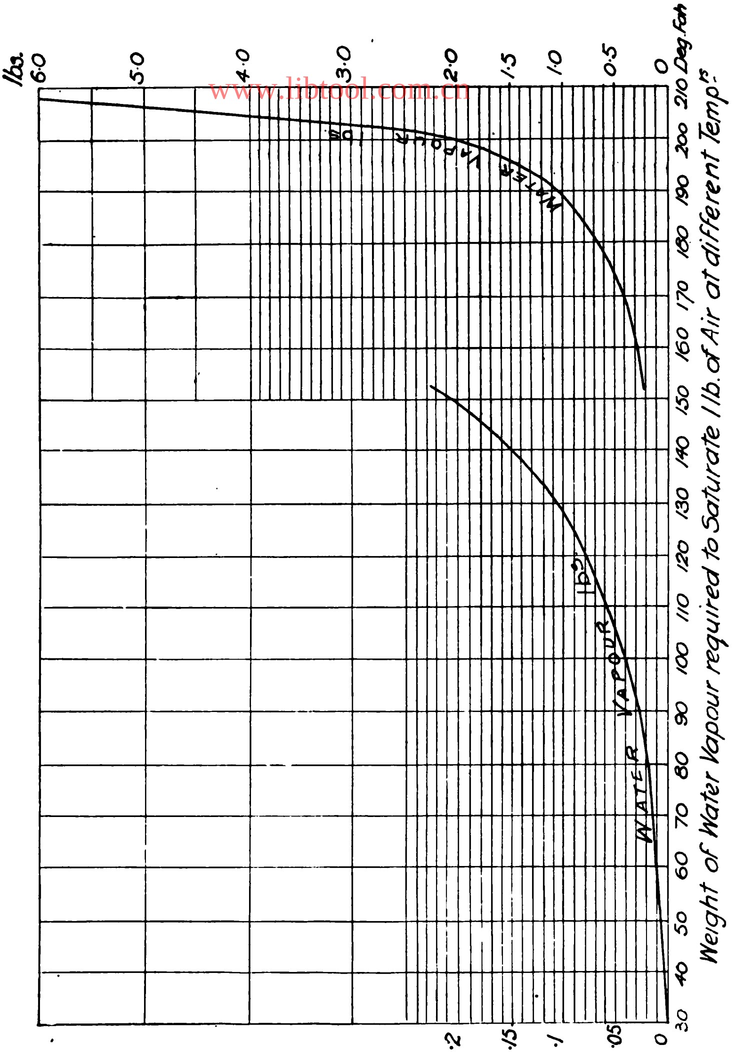
lbs.
6·0
5·0
4·0
3·0
2·0
1·5
1·0
0·5
0
Deg. Fah
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
·2
·15
·1
·05
0
WATER VAPOUR lbs
WATER VAPOUR lbs
Weight of Water Vapour required to Saturate 1 lb. of Air at different Tempʳˢ.

FIG. 103.

number of *cut-outs*, and this will be followed by a more rapid falling off of the weight of water carried into the fire for cooling purposes, thus producing gas of less thermal value—just when a reduction is most desired—and equalising the running of the engine in a most satisfactory manner.

The working of a gas producer can be tested by taking samples of the gas at short intervals, and determining the proportion of carbonic acid; as the fire works hotter the proportion of CO_2 generally falls off, and the gas becomes richer in CO, H, etc., and of higher heat value.

When any producer has been working for a lengthened period, it should be examined to ascertain how far clinker may be obstructing the area of the grate. A useful instrument for use in examining a power-gas installation is a handy portable water gauge, for testing the pressure at various points in the apparatus; by means of this the resistance offered by the fuel in the producer, the coke in the scrubber, the sawdust or other filtering material in the purifier, can readily be determined, and the periods for renewal of the filtering material can be judged.

During the trials of suction gas plants at the Royal Agricultural Society's Dreby meeting, 1906, the following particulars were taken: Lighting fuel used; anthracite or coke used; time taken from lighting fire until full load; running time; water consumed in vaporisers and scrubbers; unburnt fuel returned from the producer; total hours running at each test; coal per brake horse power per hour; water ditto; fuel used during the time the producers were "banked"; the rapidity with which the producers would respond to changes of load; time from starting a "banked" producer to engine taking full load; weight and appearance of clinker; condition of producer grate after trial runs; grate area; cross-section of generator chamber; volume of ditto; ratio of volume swept by piston to (1) grate area, (2) cross-section of furnace; B.H.P. obtained per square foot of grate area; B.H.P. per cubic foot of furnace volume; B.H.P. obtained per cubic foot swept by piston during forward stroke; indicator diagrams; maximum initial pressure;

compression pressure; vacuum at beginning of compression; Mathot diagrams, etc.

The apparatus shown in fig. 104 has been designed by Prof. N. W. Lord* for the determination of the amount of water vapour, tar, and soot in gas.

The apparatus is applied in the following manner: Before connecting up the pipe H, the tanks L and N are filled with water until it overflows at the valve I; fill the syphon P and close the pinch cock Q; connect up tube H to stop cock I, and turn on the water through the condenser F and live steam through the jacket C; then open the valve Q, when the water will be drawn out of the tanks N and L. Gas will be drawn through the apparatus into the tank L. The condenser causes any excess of moisture to be retained, with any tar and soot, in the flask M. Any increase in the weight of the flask represents the moisture, tar, etc., condensed from the volume of gas passed through the flask, which is measured by the volume of water which has run out of the syphon. The water of saturation of the gas, after passing out of the flask, is calculated by saturation tables at the temperature at which it issues from the

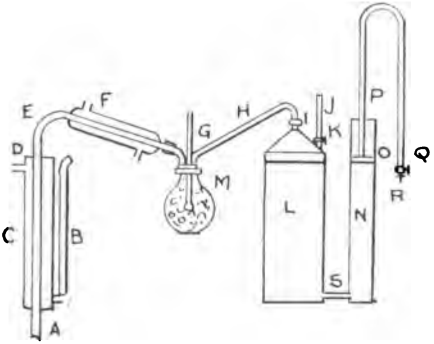

FIG. 104.—Apparatus for Determining the Water, Vapour, Tar, and Soot in Gas. Designed by Prof. Lord.

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* Journal of the American Chemical Society, vol. xxi., p. 1116 (1899).

flask. The total water in the gas, therefore, consists of the sum of that condensed and that remaining as saturating the gas as permanent vapour. After drying the contents of the flask over strong sulphuric acid until the weight becomes constant, the weight of condensed water can be determined by weighing. On igniting the asbestos fibre and weighing, the proportion of tar and soot is given.

The following formulæ enable the results of the test to be calculated:—

$$V\,s = \frac{V\,t\,(B - B\,t)}{760\,(1 + 0{\cdot}00366\,T\,t)},$$

$\frac{B\,b}{B}$ = volume of water vapour in the flask, per cent,

$\frac{B\,t}{B}$ = volume of water vapour in $V\,s$,

$$V\,d = V\,s\left(1 - \frac{B\,t}{B}\right),$$

$V\,s\,\frac{B\,b}{B}$ = total volume of saturating water vapour in $V\,s$,

$$V\,s\,\frac{B\,b}{B}\,W = W\,t,$$

$W\,t + W\,b$ = total weight of water carried in the volume $V\,d$ of gas,

from which the amount of water and tar and soot, per pound of coal can be calculated, where

B = barometric pressure,
$T\,t$ = temperature of gas in tank,
$T\,b$ = temperature of gas in flask,
$V\,t$ = volume of wet gas in tank at temperature $T\,t$,
$V\,s$ = $V\,t$ reduced to 0 deg. Cen. and 760 mm.,
$V\,d$ = volume of dry gas at 0 deg. Cen. and 760 mm.,

$B\,t$ = aqueous tension of water vapour at $T\,t$,
$B\,b$ = aqueous tension of water vapour at $T\,b$,
W = weight of 1 cubic unit of water vapour at $T\,b$,
$W\,b$ = weight of water condensed in flask,
$W\,t$ = weight of saturation vapour in volume $V\,s$.

CHAPTER XXII.

RECENT COMPLETED PATENTS.

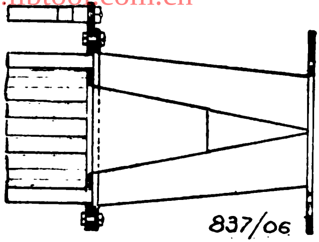
To enable gas producer designers to follow the developments in the means adapted by various workers to improve the apparatus for gasifying fuels, the following list of completed patent specifications during 1906 and part of 1907 has been extracted from *The Practical Engineer*, which each issue contains a list of inventions of the week, compiled by Messrs. Marks and Clerk. Patents relating to retort gas manufacture, acetylene gas generators, or coke ovens, have not been fully included. The numbers of the specifications indicate the proportion gas producer inventions form of the total number of applications during the period, while the variety of the points claimed as the subject of each patent will indicate the direction or special object aimed at as an improvement over existing methods. While care has been expended in the search of the list of specifications, some inventions may have been overlooked.

1906.

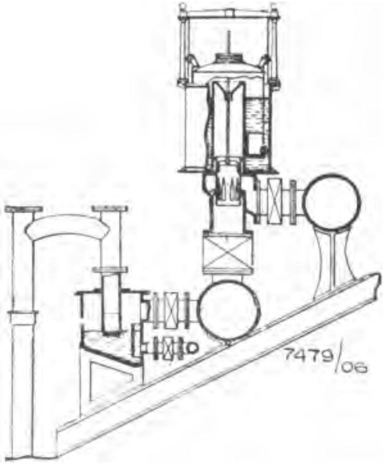
20 Bayer: Apparatus for analysing gases.
344 Chandler, Chandler, and Mullins: Grids or hurdles for supporting gas purifying material.
463 McLachlan: Gas governors.
753 Thompson (Wurts): Process and apparatus for distilling coals and other hydro-carbonaceous substances.

837 Monkhouse and Burstall: Appliances or apparatus for measuring the flow of gases and other fluids and liquids.

A group of calibrated tubes are arranged in a ring series between a pair of end plates and communicate with



casings, each containing an equalising cone, the total flow being ascertained by measuring the fall of pressure between two given points in one only of said tubes.



1003 Shilington and Hanna: Purifying, humidifying, or cooling of air or other gaseous fluids.

1100 Lake (Trump): Gas producers.

1841 Schatz: Automatic apparatus for analysing gas.

1980 Morton: Producer gas plants.

2104 Carter: Anti-vibration apparatus for gas mains.

2870 Kestner: Method of and apparatus for cleaning air or gas filters.

2907 Wilton: Purification of gases produced in the destructive distillation of coal or other carbonaceous material and apparatus therefor.

3290 Jasperson: Regulator for gas pressure.

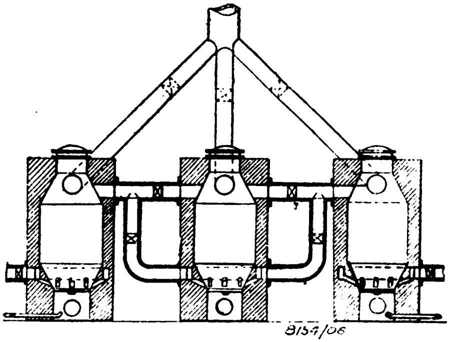
3417 Schatz: Apparatus for analysing gas.

4001 Crowden: Automatic sprinklers for extinguishing fires.

Beimann: Withdrawal of gases from gas retorts or coke ovens.

5222 Green and Horn: Apparatus for producing gas for illuminating and heating purposes from petroleum spirit or other volatile oil or spirit.

6425 Howorth (Aktiebolaget Gasaccumulator): Gas pressure regulating devices.



6935 Sepulchre: Gas generators.

7421 Mazza: Apparatus for separating the constituent elements of gaseous mixtures.

7479 Cloudsley and Colman: Apparatus for use in gas manufacture.

> The lower ends of the conduits leading from the retorts are serrated, so that any sudden rush of gas is split up into small bubbles, thus minimising the disturbance.

7538 Marshall and Hersey: Filters chiefly intended for use in connection with the purification of gas.

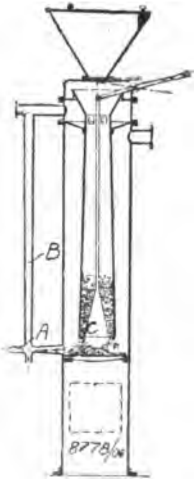
8154 Terneden and Muller: Manufacture of water gas.

> An important feature of this invention is the arrangement of more than two generators parallel in the blowing run and serially in the gas run. By thus increasing the

number of generators, the quantity of carbonic acid is considerably reduced and the calorific value of the gas correspondingly increased.

8276 Bauke: Suction gas producers.

The tar gases produced in the feeding shaft containing the bituminous material are sucked off from the shaft by means of a pipe and injector, and are forced through the branch pipe, the lower end of the outer wall, and pass into the zone of reduction situated between the grate and the lower end of the feeding shaft in order to be burnt at such place.



8760 Bauke: Manufacture of generator or producer gas.

8778 Bauke: Suction gas generators.

In the gas producer there is arranged a feeding shaft, from the upper part of which the tar gases are drawn off by means of an injector A through the tube B, and said gases, after having been mixed with air or steam, are introduced into the reduction zone. C is the shaking device consisting of a downward open cone, raised and lowered in a suitable manner.

9291 Christie: Stop cocks or valves.

9501 Tait: Combustible gaseous fuel for the generation of motive power.

9701A Cox: Gas-making plants.

10226 Bormann: Gas generators.

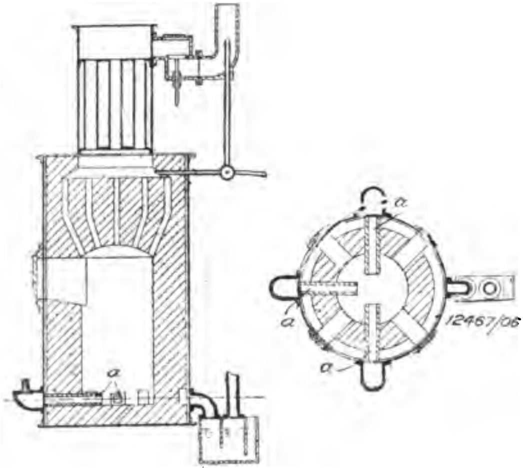
10810 Alexander: Gas supply regulators.

10814 Graham: Apparatus for condensing and purifying gases, the same being especially applicable for use in the manufacture of sulphuric and other acids.

11077 Fillunger: Method of obtaining ammonia from gas liquor.

11099 Browne: Manufacture of gas from coal and carbonaceous materials, also relating to water gas.

11125 Ewing: Sealing arrangements for hydraulic mains of gas plant.



11133 Burschell: Process for removing sulphide of hydrogen from gases.

11213 Farnham: Gas-purifying devices of suction and other gas plant.

11925 Allison (American Chemical Eduction Co.): Process of distilling coals and other hydro-carbonaceous substances.

11926 Allison (American Chemical Eduction Co.): Apparatus for distilling coals and other hydro-carbonaceous substances.

11993 Scheibe: Devices for separating admixtures from gases and vapours.

12210 Potter: Cleansing of gases.

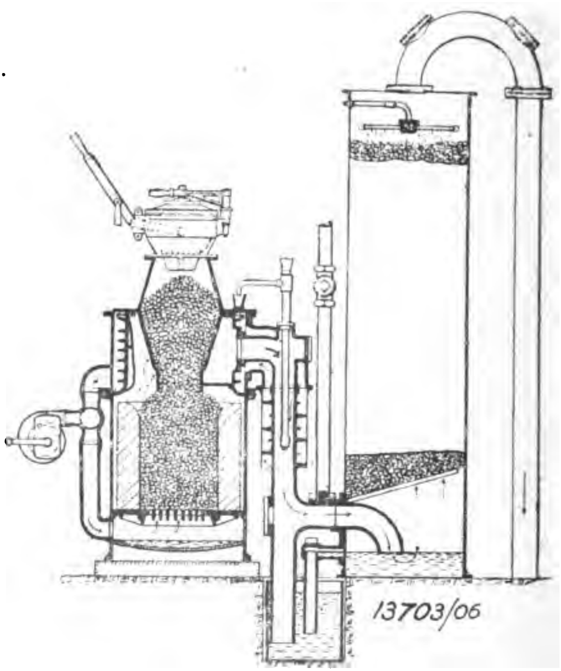
12467 Wilkie and Hutchins: Producer gas generators.

In generators wherein the "blow" is upwards and the "make" downwards removable air conduits *a* are installed for the purpose of preventing the burning away of those parts in the main lining which are round the air inlets.

13480 Elworthy and Elworthy: Manufacture of gas for illuminating, heating, or power purposes.

13510 Sepulchre: Process and apparatus for freeing gases from solid or liquid particles with which they are charged.

13598 Newton: Gas producers.



13703 Bickerton, Robson, and National Gas Engine Co.: Gas producing plant of the suction type.

The vaporising chamber is formed by a casing round the upper part of the producer, which is removable without disturbing any of the main joints of the apparatus. The air passes to the vaporiser through an annular space around the gas outlet pipe, whereby the air is preheated on its way to the vaporiser.

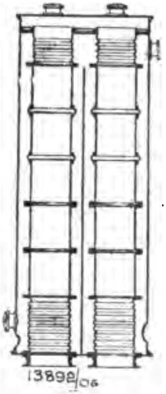
13787 Wilton: Gas washers.

13892 Dixon and Ross: Heat exchangers used in gas producer plant.

Provision is made for the expansion and contraction of the different parts of the heat exchanger by forming in the known manner the inner pipes, and if desired also the outer pipes or casing, so that whilst the inner pipes are supported at or near both their ends the heat exchanger is yet capable of expanding and contracting to any desired extent.

14097 Meurs-Gerken: Process for the separation of one or more vapours from mixtures of vapour and gas.

14365 Parker: Fuel, partial destructive distillation.



14496 Flossel: Apparatus for purifying blast furnace and other impure gases.

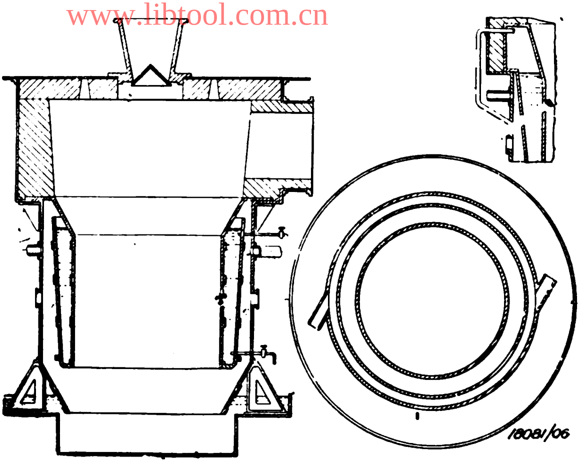
14914 Mason's Gas Power Co., Wright and Hollis: Self-closing apparatus for the poker holes of gas producers and the like.

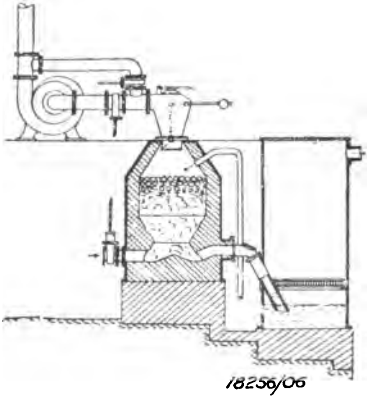
15013 Tervet: Methods of and apparatus for testing gas.

15326 Sabatier: Process for the manufacture of a gaseous mixture containing hydrogen and methane.

16218 Mason's Gas Power Co., and Wright: Construction of twin or coupled gas producers.

In a twin gas producer the two producers are constructed integral with each other and with a dividing wall common to both, each producer and its casing being of intersecting circular formation in plan. With this arrangement it is made possible to place two or more twin producers to be coupled up or built integral with each other and at the same time to allow of ample room for stoking.





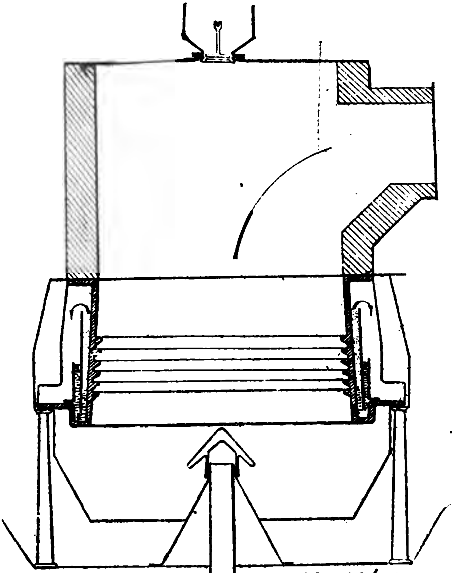
16600 Cohen: Process of and apparatus for manufacturing gas.

16911 Milbourne: Valvular arrangements for controlling and directing the passage of gas.

17087 Hutmacher: Generators for water, gas, and the like.

17504 Parker: Production of a partially coked fuel.

18033 Rehmann: Device for charging furnaces, gas generators, and the like.



19048/06

18081 Becker and Greener: Gas producers.

This producer comprises a metal generator having a water jacket in communication with an air space surrounding the same and serving to cool the generator, and thereby to obviate the necessity of lining the same with firebrick.

18256 Clark (Dellwik-Fleischer Wassergas Ges.): Water-gas producers.

The pipe connecting the producer with the fan is fitted with a by-pass with a valve adapted to entirely close the by-pass or afford alternately a large or small opening.

18351 H. J. West and Co., Webster and Chew: Apparatus for compressing and cooling air or gases.

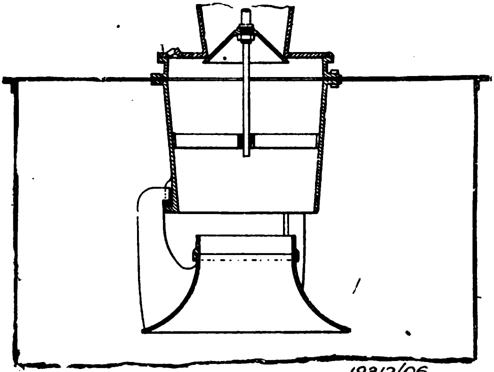
18879 Bradley: Gas producer.

Wind pipes extend across each producer chamber having separate connections for supplying air to each compartment, thus providing means for effectively regulating the supply.

19048 Deschamps: Gas producers. [Date applied for under International Convention, August 25th, 1905.]

The inner ribs of gas producers are provided with slanting lower surfaces, and the cylindrical diaphragm dividing the water jacket into two parts is higher than the outer cylindrical wall.

19115 Sellers, Capel, and Wallis: Means for generating steam for conversion into water gas in suction and pressure gas producer plants.



19312/06

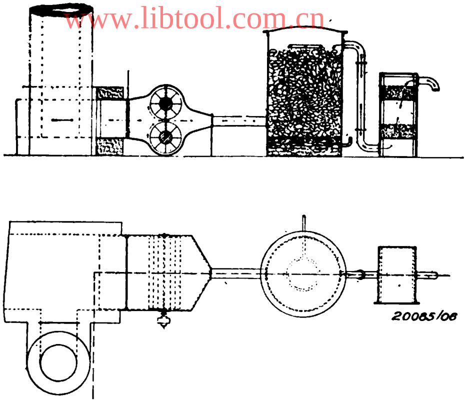
19312 Mond: Device for distributing the charge fed into a furnace, producer, or the like, or into a receiving vessel.

The device compresses a tube fixed below the hopper and a truncated hollow cone which may have curved surfaces and be provided with serrated edges, fixed below the tube in such a manner that while some of the charge falls through the cone another portion falls upon the outer surface thereof, keeping a level surface.

19513 Hubbard: Apparatus for automatically analysing mixed gases and recording the percentage therein of one of the gases.

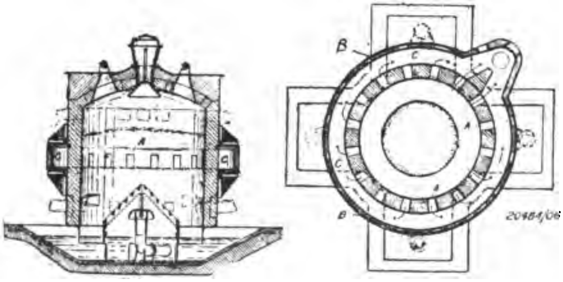
19624 Robertson, and Willans and Robinson Ltd.: Apparatus for filtering gas.

20085 Ling and Henry: Treatment of boiler flue waste gases and their subsequent utilisation by the renewal of combustion.



Steam is generated in an additional boiler from the waste gases collected from two or more boilers, the invention being in the combination of the parts.

20359 Fritz: Method for producing gas and its by-products from coal, peat, and similar substances.



20484 Mason's Gas Power Co., Hollis and Wright: Power gas producers.

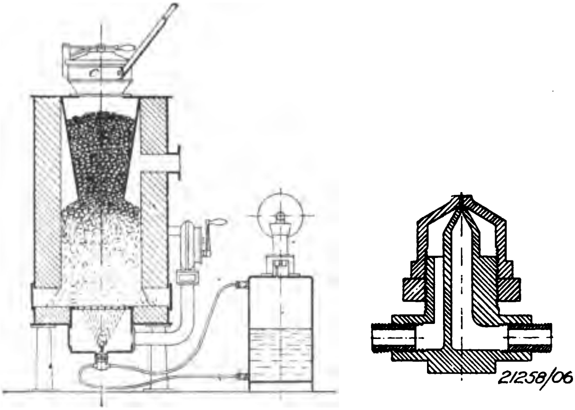
The special features of the construction are the graduated openings A, the cleaning openings B, and the manner in which the uptake is arranged in relation to the annular chamber C.

20630 Reid: Apparatus for generating gas from liquid hydrocarbons.

20670 Wilson and Downing: Apparatus or means for vaporising petroleum and other oils and fats.

21258 Dowson: Manufacture of producer gas and generators therefor.

Atomised water accompanied by a small proportion of air used for the purpose of combustion is passed directly into the generator, preventing an accumulation of lime and other deposits.



22028 Harris: Compositions for use in the production of gas from garbage or similar gas producing material.

22129 Philip and Steele: Automatic apparatus for indicating the presence of dangerous gases or vapours in mixture with air.

22511 Carpenter: Gas governors.

24047 De Bruyn: Liquid seal applicable to apparatus for measuring gas pressures.

24144 Crossley and Rigby: Ammonia recovery gas plants.

24311 De Bruyn: Apparatus for measuring gas pressures.

24405 South Staffordshire Mond Gas (Power and Heating) Co., and Pinnock: Portable gas analysis apparatus.

24624 Bentley: Combination of gas washing and cooling apparatus.

24833 Charlouis: Gas-generating plant.

24965 Hanwell and Beard: Apparatus for producing gas from liquids.

25469 Green: Gas purifiers.

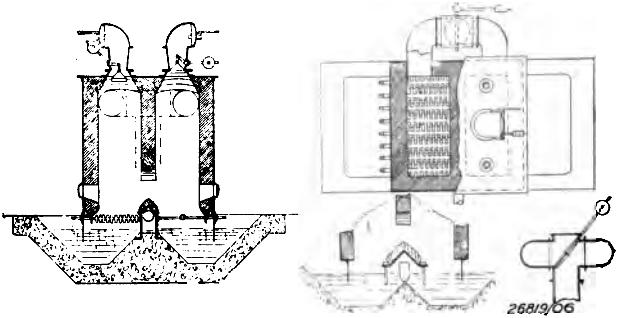
25976 Tyers, Hedley, and United Alkali Co.: Treatment of sulphuretted hydrogen, or gases containing sulphuretted hydrogen, for the obtainment of sulphur therefrom.

26097 Smith: Means for indicating or regulating pressures of gas or supply of gas.

26781 Holmes and Howell: Valves for controlling the flow of gas in purifiers.

26819 Thwaite: Method of generating combustible gas and apparatus therefor.

The volatile gases evolved from the fresh fuel, charged in one of the two vessels, are by their rapid evolution forced down the incandescent column of fuel beneath it, escaping into the associated vessel at about the third of the height of the column of fuel and flow upwards through this second column of incandescent fuel before they can finally escape into the outlet main, which is equipped with a reversal valve, the direction of such gaseous flow being made alternating by the reversal valve, common to the two generating vessels.



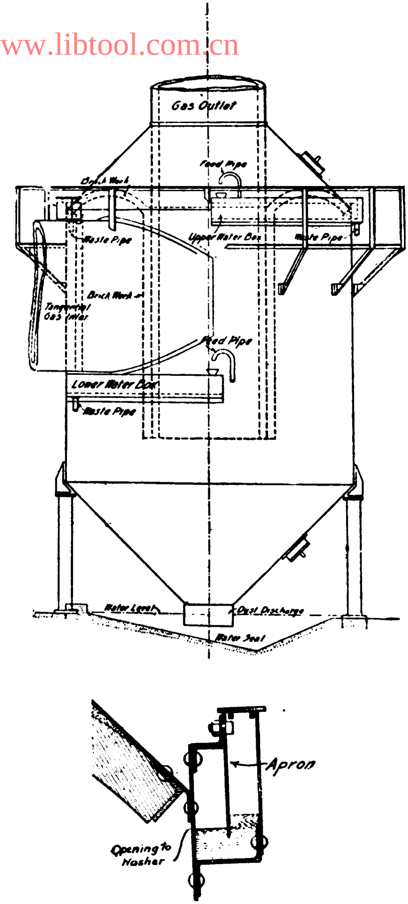
27124 Ozonair Ltd., and Rogerson: Method of and means for washing and filtering air or other gases.

27247 Hess: Apparatus for the purification of gases.

28148 Bachman: Apparatus for washing gases.

28526 Parry and Atkinson: Coal and other feeding hoppers for gas producers, furnaces, or the like.

28689 Soc. Anon. des Combustibles Industriels: Distillation and partial de-hydro-generation of hydrocarbons.


Gas Outlet
Feed Pipe
Brick Work
Waste Pipe
Upper Water Box
Waste Pipe
Brick Work
Tangential Gas Inlet
Feed Pipe
Lower Water Box
Waste Pipe
Water Level
Dust Discharge
Water Seal
Apron
Opening to Washer

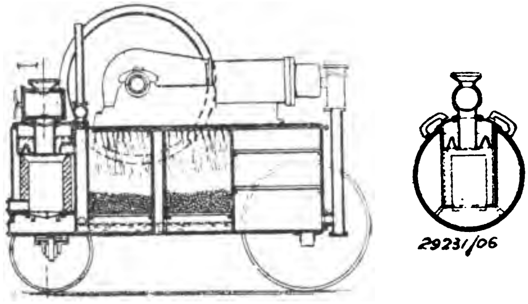
No. 28148/06.

28834 Crossley and Rigby: Improvements in suction gas producers using bituminous coal.

The fuel is first subjected to partial distillation and the tarry matter consumed, the coke being gasified later with air, or steam, or both.

29231 Hurlebusch: Portable gas plant comprising combined gas producer, purifying apparatus, and gas engine. [Date applied for under International Convention, January 15th, 1906.]

The plant is characterised by the enclosure of the gas producer, as well as the cooling and purifying apparatus, in a single outer vessel having the form of a cylindrical boiler, which serves as base for the gas engine mounted thereon.



29231/06

29471 Wilson: Gas-washing machines.

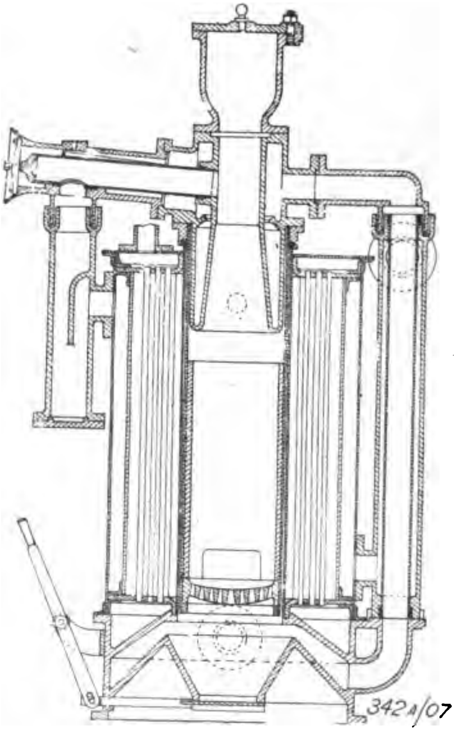
1907.

342A Clarke, Chapman, and Co., and Robson: Combined gas producer and ammonia or equivalent generator. [Date applied for under Rule 5, Patents Rules, 1905, January 5th, 1907.]

In a combined gas producer and ammonia generator or equivalent volatiliser having the producer within the generator and tubes in the generator for utilising the heat of exhaust gases from a gas engine, the construction wherein liquid is vaporised by elements in communication with the generator and mixed with air, the mixture being then passed below and through the generator grate, and the gas produced passing in contact with the vaporising elements around the ammonia generator or volatiliser and thence in contact with the conduit conducting the mixture to the generator grate, and finally to the plant in which it has to be utilised.

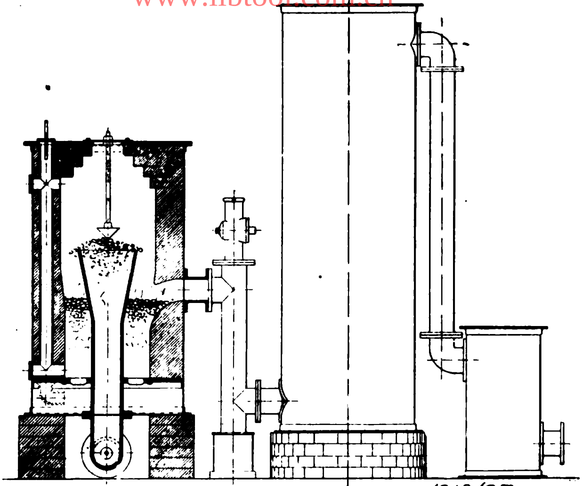
1313 Daniels, Higgins, and Daniels: Gas producers that are for use with bituminous coal or other fuel-containing volatile matters.

In a gas producer provided with a distillation retort through which the fuel is fed by any suitable apparatus situated at the lower part; the carrying of such retort through and above the layer of incandescent fuel in the producer, the volatile products escaping from the retort being collected.

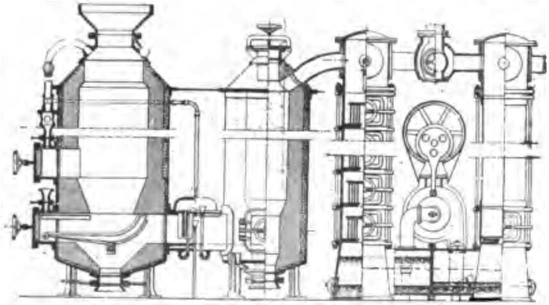


2579 Ullendorff: Dust collector for dust extracting apparatus.
4911 Sire de Vilar: Gas generators.

In the upper part of the down draught combustion shaft the fuel is subjected to primary combustion, and in the lower part to secondary combustion. A supplementary air



1313/07

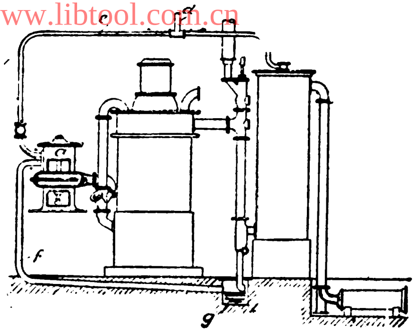


4911/07

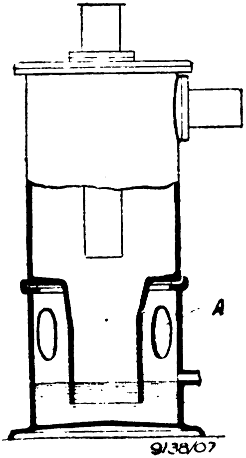
supply is introduced into the lower part of the fuel forming the fuel column in the combustion chamber. The fuel is maintained in a state of incandescence in an up-draught reducing shaft, as a result of the secondary combustion.

7405 Knuzler and Schneider: Suction gas plant.

This invention relates to a method of starting suction gas motors, wherein the blowing of the fire in the generator



7405/07

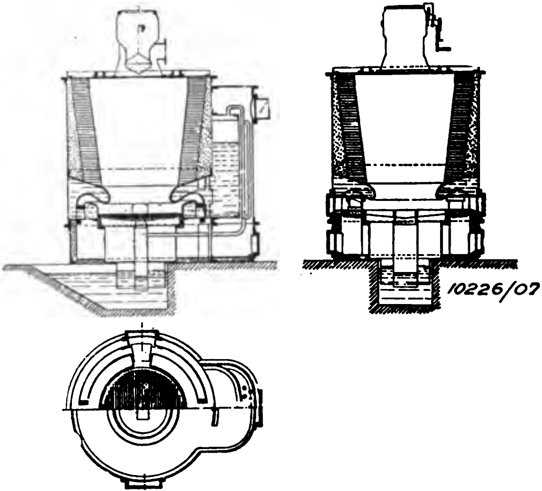


9138/07

is performed by a hydraulically-operated fan or blower *a*, the supply pipe *e* of which is provided with a cock and may be connected to the water supply pipe *d* of the scrubber, and the water pipe *f* may be connected to the waste duct of the scrubber.

9138 **Delion and Lepeu**: Safety device for use in suction gas plant. [Date applied for under International Convention, May 28th, 1906.]

A hydraulic joint is arranged between the gas washer and the engine. A reduced pipe from the gas holder extends to a certain distance above the bottom of the water seal chamber, which latter has overflow perforations in the side walls, as shown at A.



10226 **Barmann**: Gas generators.

Air inlet ports are arranged above and grate below. Above the latter lies an eduction flue for the gas producer. A ring-shaped water boiler surrounds on all sides the lower part of the generator and the eduction flue.

10752 **Munzel**: Safety devices for use in sawdust purifiers for gas apparatus.

13161 **Schmidt and Desgraz**: Apparatus for supplying coal in a continuous and uniform manner to gas producers and like apparatus.

14531 **Ransford** (Pierson and Firm of J. and O. G. Pierson): Steam generators for gas producers.

24965 **Hanwell and Beard**: Apparatus for producing gas from liquids.

25469 **Green**: Gas purifiers.

APPENDIX.

The Grice Suction Gas Producer.

The Grice Gas Engine Co. Limited, Carnoustie, Scotland, make two types of suction producers, which have several novel points, the main features being clearly shown in figs. 105 and 106, and the sectional views, figs. 107, 108, and 109.

Fig. 105 is reproduced from a photograph of a type A producer of 150 H.P. capacity, the most striking feature being that the casing of the generator is rectangular, which enables the ordinary stock of firebrick being employed for lining the generating chamber, thereby dispensing with the necessity of obtaining special bricks when being erected or relined. Besides the advantage in regard to being readily lined with bricks obtainable in almost any district, the rectangular shape of the grate lends itself to the fitting of a grate with bars which can be mechanically operated from the outside of the casing by a lever, thus enabling the single producer being run for long periods, the oscillating of the grate from time to time clearing the fire from ashes and preventing the arching of the fuel. The single producer type A is the most generally adopted, so a diagrammatic section is given in fig. 107, in which the various parts are lettered in accordance with the following description:—

Names of Parts.

A. Generator casing.

B. Ashpit to generator, to which is coupled the fan inlet, and overflow water from boiler is drained in to increase the steam.

C. Rocker bars, worked from the outside by a handle, for breaking up the clinkering ashes.

Fig. 105.—Grice Suction Plant. Type A.

D. Steam generator, showing water heater.

F. Fire-brick lining put in to drawing supplied.

G. Gas passage through water heater.

H. Air intake to boiler.

I. Steam and air conveying pipes to underneath the firebars.

J. Gas pipe to chimney and hydraulic washer.

K. Hydraulic washer for removing all grit from the gas, giving first washing process.

L. Gas pipe from washer to the collecting box.

M. Sprinkler for distributing cold water over the coke in the washer for cooling the gas.

N. Washer filled with hard coke, about 3 in. cubes, for arresting the water and presenting large cooling surface to the gas passing through.

O. Drain box, or pipe sealing chamber.

P. Drain pipe to seal box.

Q. Gas pipe to engine.

R. Collecting box for gas to engine, with drain at the bottom.

S. Overflow to drain.

T. Chimney tap.

U. Tap for testing the gas.

V. Fan for blowing up the fire and making gas for starting.

W. Double hopper for feeding the fuel.

Y. Tap for regulating water feed to the boiler.

Z. Tap for regulating water feed to the washer.

It will be noticed that the boiler, or vaporiser, is situated on, and forms the upper part of the generator, but to hasten the vaporisation, at starting up the producer and in running, there is provided a water jacket for the gas outlet pipe, through which the feed water for the vaporiser is caused to pass, thus becoming heated before it enters the boiler proper, which enables a quick start to be made.

The hot gas leaving the generator is made to pass through a hydraulic washer, which not only arrests the dusty particles carried out of the generating chamber, but forms a non-return seal. This is clearly shown in

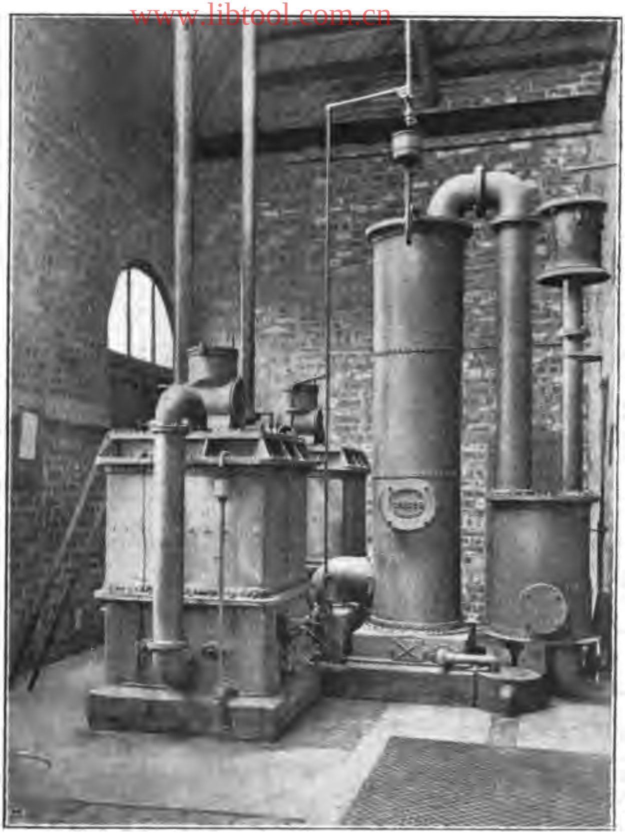


FIG. 106.—Grice Suction Gas Plant. Type B.

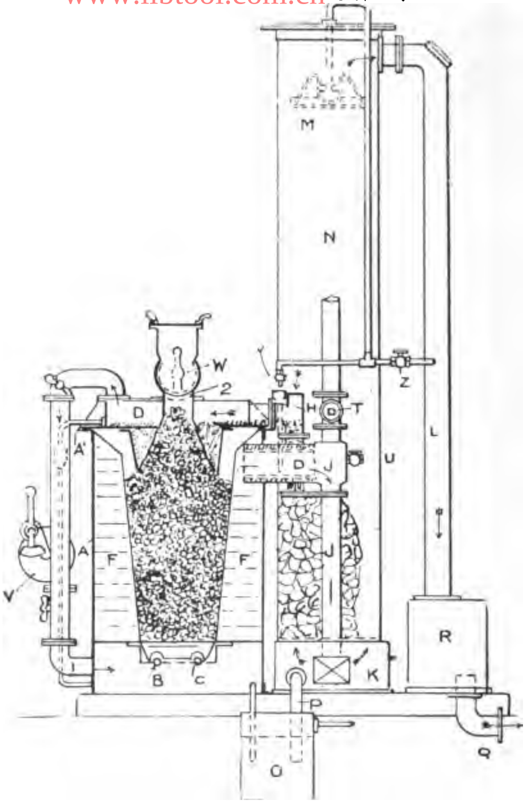


FIG. 107.—Section of Type A Producer.

fig. 105, and the removal of sludge can readily be effected by the cleaning doors provided for that purpose. This hydraulic washer is found to be very effective, and in many plants the water required is economised by collecting and re-using for considerable periods. The type "B" Grice suction producer is especially designed for

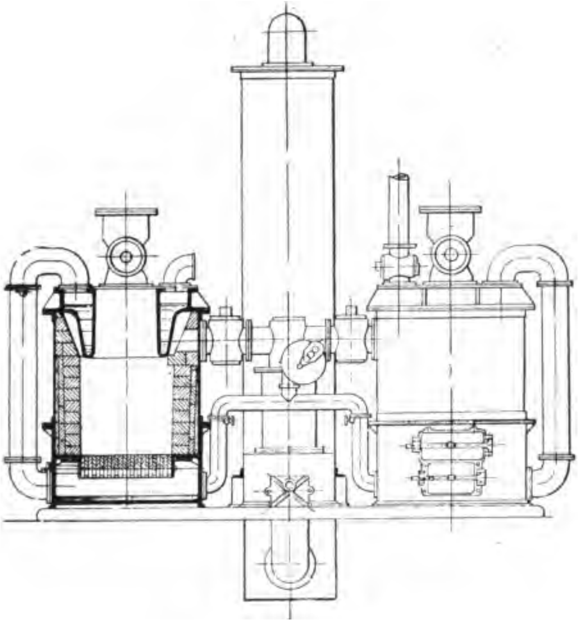


Fig. 108.—Type B Producer.

permitting of continuous running; two generators are employed, coupled by suitable valves with a common washing and drying plant. The sectional views, figs. 108 and 109 and the photograph fig. 106, require little explanation after that given of type A. When one generator has been in use for a considerable time, and has become fouled, the second is brought into use, either by hand or by the suction of the engine. A number of installations of type B have been put down for collieries, electrical works, etc., where running night and day is

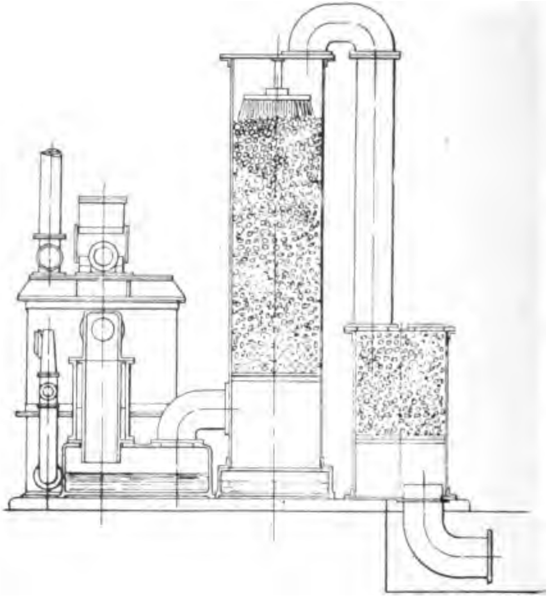


FIG. 109.—Type B Producer.

required. These producers are guaranteed to give 10 to 20 B.H.P., when coupled to a fair-sized engine, for 1d. per hour when using anthracite costing 15s. per ton.

HORNSBY-STOCKPORT SUCTION GAS PRODUCER.

Seeing that it was only in 1891 that the suction producer was first practically developed, it is good evidence of the suitability of this type of power producer to seriously enter into competition with other power generators when we find that one firm alone has supplied plants to over 205 installations, having an aggregate of over 13,000 effective horse power.

Messrs. Richard Hornsby and Sons Ltd. have issued a list of references giving the names and addresses of the firms to whom the above number of installations have been supplied. The capacity of the plants varies from 9 to 230 E.H.P., and the average about 64 E.H.P., but some of the firms have three and others two plants, while in some cases one plant supplies a couple of gas engines. Besides numerous ordinary power applications the following manufactures have adopted the Hornsby-Stockport gas plant: waterworks, ice making, cocoa roasting, printing, woollen mills, stone working, sewage pumping, flour mills, saw mills, brickmaking, bleach and dye works, tanneries, flannel manufacture, biscuit and cake making, varnish and colour works, and motor and dynamo works.

Before describing the gas plant in detail it will be interesting to review a few letters received by the firm from different users. As a stand-by plant for pumping storm water and sewage "it is always relied on to be in full work at short notice, and has not failed when required." A 90 B.H.P. engine lifts 7,000 gallons 18 ft. per minute at a cost of 2s. 9d., or 0·375d. per horse power per hour, including coal at 28s. 6d. per ton, oil 1s. per gallon, water 6d. per 1,000 gallons, attendance, etc.

A firm of brickmakers, which formerly used a portable steam engine, found their power cost when making 5,000 bricks per day at 12s., reduced to 2s. per day on an increased make of 7,000 bricks, and during three and a half years' running had no occasion to call in the aid of a mechanic.

A steam laundry, driven by a 12 B.H.P. gas engine, on town gas at 3s. 4d. per 1,000, costing 21s. $3\frac{3}{4}$d. per week, substituted a 17 B.H.P. suction plant, which they found only cost them 6s. 8d. per week, both plants doing the same work on an average of 57 hours per week.

At some stone quarries a 33 B.H.P. plant had been running night and day for three months, costing, with coal at 36s. 10d. per ton, 3d. per hour (including raking of fire), or about 10d. an hour less than when steam power was used.

Another firm found the fuel cost of suction gas for fifteen months to be £124 15s., as against £211 9s. 7d. for the previous fifteen months on town gas. As compared with oil-power fuel, one firm had made a comparison in which suction gas cost 2s., as against 9s. to 10s. for the some power by oil fuel.

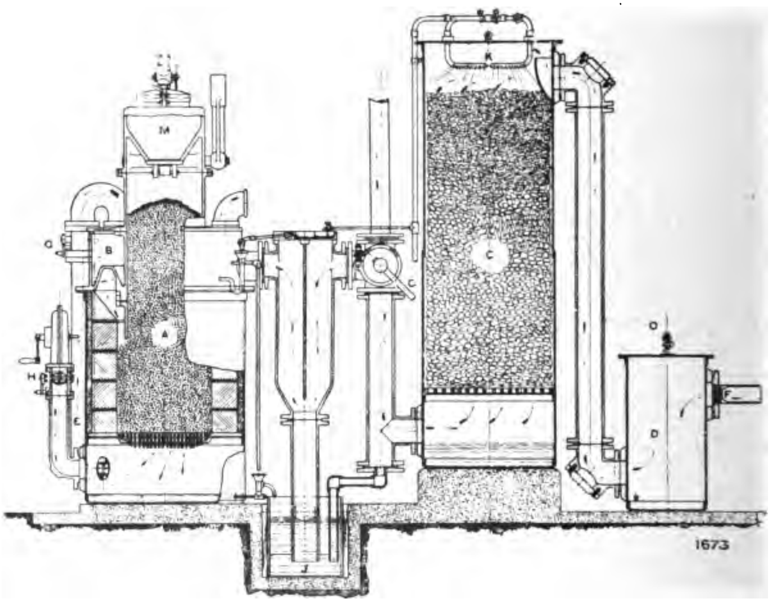


Fig. 110.—Hornsby-Stockport Suction Gas Producer.

The principal features of the Hornsby-Stockport suction gas plant will be gathered from the typical illustration fig. 110. The charging hopper M differs from most other types, in that it is fitted at the top with a protected sight cock, by means of which the condition of the fuel in the generating chamber can be observed; if the fuel becomes too far lowered in the chamber it becomes heated to redness, and the attendant can judge what amount of fuel to add; this cannot well be arranged with hoppers fitted with bell valves. The main control of the starting and stopping of the plant is by the single cock G, which either connects the generator with the scrubber or closes off the engine and cleaning apparatus, and allows the discharge of any gas direct into the atmosphere when blowing up for starting, etc. It will be noted that cleaning facilities are provided on all the pipes, etc., and that steam from the vaporiser does not enter the generator unless the engine is drawing gas, so that the fire is not cooled by excess of steam when the engine is running on light load.

This firm also manufactures a semi-pressure gas plant for use in situations where the gas is required for other purposes than for power. It consists of a combination of a suction producer and gas exhauster, with a gas holder for storage purposes, besides which they have a large plant for using bituminous coal fuel, which will be capable of supplying 1,500 H.P. when completed.

THE "SCOTIA" SUCTION GAS PRODUCER.

Messrs. D. Gorrie and Son, Perth, Scotland, have taken up the manufacture of gas-producing plants, and claim for their "Scotia" suction gas plant that it is "The latest, simplest, most economical, and best on the market, besides being the most reliable for varying loads, and requiring the least attention." As they also claim that the consumption of coal is the lowest, and consumption of water reduced to a minimum, an examination of the details of the typical plant, fig. 111, should reveal some of the features which are necessary to establish the claim to superiority over the numerous makes now entering into competition. The advantage of being the latest in the field implies very careful study of the numerous small details as experimented with by previous makers, for in general principle there is very little difference. To fix upon a standard grate area, generating chamber volume, depth of fuel, etc., is almost impossible, because fuels differing in quality and size give more or less ash, and the resistance to the passage of air varies.

In regard to simplicity the writer has so much regard for this that he would be inclined to sacrifice a point or two in efficiency in favour of fewer and simpler parts.

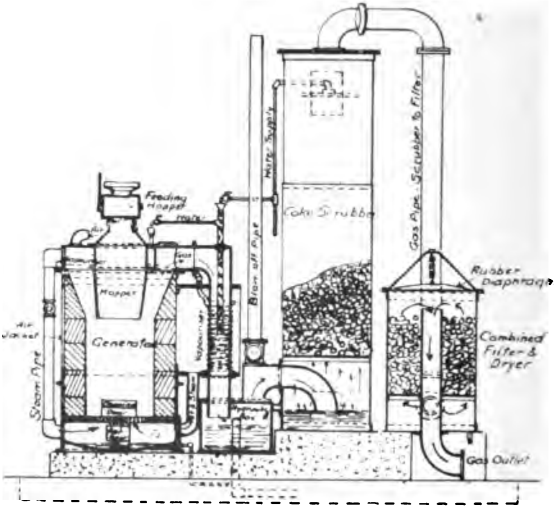


FIG. 111.—Section through the "Scotia" Suction Gas Producer.

Leaving the questions of "most economical" and "best in the market" to be proved by long periods of working and repeat orders for the plant, we may look into the question of reliability under light loads. This problem has been made a special feature in many of the previous makes, some makers applying valves for the water regulation to be manipulated by hand, while others have provided automatic methods to deal with the regulation of the steam admitted to the fire-grate to suit the load.

Again, the claim that the water consumption is reduced to a minimum involves to some extent certain other conditions, such as the class of fuel, amount of tarry matter, and the rendering the gas cool on its entrance to the engine cylinder. The quantity of water required by suction plants is rather more than is sometimes desirable, while the question of purity is also involved, because if there is any deposit of scale in the vaporising apparatus, there should be provided ready means for cleaning all surfaces with which the water comes into contact.

Applying the foregoing considerations to the sectional view, fig. 1, the makers draw attention to the design of the feeding hopper, which, by one movement only, feeds the generator in the simplest manner, and at the same time excludes the possibility of air entering the generating chamber and causing an explosion.

The vaporiser forms the top part of the generator, but the water is preliminarily heated by being made to circulate through a double tube, situated in the hot gas off-take, before it enters the vaporiser, and by this means a rapid start can be made.

The outer surface of the gas off-take is made to act as a secondary vaporiser, water overflowing from the primary vaporiser being caused to traverse the surface, cooling the gas and forming steam for admixture with the air entering the ashpit.

Both the ash and cleaning doors are provided with mica windows, which enables the state of the fire to be observed. The hydraulic box at the foot of the gas off-take pipe forms both a dust arrester and seal for preventing any back flow of air or gas. From the coke scrubber the gas passes to a combined filter and dryer; this vessel not only contains vegetable moss, or, if this is not obtainable, shavings and sawdust, but is also provided with a rubber diaphragm, spring-controlled, which acts as a gas bag to modify the flow of gas during the suction stroke of the engine.

THE "MERSEY" GAS PLANTS.

The "Mersey" patents include three types of gas producers, which possess several unique features.

While the Mersey suction producer is capable of continuous running except for a four hours' stoppage once a fortnight for overhauling the engine, the Mersey suction-pressure producer combines the conveniences of both suction and presure plants, running gas engines and providing heating gas for various purposes; and the Mersey H.G. producer provides a gas of a higher thermal quality, suitable for many purposes outside the range of ordinary producer gas.

A section view of a typical Mersey suction producer is given in fig. 112. For continuous running of a suction gas producer it is necessary that during clinkering the quality of the gas shall not be reduced through the supply of steam, or water vapour, passing to the hearth being reduced, and in the Mersey producer a special water tap is provided to enable the attendant, when clearing away the ash with the fire-door open, to supply the grate with steam.

When it is desired to clear the grate from ash, the attendant turns on a tap placed at the side of the generator, which sprays water on to the live coal, thus making the plant independent, for the time, of the vaporiser. The same tap is used for getting a rapid start, the water spray being applied until the vaporiser is hot enough to take up the supply.

Usually the vaporiser, whether of the internal or external type, is unable to provide vapour until the mass of brickwork, metal, and water has had time to reach a suitable temperature, so that the method adopted in this case not only provides for a rapid start, but enables the plant to respond to the variations in the load. The vaporiser is of the external type, constructed of cast iron.

Round the central pipe cups are fitted, which carry a special fibrous material which absorbs moisture and offers a large surface for evaporation of water, the outer case being so arranged that it can readily be removed for cleaning purposes.

Special provision has been made in this plant for cleaning all parts which may become clogged, either by the formation of scale or the use of dirty water; even the water-spraying nozzle in the washer can be removed in a few moments without having to break any joints. In place of an ordinary expansion box, there is provided a vessel which also acts as a drier for the gas, and the wood fibre used for drying is carried between two perforated plates, fastened together by a rod, so that the material can be changed in a few moments. When the gas is required for purposes other than simply driving a gas engine, as where calendars or soldering irons are to be heated, or blowpipes supplied with gas for brazing purposes, etc., the addition of a suction-pressure fan, with a patent pressure regulator, enables the gas being kept at a constant pressure, while the production of gas is automatically regulated to suit the demand. The additional

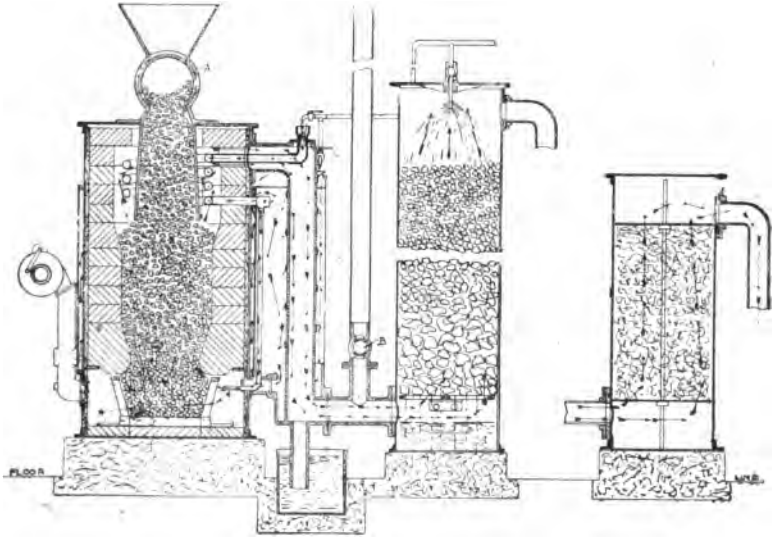


FIG. 112.—Mersey Suction Gas Producer, Power Gas Corporation Ltd.

first cost, and running cost, is low, and it is not necessary to employ a boiler, with its constant attention. The generating and washing plant in this arrangement works at a pressure below that of the atmosphere, so that the fire can be cleaned without interfering with the quality of the gas, and a notable feature is that this arrangement requires no costly gas holder.

Including labour, this plant generates a quantity of gas equal in work to 1,000 cubic feet of town's gas for a cost of 4d. to 8d., according to the cost of fuel—either anthracite, coke, or charcoal.

Where there are a number of engines to be driven, this arrangement has the advantage that the gas can be delivered to almost any distance at a practiclly constant pressure and quality. The temperature the gas is capable of developing is about 2,000 deg. Fah.

For such purposes as lighting, singeing, brazing, annealing, wire-tempering, burning and glazing pottery, manufacture of glass, smelting, etc., the Power Gas Corporation provide their H.G. type of producer, the gas from which is capable of giving a temperature of 5,200 deg. Fah., as compared with 4,700 deg. Fah. from town's or retort gas.

With fuel costing 10s. per ton, the cost is about 5d. per 600,000 B.Th.U., or equivalent to that from 1,000 cubic feet of town's gas.

The fuel used in this producer must be of free burning quality, and may be either anthracite, coke, charcoal, bituminous slack, wood blocks, wood chippings, sugar cane trash, peat, or, in fact, almost anything that is combustible. The plant is entirely automatic, except for stoking and removal of ash and clinker, and the gas ranges from 250 to 300 B.Th.U. per cubic foot.

The system employed consists of the intermittent production of water-gas and producer-gas by means of automatically-working valves. The method of working the plant is somewhat as follows:—

After the fire is started in the generator, steam is turned on at the exhauster, either from a special boiler provided, or from some other convenient source, which quickly raises the temperature of the fire.

When the fuel has reached a suitable temperature, water is turned on to the washers, and in its passage it operates a small motor connected to the valves, the speed being so regulated that the "blow" period is approximately one minute, at the end of which time the motor reverses, the valves shut off the steam to the exhauster, close the chimney valve, and admit steam to the generator for a period of one minute during the "make" stage.

Previous to the steam entering the generator, it passes through a superheater, so that when it comes in contact with the fuel it is at a red heat. The steam first passes through the green fuel in the top of the generating chamber, and in passing through the fire carries with it the volatile tarry matter which is decomposed by the incandescent zone, and made into a fixed gas, which accompanies the gas made by the steam and carbon combining.

The course of the gas from the generating chamber is first through a seal-box and into a washer, which removes mechanical impurities, and after passing through a regulating holder it is filtered to extract the sulphuretted hydrogen, etc. Before use the gas is odourised as a precaution of safety. At the end of the "make" period the motor again reverses, and the steam is shut off the generator, the chimney valve opened, and steam turned on at the exhauster during a "blow" period, these operations taking place automatically.

As the gas made during the "blow" is excluded from that produced in the "make" period, there is not much diluting nitrogen present, as will be observed from the average analyses given on page 322.

The Mersey gas plants are manufactured by the Power Gas Corporation Ltd., Stockton-on-Tees, who have acquired the whole business of the Mersey Engine and Producer Co. Ltd., and we are able to give a condensed report of an interesting test carried out at one of their suction gas power installations.

At the electricity works of the Coast Development Corporation Ltd., at Walton-on-the-Naze, a Mersey suction-producer of 80 B.H.P. was coupled to a vertical four-cylinder gas engine, rated at 65 B.H.P. normal with producer gas when running at 500 revolutions per minute, for driving a dynamo (compound wound), rated at 40 k.w. In most of the tests previously referred to, the engine was of the single cylinder Otto cycle type, but in this case, when firing every time, the suction strokes would be at the rate of 500 per minute, and the ignition and expansion of a charge would only occupy 0·12 second, thus showing that a suction producer can work satisfactorily with a practically constant suction, and that the gas produced is capable of rapid ignition with economical and efficient results. Under normal conditions the plant runs twenty minutes at no load, and then the load suddenly rises to full load; after three minutes the load gradually sinks to one-third, which is followed by twenty minutes of no load. The producer satisfactorily responds to these conditions, which is attributed to the peculiar vaporiser arrangement.

PERCENTAGE COMPOSITION BY VOLUME.

	Town's gas.	Suction or Producer gas.	H G. gas.
Carbon-dioxide	0·5	7·5	6·5
Hydrocarbons	4·8	0·0	0·4
Oxygen	0·9	0·8	0·5
Carbon-monoxide	5·9	20·7	32·7
Hydrogen	47·6	24·6	45·0
Methane	35·7	0·0	2·7
Nitrogen	4·6	46·4	12·2
	100·0	100·0	100·0
Thermal value per cubic foot, gross B. Th. U.	648	156	302

During a twelve-hour test at full load the engine only varied in speed from 500 to 508 revolutions per minute, or 1·6 per cent under full load conditions. The engine commenced to run three minutes after the plant was started.

The producer was fed at regular intervals of half-an-hour with about 33 lb. of Welsh anthracite; during the twelve hours the consumption was 793 lb.; the fire was clinkered and poked every hour, each fire-door being opened in turn.

The clinker, after the twelve-hours' run, was found to weigh 11 lb., or 1·38 per cent of the total fuel, showing the high class of the anthracite. The standby loss for 13½ hours totalled 14 lb.

During the test, owing to insufficient water provision, the inlet temperature of the cooling water for the engine was 160 deg. and the outlet 200 deg., which would have considerable effect in reducing the internal friction of the engine.

The water used in the generator during the twelve hours was 1,200 gallons, or 1·54 gallons per brake horse power per hour.

The system of ignition employed was the low-tension magneto, fitted to ignite at 50 deg. advance, and the mixture was approximately one of gas to one of air. During the twelve-hours' test the engine developed an average of 64·73 B.H.P. on a coal consumption of 66 lb. per hour, or upon the mean of the observed volt and ampere readings:—

1·6 lb. of coal per k.w. hour.
1·04 lb. „ „ b.h.p. „

Cost of fuel:—

34s. per ton = ·182d. per lb.,
= ·282d. per k.w. hour,
= ·182d. „ b.h.p. „

Cost of water for producer:—

1,200 gallons at 2s. 6d. per 1000,
= 0·071d. per k.w hour,
= 0·009d. „ b.h.p. „

Cost for lubricating oil:—

1 quart at 2s. 6d. per gallon,
= 0·015d. per k.w. hour,
= 0·009d. „ b.h.p. „

Total cost of fuel, water, and oil:—

= 0·368d. per k.w. hour,
= 0·237d. „ b.h.p. „

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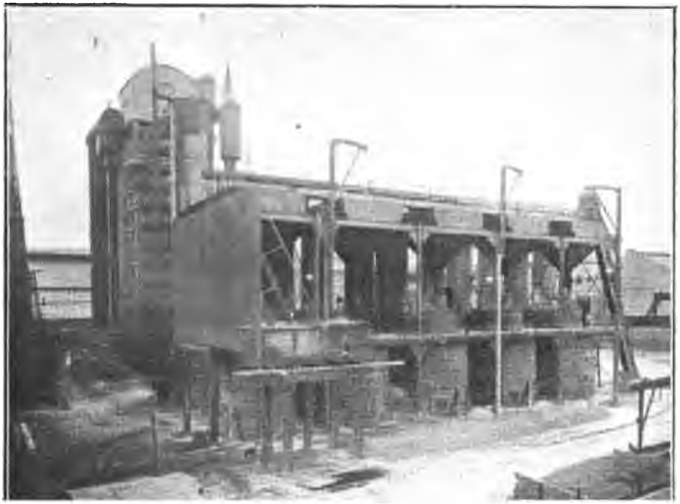

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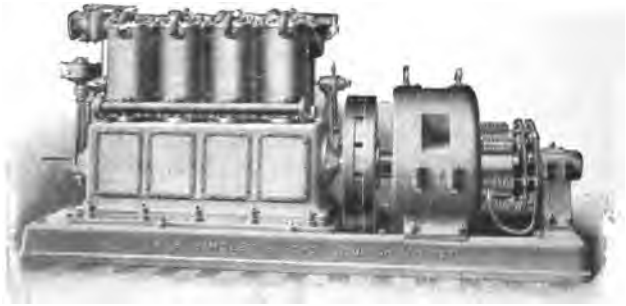

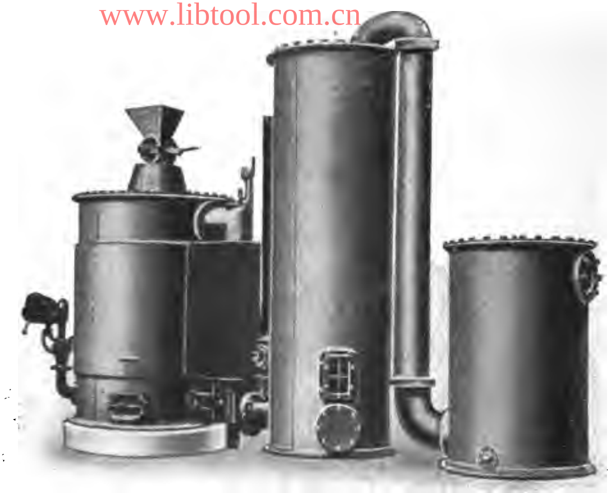

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