

PRODUCER GAS

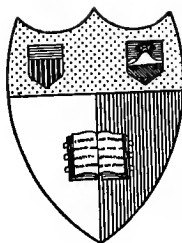
BY EMERSON DOWTON

AND

A. T. LARTER

8269
B61a

TP761
D75
1920



Cornell University Library
Ithaca, New York

BOUGHT WITH THE INCOME OF THE
SAGE ENDOWMENT FUND

THE GIFT OF

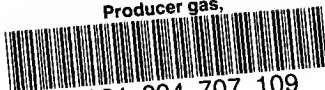
HENRY W. SAGE

1891

ENGINEERING LIBRARY

Cornell University Library
TP 761.D75 1920

Producer gas.



3 1924 004 707 109

enqr

THE UNIVERSITY OF CHICAGO

THE UNIVERSITY OF CHICAGO

the librarian.

P. 1

201-1-100.

APR 26 1962

Aff. J. I. ...

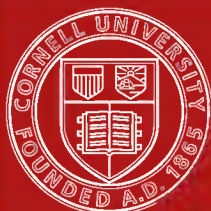
~~JUN 20 1978~~

~~MAR 14 1979~~

NCF 5/15
MAY 16 1979

~~APR 20 1983~~

~~FEB 15 1984~~



Cornell University
Library

The original of this book is in
the Cornell University Library.

There are no known copyright restrictions in
the United States on the use of the text.

PRODUCER GAS

PRODUCER GAS

BY

J. EMERSON DOWSON

M. INST. C. E., M. INST. M. E. (*retired*)

AND

A. T. LARTER

M. B. E., B. SC. (LONDON)

ASSOCIATE OF THE CITY AND GUILDS OF LONDON INSTITUTE



Fourth Edition

WITH ILLUSTRATIONS

LONGMANS, GREEN, AND CO.

39 PATERNOSTER ROW, LONDON

FOURTH AVENUE AND 30TH STREET, NEW YORK

BOMBAY, CALCUTTA, AND MADRAS

1920

All rights reserved

A494806

PREFACE TO FOURTH EDITION

It is so long ago since our First Edition appeared, and such a great development has since taken place in the use of Producer Gas, that we have taken the opportunity of thoroughly overhauling what was said originally, so as to bring the subject up to date. The principles on which this gas depends remain, but the application of the gas in several directions has grown extensively, and with wider experience and a better understanding of the subject, great improvements have been made not only in the producer itself but in the various ways of treating the gas, especially for engine work.

When our first edition was written, no gas had been made from bituminous coal which could be used for gas-engines; tar and other troubles seemed to be insuperable. We were then restricted to anthracite or coke, but now there are many plants and engines working satisfactorily with bituminous coal from different localities. Beyond this again means have been found to make good producer gas from peat, waste wood (such as chips, shavings, and sawdust), tan, cotton seed, and numerous other waste products. All these we have dealt with in the present edition.

As was to be expected, during the five years of war there was little or no research in connection with producer gas, but since then the restriction in the output of coal, and its very high cost of production, have led to increased attention being given to ways of economising fuel, and of finding substitutes for coal. Producer gas cannot do all, but it can do a great deal to mitigate these troubles.

We have devoted a new Chapter to Producer Gas from Peat, and we think that what has already been accomplished is not only interesting, but encouraging. This important subject certainly deserves serious attention.

We have also added a new Chapter on Gas Traction for road vehicles; this subject is still in the experimental stage, but there is no reason why it should not succeed. The useful Report of the Inter-Departmental Committee, on the employment of gas as a source of power, shows clearly that a great saving in working cost can be effected by using producer gas from a suction plant instead of petrol; it will also have the beneficial effect of using solid fuel from our own country instead of our being dependent on a more or less precarious supply of oil from abroad. The subject is only waiting for some one to devise a special suction plant which will meet the exacting requirements of road service, especially for lorries and commercial vehicles. The great increase in the number of these vehicles, and the exceedingly high price of petrol, have created a real demand for gas power.

There is also a new chapter on Gas Propulsion of Vessels. Some progress has been made in various countries in the use of gas power for propelling vessels of small size, and we are able to give particulars of an American schooner which has twice crossed the Atlantic with auxiliary gas power. In this vessel the cooling and scrubbing of the gas is on new lines, and the extremely small size of the only scrubber used is remarkable. So far all these vessels have worked with anthracite, coke, or charcoal; we are now waiting the advent of a simple and trustworthy plant to work with bituminous coal. There should then be a great opening for coasting vessels, and others of moderate size.

Our cordial thanks are due to various Engineers and Makers of Gas Plants who have sent us recent information as to tests and improvements they have made.

J. E. D.

A. T. L.

September, 1920.

PREFACE TO FIRST EDITION

IN the thirty odd years which I have devoted to the subject of Producer Gas and its applications, it has been my good fortune to make many pleasing friendships here and in other countries. Like most people, I have had my disappointments and troubles, but I have been greatly encouraged and assisted by the kind consideration and co-operation with which I have met. I feel especially indebted to Professor Ayrton, because he first gave me a helping hand in the most disinterested way. In 1881 I exhibited my apparatus at the Paris Electrical Exhibition, and there and then he volunteered to give a lecture on the subject in the Salle du Congrès, in order to draw attention to what was being done, and to what it might lead to. I trust that the progress since made may be considered a justification of the interest he then awakened in the subject.

I am also indebted to some of the makers of gas-engines. Not unnaturally they were at first disposed to think that it would not be to their interest to work their engines with producer gas, as it was so much weaker than town gas: the reputation of the engine itself was not then fully established, and they were fearful lest by using producer gas they might add to the difficulties with which they had to contend. That was in the days of small engines, when the consumption of gas was not great, and when the cost of the gas was of minor importance. Later they realised that the future of gas power depended largely on producer gas, and I had the advantage of their co-operation.

I am fully conscious that the growing importance of producer gas demands a more exhaustive treatment than I have been able to give it in the limited time at my disposal. I am also afraid

that in the course of what I have written I may have given undue prominence to what I have done myself; but, frankly, I have endeavoured to avoid doing so, and I would ask that allowance be made for the fact that for many years my mind has been soaked with the subject and that to a considerable extent I have been obliged to seek results from trials and experiments I made myself.

Producer gas has now a recognised position in practical work, and I am confident that in the near future its adoption will be greatly extended; it is, therefore, desirable that its production and application should be considered theoretically as well as practically. Mere rule of thumb cannot be right. I trust, therefore, that this little work may be the forerunner of some more complete and exhaustive treatment of the subject. There are numerous books on the theory and practice of the gas-engine, but so far as I am aware there is no complete work on producer gas.

I should add that the pressure of business has made such demands on my time that I could not have undertaken the preparation of what I now venture to put forward without the help and co-operation of my assistant, Mr. Larter, and I have to thank him for the care and thought he has brought to bear on the subject.

I also desire to thank the various makers of gas plants who have been good enough to send me illustrations and particulars of their apparatus.

J. EMERSON DOWSON.

September, 1906.

CONTENTS

PREFACE TO FOURTH EDITION	PAGE v
PREFACE TO FIRST EDITION	vii
INTRODUCTION	xv

CHAPTER I

THEORY OF PRODUCER GAS

Definition—Method of gas production—Reactions between air and carbon—Composition of best gas theoretically obtainable—Temperature of the gas—Reactions between steam and carbon—Effect of steam in producer—Theoretical composition of gas from air, steam, and carbon—Gas from steam and carbon—Air-gas, water-gas, and semi-water-gas	1
---	---

CHAPTER II

THEORY OF PRODUCER GAS (continued)

Comparison of theoretical and practical results—Effect of volatile constituents of the fuel—Extent to which the theoretical reactions are followed—Reasons—Theoretical effects of heat losses—Formation of carbon dioxide instead of carbon monoxide—Effect of this considered theoretically—Summary	20
--	----

CHAPTER III

THEORY OF PRODUCER GAS (continued)

Influence of the conditions on the chemical reactions—Depth of fuel—Physical condition of the fuel—Size of fuel—Sectional area of fire and velocity of blast—Influence of temperature on the velocity of the reactions—Reversible reactions—Equilibrium—Effect of temperature and pressure on the equilibrium—Equilibrium between carbon dioxide, carbon monoxide, and carbon at different temperatures—Effect of atmospheric nitrogen—Influence of temperature on the reactions with steam—Application to water-gas—Dissociation—Conditions necessary to secure high thermal efficiency—Conditions necessary to secure high calorific power	38
--	----

CHAPTER IV

FURNACE WORK

Heating work divided into two classes—Loss of heat in converting solid fuel into combustible gas—Losses in firing with solid fuel—Advantages of gas firing—Bischof's gas producer—Siemens' gas producer—His regenerative	
--	--

furnace—Development of the gas-producer—Tessié du Motay—Brook and Wilson—Morgan—Ehrhardt and Sehmer—Wood & Co.'s automatic producer—Lowe's water-gas plant—Uses of water-gas—Dellwik-Fleischer—Kramers and Aarts—Perry & Co.—Development of gas-fired furnaces—Gaillard and Haillet—Comparison of gas-fired and coal-fired reverberatory furnaces—Gas-fired furnaces for various purposes—Quantity of steam in the air blast—Heating steam-boilers with producer gas—The Bonecourt boiler	63
---	----

CHAPTER V

HEATING WORK (VARIOUS)

Necessity of cleaning the gas—Uniform pressure required—Plain burners—Atmospheric burners—Blowpipes—High calorific power essential—Early Dowson plant—Examples of gas-producer installations for heating—Various heating processes for which producer gas is used—Effect of products of combustion on food materials—Effect of sulphur in the fuel	102
--	-----

CHAPTER VI

ENGINE WORK

Position of the gas-engine before 1879—Early experiments with producer gas as fuel for gas-engines, 1879 and 1881—Improvements in gas-engines for producer gas—Increased compression—Scavenging—Increased heat efficiency—Fuel consumption—Cooling the gas—Moisture in gas and its condensation—Hydrogen in producer gas and its effect on the calorific power and on the ignition—Ignition in gas-engines—Fuels suitable for gas for engine work—The Humphrey internal combustion pump	113
---	-----

CHAPTER VII

SUCTION PLANTS

The principle of the suction plant—Bénier's producer, 1894—Improvements—Methods of generating steam—Advantage of heating air supply—Quantity of steam in saturated air—Quantity and control of the steam used in suction gas-producers—Tests of suction plants with anthracite and with coke—Comparison of results obtained with anthracite and with coke—Comparison of results obtained in pressure plants and in suction plants—Royal Agricultural Society's trials at Derby—Some typical suction plants described	133
--	-----

CHAPTER VIII

SUCTION PLANTS (continued)

Loss of engine power with suction plants—Various causes considered—Importance of reducing the resistances—Distance of the plant from the engine—Losses by fluid friction—Working with reduced load on the engine—Importance of maintaining the temperature of the fire—Effect of suddenly increasing the load—Effect of suddenly decreasing the load—Advantages of suction plants	160
---	-----

CHAPTER IX

GAS FROM BITUMINOUS COAL FOR ENGINE WORK

	PAGE
Clean gas necessary—Difficulties to be overcome—The Mond gas plant— Recovery of ammonium sulphate—Distribution of producer gas over large areas—Bone and Wheeler's experiments with different proportions of air and steam in the blast—Various plants using bituminous coal— Methods of destroying the tar in the producer—Down-draught gas producers—Suction type—Deschamps—Dowson suction plant with up-and-down draught—Fichet and Heurtey—Crossley—Underfeed types —Boutillier—Farnham—Plants using two producers—General survey of the subject	175

CHAPTER X

PRODUCER GAS FROM PEAT

Peat industry in Europe—Difficulties to be overcome in using peat in gas- producers—Moisture in peat and its removal—Crossley Bros.' tests using peat in suction plants—Recovery of ammonium sulphate—Continental installations—Crossley plant at Portadown, Ireland—General review— By-products	198
--	-----

CHAPTER XI

GAS TRACTION ON ROADS

Conditions to be met—Comparison with conditions of a stationary plant— Effect on general design of producer—Depth of fire—Early experiments, 1901 and 1903—Parker and Bamber's tests with 20 H.P. lorry—Inter- Departmental Committee on Portable Suction Gas-Producers—Col. Smith's producer	209
---	-----

CHAPTER XII

GAS PROPULSION OF VESSELS

Suction-gas plants used on inland waterways—Capitaine, 1904—Sea-going vessels—H.M.S. <i>Rattler</i> —Föttinger's hydraulic transformer—Messrs. Holzapfel's experiments—The <i>Zeemeuw</i> , 1911—Galusha gas plant for marine work—Four-masted schooner with gas power as auxiliary— Trans-Atlantic voyages	218
---	-----

CHAPTER XIII

STAND-BY LOSSES

Early experiments with Dowson gas-producers, 1881–1893—Mr. Donkin's experiments with steam-boilers, 1898—Later tests of stand-by losses in gas-producers and in steam-boilers—Reasons for the smaller loss with gas-producers—Comparative results based on the averages of the tests described	227
--	-----

CHAPTER XIV

COMPARISON OF GAS AND STEAM POWER

PAGE

Data used in comparing the heat efficiencies—Heat efficiency diagrams for gas and steam power installations of 40 B.H.P. and 250 B.H.P.—Comparison of the results—Heat efficiencies at reduced loads—U.S. Geological Survey tests with bituminous coal and with lignite—Various advantages of gas power	235
---	-----

CHAPTER XV

FUEL

Fuels used for producer gas—Their chemical composition, and mode of formation—Wood—Wood-charcoal—Peat—Peat-charcoal—Brown coal or lignite—Common coal—Gas-coke—Oven-coke—Anthracite—Geographical distribution of anthracite—Sizing—Ash in anthracite and the formation of clinker—Effect of dust in anthracite—Volatile matter in anthracite—Scotch anthracite—Belgian and French anthracite . . .	247
--	-----

CHAPTER XVI

ANALYSIS OF FUEL AND OF PRODUCER GAS

Ultimate and proximate analysis of fuel—Sampling—Determination of moisture, volatile matter, ash, fixed carbon, sulphur—Analysis of producer gas—Methods of collecting the sample—Apparatus used for the analysis and its manipulation—Absorption of carbon dioxide, oxygen, carbon monoxide—Determination of hydrogen and methane—Direct determination of nitrogen—Absorption of ethylene—Determination of sulphur	266
---	-----

CHAPTER XVII

CALORIFIC POWER OF SOLID AND GASEOUS FUELS

Importance of knowing the calorific power—Determination of the calorific power of solid fuels—The bomb calorimeter—Calorimeters using oxygen at atmospheric pressure—The Lewis Thompson calorimeter—Comparison of results obtained with different types of calorimeter—Calorific power of solid fuel calculated from the ultimate analysis or from the proximate analysis—Determination of the calorific power of gases—Junkers' calorimeter—Gross and nett calorific powers—Other calorimeters with continuous combustion and continuous flow—Recording calorimeter—The use of the bomb calorimeter for gases—The Witz bomb—Calorific power of gases calculated from the analysis	280
--	-----

CHAPTER XVIII

PRACTICAL NOTES

Carbon monoxide poisoning—Working two or more producers together—Depth of fire—Stirring the fire—Removal of condensed moisture—Testing the pressure of the gas—Lining of gas-producers—Test flames—Starting a gas-fired oven or furnace—Gasholders—Steam supply—Overflow water—Gas plants at high altitudes	307
---	-----

APPENDIX A. (See CHAPTER VII., p. 144.)

	PAGE
TABLE XLI.—Trial of 30 B.H.P. Suction Plant with Anthracite	318
TABLE XLII.—Trial of 40 B.H.P. Suction Plant with Anthracite	319
TABLE XLIII.—Trial of 40 B.H.P. Suction Plant with Coke	320

APPENDIX B

THEORETICAL EXPLANATIONS AND REFERENCE DATA

Temperature—Heat units—Latent heat of steam—Specific heat—Maximum pressure of aqueous vapour—The laws of gas—Reduction of the volume of a gas to the standard temperature and pressure—Chemical equations, Molecular weights and densities of gases—Specific heats of gases—Molecular heat of gases—Calorific power—Calorific intensity—Corrections for altitude—Metric equivalents—General data	321
INDEX	341

INTRODUCTION

THE use of Producer Gas is now so extensive, it is required for so many different purposes, and is made with so many kinds of fuel, that we venture to think the time has arrived to take a comprehensive view of the whole subject.

A good deal is known about the practical working of gas-producers in connection with furnaces and gas-engines; but much less is known about the thermo-chemistry of the subject, and the principles and conditions on which the successful working of gas-producers depends. We have, therefore, devoted our first three chapters to a consideration of the formation of producer gas from a strictly theoretical point of view, and it seems to us that this is the only way of getting to understand the rather complicated conditions under which the best gas can be made. Moreover, it is essential that the principles which underlie the process should be clearly grasped if we wish to attain the best results. On these lines we have discussed the subject in various aspects, and have shown what is the theoretical best which might conceivably be attained under various conditions of working. We have then compared with the theoretical best the actual results obtained in practice, in known types of gas-producers. These comparisons have led us to consider various side issues, and we think they will not be without interest.

In connection with furnace work it was Bischof of Mägdensburg in the Harz who made the first gas-producer; but no great advance was made until Frederick Siemens brought out his combination of gas-producer and regenerative furnace in 1857. This important invention and other subsequent improvements

were introduced in this country by his brother, the late Sir William Siemens, and we are chiefly indebted to the latter for the great impetus he gave to the use of producer gas for furnaces requiring high and uniform temperatures. He was both scientific and practical, and he proved by actual results, on a full working-scale, that there was not only a saving in fuel by converting it into a combustible gas (before burning it in the furnace), but that many important operations in industrial processes could be performed with gas-heated furnaces, which could not be effected by direct firing with solid fuel. Various modifications and improvements in gas-producers and furnaces have since been made by others, and each notable type is discussed; but we have purposely avoided mere details or alterations in the form of construction in order that the main principles should be kept steadily in view.

We have shown that for furnace work the gas is used in bulk, and that the crude gas is taken direct from the producer to the furnace. For smaller work, as for instance where the gas must pass through small cocks and burners, the gas must be specially treated before it is used, and in 1878 Mr. J. E. Dowson devised a complete gas-plant for this purpose. He had specially in view the making of fuel-gas strong enough and clean enough to be used for factory and domestic work, and this branch of work has been very successful.

A still more important development in the use of producer gas has taken place in connection with gas-engines. Mr. Dowson read his first paper on the subject in 1881, at the York Meeting of the British Association for the Advancement of Science, and he then showed a set of his plant working a 3 H.P. Otto gas-engine. It was on this occasion that the late Sir Frederick Bramwell made his memorable prophecy to the effect that in fifty years the gas-engine would have superseded the steam-engine. We need hardly concern ourselves at present with the downfall of the steam-engine, our opinion being that the gas-engine and the steam-engine have certain well-defined characteristics, and that each is more or less suitable than the other for certain kinds of work. We can afford to await the result of actual experience; but we may say that since the prophecy was made there has certainly been a remarkable development, not only in the use of

gas power in lieu of steam, but also in the size of gas-engines. The horizontal type of Otto engine was patented in 1876, and we believe we are right in saying that at the time of the York Meeting, above referred to, there was no gas-engine working which developed more than about 12 B.H.P., certainly not more than 20 B.H.P. It is also certain that no gas-engine, other than the 3 H.P. at York, had then worked with producer gas. At the present time, however, there are many gas-engines of 1500 and 2000 B.H.P. working satisfactorily with producer gas or blast-furnace gas; and the number of engines working with producer gas is countless.

During the last twenty years an interesting development has taken place in the gas-plants used with gas-engines. We refer to what is generally known as the *suction* type of plant; and as this branch of the subject is comparatively new, and several interesting problems are involved in it, we have examined them closely in order that the right principles to be followed may be clearly understood. When it was proved that a gas-engine could be worked satisfactorily and economically with producer gas, the makers of gas-engines realised that it would be worth while to construct larger engines than could be worked profitably with such an expensive fuel as ordinary town lighting gas. Since the introduction of the suction plant there has been a still more intimate connection between the gas-plant and the engine, and one consequence of this has been that greater attention has been given to the design and adjustments of the engine, so that the comparatively weak producer gas may be used to better advantage. For a long time the peculiarities of producer gas were not sufficiently considered; the engine was designed for town gas, and its weaker rival had more or less to take its chance. We have endeavoured to bring together the theoretical and practical considerations on which a gas-power plant depends, and although good results have already been attained, we feel sure that further advance will be made now that skilled attention is being given to the subject and engine-makers realise that the future of their engines will to a great extent depend on their working with producer gas. The thermodynamic problems connected with the gas-engine alone are numerous and difficult, and for some time past they have

engaged the attention of some of the best experimenters in this country and in others. Less attention has been given to the plant which supplied the engine with gas, but this branch of the subject will well repay closer investigation.

We are convinced that the use of producer gas will continue to be greatly extended, and we say this because we believe that for many purposes the conversion of solid fuel into gas is right in principle and right in practice. Besides this, there is the encouraging fact that the subject is better understood and better appreciated than it was even a few years ago. To a certain extent this may be attributed to the spread of technical instruction, but it is also largely due to the fact that the price of coal has risen seriously, while at the same time competition with other countries has greatly increased. These two facts alone have made it necessary for manufacturers to consider closely any saving in fuel which can be effected in a simple and practical manner. They are now realising that the use of producer gas for heating and power is not a mere fad, but a useful and economical system; and it is tolerably certain that what is cheapest and most efficient will in the end be generally adopted.

PRODUCER GAS

CHAPTER I

THEORY OF PRODUCER GAS

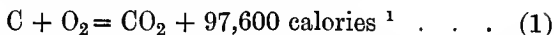
TECHNICALLY, "producer gas" is understood to mean the gas which is obtained by the partial combustion of fuel in a gas-producer. This is not a very happy expression, as strictly speaking a retort used for distilling coal-gas may be said to be a gas-producer. It is, however, an accepted term among engineers, and it would be somewhat pedantic to quarrel with it now that it is a common expression with a fairly definite meaning. A gas-producer may be defined as an apparatus for converting solid fuel into a combustible gas; and the gas produced is usually a mixture in varying proportions of carbon monoxide, hydrogen, gaseous hydrocarbons (chiefly methane or marsh gas), carbon dioxide, and nitrogen. The first three of these constituents are combustible, and the value of the gas as a fuel depends on the proportions in which they are present; the carbon dioxide and nitrogen are diluent gases which lower the flame temperature of the combustible gases when they are burnt.

Producer gas can be obtained from almost any carbonaceous fuel, and the kind of fuel used depends, not only on the purpose for which the gas is to be used, but on its cost and the ease with which it can be procured in different localities. In practice the gas is generally made from bituminous or semi-bituminous coal, or from anthracite or coke; but for certain purposes brown coal (lignite), peat, charcoal, wood refuse, etc., are used. The composition of the gas is largely influenced by the nature of the fuel, and this will be more fully discussed hereafter.

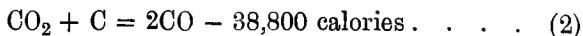
Speaking generally, producer gas is made by forcing or drawing air, with or without the addition of steam or water-vapour,

through a deep bed of fuel in a closed producer. The fuel is gradually consumed and the gas made is led away to wherever it is required. An important characteristic of the process is that no external heat is applied to the producer, as in the case of an ordinary gas retort; when once the burning of the fuel *inside* the producer has been started the air which is used to make the gas keeps up a continuous process of combustion, and a sufficiently high temperature is maintained to decompose the steam and to effect other necessary reactions which will be presently described.

The most important constituent of the fuels commonly used for making producer gas is carbon; and for the purpose of explaining the theory of the process we will, in the first instance, consider the action of air alone on pure carbon under conditions similar to those which obtain in a producer. Gas made by burning charcoal with a blast of air (without steam) approximates closely to this, but to simplify the case, we will suppose that the fuel used is carbon. As is well known, about four-fifths of the volume of the atmosphere consists of nitrogen, and although this affects the temperature attained, and therefore modifies the reactions to a certain extent, it does not in any way affect the *quantities* of heat with which we are concerned. We will, therefore, neglect these considerations for the moment, and merely consider the combination which takes place between oxygen and carbon. If there were a shallow fire in the producer and an abundant supply of air the carbon would be completely oxidised; the product of this complete combustion would be carbon dioxide, while the quantity of heat developed from the combustion of 12 kilos of carbon would be 97,600 calories:—



But if there were a sufficient depth of carbon in the producer, the resulting gas would be carbon monoxide instead of carbon dioxide, for when there is an excess of highly heated carbon the carbon dioxide formed in the lower part of the fire is reduced to carbon monoxide:—



In this case, heat must be supplied in order that the reaction

¹ Unless otherwise stated, the term "calorie" should be understood to mean the large calorie, or kilogram heat unit, = 3.968 B.Th.U.

between carbon dioxide and carbon may take place, and the quantity of heat required is 38,800 calories when 12 kilos of carbon react with the carbon dioxide formed by the complete combustion of another 12 kilos of carbon.

Carbon monoxide may also be formed by the direct combination of the carbon with oxygen:—



The question whether carbon monoxide is formed by the direct combination of carbon and oxygen, as in equation (3), or whether carbon dioxide is first formed and afterwards converted to carbon monoxide, as in equations (1) and (2), has been much discussed. The experiments of Rhead and Wheeler¹ show that at temperatures up to 500° C. the action of air on carbon leads to the direct formation of both carbon monoxide and carbon dioxide, and it is probable that in a gas-producer both of the reactions (1) and (3) occur. Gases drawn from a producer in the region near the grate or air inlets contain an excessive proportion of carbon dioxide, and whether this be produced by direct combination (equation 1), or by the combustion of the carbon monoxide at first formed, it is clear that in a producer we must ensure suitable conditions for the conversion of carbon dioxide to carbon monoxide (equation 3) in the upper part of the fuel bed.

The *raison d'être* of the producer is therefore to bring about a partial combustion of the fuel, *i.e.* the conversion of the carbon to carbon monoxide, either by reactions (1) and (2) or by reaction (3). If the combustion were complete, the gas which leaves the producer would be incombustible and useless as a heating agent.

The action of the producer will be better understood by referring to the accompanying Fig. 1. In this **A** represents the firebars or grate, **B** is the air inlet, **C** is the column of fuel, **D** is a hopper with close-fitting valve through which the fuel is introduced, and **E** is the gas outlet. After the fire has been lighted, and built up to the height required to ensure the necessary reactions, the gas produced passes away through the outlet **E** and can then be conveyed in a pipe or flue wherever it may be required.

¹ Rhead and Wheeler, "The Combustion of Carbon." *Transactions of the Chem. Soc.*, 1912, ci. p. 846.

It is easy to see that the same result is attained by either of the two methods by which carbon monoxide may be produced.

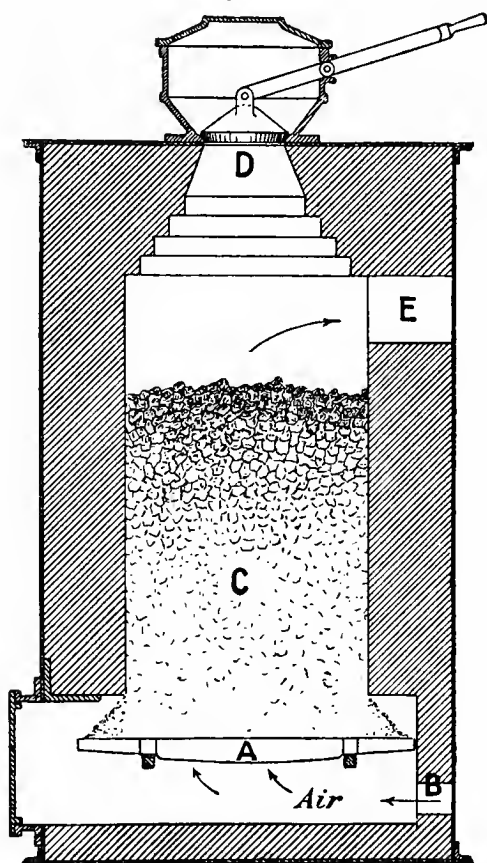
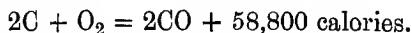


FIG. 1.—Gas-producer working with air only.

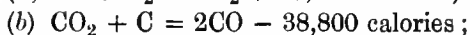
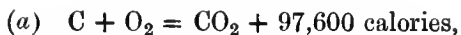
On the one hand, 24 kilos of carbon are converted to carbon monoxide by direct union with oxygen, the heat liberated being 58,800 calories, according to equation (3). On the other hand, 12 kilos of carbon are converted to carbon dioxide, and 97,600 calories are set free, according to equation (1); and subsequently the whole of this carbon dioxide reacts with another 12 kilos of carbon to form carbon monoxide, and 38,800 calories are absorbed, in accordance with equation (2). The final result of this twofold process is the conversion of 24 kilos of carbon to carbon monoxide and the liberation of

$97,600 - 38,800 = 58,800$ calories, since the only heat available to enable reaction (2) to take place is the heat liberated during the conversion of the 12 kilos of carbon to carbon dioxide. The two ways in which the carbon may be converted to carbon monoxide are represented by the following equations:—

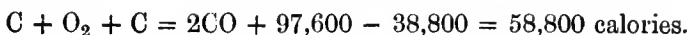
In the first case—



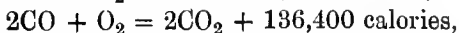
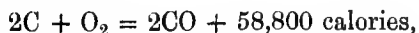
In the second case, the following reactions take place in succession:—



the final result of these two processes being expressed by the equation—



In the same way, it may be shown that the final result of the complete combustion of carbon is the same whether it takes place in one stage (equation 1) as in an open fire, or whether carbon monoxide is formed in a producer and afterwards burnt to carbon dioxide. In the former case we have 12 kilos of carbon converted to carbon dioxide, with the liberation of 97,600 calories ; in the latter case the same amount of heat is liberated in two successive reactions. Taking 24 kilos of carbon, the changes are represented by the equations—



and the final result of the two processes in the conversion of 24 kilos of carbon to carbon dioxide, with the liberation of 195,200 ($2 \times 97,600$) calories.

We see from this that when carbon is converted to carbon monoxide in the producer about 30 per cent. of the heat of combustion of the carbon is liberated ; the remaining 70 per cent. will be liberated when the carbon monoxide is afterwards burnt to carbon dioxide in a furnace or engine, etc. As this is the theoretical best when using air only, it may be assumed that the practical best is still less favourable, and *prima facie* the performance does not seem a promising one. It should, however, be understood that not all the heat set free in a producer need be lost ; a large proportion may be carried away in the form of sensible heat by the gas, which leaves the producer at a high temperature ; and if the gas can be used while it is hot not much of this sensible heat will be lost. The amount of the loss will depend on the extent to which the gas is cooled before it is used. Theoretically, there is no reason why the use of producer gas in place of solid fuel should necessarily involve a loss of part of the heat available by the direct combustion of the solid fuel, although a considerable proportion of that heat is liberated during the conversion of the

solid fuel into producer gas. In practice, however, this economy cannot be fully realised, but it can be approached. The reason lies in the fact that it is not possible to avoid loss of heat by radiation, or to convey sensible heat from one point to another without loss, especially when the temperatures are high.

If we take into consideration the quantity of nitrogen present in the air used in the producer, it is easy to calculate for our assumed case the composition of the best gas that can be made. Following the equation (3), 24 kilos of carbon yield two volumes (44·64 cubic meters¹) of carbon monoxide, and one volume (22·32 c.ms.) of oxygen is required for the process. The atmosphere contains almost exactly 21 per cent. by volume of oxygen, and we may consider the remaining 79 per cent. to consist of nitrogen.² The oxygen used in the reaction is therefore associated with $\frac{7.9}{2.1}$ or 3·76 volumes (83·92 c.ms.) of nitrogen, and the producer gas will consist of 2 volumes of carbon monoxide mixed with 3·76 volumes of nitrogen. Its composition will therefore be—

Carbon monoxide	34·7 per cent. by volume.
Nitrogen	65·3 " "
	<hr/>
	100·0
	<hr/>

and the volume of gas obtained from 24 kilos of carbon will be $44·64 + 83·92 = 128·56$ cubic meters, or 5·36 c.m. per kilo of carbon. The densities of carbon monoxide and nitrogen are alike, so that the percentage composition by weight will be represented by the same figures as for the volumes. The calorific power of this gas will be 1057 calories per cubic meter, or 118·8 B.Th.U. per cubic foot.

It will also be well to determine the temperature which would be attained in a producer yielding gas of the above composition, although the calculation can only be approximate, as several assumptions must be made. In the first place, part of the heat given out in the producer would be lost by radiation, conduction, etc., and some estimate must be formed of its quantity. We shall

¹ Unless otherwise stated, all gas volumes are measured dry at 0° C. and 760 mm. pressure. See Appendix B, section 7.

² As a matter of fact, dry air has the following composition by volume :—Oxygen, 20·9 per cent. ; nitrogen, 78·2 per cent. ; argon, etc., 0·9 per cent. (The small amounts of carbon dioxide and ammonia are neglected.)

probably not be far wrong in assuming this to be 8 per cent. of the heat of combustion of the fuel. The sensible heat of the gas as the latter leaves the producer would therefore be about 22 per cent. of the heat of combustion, and taking 12 kilos of carbon as a convenient unit for purposes of calculation, this sensible heat would amount to $97,600 \times 0.22 = 21,472$ calories. The quantity of carbon monoxide formed is 28 kilos, and it is mixed with 53 kilos of nitrogen. The specific heats of the two gases at constant pressure are almost identical, viz. 0.244 and 0.245, and assuming them to be constant over the whole range of temperature, the heat required to raise the temperature of the 81 kilos of producer gas through 1°C . will be $81 \times 0.245 = 19.845$ calories; the temperature of the hot gases as they leave the fuel bed would accordingly be $\frac{21472}{19.845} = 1080^{\circ}\text{C}$.

It will be seen from this that the temperature in a producer worked with a blast of air alone must of necessity be high. With such high temperatures serious practical difficulties present themselves, and they will be further considered in subsequent chapters.

To avoid these practical difficulties, and for other reasons, the almost invariable practice is to add to the air sent into the producer a certain quantity of steam, or aqueous vapour, as indicated in Fig. 2. In this **A** represents the grate or firebars; **B**, the inlet for steam and air; **C**, the fuel; **D**, the hopper through which the fuel is introduced; and **E**, the gas outlet. There is always some moisture in the air itself, but this is not nearly sufficient, and it is usual to generate steam specially for this purpose.

We will now consider theoretically the case of a producer in which pure carbon is converted into gas by means of air mixed with steam. In other words, we will consider how steam reacts with the substances with which it comes in contact in the producer, viz. carbon, carbon monoxide, and carbon dioxide. When steam (H_2O) interacts with carbon at a sufficiently high temperature it is decomposed and an equal volume of hydrogen is produced; the oxygen of the steam combines with the carbon to form either carbon monoxide or carbon dioxide, according to the conditions under which the reaction takes place. Now, when 2 kilos of

hydrogen combine with oxygen to form 18 kilos of water-vapour the quantity of heat liberated is 58,200 calories, and when this

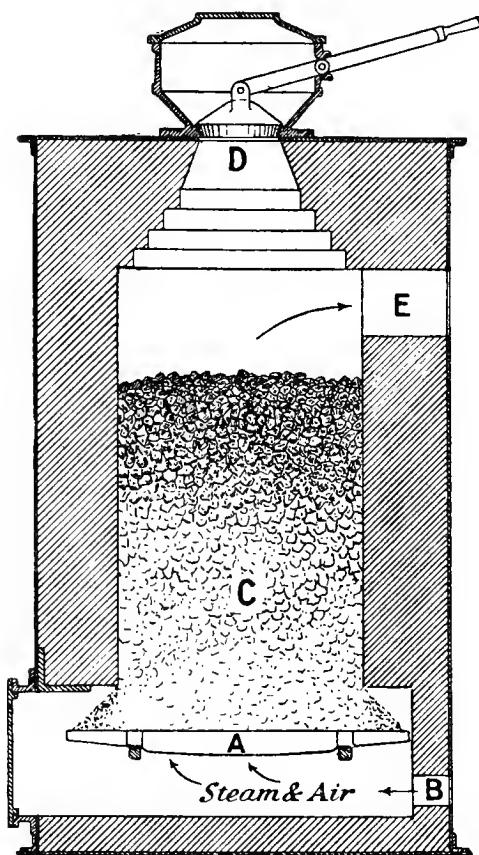
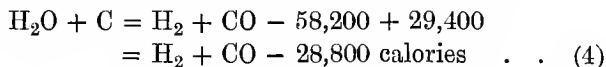


FIG. 2.—Gas-producer working with steam and air.

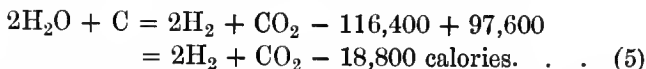
water-vapour is decomposed by the action of carbon at high temperature, or by any other means, an equal amount of heat is absorbed. The combination of the oxygen of the steam with the carbon is, however, accompanied by the evolution of heat, according to either of the equations (1) or (3), and the thermal effect of the decomposition of steam by carbon is equal to the sum of the thermal effects of the two separate processes. In the first case, when the products of the reaction are hydrogen and carbon monoxide, the quantity of heat liberated by the formation of the latter from 16

kilos of oxygen is 29,400 calories, and the equation may accordingly be written—



In the second case, when the products formed are hydrogen and carbon dioxide, we must first suppose that 36 kilos of steam are decomposed, yielding 4 kilos of hydrogen and 32 kilos of oxygen, with the absorption of 116,400 calories. The combination of the 32 kilos of oxygen with carbon to form carbon dioxide

liberates 97,600 calories, and the reaction is therefore represented by the equation—



It will be observed that in both cases there is a large absorption of heat, and it is at once apparent why the addition of even small quantities of steam to the air-blast of a producer reduces the working temperature. Part of the sensible heat is absorbed by the reactions which take place between the steam and the incandescent carbon, so that the gas leaves the producer at a lower temperature than is the case when air alone is used; the heat so absorbed is stored up in the gas, and is again set free when the gas is burnt. In other words, the effect of the presence of steam in the air-blast is that a smaller proportion of the total heat of combustion of the fuel is liberated in the form of sensible heat in the producer, and a larger proportion is represented by the heat of combustion of the producer gas. A rough indication of the effect produced on the fire in the producer, when steam is used, is shown in Fig. 2; in this the column of fuel is darker (*i.e.* cooler) than in Fig. 1, where no steam is used. The effect is especially noticeable near the top of the fuel.

It should be clearly understood that from the point of view of the heat quantities involved the use of steam in a gas-producer is simply a means for absorbing the sensible heat developed by the partial combustion of carbon, and storing it for future use. Obviously there can be no actual increase of the total amount of heat which can be obtained from a given quantity of fuel. From equation (4), it would appear that from 12 kilos of carbon there can be obtained (theoretically) a quantity of gas which when burnt will give out 58,200 calories by the combustion of the hydrogen, and 68,200 calories by the combustion of the carbon monoxide which it contains, or 126,400 calories in all; although the original 12 kilos of carbon would only yield 97,600 calories when burnt in air. In consequence of the action of steam on the carbon there is apparently an increase of 28,800 calories in the quantity of heat which can be obtained by the combustion of the 12 kilos of carbon; the explanation is that exactly 28,800 calories must be supplied in order that the reaction represented by equation (4) may take place. The heat which is required for

this is provided by the union of carbon with the air in the blast (equations 1 and 3), and if it were not made use of in this manner it would be partly lost by radiation, and partly carried away as sensible heat by the producer gas.

Besides avoiding excessive heat in the producer the use of steam has the further practical advantage that a gas of considerably greater calorific power per unit volume can be obtained than is possible when air alone is used. In the latter case it has already been shown that every volume of carbon monoxide in the gas is mixed with 3.76 volumes of nitrogen; but equation (4) shows that when steam is used the gas which is formed by its decomposition is free from nitrogen. It follows that in a producer burning carbon in a mixed blast of air and steam the greater the quantity of steam decomposed in accordance with equation (4), relatively to the quantity of carbon consumed in accordance with equation (3), the greater will be the proportion of the combustible gases (carbon monoxide and hydrogen) to the total volume of producer gas formed; and the calorific power of unit volume of the producer gas will accordingly be greater also. A similar statement will be equally correct if the steam admitted to the producer is decomposed according to equation (5). In this case the hydrogen (which has approximately the same calorific power per unit volume as carbon monoxide) is mixed with an equal volume of the incombustible gas, carbon dioxide; but since the carbon monoxide, formed by the action of air on the carbon, is mixed with nearly twice its own volume of incombustible gas (in this case nitrogen) the use of hydrogen will in this case also increase the calorific power of the gas, though not to the same extent for a given ratio of steam to air. When it is desired to obtain a rich producer gas containing as high a proportion as possible of combustible gases and having a high calorific power it becomes important to decompose as much steam as possible in the producer by the reaction which is expressed in equation (4). The decomposition of steam with the formation of hydrogen and carbon dioxide, as in equation (5), will have a similar effect, but however great the proportion of steam to air may be the increase of calorific power due to the use of steam will necessarily be less than when the interaction takes place in accordance with equation (4).

In order to determine what is the theoretical limit to which this advantage can be pushed, we will assume that all the sensible heat of the gases leaving the producer and all the heat which would otherwise be lost by radiation are made use of in raising the steam and in heating the blast; that is to say, we will assume that there are no heat losses, so that the whole of the heat of combustion of the fuel will be available as heat of combustion of the gas which is produced. This will be the case only if the quantity of heat absorbed by the interaction of steam and carbon be just equal to the quantity of heat evolved by the formation of carbon monoxide from carbon and the oxygen of the air in the blast. The maximum quantity of steam which can be decomposed is fixed by this consideration; if more steam than this were decomposed the temperature of the producer would fall rapidly, until it became too low for the reaction to take place; if the quantity of steam decomposed were too small the temperature of the producer would rise, and the total heat of combustion of the gas would be less than that of the fuel from which it was obtained.

Under the conditions which we have assumed, for every 12 kilos of carbon converted to carbon monoxide in accordance with equation (3), there are 29,400 calories available to enable the reactions between steam and carbon to take place. The richest gas will be obtained if the working conditions can be regulated so that the steam and carbon interact wholly according to equation (4). In this case, 28,800 calories are required for the decomposition of 18 kilos of steam by carbon, and to this must be added the latent heat of the steam, since we have supposed that the steam is generated by the sensible heat of the producer gases, and therefore ultimately by the heat which is evolved by the formation of carbon monoxide from carbon and atmospheric oxygen in the producer. Making the calculation in this way we shall find the composition of the ideal producer gas which can theoretically be made in a self-contained system with no heat losses, where the only source of heat is the oxidation of carbon in the producer, and where no heat is supplied in any other way. This case is therefore not quite on the same lines as many practical cases, where steam is taken from an independent steam boiler.

The latent heat of 18 kilos of water-vapour at 20° C. amounts to 10,800 calories, so that the heat required to convert 18 kilos of water at 20° C. to steam, and to decompose the steam in the producer, with the formation of carbon monoxide and hydrogen, is $28,800 + 10,800 = 39,600$ calories. The quantity of steam which theoretically can be decomposed is—

$$18 \times \frac{29,400}{39,600} \text{ or } 18 \times 0.74 \text{ kilos}$$

for every 12 kilos of carbon converted to carbon monoxide by the air in the blast. The gas which is formed will be made up in the following way :—

Carbon monoxide	1.00 vol. (22.32 c.m.)	} from the reaction of carbon with the air of blast.
Nitrogen	1.88 „	
Carbon monoxide	0.74 „	} from the reaction of carbon with the steam of blast.
Hydrogen	0.74 „	
Total	4.36 „	

Its percentage composition by volume is as follows :—

Carbon monoxide	39.9	} combustible gases = 56.9
Hydrogen	17.0	
Nitrogen	43.1	
Total	100.0	

and its calorific power is 1740 calories per cubic meter, or 195.6 B.Th.U. per cubic foot.¹

The quantity of gas obtained amounts to 4.36 volumes, or 4.36×22.32 c.ms.; the carbon used is 12 kilos consumed by the air of the blast, and $12 \times 0.74 = 8.88$ kilos used in the reaction with steam, making a total of 20.88 kilos of carbon. The yield of gas is therefore—

$$\frac{4.36 \times 22.32}{20.88} = 4.65 \text{ c.m. per kilo of carbon burnt.}$$

For every 20.88 kilos of carbon consumed, the weight of steam decomposed is $18 \times 0.74 = 13.32$ kilos, or 0.64 kilo of steam per kilo of carbon.

Comparing this result with that obtained when the blast consists of air alone (p. 6), we see that when steam is added to

¹ In stating the calorific power of a gas, the higher value is given unless otherwise stated. See p. 297.

the blast and decomposed in accordance with equation (4), a rather smaller volume of a much richer gas is obtained from each kilo of carbon consumed.

Without at present discussing in detail the conditions under which the various reactions take place, it may be mentioned that in order to obtain only hydrogen and carbon monoxide from the reaction between steam and carbon a high temperature is necessary; but for practical reasons it may be more advantageous in some cases to work at a lower temperature, and to allow the decomposition of the steam to take place with the formation of carbon dioxide and hydrogen (equation 5). This course is, in fact, essential when it is desired to recover the nitrogen of the fuel in the form of ammonia, as in the Mond and other forms of recovery plants.

Proceeding on the same lines as above, we can determine the theoretical composition of a producer gas made in this way without heat losses. According to equation (5), 18,800 calories are required for the decomposition of 36 kilos of steam in the producer. Adding to this the latent heat of the steam, 21,600 calories, the total heat required to convert 36 kilos of water at 20° C. to steam, and to decompose the latter in the producer, is 40,400 calories. The quantity of steam which can be decomposed is—

$$36 \times \frac{29,400}{40,400} = 36 \times 0.73 = 26.88 \text{ kilos}$$

for every 12 kilos of carbon consumed in accordance with equation (3).

The gas therefore consists of—

Carbon monoxide	1.00 vol. (containing 12 kilos carbon)	} from the reaction between carbon and the air of the blast.
Nitrogen	1.88 „	
Hydrogen	1.46 „	} from the reaction between carbon and steam.
Carbon dioxide	0.73 „ (containing $12 \times 0.73 = 8.76$ kilos of carbon)	
Total	<u>5.07</u> „ (containing 20.76 kilos carbon)	

And the quantity of steam used is $\frac{26.88}{20.76}$ or 1.29 kilos per kilo of carbon.

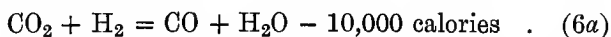
The percentage composition of this gas by volume is as follows :—

Carbon monoxide	19·7	} combustible gases = 48·5
Hydrogen	28·8	
Carbon dioxide	14·4	} diluent gases = 51·5
Nitrogen	37·1	
Total	100·0	

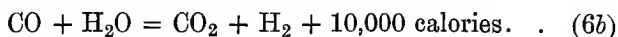
and its calorific power is 1490 calories per cubic meter, or 167·5 B.Th.U. per cubic foot. The yield of gas is $5·07 \times 22·32$ c.ms. from 20·76 kilos of carbon, or 5·45 c.ms. per kilo of carbon consumed.

The volume of gas obtained is thus almost identical with the volume of gas which theoretically can be obtained from carbon and air alone, but as in the case previously considered the calorific power of the gas is considerably higher when steam is used.

In the examples which have been discussed it has been tacitly assumed that the steam reacts only with the solid carbon in the producer, and that the gases formed do not interact among themselves. As a matter of fact, however, this assumption is not strictly correct. If a mixture of equal volumes of hydrogen and carbon dioxide be raised to a high temperature, such as that which prevails in a gas-producer, part of the gases will interact to form carbon monoxide and steam, with an absorption of heat, thus—



On the other hand, a mixture of carbon monoxide and steam under the same conditions will react to a certain extent in the opposite sense, forming carbon dioxide and hydrogen with liberation of heat—



In each case, the extent to which the reaction proceeds will depend on the temperature and the relative quantities of the reacting gases—carbon dioxide and hydrogen in the former case, carbon monoxide and steam in the latter. At a given temperature and with given quantities of the gases, there is always a definite composition towards which the mixture tends

to approach, and when that composition is reached no further reaction will take place if the temperature be kept constant. In general it may be said that a mixture of either carbon dioxide and hydrogen, or carbon monoxide and steam, at any temperature which occurs in the practical working of a gas-producer, will undergo a chemical change resulting in the formation of a mixture of all four gases, in proportions which can be calculated if the conditions are known.

We have given above certain calculations for the theoretical composition of producer gas when the process is carried out without loss of heat, and before leaving this part of the subject we must inquire whether the reactions which may take place between carbon monoxide and steam, or between carbon dioxide and hydrogen, would modify the conclusions which have been arrived at.

In the first case—in which the whole of the steam was assumed to be decomposed with the formation of carbon monoxide and hydrogen—the gas does not contain either of the pairs of substances which can interact, for if the hot gas leaving the producer consists only of hydrogen, carbon monoxide, and nitrogen, no further change will take place. In the producer itself, however, there is a mixture of carbon monoxide and steam, and if these gases interact heat will be evolved and there will be an excess of sensible heat developed in the producer and not absorbed by an endothermic change, so that the efficiency of the process will be lowered. If it be assumed that more steam is used, in quantity sufficient to replace that which is used up by this reaction, it will be found that all the heat evolved is required to raise the necessary steam, or, in other words, if the H_2O in equations (6a) and (6b) is assumed to be in the liquid state, there is no heat change in either case. The result of the interaction of carbon monoxide and steam in the producer is therefore simply the replacement of a small proportion of the carbon monoxide in the gas by an equal volume of hydrogen (having almost exactly the same heating value) mixed with its own volume of carbon dioxide. The gas will therefore be richest if this reaction does not take place, and we are justified in considering the figures given on page 12 as representing the richest producer gas which theoretically can be obtained by the action

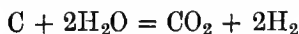
of a mixture of air and steam on carbon when no auxiliary heat is supplied to the producer.

In the second case, in which it was assumed that the steam was decomposed with the formation of carbon dioxide and hydrogen (equation 5), the gas leaving the producer contains carbon monoxide, hydrogen, and carbon dioxide. While hot, a certain proportion of the two gases last mentioned may react to form carbon monoxide and steam. The heat absorbed in this change is almost exactly equal to the heat given up by the condensation of the steam produced, and since it was assumed that all the heat to be obtained by cooling the gas was to be returned to the producer, the final thermal effect of this change is again zero. Its result is simply a slight enrichment of the gas, since hydrogen is replaced by an equal volume of carbon monoxide, and carbon dioxide is replaced by steam which is subsequently condensed, so that the percentage of incombustible gases is reduced. We have already pointed out that, under given conditions, the reaction $\text{CO}_2 + \text{H}_2 = \text{CO} + \text{H}_2\text{O}$ will proceed until a certain quantity of steam is formed, and that no further change will then take place. Hence, if a slight excess of steam were used in the production of the gas, the hot gases would contain carbon monoxide, steam, hydrogen, and carbon dioxide, and it may be assumed that the quantity of steam may be such that no further change would take place in the composition of the hot gas. This steam would be subsequently condensed when the gas is cooled, and the heat given up would be used in raising an equal quantity of steam which would again pass through the producer. If we suppose that this is actually done the calculation which was made will still hold good, but it should be noted that the producer gas while hot necessarily contains a small proportion of steam and the figures given only represent its composition after cooling.

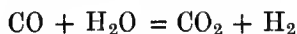
To what extent the reactions (6a) and (6b) actually do take place will be discussed later (Chapter III.); for present purposes it is only necessary to show that they need not be taken into account in calculating the theoretical composition of the ideal producer gas made without heat losses.

In the processes which have so far been considered, the gas necessarily contains a considerable proportion of nitrogen derived

from the air used for the conversion of carbon to carbon monoxide. If the gases formed by the action of steam on carbon could be kept separate from the products of the action of air on the carbon a producer gas free from nitrogen, and consisting theoretically of carbon monoxide and hydrogen only, could be obtained. This is the principle adopted in the manufacture of "water-gas"; the method used is to blow the fire in the producer alternately with air and steam, the gases obtained during the two processes being kept separate. The object of this process is to obtain a producer gas free from incombustible constituents; the process must therefore be carried out in such a manner that the steam and carbon interact to form hydrogen and carbon monoxide, whilst the formation of carbon dioxide by the reactions—



and—

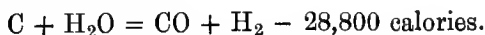


must be prevented as far as possible. The ideal water-gas consists of a mixture of equal volumes of carbon monoxide and hydrogen. The actual process of making this gas is intermittent, and involves various practical difficulties and drawbacks, which are mentioned in Chapter IV. For the present we will consider an ideal case, where the process is represented by the following reactions:—

During the air-blow—



and during the steam-blow—



Water-gas made in this way would have the following composition:—

Carbon monoxide	50.0 per cent. by volume.
Hydrogen	50.0 " "
Total	<u>100.0</u>

Its calorific power would be 3065 calories per cubic meter, or 344.5 B.Th.U. per cubic foot.

If the process could be carried out in an ideal manner, without loss of heat (all the sensible heat which is carried away by the hot gases, as well as the heat of combustion of the gas

produced during the air-blow and the radiated heat, being returned to the producer by regenerative processes), it would only be necessary during the air-blow to have sufficient carbon to make good the heat absorbed by the reaction between carbon and steam. If the materials used were solid carbon and water at 20° C., then the quantity of heat required for the formation of 44.64 c.m. of water-gas from 12 kilos of carbon and 18 kilos water, would be 10,800 calories to evaporate the water, and 28,800 calories for the subsequent chemical change, or a total of 39,600 calories. The quantity of carbon which must be burnt to carbon dioxide during the air-blow to supply this heat would be—

$$12 \times \frac{39,600}{97,600} \text{ or } 12 \times 0.406 \text{ kilos.}$$

Thus to produce 1 c.m. of water-gas of the above composition the theoretical quantities of carbon used would be—

$$\frac{12 \times 0.406}{44.64} = 0.109 \text{ kilo during the air-blow,}$$

$$\text{and } \frac{12}{44.64} = 0.269 \text{ kilo during the steam-blow.}$$

$$\text{Total . . } \underline{0.378 \text{ kilo.}}$$

One kilo of carbon would, therefore, yield 2.65 c.m. of water-gas.

If during the air-blow the carbon were wholly converted to carbon monoxide, and only the sensible heat of the producer gas so formed were recovered but not its heat of combustion, the amount of carbon required during the air-blow, in order to supply the heat necessary for the subsequent formation of 44.64 c.m. of water-gas, would be—

$$12 \times \frac{39,600}{29,400} = 12 \times 1.347 \text{ kilos.}$$

The quantity of carbon used in the production of 1 c.m. of ideal water-gas, under these conditions, would therefore be—

$$\frac{12 \times 1.347}{44.64} = 0.362 \text{ kilo during the air-blow,}$$

and as before—

$$\begin{array}{l} \text{Total . . } \underline{0.269 \text{ kilo during the steam-blow}} \\ \underline{0.631 \text{ kilo.}} \end{array}$$

One kilo of carbon would therefore yield 1.585 c.ms. of water-gas, and in addition it would yield during the air-blow 3.07 c.ms. of gas having the composition given on page 6, and a calorific power of 1057 calories per cubic meter; the water-gas would yield on combustion 60 per cent., and the air-gas 40 per cent. of the heat of combustion of the carbon used. In actual practice the results are far indeed from these: the reasons for this are mentioned in Chapter IV.

The ideal semi-water-gas, the composition of which is given on p. 12, may be looked upon as a mixture of 2.88 volumes of the ideal air-gas, with 1.48 volumes of the ideal water-gas, as is obvious from the method by which its composition was calculated. The same semi-water-gas would also be produced if the water-gas part of the process were carried out in a theoretically perfect manner, if the carbon monoxide were made without carbon dioxide during the air-blow, and if the alternating air-gas and water-gas thus made were collected in the same gas-holder and there allowed to mix.

The various cases for which the ideal composition of producer gas has been calculated may be taken as the types of the principal classes of producer gas which are met with in practical work. On the one hand we have the process in which gas is made by the action of an air-blast on solid carbonaceous fuel, and for convenience we will refer to producer gas made in this way as "air-gas."¹ On the other hand there is the gas made by the action of a steam-blast on incandescent fuel, which is universally known as "water-gas"; and intermediate between these two we have gases of varying composition obtained by the action of a mixed blast of air and steam on solid carbonaceous fuel. This last kind of gas is sometimes called "semi-water-gas," or "mixed gas," and apart from ordinary lighting gas it is this type of producer gas which is now almost invariably used for driving gas engines and for heating work. In France producer gas is called "gaz pauvre" and in Germany "generatorgas."

¹ The term "air-gas" is sometimes used to describe a lighting gas made by bubbling air through volatile liquid hydrocarbons, such as gasoline, pentane, etc.; but as this work deals only with producer gas there need be no fear of confusion arising from this source. It may be added that it is undesirable that the name of the inventor of a gas plant should be given to the gas made in his plant, unless it involves some entirely new process for making gas. The apparatus alone should bear the inventor's name.

CHAPTER II

THEORY OF PRODUCER GAS (CONTINUED)

IN the previous chapter we have shown that the numerous varieties of producer gas may be broadly classified under three heads—air-gas, water-gas, and semi-water-gas—according to the process by which the gas is made. In each case the theory of the process has been considered on the supposition that the fuel used was pure carbon, and calculations have been made to show what should be the theoretical composition of the gas in each case if the process could be carried out without loss of heat and strictly in accordance with the chemical equations which we have given. The results obtained will serve as a standard of comparison with those obtained in practice, somewhat in the way that the thermal efficiency of a heat-engine may be compared with the calculated thermal efficiency of a perfect engine operating under like conditions.

The theoretical results for each of the three types of gas are summarised in Table I., and for each type a parallel column shows typical results obtained in practical working. We propose in this chapter to discuss the various points of difference between the theoretical and practical results, and from a consideration of the causes of these differences to draw some conclusions as to the methods to be adopted in order to secure the highest efficiency in working and the best practical results.

In practical working it is not to be expected that the results obtained will be as good as those which have been shown by calculation to be the best theoretically obtainable, but a comparison of the figures given in Table I. will be instructive, and it will show that the differences are not so great as might have been expected. Moreover, the results given in this table as representing actual practice have not been selected as exceptionally favourable ones; they are presented as examples of what

	1	2	3	4	5	6	7	8	9	10
<i>Fuel used.</i>	Carbon. 100% Ideal air-gas— C + O = CO (page 8).	Air-gas made in small Downs gas plant. Coke. C, 95% H ₂ O— Ash, 5%	Carbon. 100% Ideal semi-water-gas— C + H ₂ O = CO + H ₂ (page 12).	Semi-water-gas made at Millwall in Downs gas plant. Anthra- cite.	Carbon. 100% Ideal semi-water-gas— C + O = CO (page 14).	Bituminous coal. H ₂ O, 8.6% Ash, 10.42% Total C, 62.63% Volatile matter (ex- cluding C), 18.29% In Mond gas plant.	Carbon. 100% Ideal water-gas, when CO ₂ is formed during the blow (page 17).	Water-gas made by the Böttchler-Fischer process. Coke. C, 87.4% of dry coke.	Carbon. 100% Ideal water-gas, when air-gas is formed during the blow (page 18).	Water-gas made at Köpen. Coke. C, 81.8% H ₂ O, 10.6% Ash, 10.6% H ₂ O, 2.0% O ₂ + N ₂ , 2.1% 44.0% 48.6% 0.4% 3.3% 3.7% 93.0% 287.8% 323.5%
<i>Composition of gas (per cent. by volume).—</i>										
Carbon monoxide	34.7	32.6	39.9	27.6	19.7	11.0	50.0	42.0	50.0	44.0
Hydrogen	—	1.0	17.0	15.3	28.8	29.0	50.0	49.15	50.0	48.6
Methane	—	—	—	1.4	—	2.0	—	0.55	—	0.4
Carbon dioxide	—	1.4	—	3.9	14.4	16.0	—	3.9	—	3.3
Oxygen	—	—	—	—	—	—	—	—	—	—
Nitrogen	65.3	65.0	43.1	51.8	37.1	42.0	—	3.5	—	3.7
<i>Total combustible gases</i>	34.7	33.6	56.9	44.3	48.5	42.0	100	92.6	100	93.0
<i>Caloric power (higher value).—</i>										
Calories per cubic meter	1637	1023	1740	1450	1490	1422	3065	2856	3065	287.8
British thermal units per cubic foot	118.8	115.0	195.6	163	167.5	160.0	344.5	321	344.5	323.5
<i>Caloric intensity (theoretical, see Appendix B).—</i>										
Centigrade degrees	1563	1529	1826	1646	1617	1558	2062	2023	2062	2021
Fahrenheit degrees	2845	2784	3319	2995	2943	2836	3744	3674	3744	3670
<i>Yield of gas.—</i>										
Cubic meters per kilo of fuel	5.36	5.17	4.65	4.37	5.45	3.69	2.65	1.72	1.585	1.13
Cubic feet per ton of fuel	192,000	186,000	167,000	157,000	195,000	132,500	93,000	61,000	57,000	40,500
<i>Thermal efficiency (cold gas)—per cent.</i>	70	—	100	80.6	100	84.1 ¹	100	66.1	100	42.1
<i>Steam used—kilos per kilo of fuel</i>	—	0.04 ²	0.64	{ about } { 0.75 }	1.29	{ supplied, 2.5 } { decomposed, 0.5 }	1.07 ²	—	0.61 ²	—
<i>Air used—</i>										
Kilos per kilo of fuel	5.73	5.57	3.29	3.70	3.31	2.53	3.30 ²	—	3.29 ²	—
Cubic meters per cubic meter of gas	0.83	0.83	0.55	0.655	0.47	0.885	0.46	—	1.69	—
<i>Air required for combustion of one cubic meter of gas (cubic meters)</i>	0.83	0.80	1.35	1.15	1.15	1.15	2.38	2.24	2.38	2.24

¹ Excluding fuel used for raising steam.

² Derived from moisture in atmosphere.

³ Reckoned on total fuel used.

is actually done with well-known types of gas-producer plant in which the processes are used which have been considered theoretically in Chapter I. The figures given in column 2 of Table I. were obtained with a small Dowson gas plant working without steam, the air being forced through the producer by a positive blower; column 4 gives the results obtained from a 250-B.H.P. Dowson plant at the works of Messrs. J. & E. Wright of Millwall;¹ column 6 gives results published by Mr. H. A. Humphrey,² and obtained with a Mond plant at the chemical works of Messrs. Brunner, Mond & Co. at Winnington; column 8 is based on the results obtained by Prof. W. A. Bone, F.R.S., with a Dellwik-Fleischer water-gas plant;³ and the figures in column 10 represent water-gas made at Essen,⁴ for lighting and for driving gas engines, the air-gas formed during the air-blow being used for heating steam boilers. In this Table the thermal efficiencies are based upon the total fuel consumption, including fuel used for raising the necessary steam, except where otherwise stated.

One of the principal causes of the differences between the actual and the theoretical results is that the fuels used in practice contain other constituents than carbon, which alone was taken into account in the calculations made in the previous chapter. With the exception of coke and charcoal, all ordinary fuels when subjected to heat give off smaller or greater quantities of volatile substances; and if the temperature be high and the heating sufficiently prolonged the residue of the fuel which is left consists almost entirely of carbon together with the incombustible mineral constituents. In a gas-producer working in the ordinary way with an upward draught, as described on p. 3, each fresh charge of fuel is heated and is thus subjected to this process of distillation before it descends into the zone where partial combustion takes place, and the volatile substances which are distilled off mix with the gas that is being formed according to the chemical changes which have been discussed in the previous chapter. The fuel which takes part in these chemical reactions is not the raw

¹ *Proceedings Inst. C.E.*, 1901, vol. cxliv. p. 269.

² *Proceedings Inst. M.E.*, 1901, p. 73.

³ Greenwood, "Industrial Gases" (1920), p. 320.

⁴ Fischer's "Handbuch der chemischen technologie," vol. i. p. 50 (15th German edition).

fuel that is put in the producer, but is the residue which is left when the raw fuel has been more or less completely deprived of its volatile constituents by the action of heat. The gas actually obtained from such fuel may therefore be regarded as consisting of a producer gas obtained from pure carbon, mixed with the volatile substances given off by the distillation of the fuel. The composition of the gas will depend largely on the nature and amount of these volatile substances. They vary very considerably, as almost all classes of fuels are used, from anthracite, which contains very little volatile matter, to peat, wood, or even sawdust at the other extreme. The volatile constituents of different fuels are discussed more fully in Chapter XV. on Fuel, and it will be sufficient for our present purpose to point out that they consist partly of gases and partly of condensable vapours, and that for many purposes the latter must be condensed and separated from the producer gas before it can be used. In the case of bituminous or semi-bituminous coals, lignite, peat, and other fuels rich in oxygen and hydrogen, the quantity of tarry matter which is given off on distillation is very considerable and may represent as much as 8 or 9 per cent. of the total heating value of the fuel. When the gas is cooled and scrubbed before use the tar which is separated has little value, and there is thus an unavoidable waste on this account in the use of such fuels in producers where clean cool gas is required. It is therefore an important point in the design of gas-producers for use with bituminous fuels to arrange that the tarry vapours may either be burnt in the producer itself, or decomposed and converted to combustible gases which will not condense at ordinary temperatures. This point is further discussed in Chapter IX. on Gas from Bituminous Coal for Engine Work.

Confining our attention to the case of a cool clean gas, to which all the analyses in Table I. refer, the composition of the gas will be affected by the nature of the *gaseous* products of distillation of the fuel. For the air-gas (column 2) and water-gas (columns 8 and 10) the fuel used was ordinary gas-coke; as it had already been strongly heated for a considerable time in retorts there were practically no gases distilled off from it by the action of heat alone in the producer, and the composition of the producer gas obtained from it agrees well with the

calculated figures given in columns 1, 7, and 9. The fuels used in the production of the semi-water-gases referred to in columns 4 and 6 were anthracite and bituminous coal respectively, and in these cases the gas formed from the fixed carbon in the fuel was mixed with a certain quantity of other gases given up by the action of heat on the fuel. The following analyses will show the general character of the gases which are given off by the action of heat on fuels of this class:—

*Gas evolved on heating Anthracite
without Air.*

1 kilo of anthracite yielded 0·168 c.m. of gas of the following composition:—

	Per cent. by volume.
Carbon monoxide	4·3
Hydrogen	70·6
Methane	18·9
Carbon dioxide	1·1
Oxygen	—
Nitrogen	5·1
Total	100·0

*Gas evolved on heating Bituminous
Coal without Air.*

1 kilo of coal yielded 0·168 c.m. of gas of the following composition:—

	Per cent. by volume.
Carbon monoxide	13·2
Hydrogen	36·0
Methane	40·9
Carbon dioxide	3·6
Oxygen	—
Nitrogen	6·3
Total	100·0

It will be noticed that anthracite on heating yields both hydrogen and methane, and we should expect that a producer gas made from anthracite would contain a greater proportion of these two constituents than gas made under similar conditions from coke. That this is actually the case is shown by the following analyses of producer gas made from coke and from anthracite respectively in the same producer and under as nearly the same conditions as were practically possible:—

Gas made from Coke.

	Per cent. by volume.
Carbon monoxide	22·6
Hydrogen	14·3
Methane	0·75
Carbon dioxide	8·45
Oxygen	0·2
Nitrogen	53·7
Total	100·0

Heating value . 1201 calories per cubic
meter.
" " . 135 B.Th.U. per
cubic foot.

Gas made from Anthracite.

	Per cent. by volume.
Carbon monoxide	20·1
Hydrogen	19·25
Methane	1·2
Carbon dioxide	9·25
Oxygen	0·15
Nitrogen	50·05
Total	100·0

Heating value . 1326 calories per cubic
meter.
" " . 149 B.Th.U. per
cubic foot.

The percentage of combustible constituents varies in different samples of fuel, especially with anthracite, and a more exact comparison may be made by taking volumes of the two gases which contain the same weight of carbon. Taking the above analyses as a basis, there will be 100 volumes of gas made from coke and 104 volumes of gas made from anthracite, and they will consist of the following:—

<i>Gas made from Coke.</i>		<i>Gas made from Anthracite.</i>	
	Volumes.		Volumes.
Carbon monoxide	22·6	Carbon monoxide	20·9
Hydrogen	14·3	Hydrogen	20·05
Methane	0·75	Methane	1·25
Carbon dioxide	8·45	Carbon dioxide	9·6
Oxygen	0·2	Oxygen	0·15
Nitrogen	53·7	Nitrogen	52·05
Total	100·0	Total	104·0

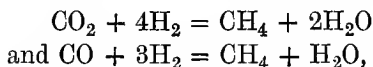
The most notable feature in comparing these two sets of figures is the greater proportion of hydrogen and of methane in the gas made from anthracite. In the gas made from coke the hydrogen is formed almost entirely from the decomposition of steam in the producer; the excess of hydrogen in the gas made from anthracite is accounted for by the fact that this fuel contains from two to five per cent. by weight of hydrogen, and a part of this is set free when the anthracite is heated. The superiority of anthracite over coke as fuel for the production of gas of good heating value consists chiefly in the fact that it gives a richer gas, owing to the hydrogen and methane which it yields when heated.

In the same way the effect of the volatile constituents of bituminous fuel is to increase the amounts of hydrogen and methane in the semi-water-gas obtained from it, and this fact must be borne in mind in comparing the figures of column 5 (referring to a gas made from pure carbon) with those of column 6, which represent the composition of a gas made from a bituminous coal. This case, however, is not quite so simple as that of the semi-water-gas made from anthracite, for the Mond producer is so designed that the tarry vapours given off by the distillation of the fuel in the upper part of the producer are partially converted into fixed gases before they enter the scrubbing plant. In this case, therefore, the gas formed from the volatile part of the

fuel by the action of heat alone may be very different in composition from the gases obtained by heating a sample of the fuel in a laboratory test. The greater part of this semi-water-gas is, however, formed by the interactions of air, steam, and the fixed carbon in the fuel, so that the comparison of the figures of columns 5 and 6 of Table I. is not without value.

We are now in a better position to understand the differences between the calculated theoretical results and those actually obtained in practice. Comparing columns 1 and 2, the differences are very slight, showing that the chemical reactions have actually taken place almost exactly as was assumed in Chapter I. for a case of this kind. In the two examples of semi-water-gas in Table I. it might have been expected from what has already been said that the proportion of hydrogen in the gases would have exceeded the calculated figures rather than have fallen short of them; as a fact, while the percentage of hydrogen is only about the same as the calculated value, it does actually bear a greater ratio to the amount of carbon in the gas than in the theoretical cases.

The methane in semi-water-gas is produced, as has already been pointed out, by the action of heat on anthracite or bituminous coal. We have often found, however, that semi-water-gas made from coke contains a small amount of methane (generally about 0.5 per cent. by volume), and it is therefore interesting to inquire whether this gas can be formed in the producer synthetically, as well as by the decomposition of other hydrocarbons. Bone and Jerdan¹ have shown that at 1200° C. small quantities of methane are formed by the direct union of carbon and hydrogen, and that this is the only hydrocarbon formed. Other compounds of carbon and hydrogen are decomposed at this temperature with the formation of methane, carbon, and hydrogen. Further, it is well known that carbon dioxide or carbon monoxide can react with hydrogen, methane being formed, according to the equations—



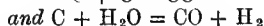
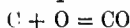
but these reactions only take place in the presence of some

¹ *Journal of the Chemical Society : Proceedings*, 1901, vol. xvii. p. 162; *Transactions*, 1897, vol. lxxi. p. 52.

catalytic agent such as reduced nickel, or under the influence of the electric spark, and Bone and Jerdan showed that no methane was formed by the action of heat alone on a mixture of carbon monoxide and hydrogen. We may therefore suppose that the methane in producer gas is due chiefly to the decomposition by heat of the volatile constituents of the fuel, but that it may also be formed to some extent by the direct union of carbon and hydrogen when the producer is worked at a high temperature.

As regards the remaining constituents of the semi-water-gas, viz. carbon monoxide, carbon dioxide, and nitrogen, the differences are much more marked. Broadly speaking, there are in each case smaller proportions of the combustible gas carbon monoxide, and larger proportions of the incombustible gases carbon dioxide and nitrogen, in the practical results than in the ideal gases. Even in the case of air-gas made from coke, if we leave out of consideration the presence of hydrogen, which is due simply to the decomposition of the moisture present in the air used for the process, the difference between theory and practice is of the character just indicated; in the other examples the differences are somewhat obscured by the fact that a certain quantity of hydrogen, etc., has been added to the gases formed by the chemical reactions on which the theoretical results are based, so that the *percentages* of the other constituents of the producer gas are reduced. To get a better idea of the extent to which the theoretical chemical reactions are followed, we give below the composition of so much of each of the gases in columns 4 and 6 as contains the same amount of carbon as 100 volumes of the corresponding ideal gas:—

Ideal Semi-water-gas formed according to the Equations—



100 vols. (containing 39.9 parts of carbon) consist of—

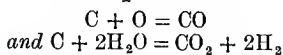
	Per cent. by volume.
Carbon monoxide	39.9
Hydrogen	17.0
Methane	—
Carbon dioxide	—
Nitrogen	43.1
Total	100.0

Semi-water-gas made at Millwall.

121.3 vols. (containing the same amount of carbon) consist of—

	Volumes.
Carbon monoxide	33.5
Hydrogen	18.6
Methane	1.7
Carbon dioxide	4.7
Nitrogen	62.8
Total	121.3

Semi-water-gas formed according to the Equations—



100 vols. (containing 34.1 parts of carbon) consist of—

	Per cent. by volume.
Carbon monoxide	19.7
Hydrogen	28.8
Methane	—
Carbon dioxide	14.4
Nitrogen	37.1
Total	100.0

Semi-water-gas made at Winnington.

117.6 vols. (containing the same amount of carbon) consist of—

	Volumes.
Carbon monoxide	12.9
Hydrogen	34.1
Methane	2.4
Carbon dioxide	18.8
Nitrogen	49.4
Total	117.6

For producer gas made from anthracite or bituminous coal it would be impossible to give an exact comparison between theory and practice, unless the composition of the distillation gases and also their volume in relation to the amount of fixed carbon in the fuel were accurately known. Nevertheless, it is clear from the above figures that so far as the reactions between air, steam, and carbon are concerned, the departures from theory are in the direction indicated, viz. that there is in practical working an amount of carbon dioxide greater than that shown by theory, while the proportion of carbon monoxide is less. Remembering that the semi-water-gas of columns 4 and 6 may be considered as true semi-water-gas (formed from steam, air, and carbon) diluted with distillation gases containing little carbon dioxide and nitrogen, we should expect to find the percentages of the two latter gases less, rather than greater, in practice than in theory. Since the reverse is actually the case, we should find, if we could distinguish the distillation gases from the producer gas (which together make up the semi-water-gas), considerably higher proportions of carbon dioxide and nitrogen in the producer-gas portion than is indicated by theory.

In part this is due to the fact that the heat of combustion of the carbon cannot be completely utilised, while the calculations for semi-water-gas in Chapter I. were based on the assumption that no heat losses took place. Certain sources of heat loss are always present, although by suitable design they can be minimised. For example, radiation from the gas producer and from the pipes conveying hot gases is unavoidable; but it is not unusual to

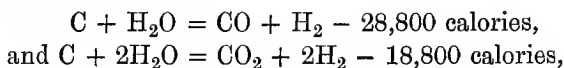
recover a portion of this heat by having an outer casing round the producer and outlet pipes, the air-supply for the producer being drawn through this casing and being heated before it reaches the fire. The principal heat loss is, however, in the large quantity carried away by the gas as it leaves the producer; and a considerable proportion of this heat may be utilised in raising the steam required for making the gas, by passing the hot gas through a tubular boiler or other suitable contrivance. In practice the gas must leave the last-named apparatus at a temperature considerably above that of the steam which is produced, so that only a portion of the sensible heat of the gases is recovered; moreover, as the gases are cooled it becomes more difficult to make use of their sensible heat, and a point is soon reached at which it is no longer useful to increase the cost of the plant for the sake of a slightly increased economy of heat. Thus in practice, when the gas is to be used cold, it is necessary to abstract the remaining sensible heat of the gas without making use of the heat withdrawn. Usually this is done by transferring the heat to a supply of cold water which is mixed intimately with the gas. There is one notable exception in which the hot water obtained from the cooling tower is used to heat the air-supply for the producer and to saturate it with vapour; but even in this case the recovery of heat is necessarily far from complete.

It may be pointed out here that the heat required to raise the actual amount of steam used in making the semi-water-gas referred to in column 3 is equivalent to the heat given up by the producer gas in cooling through 300-350° C. Actually the steam was raised in a separate boiler and the thermal efficiency of the plant was therefore less than it would have been had the steam been raised from the sensible heat of the gases leaving the producer, but the composition of this gas is the same as it would have been in that case.

If the fuel used is moist there is a further loss, because heat is required to evaporate the moisture. In a simple producer worked with an up-draught and with the fuel introduced at the top, as in Fig. 2, the moisture is evaporated and passes away with the gas, and is subsequently condensed when the gas is cooled. Ordinarily the loss is but small; for example, in the case of anthracite containing 5 per cent. of moisture, a figure rather

above than below the average, only about 0·3 per cent. of the heat of combustion of the fuel would be lost in evaporating the moisture which it contains. In some cases, however, the effect of moisture in the fuel is more serious. In the case of air-dried peat, for instance, which contains at the least from 20 to 25 per cent. of moisture, and has a heat of combustion only about one-half that of anthracite, the heat used up in evaporating the moisture would be about 3 per cent. of the total heat of combustion of the fuel.

The final result of all such heat losses is that the reactions which require heat, viz.—



cannot take place to the extent assumed in the calculation given in Chapter I. (see p. 12). Following the method of calculation there used, the result is seen to be that the gas formed by the action of air and steam on the fixed carbon of the fuel contains less hydrogen, slightly less carbon monoxide, and more nitrogen than the ideal gas. When the steam is raised in a separate boiler, as in the case referred to in column 4 of Table I., a certain quantity of heat is supplied to the producer in addition to that derived from the combustion of the fuel in the producer, and it might be expected that this would compensate for heat losses and enable gas to be obtained having a composition more nearly approaching that of the ideal gas. The quantity of steam which can be decomposed is, however, limited in practice by the necessity of maintaining a high temperature in the producer fire.

Where the steam is decomposed with formation of carbon dioxide and hydrogen we should expect as the result of heat losses to find less carbon dioxide in the actual than in the ideal gas, since the formation of this constituent by the reaction between steam and carbon is hindered equally with the formation of hydrogen. Actually, however, the percentage of carbon dioxide is greater in this case than the calculated number, pointing to the fact that, in consequence of the lower temperature of the producer fire with this method of working, some considerable portion of the carbon dioxide produced by the reaction—

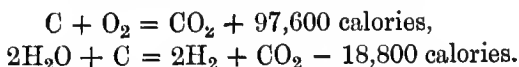


escapes the subsequent change to carbon monoxide. This is one of the most important points in which the practical results differ from the theoretical, and it is worth while to consider the consequences to which it may lead.

Regarded from the standpoint of thermal efficiency, the effect of the combination of carbon in the producer with the oxygen of the air to form carbon dioxide without subsequent reduction to carbon monoxide would be to render more heat available for the reactions between steam and carbon in which heat is absorbed. Theoretically, therefore, a greater quantity of steam could be decomposed than is possible when carbon monoxide is the sole product of the reaction between carbon and atmospheric oxygen. By following the method used in the previous chapter we can calculate what would be the composition of a producer gas formed in this way, assuming the absence of heat losses. Two cases are possible, because the reaction between steam and carbon may take place in two ways; but it may be said at once that under the conditions which are necessary to bring about the change expressed by the equation—



the action of air on carbon leads to the formation of carbon monoxide accompanied by a comparatively small amount of carbon dioxide.¹ Hence we need only consider the alternative case, viz. that of a producer gas formed (without heat loss) by the reactions—



We do not suggest that it is possible for a producer gas to approximate very closely to this assumed case. It has already been shown that in practice, when the steam and carbon interact in accordance with the second of these two equations, the air and carbon interact so as to form both carbon monoxide and carbon dioxide. We do not know the relative amount of these two gases formed by the reaction between air and carbon in this case, but by assuming that the union of carbon and atmospheric oxygen in the producer leads to the formation of the dioxide only we

¹ See Chapter III., pp. 52-60.

shall get the extreme result; and we can also calculate the theoretical results for some assumed intermediate cases.

For every 12 kilos of carbon which combine with oxygen, in accordance with equation (1) in Chapter I., one volume (22·32 c.m.) of carbon dioxide is formed and 97,600 calories are liberated. According to equation (5), the interaction of 36 kilos of steam with 12 kilos of carbon gives rise to the formation of two volumes of hydrogen and one volume of carbon dioxide, and 18,800 calories are absorbed. To this we must add the latent heat of the steam, viz. 21,600 calories (see p. 13), so that the heat which must be supplied is $18,800 + 21,600 = 40,400$ calories. If all the heat liberated in the combustion of 12 kilos of carbon be used up in the decomposition of steam by a further quantity of carbon, the quantity of steam decomposed will be—

$$36 \times \frac{97,600}{40,400} \text{ or } 36 \times 2.416 \text{ kilos.}$$

The gas will, therefore, consist of—

Carbon dioxide	1.00 vol. containing 12 kilos of carbon	} From air and carbon.
Nitrogen	3.76 vols.	
Carbon dioxide	2.416 vols. containing $12 \times 2.416 = 28.99$ kilos carbon	} From steam and carbon.
Hydrogen	4.83 vols.	
Total	12.00 vols. containing 40.99 kilos carbon.	

The quantity of steam used is $\frac{36 \times 2.416}{40.99}$, or 2.12 kilos per kilo of carbon.

The composition of this gas by volume will be as follows:—

Carbon dioxide	28.45 per cent.
Hydrogen	40.25 "
Nitrogen	31.30 "
Total	100.00

Its heating value will be 1243 calories per cubic meter, or 139.7 B.Th.U. per cubic foot; and the yield of gas will be 12.01×22.32 c.ms. from 40.99 kilos of carbon, or 6.54 cubic meters per kilo of carbon.

It will thus be seen that the gas formed in this way is weaker than that referred to in column 5 of Table I., although there is a correspondingly greater volume of gas from each kilo of carbon

consumed, as we have assumed an entire absence of heat losses.

We have now dealt with the two extreme cases; we have assumed that the reaction between carbon and air gives rise in the one to carbon monoxide, and in the other to carbon dioxide.

It is easy to calculate the theoretical results when different proportions of carbon monoxide and dioxide are produced from air and carbon, and this has been done for several cases. The results are given in Table II., and are shown graphically by the curves of

TABLE II.—THEORETICAL COMPOSITION OF SEMI-WATER-GAS WHEN DIFFERENT PROPORTIONS OF CO_2 AND CO ARE FORMED BY THE ACTION OF AIR ON CARBON (ASSUMING STEAM TO BE DECOMPOSED IN ACCORDANCE WITH EQUATION (5), p. 9).

Reaction between air and carbon: Proportions of CO and CO_2 formed per cent. by volume.		Composition of semi-water-gas per cent. by volume.					Steam used per kilo of carbon.	Gas formed per kilo of carbon.	Calorific power of gas (higher value).	
CO	CO_2	CO_2	CO	H_2	N_2	Kilos.	Cubic meters.	Calories per cubic meter.	B.Th.U. per cubic foot.	
—	100	28.45	—	40.25	31.3	2.12	6.54	1243	139.7	
10	90	27.8	0.9	39.7	31.6	2.08	6.48	1254	140.9	
20	80	27.1	1.9	39.15	31.85	2.02	6.41	1267	142.4	
30	70	26.3	3.0	38.5	32.2	1.97	6.34	1282	144.0	
40	60	25.35	4.3	37.7	32.65	1.91	6.26	1298	145.8	
50	50	24.3	5.85	36.8	33.05	1.83	6.17	1316	147.9	
60	40	23.0	7.65	35.8	33.55	1.75	6.07	1340	150.5	
70	30	21.5	9.8	34.55	34.15	1.66	5.95	1366	153.5	
80	20	19.6	12.4	33.0	35.0	1.55	5.81	1398	157.1	
90	10	17.3	15.65	31.1	35.95	1.42	5.65	1438	161.6	
100	0	14.4	19.7	28.8	37.1	1.26	5.45	1490	167.5	

Figs. 3 and 4. In these diagrams the horizontal axis is divided into 100 parts, and the ordinate representing the theoretical composition, etc., of the gas in any particular case is set up against an abscissa which represents the proportion of carbon monoxide in the assumed mixture of carbon monoxide and dioxide formed by the action of atmospheric oxygen on the carbon. Thus, if under certain conditions of temperature, etc., it is assumed that the reaction between air and carbon will yield 80 per cent. of the monoxide and 20 per cent. of dioxide, the theoretical composition of the semi-water-gas is represented by the ordinate **AB**

in Figs. 3 and 4. In Fig. 3 the ordinate at any point is divided up to represent the proportions of carbon monoxide, hydrogen, carbon dioxide, and nitrogen in the gas. In Fig. 4 the percentage

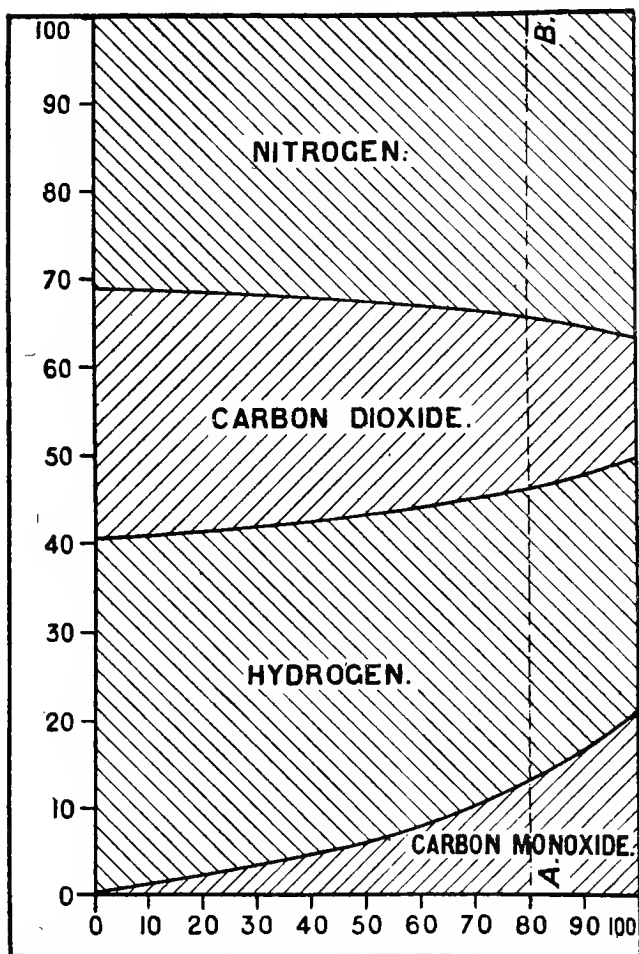


FIG. 3.—Theoretical composition of semi-water-gas, when different proportions of CO and CO_2 are formed by the action of air on carbon.

of each constituent is measured independently from the same horizontal axis, and other data are also given in the same diagram.

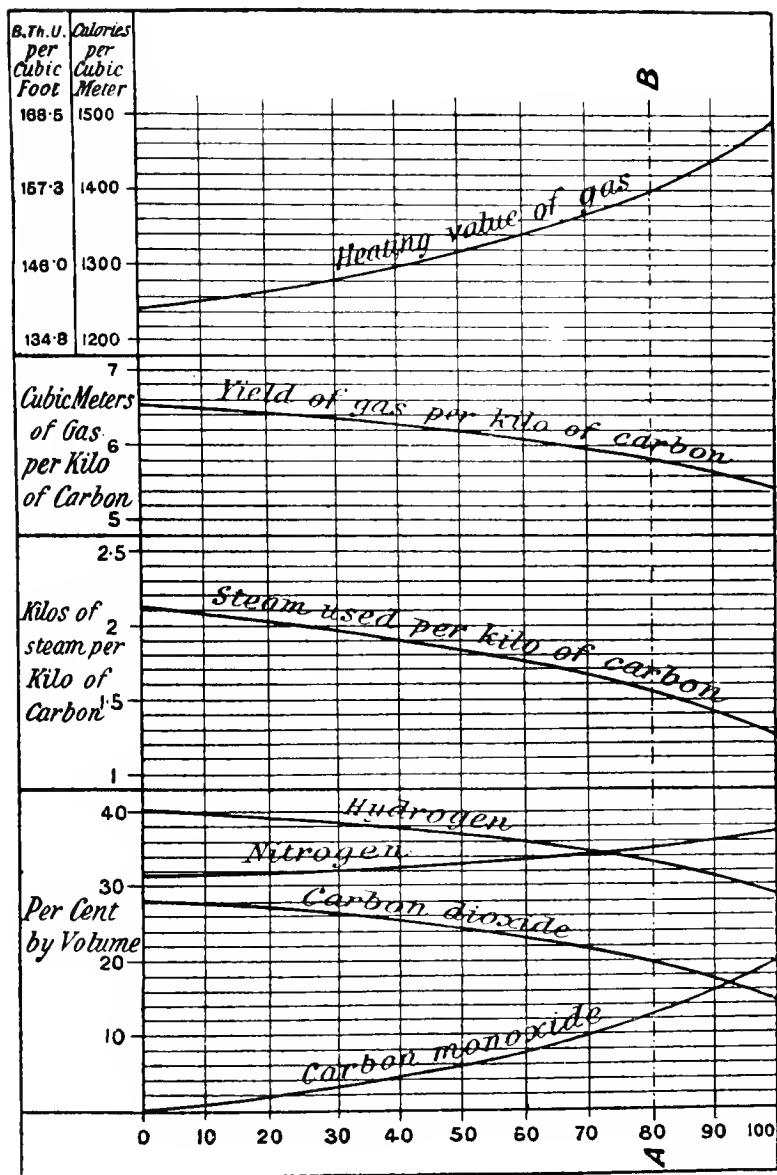
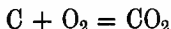
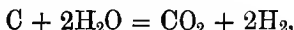


FIG. 4.—Theoretical composition, etc., of semi-water-gas, when different proportions of CO and CO₂ are formed by the action of air on carbon.

It will be seen from these diagrams that as the proportion of carbon dioxide formed by the reaction—

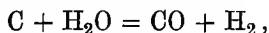


increases, if the heat liberated is still recovered by the decomposition of steam by the reaction—

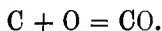


then the percentages of carbon dioxide and hydrogen in the gas increase and the percentages of carbon monoxide and nitrogen decrease; while the quantity of steam used increases and the heating value of the gas decreases.

Thus, in consequence of the fact that the action of air on carbon may lead to the formation, not of carbon monoxide only as was assumed in Chapter I., but of a mixture of carbon monoxide and carbon dioxide, the quantity of heat available for the reaction between carbon and steam may be greater, and the theoretical composition of semi-water-gas somewhat different from the figures given in Chapter I. As we shall see in the next chapter, a high temperature is required for the reaction—



and at the same temperature very little carbon dioxide is formed by the action of air on carbon, the change being practically that represented by the equation—



The figures based on these two reactions, and summarised in column 3 of Table I., may therefore be taken as a standard of comparison for semi-water-gas made at a high temperature.

The difference between the practical results obtained in gas producers and the results which should be obtained theoretically when no heat is wasted are thus seen to be due principally to three causes. Firstly, the fuel used is not pure carbon but contains volatile constituents which mix with the gas and enrich it; secondly, in actual practice a considerable proportion of the heat of the fuel is lost in the process of converting the solid fuel into cool clean gas—and consequently in the cases of semi-water-gas and water-gas the amount of heat available for decomposition of steam is less than the theoretical quantity, so that either the

calorific power of the gas or the yield of gas per kilo of fuel (or both of these) is less than should theoretically be the case; and, finally, the theoretical composition of the gas is not attained because the reactions do not take place completely in accordance with the assumed equations.

The principle that the sensible heat of the gas should be recovered as completely as possible and returned to the producer needs no further emphasis. Means for accomplishing this end are provided in some of the principal types of gas-producer plants, and the production of the steam by the sensible heat of the producer gas is a typical feature of most modern suction plants. We shall proceed in the next chapter to study the chemical reactions, with the object of showing what are the conditions which must be observed in order that they may take place in the manner we have assumed in Chapter I.

CHAPTER III

THEORY OF PRODUCER GAS (CONTINUED)

It has already been mentioned that to obtain a combustible gas there must be a sufficient depth of incandescent fuel in the producer. The passage of a rapid current of air through a thin layer of fuel leads to complete combustion of the fuel, and the hot gases which leave such a fire consist of carbon dioxide mixed with the nitrogen of the air used for the combustion of the fuel, together with a large excess of unburnt air. With a thicker layer of fuel, the amount of air mixed with the products of combustion is less, and there may be a small proportion of carbon monoxide present. With the fuel bed deeper still a combustible gas is obtained which is free from air and contains a fair proportion of carbon monoxide; within limits, the proportion of carbon monoxide can be increased and that of carbon dioxide decreased by increasing the depth of the bed of fuel. This has the double effect of increasing the surface of hot carbon with which the gas comes into contact during its passage through the fire, and of increasing the time during which the reacting substances are in contact with one another. With the air blast passing at a given velocity through the fire, if the depth of fuel be increased a point will soon be reached at which a further increase has no effect on the proportion of carbon monoxide in the gas; and in practice, in any given case, the depth of fuel should not be much greater than this.

The effect of the depth of incandescent fuel on the formation of carbon monoxide is well illustrated in some experiments carried out by Wendt,¹ in which samples of gas were drawn at different levels from a fuel-bed 7 ft. 3 ins. (221 cms.) deep in a producer worked with bituminous coal and with an air-blast.

¹ *Stahl und Eisen*, 1906, vol. 26, p. 1184.

The analysis of the various samples gave the following figures (per cent. by volume):—

TABLE III.—EFFECT OF DEPTH OF FUEL ON FORMATION OF CARBON MONOXIDE.

Height above blast inlet.		CO ₂	CO	H ₂	CH ₄	N ₂
ins.	cms.					
87	221	1.0	30.9	6.4	3.2	58.5
60	152	2.0	27.2	12.3	4.2	54.3
50	127	2.0	26.7	10.0	3.8	57.5
40	101	1.0	28.9	11.9	2.0	56.2
30	76	0.8	32.7	0.7	0.4	65.4
20	51	0.2	84.5	—	—	65.3
10	25	—	34.5	—	—	65.5
0	0	8.8	19.6	—	—	71.6

The hydrogen and methane in the gas drawn off at the higher levels was formed by the decomposition of the volatile constituents of the bituminous coal, but we are more particularly concerned with the reactions in the lower part of the fuel bed, say below 30 ins. (76 cms.), where the fuel has already been deprived of its volatile constituents in its passage through the upper part of the producer. It will be seen that the conversion of the carbon dioxide present at the level of the blast inlet to carbon monoxide was complete in the lower 10 to 20 ins. (25 to 51 cms.) of the fuel column in this case. The gradual increase in the proportion of carbon dioxide at higher levels was probably due in part to the production of carbon dioxide by the decomposition of the volatile constituents of the raw fuel, and in part to the reversal of the reaction $\text{CO}_2 + \text{C} = 2\text{CO}$ at the lower temperatures (see p. 49). Similar experiments made when the producer was blown with steam and air showed that the proportion of carbon dioxide was least and the proportion of carbon monoxide greatest at a point 30 ins. (76 cms.) above the level of the blast inlet. The temperature of the fire was lower owing to the presence of steam in the blast, and a greater depth of fire was necessary for the conversion of the carbon monoxide to carbon dioxide.

No definite rule can be given as to the depth of fuel required, as this will depend on the velocity of the blast and on the size and physical condition of the fuel. The influence of these

factors is well illustrated by some experiments carried out by M. Boudouard.¹

A certain quantity of carbon dioxide was confined in a porcelain tube in the presence of carbon, and the tube and its contents were kept at a known temperature for a certain time. At the end of the experiment the gases were removed from the tube and analysed, the amount of carbon monoxide formed under known conditions being thus ascertained. In this way Boudouard was able to vary only one condition at a time, and thus obtained some valuable results as to the effects produced by different conditions. We cannot here give all his experimental results, but will quote sufficient to illustrate the conclusions at which he arrived.

To study the influence of the physical condition of the fuel, parallel experiments were made in the manner just described, using wood charcoal, gas carbon, and coke respectively in three separate tubes. A fourth experiment was made with some finely divided carbon prepared by a chemical process. In each case the porcelain tube containing carbon and carbon dioxide was heated to 800° C. (1472° F.) for 8 minutes, and the gas in the tube was then analysed. The results obtained were as follows:—

TABLE IV.—EFFECT OF PHYSICAL CONDITION OF FUEL ON FORMATION OF CARBON MONOXIDE.

	Per cent. by volume.	
	Carbon dioxide.	Carbon monoxide.
Finely divided carbon	13·6	86·4
Wood charcoal, in pieces 2 to 5 mm. cube .	39·9	60·1
Coke " " " .	79·1	20·9
Gas carbon " " " .	80·1	19·9

It will be seen that in no case is the conversion of the carbon dioxide to monoxide complete; the change proceeded furthest with the finely divided carbon and nearly as far with wood charcoal. With coke and with gas carbon comparatively little carbon monoxide was formed. These results clearly show that the reaction—



¹ *Annales de Chimie et de Physique*, 1901, series vii. vol. 24, pp. 5–85.

proceeds most rapidly if the carbon is in a highly porous condition. In a gas-producer the reacting gases are in contact with the hot fuel for a very short time (probably not more than one second); it is, therefore, all important that the chemical changes shall take place as rapidly as possible. Although the time allowed in the experiments quoted was as much as 8 minutes, it should be remembered that there was no movement of the gases through the carbon such as would be the case in a producer, and it is a fair inference that, other things being equal, the percentage of carbon monoxide obtained in a gas-producer would be higher if the fuel were of a porous nature than it would be if the fuel were dense and exposed little surface to the gas. From this point of view, wood charcoal would be almost an ideal fuel for use in a gas-producer.

The influence of the size of the fuel is shown by experiments similar to the above, but the carbon in its various forms was used in larger pieces (described as of the size of a hazel-nut, *noisette*). The following results were obtained, the tubes being heated for 8 minutes at 800° C. (1472° F.):—

TABLE V.—EFFECT OF SIZE OF FUEL ON FORMATION OF CARBON MONOXIDE.

	Percentage by volume.	
	Carbon dioxide.	Carbon monoxide.
Wood charcoal, 2 mm. to 5 mm.	39.9	60.1
" " size of a nut	17.1	82.9
Coke, 2 mm. to 5 mm.	79.1	20.9
" size of a nut	83.6	16.4
Gas carbon, 2 mm. to 5 mm.	80.1	19.9
" size of a nut	86.7	13.3

With coke and gas-carbon, both comparatively non-porous materials, the change proceeded more rapidly with the smaller pieces than with the larger. With wood charcoal the reverse was the case, and this is probably due to the fact that the highly porous character of this fuel masked the influence of so small a variation in the size of the pieces used. In gas-producers the fuels generally used resemble coke or gas-carbon rather than wood charcoal, and it is easy to understand why the reaction

should proceed more rapidly with the smaller pieces. A larger surface of hot carbon is exposed to the action of the gases passing through the producer, and the interstices between the separate pieces of fuel are smaller, so that the gas is brought into more intimate contact with the hot carbon. It is clearly of importance both for the conversion of carbon dioxide to monoxide and for the decomposition of the steam, that the fuel should be used in as small pieces as possible. In practice the limit of size is determined by the consideration that the smaller the fuel the greater is the back pressure against the blast; and, further, there is always a certain loss of fuel due to unburnt carbon which is mixed with the ash, and if the producer be one in which some form of grate is used to support the fire and to distribute the air evenly through it, the loss of fuel with the ash is greater with the smaller fuel. When the fire is supported by a solid hearth or table the loss of fuel due to an open grate is avoided. A small fuel generally contains a good deal of the dust or powder formed in crushing it, and when such fuel is used the quantity of dust carried away by the current of gas may add to the difficulty of cleaning it sufficiently when it is to be used in engines or small burners.

Another factor which can be controlled, and which affects the results obtained, is the sectional area of the producer fire in relation to the rate at which gas is being made, or, in other words, the velocity of the blast through the fire. To illustrate the importance of this, we again quote some experimental results obtained by Boudouard. A porcelain tube, 30 mm. ($1\frac{3}{16}$ ins.) in diameter and 270 mm. ($10\frac{1}{2}$ ins.) long, was packed with pieces of coke about 5 mm. ($\frac{1}{5}$ in.) in diameter, and the tube and its contents were placed in a furnace the temperature of which was kept at 800° C. (1472° F.). A current of air was passed through the heated column of coke at different rates, and in each case the proportions of carbon monoxide and dioxide in the gas issuing from the tube were determined by analysis. The following are the results obtained :—

TABLE VI.—EFFECT OF VELOCITY OF AIR-CURRENTS THROUGH HEATED CARBON.

No. of experiment.	Velocity of air. Liters per minute.	Percentage by volume in issuing gas.		Proportion of carbon converted to—	
		CO ₂	CO	CO ₂	CO
1	0·10	18·20	5·20	77·8	22·2
2	0·27	18·43	3·80	82·9	17·1
3	1·30	18·92	1·88	91·0	9·0
4	1·465	19·90	1·83	91·6	8·4
5	3·20	19·40	0·93	95·4	4·6

It will be seen that the more rapid the current of air the greater the proportion of carbon dioxide, and the less that of carbon monoxide, formed by the interaction of air with carbon. In a gas-producer, other conditions remaining unaltered, the completion of the reactions will be favoured by a slow draught, since the time during which the gases and the hot carbon are in contact is thereby increased.

It may be added that all that has been said as to the influence of the various conditions mentioned in the reactions between air and carbon may also be taken to apply generally to the reactions in which steam takes part.

The four conditions which have been mentioned—depth of fuel, porosity of the fuel, the size of the pieces used, and the velocity of the blast—are all interdependent; for example, the depth of fuel required to give the best results will depend on the nature of the fuel, its size, and the velocity of the air-blast. In any given practical case the depth of fuel and the velocity of air-blast must be arranged to suit the character of the fuel which is to be employed. From the general considerations we have already discussed it is obviously desirable that the velocity of the blast should not be excessive. In other words, the producer should have a sectional area large enough for a given rate of gas production; the depth of fuel to be used will then be determined from a consideration of the nature of the fuel and the velocity of the blast. The sectional area of the producer and the velocity of the blast must also be determined with due regard to the effect on the working temperature in the producer fire. For reasons which will be explained presently it is necessary to maintain the

fuel at a relatively high temperature, therefore the velocity of the blast through the fire cannot be reduced below a certain limit in any given case. On the other hand, if the velocity of the blast be too high in order to keep up the temperature practical difficulties may arise from the formation of hard clinkers adhering to the firebrick lining of the producer. The designer of a gas-producer has therefore to provide for as high a velocity of blast as can safely be allowed without incurring these disadvantages. The depth of fuel must be sufficient to ensure the completion of the reactions with the given velocity of the blast, also to cover variation in the depth of incandescent fuel whilst working. In many producers, as the fuel is gradually consumed the depth of fire decreases until fresh fuel is added and has become incandescent. Also in many producers the clinkers and ashes accumulate on the grate or hearth and are removed at intervals; in the meantime the effective depth of the fuel bed is reduced, and this must be allowed for. Practical design must in addition provide a reasonable margin for accidental variations in the depth of fuel, such as may occur through lack of attention in careless hands. Several devices have been patented which have for their object the prevention of clinkers, and a few are met with in actual practice, but all will be ineffective unless the dimensions of the producer in relation to its output, and the proportion of steam to air, are such that the temperature attained is not excessive.

We now have to consider the influence of the temperature on the reactions. This is of importance in two ways: the temperature of the reacting substances may affect the velocity with which the change takes place; and it may also affect the final result of the reaction either as to the nature of the substances formed, or as to the quantities in which the reacting substances and the products formed from them are present together when no further change takes place. Like most chemical changes, those with which we are concerned take place most quickly at high temperatures, the velocity of the change increasing very rapidly with a rise of temperature. As a rough general rule, it may be taken that the velocity doubles itself with each 10° C. (18° F.) rise in temperature.¹ We may again quote some of Boudouard's

¹ *Industrial Gases*, H. C. Greenwood, p. 17.

experimental results to illustrate this in the case of the conversion of carbon dioxide to carbon monoxide by interaction with carbon. As before, the experiments consisted in heating a known volume of carbon dioxide with carbon in a porcelain tube at a definite temperature, but in this case two separate sets of experiments were made, one at 650° C. (1202° F.), the other at 800° C. (1472° F.). In each set of experiments tubes were heated for different lengths of time and the proportions of carbon dioxide and carbon monoxide were then determined, so that the progress of the change could be observed. Using carbon in the form of wood charcoal, the following results were obtained:—

TABLE VII.—INFLUENCE OF TEMPERATURE ON THE CONVERSION OF CO₂ TO CO (*Boudouard*).

Time.	At 650° C. (1202° F.).		Time.	At 800° C. (1472° F.).	
	CO ₂ per cent.	CO per cent.		CO ₂ per cent.	CO per cent.
0 minutes	100·0	—	0 minutes	100·0	—
8 "	81·8	18·2	8 "	17·1	82·9
64 "	71·7	28·3	1 hour	6·1	93·9
6 hours	65·2	34·8	6 hours	6·7	93·3
8 "	63·1	36·9			
9 "	62·4	37·6			
12 "	61·5	38·5			

These results are represented diagrammatically in Fig. 5, in which the horizontal scale gives the number of hours during which the tube has been heated, while the percentage of carbon dioxide remaining unchanged at the end of any time is shown by the vertical height of the curve above the time axis. Curves are drawn in this way to represent the result of each set of experiments, and they show very clearly how much more rapidly the conversion of carbon dioxide to carbon monoxide takes place at the higher temperature.

The rate of conversion of carbon dioxide and carbon monoxide, under conditions more nearly resembling those which prevail in a gas-producer, has been determined accurately at high temperatures by Messrs. T. F. E. Rhead and R. V. Wheeler.¹

¹ *Transactions of the Chemical Society*, vol. 101, p. 831.

In their experiments carbon dioxide, or a mixture of carbon dioxide and nitrogen, was circulated continuously in a closed system through a porcelain tube containing pure wood charcoal heated to a definite temperature in an electric resistance furnace. The extent of change in the gas was determined by measuring the increase of pressure due to the formation of two volumes of

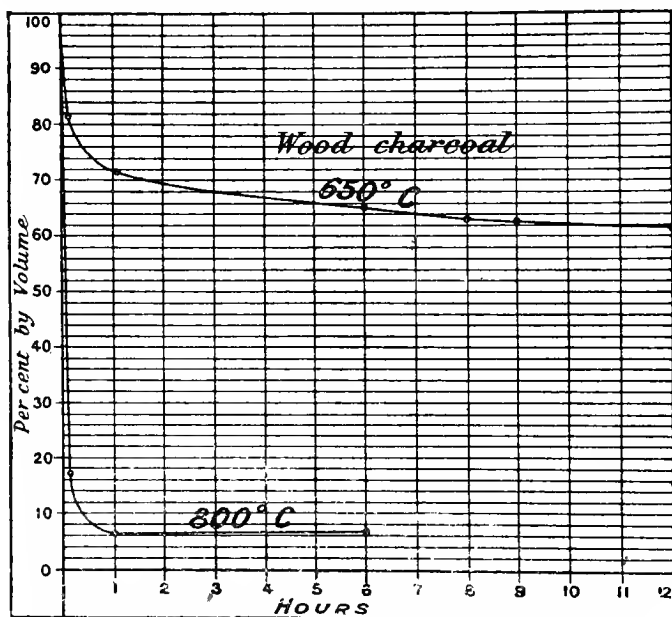


FIG. 5.—Influence of temperature on the conversion of CO_2 to CO .

carbon monoxide from each unit volume of carbon dioxide undergoing change. In one series of experiments the gas used consisted of 20 per cent. carbon dioxide and 80 per cent. nitrogen (the mixture which would be formed by the complete combustion of carbon in air), and the temperature was raised by steps of 50°C . (90°F .) from 900° to 1100°C . (1652° to 2012°F .). With the same rate of circulation of the gas through the incandescent charcoal, the proportion of carbon dioxide converted to carbon monoxide in 10 minutes at the different temperatures was:—

TABLE VIII.—INFLUENCE OF TEMPERATURE ON THE CONVERSION OF CO_2 TO CO (*Rhead and Wheeler*).

Temperature.		Carbon dioxide converted, per cent. by volume.
Degrees Cent.	Degrees Fahr.	
900	1652	1.4
950	1742	8.3
1000	1832	33.3
1050	1922	73.4
1100	2012	91.3

In a gas-producer, as has already been pointed out, the gases are in contact with the fuel for only a very brief period of time, and it is important that the velocity of the reactions should be great in order that the changes may be as complete as possible. Messrs. Rhead and Wheeler conclude from their figures that for the short time of contact that can be allowed in a producer, the temperature in the fuel-bed (*i.e.* in the lower part of it) must be over 1100°C . (2012°F .) to ensure fairly complete reduction of the carbon dioxide.

Before leaving the question of the effect of temperature on the velocity of the reactions, it may be well to point out that this effect will be of the same nature whatever be the size or physical condition of the fuel used. Thus the experiments quoted refer to the interaction of carbon dioxide with wood charcoal—a form of carbon which is very reactive owing to its great porosity. It is equally true that a high temperature is necessary in order that the change may take place with sufficient rapidity when we are dealing with such fuels as are used in practice. Indeed, with these comparatively non-porous fuels, such as anthracite, coke, or bituminous coal, a higher temperature would be required to give as good results as could be obtained with wood charcoal. In Fig. 6 we show in diagram form some results obtained by Boudouard with coke at 800°C . (1472°F .) These experiments were made in exactly the same way as the experiments with wood charcoal, represented in Fig. 5; and for the purpose of comparison, we have reproduced in Fig. 6 the curve for wood charcoal at 800°C . in Fig. 5. It will be seen that at the same temperature the change is much slower with coke, and that after

only a few minutes' heating the change may be nearly complete with wood charcoal, while it is only beginning to show itself with coke. A comparison of the curves shown in Fig. 5 for wood charcoal at 650° C. (1202° F.) and at 800° C. (1472° F.) will suggest that with coke at a still higher temperature than 800° C. the initial part of the curve would be much steeper, so that the change would be well advanced during the first few minutes.

We may suppose, therefore, that with any given fuel the

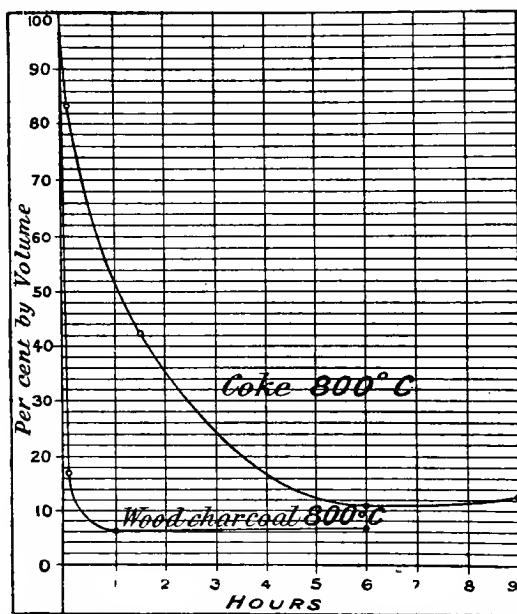


FIG. 6.—Conversion of CO_2 to CO with wood charcoal and with coke at 800° C.

conditions may be such that the change takes place with sufficient rapidity to ensure its practical completion in the producer. It does not necessarily follow, however, that the carbon dioxide will be completely converted to carbon monoxide. In this respect the reaction we are now considering resembles that referred to on p. 14 (Chapter I.), for at any given temperature there is always a certain proportion of the reacting substances left unchanged, however long they are kept in contact with one another. The experiments already quoted show that at 650° C. (1202° F.) the

final result of the interaction of carbon and carbon dioxide is the production of a gaseous mixture containing 61·5 volumes of carbon dioxide and 38·5 volumes of carbon monoxide; while at 800° C. (1472° F.) the composition of the mixed gases in contact with carbon when no further change takes place is 7 volumes of carbon dioxide with 93 volumes of carbon monoxide. Experiments made at 925° C. (1687° F.) showed that at that temperature a mixture containing only 4 volumes of carbon dioxide with 96 volumes of carbon monoxide can be obtained. What is of particular importance here is that at any given temperature, however long a time is allowed for the reaction to take place, the change of carbon dioxide to carbon monoxide will be incomplete, and the proportion of carbon dioxide left unchanged cannot be less than has just been stated for those three particular temperatures. It will also be apparent from these figures that the higher the temperature the smaller is the proportion of carbon dioxide which is left unchanged in the presence of carbon and carbon monoxide.

The reaction between carbon and carbon dioxide is what is called a "reversible reaction"; that is to say, the change may take place in either direction according to the conditions. For example, if a mixture of equal volumes of carbon dioxide and carbon monoxide were heated with carbon at 650° C. (1202° F.) in a closed tube, Boudouard's experiments show that change would take place according to the equation—



Heat would be liberated, and the mixture of gases in the tube would consist finally of 61·5 per cent. (by volume) of CO_2 , and 38·5 per cent. of carbon monoxide. Supposing, however, that the same mixture of equal volumes of carbon dioxide and monoxide had been heated with carbon at 800° C. (1472° F.), the change would have taken place in the reverse sense, according to the equation—



Heat would be absorbed, and the mixture of gases would finally have the composition—carbon dioxide 7 per cent., and carbon monoxide 93 per cent. (by volume). The change is therefore reversible, the direction of change depending on the conditions; .

it is usually considered that the change takes place in both directions simultaneously but that at different temperatures the velocities of the direct and inverse changes are different, so that at low temperatures the reaction (*a*) takes place more rapidly than the reaction (*b*); while at higher temperatures (*b*) takes place more rapidly than (*a*), the result being an apparent reversal of the direction of the reaction as the temperature is increased. It is easy to see from this why at any given temperature there is a definite limit to the proportion of carbon dioxide which can be converted to carbon monoxide. Taking, for example, the temperature of 800° C. (1472° F.), if we commence with a tube containing carbon dioxide and carbon these substances will interact and form carbon monoxide. As soon as this is formed the reverse change will commence, and the quantity of carbon monoxide changed back to the dioxide per second will be greater as the amount of carbon monoxide present increases. Similarly, the quantity of carbon dioxide changed to carbon monoxide per second will be less as the amount of carbon dioxide present decreases; so that eventually a state will be reached in which carbon dioxide is being converted to carbon monoxide at the same rate as that at which the reverse change is taking place. There is then no further alteration in the composition of the gas, although the two changes are still going on.

The substances concerned—carbon, carbon monoxide, and carbon dioxide—are then said to be in equilibrium. At the temperature of 800° C. (1472° F.) the reaction—



takes place much more rapidly than the reverse change; in other words, the proportion of the molecules of CO_2 which are changed per second to CO is greater than the proportion of molecules of CO which are changed per second to CO_2 . The condition of equilibrium is established when equal numbers of molecules are undergoing change in the two ways, and the number of CO_2 molecules present will then be less than the number of CO molecules, the relative amounts of the two gases depending upon the relative velocities of the direct and inverse reactions at this temperature. Since at any temperature the reactions proceed with a definite velocity depending on the temperature, it follows

that at any temperature there are definite proportions in which the two gases can exist together in the presence of carbon without undergoing further change. The quantity of solid carbon which is present does not affect the final composition of the gaseous mixture; theoretically it is only necessary that there should be sufficient carbon for the conversion of carbon dioxide to monoxide, although in practice it is necessary to have a large excess of fuel in order that a considerable surface may be exposed to the action of the hot gases, so that the changes may be completed within a reasonable time.

Other external conditions besides temperature may affect the proportions in which the substances involved in a reversible chemical change can remain in equilibrium with one another; but so far as the reactions which take place in a gas-producer are concerned the only other factor of which it is necessary to speak is the pressure.

The nature of the effect of a change in the external conditions (*i.e.* temperature or pressure) on the final result of a reversible reaction can be deduced from the following general law: "When any system is in chemical equilibrium, a change in one of the factors which determine the equilibrium produces a change in the system, the effect of which is opposite to that of the former change." (Le Chatelier.) Thus, in the case before us the conversion of carbon dioxide to carbon monoxide is accompanied by an absorption of heat. If, then, we have these substances in equilibrium with one another in the presence of carbon at 800°C . (1472°F .), and the temperature be increased, the change which takes place will be one which tends to lower the temperature, *i.e.* more carbon dioxide will be converted to carbon monoxide, this change absorbing heat and so opposing the alteration in temperature. Therefore, the higher the temperature the greater is the proportion of carbon monoxide which can be formed by the action of carbon dioxide upon an excess of carbon.

The effect of a change in pressure can be similarly deduced. Supposing the substances are in equilibrium at a certain temperature and at atmospheric pressure, and that the pressure is increased, then a change in the composition of the gases will take place tending to reduce the pressure. But the conversion of carbon dioxide to carbon monoxide leads to an increase of

volume, each volume of carbon dioxide yielding two volumes of the monoxide. Consequently an increase of pressure will disturb the equilibrium, and lead to the formation of a mixture of gases containing more carbon dioxide and less carbon monoxide. The amount of this effect is small.

From the results of the experiments carried out by Boudouard at different temperatures it is possible to calculate the proportions of carbon dioxide and carbon monoxide which can be obtained at any temperature as the final result of the interaction of carbon dioxide and carbon. If the mixture of carbon dioxide and carbon monoxide is always at atmospheric pressure the following are the results calculated from the formula given by Boudouard¹:—

TABLE IX.—PROPORTIONS OF CO₂ AND CO IN EQUILIBRIUM WITH CARBON AT DIFFERENT TEMPERATURES, AND AT ATMOSPHERIC PRESSURE (*Boudouard*).

Temperature.		Per cent. by volume.	
Degrees Cent.	Degrees Fahr.	Carbon dioxide.	Carbon monoxide.
446	835	98	2
495	923	95	5
538	1000	90	10
588	1090	80	20
623	1153	70	30
651	1204	60	40
678	1252	50	50
703	1297	40	60
731	1348	30	70
747	1377	25	75
764	1405	20	80
786	1447	15	85
814	1495	10	90
834	1531	7.5	92.5
861	1582	5	95
877	1611	4	96
897	1647	3	97
925	1697	2	98
977	1791	1	99
1030	1886	0.5	99.5

¹ The formula referred to is—

$$-\frac{21,000}{T} + \log P + \log \frac{c}{c_1} = \text{constant}$$

where T = temperature (absolute); P = total pressure of CO and CO₂ in atmospheres; and c and c₁ are the concentrations of CO₂ and CO respectively, *i.e.* the number of gram-molecules in 22.32 liters of the mixed gases. c and c₁ are, there-

The highest temperature used in these experiments was 925° C. (1697° F.), and the results are based on a small number of experiments. Later and more accurate experiments made by Messrs. Rhead and Wheeler¹ gave the following results:—

TABLE X.—PROPORTIONS OF CO₂ AND CO IN EQUILIBRIUM WITH CARBON AT DIFFERENT TEMPERATURES AND AT ATMOSPHERIC PRESSURE (*Rhead and Wheeler*).

Temperature.		Per cent. by volume.	
Degrees C.	Degrees Fahr.	Carbon dioxide.	Carbon monoxide.
850	1562	6.23	93.77
900	1652	2.22	97.78
950	1742	1.32	98.68
1000	1832	0.59	99.41
1050	1922	0.37	99.63
1100	2012	0.15	99.85
1200	2192	0.06	99.94

These results agree closely with the calculated values given in Table IX.

Fig. 7 represents these results diagrammatically; the scale of temperature is taken horizontally, and the vertical height of the curve above the temperature axis represents the percentage of carbon monoxide in the mixture of gases. The vertical distance from the top edge of the diagram down to the curve consequently represents the percentage of carbon dioxide which remains unchanged at any particular temperature.

This diagram shows very clearly how important is the influence of a high temperature in increasing the proportion of carbon monoxide which can be obtained from carbon dioxide and carbon; and it also shows that beyond a certain point, which is probably

fore, numerically equal to the percentages by volume divided by 100, and in the case considered $P = 1$, so that $\log P = 0$.

The value of the constant is deduced from three experiments, viz. at 650° C., 800° C., and 925° C.; the three values obtained are -21.4, -22.2, and -20.6, and the mean value -21.4 is used in the calculations. These results will serve to illustrate the nature of the effect of temperature on the equilibrium, but there were no actual determinations of the equilibrium at the higher temperatures, and the reader is referred for actual figures to the more accurate experiments of Messrs. Rhead and Wheeler quoted above.

¹ *Transactions of the Chemical Society*, 1910, vol. 97, p. 2178; 1911, vol. 99, p. 1140.

about 1000°C ., there is practically no further gain to be derived from increased temperature, so far as the equilibrium is concerned; for at this temperature the reaction does not cease until practically the whole of the carbon dioxide has been converted to carbon monoxide.

In actual practice the gases are largely diluted with nitrogen, so that it is of greater practical interest to consider the final

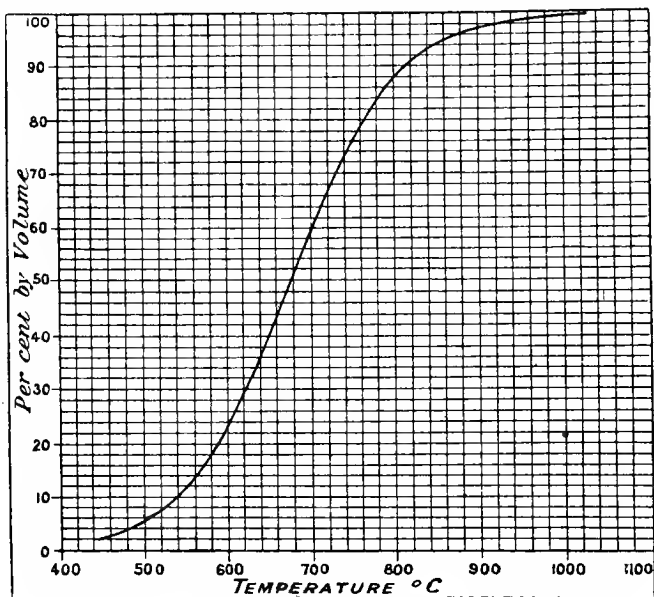


FIG. 7.—Proportions of CO_2 and CO in equilibrium with carbon at different temperatures.

result of the reaction between *air* and carbon at various temperatures.

If the oxygen of the air be first of all completely burnt to carbon dioxide we then have carbon in presence of a gaseous mixture consisting of approximately one volume of carbon dioxide and four volumes of nitrogen, the mixture being at atmospheric pressure. The pressure of the carbon dioxide is therefore only one-fifth of an atmosphere. If the temperature be high, so that the conversion to carbon monoxide is nearly complete, then one volume of carbon dioxide becomes two volumes of carbon

monoxide, which is mixed with four volumes of nitrogen. The mixture being at atmospheric pressure, the pressure of the carbon monoxide is one-third of the whole, *i.e.* one-third of an atmosphere. This change in the pressure of the reacting gases as the proportion of dioxide and monoxide alters must be taken into account in calculating the proportions which will represent the final equilibrium at any temperature, and we have calculated in this way (from Boudouard's equation) what would be the final composition of the gases formed from air and carbon at different temperatures when the products of the reaction remain at atmospheric pressure.¹

These results are given in the following table:—

TABLE XI.—COMPOSITION OF GAS FORMED BY THE ACTION OF AIR ON CARBON AT VARIOUS TEMPERATURES.

Temperatures.		Per cent. by volume.		
Degrees Cent.	Degrees Fahr.	Carbon dioxide.	Carbon monoxide.	Nitrogen.
457	855	19.7	0.5	79.8
494	921	19.4	1.0	79.6
535	995	18.8	2.0	79.2
596	1105	17.1	4.9	78.0
651	1204	14.8	9.5	76.2
689	1272	11.6	13.9	74.5
722	1332	9.1	18.2	72.7
753	1387	6.7	22.2	71.1
790	1454	4.3	26.1	69.6
843	1549	2.1	29.8	68.1
907	1665	0.8	31.9	67.3
958	1756	0.4	32.6	67.0
1012	1854	0.2	33.0	66.8

Fig. 8 is drawn in the same way as the preceding diagram to represent these results. The height of the lower curve from the horizontal axis gives the percentage of carbon monoxide in the products formed from air and carbon at any temperature; the vertical distance from the lower to the upper curve gives the percentage of carbon dioxide, and the remainder of the gas is nitrogen. Thus at 800° C. (1472° F.), the proportions are: CO 27 per cent., CO₂ 3.8 per cent., and N₂ 69.2 per cent.

A consideration of these two diagrams (Figs. 7 and 8) will

¹ See footnote to p. 52.

make it clear that a high temperature is necessary, not only that the formation of carbon monoxide may take place quickly enough, but also in order that it may be possible at all to change the greater part of the carbon dioxide into the monoxide. For reasons already explained we do not rely on Boudouard's results to show what temperature should actually be employed, but, judging from our general experience, we agree with the conclusion of Messrs. Rhead and Wheeler, quoted on page 47, that the temperature should be over 1100° C. (2012° F.). It seems that at this temperature the proportion of carbon dioxide which necessarily remains unchanged is quite small, and the velocity of the change is sufficient to enable it to proceed nearly to its limit in the short

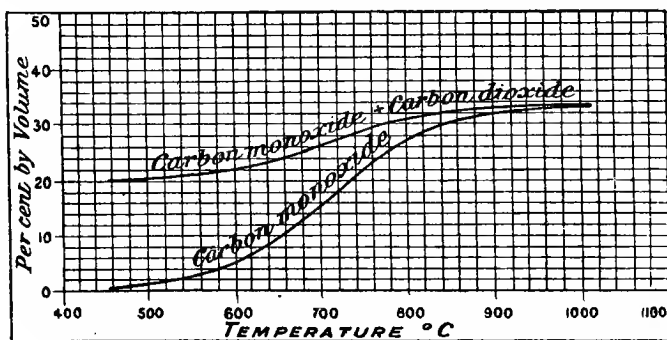


FIG. 8.—Composition of gas formed by the action of air on carbon at various temperatures.

time occupied by the passage of the gases through the fuel in the producer.

The foregoing considerations, depending on the fact that the reaction between carbon and carbon dioxide is a reversible one, make it clear that in practice there must always be some proportion of carbon dioxide in producer gas. Not only is it impossible to reduce the proportion of carbon dioxide below a definite percentage depending on the temperature, but it is also possible for the carbon monoxide to be partially changed back to carbon dioxide and carbon after the gases have left the bed of fuel, in consequence of the reaction—



According to Boudouard, this decomposition must be held to

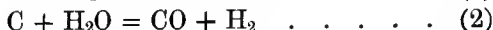
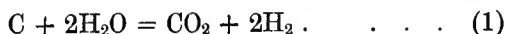
explain, to some extent at least, the deposits of soot in the connecting pipes and coolers of a gas-producer plant.

There is, of course, no difficulty in attaining a very high temperature in a generator for the production of air-gas; it is, in fact, customary to add a small proportion of steam to the blast in order to keep down its temperature, in view of the practical difficulties which have to be considered. We are, however, able to refer to an instance in which this expedient was carefully avoided, since it was essential that the gas should contain as little hydrogen as possible. The composition of the gas is given in column 2 of Table I. (p. 21), and it is interesting to note that although the temperature must have been considerably over 1000°C . (1832°F .), so that theoretically the gas formed in the producer could have contained very little carbon dioxide, as it probably did actually contain only a fraction of one per cent., yet the cooled and scrubbed gas contained as much as 1.4 per cent. carbon dioxide, which may have been formed by the reaction—



occurring during the cooling of the producer gas.

We now come to the consideration of the reactions in which steam takes part. These are three in number, viz.—



The last of these is a reversible reaction (see p. 14, Chapter I) and should accordingly be written—



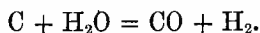
The course of the reaction between the steam and carbon depends chiefly upon the temperature. It is found that at low temperatures, *e.g.* 600°C . (1112°F .), the products are principally carbon dioxide and hydrogen, *i.e.* the reaction is—



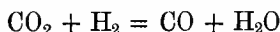
although there is, of course, more than sufficient carbon present for the decomposition of the whole of the steam according to the equation (2).

At higher temperatures less carbon dioxide is formed and

more carbon monoxide; and at 1000° C. (1832° F.) the reaction is very nearly that represented by the equation—



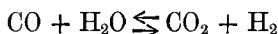
It will be noticed that the reaction (2) may be regarded as the result of the reactions (1) and (3) occurring together. Thus, if the first product of the action of steam and carbon is a mixture of one volume of carbon dioxide with two volumes of hydrogen, then the carbon dioxide and hydrogen may, under suitable conditions, interact to form carbon monoxide and steam—



and if all the carbon dioxide were converted in this way to carbon monoxide half of the hydrogen would be converted back to steam, and the final result would be the production of one volume of carbon monoxide mixed with one volume of hydrogen, as represented in equation (2).

It is not necessary for our present purpose to know whether this double change actually occurs when carbon monoxide and hydrogen are formed from carbon and steam. Whether this be so, or whether the action takes place directly in accordance with the equation (2), the final products will not be carbon monoxide and hydrogen unless the conditions are such as will prevent the formation of carbon dioxide from the interaction of carbon monoxide with steam.

It is therefore important to consider the reversible reaction—



from this point of view. The effect of the conditions of temperature and pressure on this reaction may be deduced by exactly the same method as was adopted in considering the reaction $\text{CO}_2 + \text{C} \rightleftharpoons 2\text{CO}$ (see p. 51). In this case the change of carbon dioxide and hydrogen to carbon monoxide and steam is attended with absorption of heat; therefore a rise of temperature will increase the proportion of carbon monoxide and steam, and decrease the proportions of carbon dioxide and hydrogen in the mixture of gases which are in equilibrium.¹ We may therefore

¹ It may be noted, in passing, that this reaction does not involve any change of volume, and therefore change of pressure has no effect at all on the composition of the mixture of gases in equilibrium with one another at any temperature.

say that at high temperatures carbon dioxide and hydrogen will react to form carbon monoxide and steam, while at lower temperatures the reverse will occur. This is a point of great importance in the production of water-gas. This gas is largely manufactured in Gas Works and, after being carburetted, it is mixed with the retort gas, and the mixture is distributed for illuminating purposes. The presence of carbon dioxide would be very objectionable, as the illuminating power of the gas would be seriously reduced by it, and it is generally held that the water-gas as it leaves the producers should not contain more than 4 per cent. of carbon dioxide.

In practice it is found that during the steam-blow of a water-gas producer, if the temperature is 1200° C. (2192° F.) or over, there is practically no carbon dioxide produced; at 1100° C. (2012° F.) carbon dioxide is formed in appreciable quantities; and at 900° C. (1652° F.) the amount of carbon dioxide is more than can be considered satisfactory. Also at the lower temperatures part of the steam remains unchanged.

The actual composition of the gas formed by the action of steam on carbon at different temperatures, and the proportion of the steam which is decomposed, have been determined by Bunte¹ and Harris as follows:—

TABLE XII.—ACTION OF STEAM ON CARBON AT VARIOUS TEMPERATURES.

Temperature.		Percentage of steam decomposed.	Composition by volume of dry gas produced.		
Degrees Cent.	Degrees Fahr.		Hydrogen.	Carbon monoxide.	Carbon dioxide.
674	1245	8.8	65.2	4.9	29.8
758	1396	25.3	65.2	7.8	27.0
898	1540	41.0	61.9	15.1	22.9
954	1749	70.2	53.3	39.3	6.8
1010	1850	94.0	48.8	49.7	1.5
1060	1940	93.0	50.7	48.0	1.3
1135	2057	99.4	50.9	48.5	0.6

These figures represent the composition of the gas after removal of the undecomposed steam.

In a producer for semi-water-gas similar considerations will

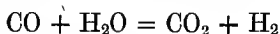
¹ *Journal für Gasbeleuchtung*, 1894, vol. 37, p. 81.

hold true, but here it is permissible to have considerably more than 4 per cent. of carbon dioxide. When it is desired to obtain a gas of high calorific power it is best that the interaction of steam and carbon should give hydrogen and carbon monoxide, not carbon dioxide; and not only is the percentage of carbon dioxide in the gas reduced by this means, but less steam is used, which in practice means economy in working.

To ensure this condition the temperature should be high, say 1100°C. (2012°F.); this high temperature will also allow any carbon dioxide—formed either from air or pure steam—to react according to the equation—



up to the limit corresponding to the temperature, and it will prevent the reaction—



taking place to a serious extent.

In considering the effect of temperature on the reactions we have spoken of temperatures of 1100°C. (2012°F.) and over, and it may be well, therefore, to refer briefly to the question of dissociation, to show that we are justified in the tacit assumption that its effects may be neglected.

It is universally recognised that at high temperatures both carbon dioxide and steam are partially decomposed into simpler substances, but authorities differ as to the temperature at which this effect first becomes appreciable. Mallard and Le Chatelier state that the dissociation of carbon dioxide does not occur below 1800°C. (3272°F.), and only amounts to 5 per cent. of the whole at 2000°C. (3632°F.); while steam is not decomposed by heat below 2500°C. (4532°F.), and the amount of steam decomposed is very slight at 3300°C. (5972°F.). On the other hand, some writers on gas-engines, relying on the early experiments on dissociation by Deville, consider that dissociation takes place between 1000°C. (1832°F.) and 1200°C. (2192°F.). The question is an important one for the theory of the gas-engine, for temperatures as high as 1850°C. (3362°F.) are not uncommon as the result of the explosion in the gas-engine cylinder; but even supposing that dissociation occurs at the lower temperatures mentioned (1000°C. to 1200°C.), it can have very little

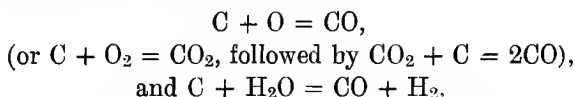
effect upon the actions in a gas-producer, for the dissociation would be only just commencing at the highest temperatures we have considered and its extent would be very slight.

In Chapter I. we have considered the reactions from the point of view of heat efficiency, and it may be well to indicate the bearing upon this of the considerations discussed in the present chapter. It will be remembered that in order to secure the highest possible heat efficiency it is necessary to recover as much as possible of the sensible heat of the gas, and of the heat which would otherwise be lost by radiation from the producer itself, and to utilise the heat so recovered by means of the endothermic reactions in the producer. Now, whether the working temperature of the producer be high or low the waste heat can be at least partially recovered by using it to raise steam for the producer and to heat the air with which the latter is supplied; but the steam obtained cannot be completely decomposed in the producer at a low temperature (see p. 59); and, further, if the temperature be low, the endothermic reaction between carbon dioxide and carbon can only occur to a limited extent (see p. 56). The formation of carbon dioxide instead of carbon monoxide does not of itself imply inefficient working, for the extra heat liberated owing to the complete combustion of carbon instead of its partial combustion to carbon monoxide could theoretically be utilised in the decomposition of steam. At a low temperature, however, we have seen that the bulk of the steam will pass unchanged through the producer, and the waste heat used in raising this steam is therefore not really "recovered," so that the producer cannot have a very high efficiency. In the Mond plant a low working temperature is employed for the sake of obtaining ammonia from the nitrogen in the fuel, and it is well known that only one-fifth of the steam used is decomposed. In spite of this, however, the efficiency of the plant is stated to be as high as 80 per cent.; but in order to secure this it is necessary to use a large excess of steam, so that the small proportion of it which is decomposed is sufficient to absorb the heat evolved in the formation of carbon dioxide and carbon monoxide from air and carbon. A large and expensive plant is therefore necessary to condense the undecomposed steam which accompanies the gas, and to use, as far as is practically

possible, the heat which it represents, by heating the air and evaporating the water for use in the producer.

For an ordinary small producer plant such expedients are out of the question, and even if they were adopted the heat efficiency could hardly exceed 80 per cent., whereas by working at a higher temperature a simple apparatus of the type described in Chapter VII. (Fig. 46) may have an efficiency as high as 90 per cent.

In some cases it is necessary for the successful application of producer gas that the gas should be of high calorific power, and this consideration may then be more important than that of heat efficiency and economy of fuel. It will have been gathered from Chapter I. that semi-water-gas will have its highest calorific power if the reactions take place strictly in accordance with the equations—



the quantity of steam decomposed being just sufficient to utilise all the heat liberated by the conversion of carbon to carbon monoxide. In order to approximate to this ideal process it would be necessary that nearly all the sensible heat of the gas and the radiated heat of the producer should be recovered and returned to the producer, and also that the conditions should be such as would enable the reactions to take place in the manner indicated. We have shown in this chapter what these conditions are; for all purposes the conditions dealt with on p. 43 should be observed; and when a rich gas is desired it is specially necessary that the working temperature should be high.

CHAPTER IV

FURNACE WORK

IN the previous chapters we have considered the question of producer gas from a theoretical point of view, and in the present and following chapters we propose to deal more especially with its practical applications. To treat the subject in chronological order we will first take furnace and other heating work, as producer gas was first used for this purpose. We will afterwards consider the use of producer gas for driving gas-engines, as this is a more modern development.

In considering the use of producer gas for heating work the subject naturally divides itself broadly into two kinds or classes of work, and each should be treated separately. In the first place, there is the heating of furnaces, steam-boilers, drying floors, large evaporating pans, and other apparatus for which it is necessary or desirable to have large flames and to burn the gas in considerable quantities. In such cases it is simplest and best to take hot crude gas direct from the producer to the furnace, without passing it through scrubbers or a gasholder. For such operations it would in fact be a disadvantage to cool and clean the gas, as the condensable hydrocarbon vapours which always accompany gas made from bituminous coal in ordinary producers would then be removed. This would not only be wasteful, but the flame temperature in the combustion chamber would be reduced. It is also desirable to take the gas hot from the producer in order that its sensible heat may be used and greater economy effected.

On the other hand, if the gas is to be used in burners or in small jets, and especially if the size of the flames is to be controlled by small cocks so that the heat given off may be constant or varied at will, it is essential that the gas should be clean, in order that it may not cause tarry or other troublesome

deposits; it is also important that the pressure of the gas at the burners should be steady. This branch of the subject will be dealt with fully in Chapter V.

We have thought it best to emphasise the different conditions under which gas is used for the two kinds or classes of work referred to, and with these broad distinctions in view we will now consider the production of gas for furnaces and similar work. We will also say so much about the application of the gas to its particular work as may be necessary to give a connected idea of the combination of producer and furnace. It would be beyond the scope of this book to describe the many varieties of furnace used for different purposes, and for the same reason we do not attempt to describe the various types of gas-engines. We desire rather to confine ourselves to the theories and principles involved, and to give examples of their practical application, in order to make them understood and appreciated.

In ordinary fires the intention is to burn the solid fuel completely *in situ*, and if any combustible gas passes away unburnt it indicates a defect in the system. On the other hand, the function of a gas-producer is to convert the solid fuel into a combustible gas, which can be used near the producer or conveyed far or near to wherever it may be most convenient or desirable to burn it. It is largely a question of convenience, and it must not be supposed that it is in any way possible to add to the heat energy of the fuel from which the gas is derived. We know, from what has been said in Chapter I., that the constituents of the coal or other fuel used can only yield a certain definite amount of heat, which we express in heat units. We cannot add to this amount; we can only endeavour to use the heat to the best advantage. In some cases it is more convenient and more economical to burn the solid fuel in a furnace, and to let the heat obtained pass direct to whatever has to be heated. In other cases it is more convenient and more economical to convert the fuel into producer gas, and afterwards to burn this gas for the purpose of developing heat where it may be required. Necessarily, less heat will be liberated by the combustion of the producer gas than can be obtained by the complete combustion of the solid fuel in a furnace, since, for reasons already explained (Chapter I.), it is not possible in practice to carry out the process of gas-

production with its theoretical efficiency of 100 per cent. In ordinary producers, such as are used for furnace work, the heat efficiency seldom exceeds 80 per cent., and is usually less. How, then, we may ask, can it be economical to convert the fuel into gas, if 20 per cent. of its heat energy is lost in the process of making the gas? The answer is not a simple one and involves several explanations, but in the end it will be seen to be satisfactory.

In the first place we know, as a matter of common experience, that when we put coal on a fire there is at once a certain amount of smoke given off, which escapes unburnt and is therefore lost so far as its heating properties are concerned. This smoke consists chiefly of hydrocarbon vapours which are disengaged as soon as the coal is heated; they leave the upper part of the fire at a lower temperature than is necessary for them to burn. The amount of smoke varies with the nature of the coal or other fuel used; it also depends on the condition of the fire when the raw coal is added, on the chimney draught, and on other minor considerations. A further considerable loss is due to the heated currents of gas, air, smoke, etc., which are carried up the chimney, commonly known as the convection currents. Theoretically a kilo of average coal requires about 9 c.m., or one pound of coal requires about 150 c. ft. of air for its combustion, but in practice double or treble this quantity of air is often required. The reason is not far to seek: if the fire is not shallow, and if the air-draught is not sufficiently rapid, carbon monoxide will be formed, and there will not be complete combustion of the fuel in the furnace. On the other hand, if there is a shallow fire, and a sufficiently strong draught to ensure complete combustion, there must be a large excess of air drawn in; and as all the nitrogen of the air as well as the oxygen which does not combine with the fuel is heated at the expense of the fuel, it follows that the heat they carry away, as well as that of the products of combustion, is lost. Obviously these heat losses can be reduced if the hot gases and products of combustion can be made to give up some of their heat to the apparatus to be heated, as in the case of a steam-boiler where the heated currents are made to pass through tubes and flues which impart heat to the water in the boiler. But with many furnaces there must not only be a strong draught of air to burn the solid fuel quickly—to get the

heat required—but the products of combustion and the accompanying air-currents, when they leave the furnace, pass away up the chimney at a high temperature, and the loss of heat entailed owing to the large excess of air is great. Good steam-boilers have a heat efficiency of 70 to 80 per cent., but in some high temperature furnaces fired with solid fuel it is estimated that only 5 to 10 per cent. of the heat value of the fuel is actually used.¹

There are other losses of heat than those above referred to, principally that of radiation, but for the moment we will suppose that for heating a given furnace or other apparatus the loss from radiation, etc., may be the same with gas as with a solid fire. Let us then consider whether the principal losses we have mentioned would be the same if gas were substituted for solid fuel. In the first place, with gas there need not be any smoke and with reasonable care there should be no unburnt gas to escape up the chimney, it being much more easy to ensure complete combustion with gas than with solid fuel. The gas is not like a solid body, and it is comparatively easy for each molecule of oxygen to come in contact with the molecule of gas with which it is to combine. Usually producer gas requires theoretically about an equal volume of air for its combustion, and in practice little more than this is actually needed. The bearing of this is important and should be appreciated. Theoretically, the coal burnt in a furnace requires a definite amount of air for its complete combustion, and precisely the same total amount of air will be required if the coal is first partially burnt in the producer, and the gas is afterwards burnt to carbon dioxide. But in the latter case practice requires a little more air than theory suggests; whereas in the case of direct firing practice requires the theoretical quantity of air to be doubled or even trebled. If, for example, we assume that a kilo of average coal requires theoretically 9 c.m. of air for its combustion we may assume that in practice it will not be necessary to draw into the gas-producer and into the gas furnace a total of more than 10 c.m. of air per kilo of coal consumed; but for the fire of a furnace or boiler it will be necessary to draw in say 20 to 30 c.m. of air per kilo of coal burnt. In the latter case, therefore, the quantity of the flue

¹ "Encyc. Brit.," 10th edition, vol. xxviii. p. 600.

gases is much greater, and as these gases leave at a high temperature the heat which they carry away with them represents a serious loss.

In the case of a furnace in which the products of combustion leave at a temperature of 800° C. the loss of heat due to this cause will be greater for direct firing than for gas firing by the amount of heat carried away by the extra 20 c.m. of air which are used per kilo of coal, *i.e.* by about 4900 calories. In other words, when the flue gases leave at this high temperature over 60 per cent. more fuel is required for direct firing than for gas firing, merely to heat the excess of air which is unavoidable in that case. Even where the conditions are most favourable for direct firing, as in the case of a steam-boiler, this loss is not inconsiderable. If the flue gases are cooled to say 200° C., or say 185° above the atmospheric temperature, the heat carried away by 20 c.m. of air will be about 1140 calories, or about one-seventh of the total heat of combustion of the fuel.

We have yet to consider another very important saving when gas is used for furnace work; we refer to the fact that when the heated products of combustion leave the furnace proper they can with ease be made to give up the bulk of their heat to the ingoing air required for the combustion of the gas. In this way the air is heated by what would otherwise be waste heat, and this not only reduces the heat losses considerably, but as the air for combustion is highly heated before it meets the gas a much higher temperature can be developed in the furnace. This cannot be done effectually with an ordinary fire, as it would involve a much stronger draught and this increase of draught would increase the excess of air drawn in, with its attendant loss of heat.

For furnace work, if we allow for the absence of smoke, the more complete combustion of fuel in the gaseous form with a much smaller quantity of air than is necessary for solid fuel, and finally, the heating of the air for combustion by the waste heat of the furnace, we shall probably not be wrong in saying that in most cases the heat losses by direct firing may be four or five times as great as by gas firing. On the other hand, we have to allow for a loss of about 20 per cent. of the total heat of the fuel in the process of conversion in the producer; but the net result will show a considerable saving in favour of heating by gas.

Apart from these numerous advantages, there are several other practical considerations which have added greatly to the usefulness of gas for furnace work. For instance, it is a distinct gain in many metallurgical and other operations to maintain a uniform temperature in the furnace, and to be able to raise or lower it as occasion may require. This can be easily accomplished with gas by regulating the gas admission valves, but it is much more difficult and is generally imperfectly done in direct firing with solid fuel. We have also seen that the latter requires a large excess of air, and when the free oxygen of this air comes in contact with metals or other substances having an affinity for it they are more or less oxidised. If producer gas is used there need be no free oxygen, and consequently there need be no oxidation. The gas may even be used to deoxidise the surface of the metal, etc., in the furnace, by the simple expedient of reducing the supply of air to the gas. In this way there is not enough free oxygen to complete the combustion of the gas, and so much of it as is not oxidised seeks oxygen from the oxidised surface of the metal, etc., with which it may come in contact. This is what is known as a "reducing" action. By way of illustration, let us suppose that a plate or bar of iron (free from oxide) is put into a furnace sufficiently heated by an oxidising flame; the surface of the iron will be more or less converted into magnetic iron oxide (Fe_3O_4). But if the iron were coated with rust, or with a scale of iron oxide, and if it were put into a furnace heated by a reducing flame, the gas would attack the iron oxide and take to itself all or part of the oxygen contained in the latter. A further advantage of gas is that it can be conveyed in pipes or flues from one or more producers to one or any number of furnaces wherever they may be situated. For some operations it is also desirable to heat one part of a furnace more than another; in others the heat should be uniform throughout, and all this can be effected more easily and more thoroughly with gas.

The first internally fired gas-producer was introduced by Bischof,¹ of Mägdesprung in the Harz, in 1839, and a sectional view of it is given in Fig. 9. The theory of its action is similar to that of Fig. 1 (p. 4), the air being drawn in by a chimney

¹ Crookes and Röhrig, "Practical Treatise on Metallurgy," vol. iii. p. 495.

draught through the openings **AA**, and through the firebars **B**, the fuel being introduced at **C**, and the gas escaping at the outlet **D**. Since then there have been numerous modifications and new departures in this country and in others, but many of them have a mere historical interest, and we propose to select only such as may help our readers to appreciate the developments and improvements which have occurred. Those who wish to trace the growth of the subject historically cannot do better than consult the paper of Mr. F. J. Rowan on "Gas Producers," in

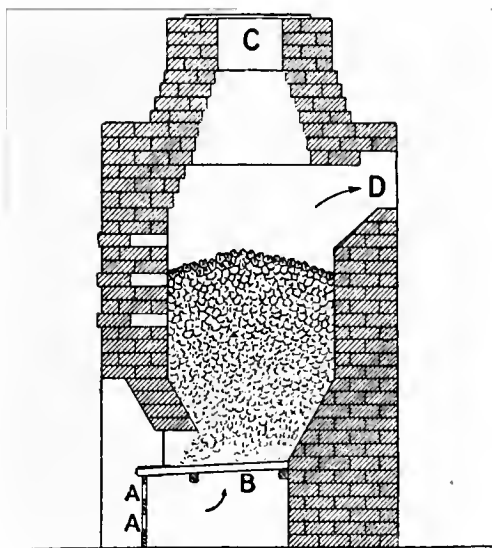


FIG. 9.—Bischof gas-producer.

vol. lxxxiv. of the *Proceedings Inst. C.E.* (1885), and the useful book of M. Jules Deschamps on "Les Gazogènes" (1902). Bischof invented his producer at a time when a good deal of attention was being given to the use of waste gases from coal-fired furnaces; and at that time the latter were more in favour among metallurgists because gas firing involved the use of a separate apparatus to produce the gas. Experiments with varying success were carried out, chiefly in Austria and France, but it was not until after F. Siemens (1857) had invented his combined gas-producer and regenerative furnace that the subject really made headway. The invention was introduced in this

country by his brother, the late Sir William Siemens, and in 1861 he patented the arrangement shown in Fig. 10. This he described as follows: ¹ "The regenerative gas furnace consists of two essential parts. The gas-producer in which the coal or other fuel used is converted into a combustible gas, and the furnace, with its 'regenerators,' or chambers for storing the

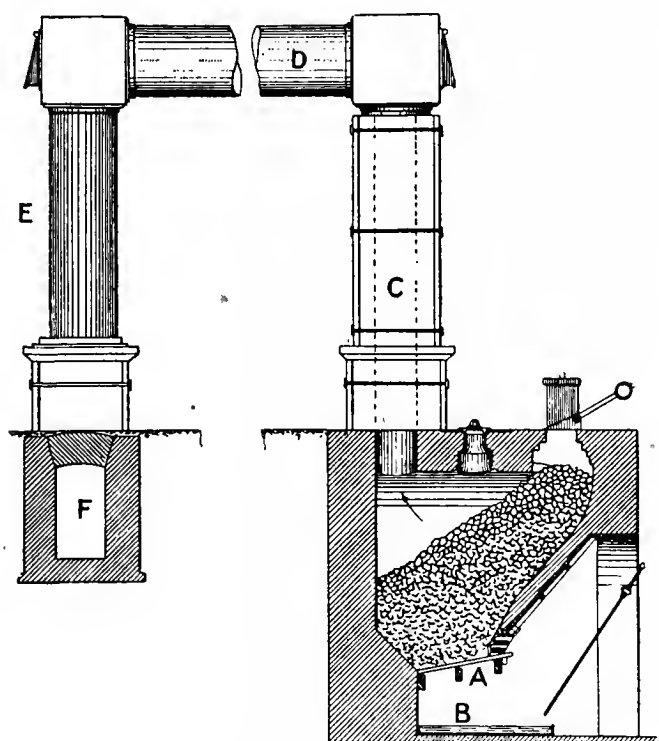


FIG. 10.—Siemens gas-producer.

waste heat of the flame, and giving it up to the incoming air and gas." The air was drawn into the producer between the firebars **A**, while a certain amount of water in the trough **B** was vapourised by the heat of the fire above, and this water-vapour mixed with the air and was drawn with it into the fire. The theory of the action of this producer is similar to that of Fig. 2 (p. 8), and

¹ Crookes and Röhrig, vol. iii, p. 532. See also Percy's "Metallurgy (Fuel)," p. 524.

the following is given as the composition of the gas at the Glass Works of St. Gobain, France, the fuel used being a mixture of caking and non-caking coals :—

Carbonic oxide	23·7 per cent. by volume.
Hydrogen	8·0 " "
Methane	2·2 " "
Carbonic acid	4·1 " "
Oxygen	0·4 " "
Nitrogen	61·5 " "
<hr/>	
Total	99·9
<hr/>	

A novel and ingenious method was adopted for obtaining the necessary in-draught of air and for causing the gas produced to flow to the furnace. From the producer there was a vertical uptake **C**, usually built of brickwork, and from the top of this there was a long horizontal iron tube **D**, of large diameter, in the direction of the furnace; at the furnace end of the tube there was another vertical tube **E**, leading to the gas flue **F** of the furnace. The hot gas rose from the producer, and as it passed through the above-mentioned tubes its temperature fell considerably; consequently its density was greater at the furnace end, and this caused a suction and an in-draught of air at the producer end. In some cases the vertical cooling tube near the furnace was made longer than the uptake from the producer, so as to form a syphon with long and short legs. In connection with his gas-producer Siemens used various furnaces of special construction, and a typical illustration is given in Fig. 11. It will be seen that under the bed of the furnace **A** there were four large chambers, **B**, **C**, **D**, **E**, packed loosely with firebricks. When the furnace was working, the hot products of combustion were made to pass downwards through two of these chambers, say **D** and **E**, while the air and gas passed upwards through **B** and **C**; after a certain lapse of time, usually from 20 to 30 minutes, the direction of the currents was reversed by means of suitable valves, so that the products of combustion passed through **B** and **C**, and the gas and air through **D** and **E**. With regular reversals of the currents, it will be readily understood that the loose or chequered firebricks were highly heated by the outgoing products of combustion, while the gas and air were heated by passing over the

highly heated surfaces of the bricks. Siemens called this a "regenerative" furnace, and although it would be more accurate to say that there was a recovery or accumulation rather than a regeneration of heat, the term is now an accepted one among engineers in this country. In France it is called *récupérateur*, and that is better. Be the name what it may, we are indebted to Siemens for showing us that with his particular combination of producer and furnace he was not only able to convert solid fuel of many kinds into useful gas, but that by this means very high temperatures could be developed. In fact, by his skilful

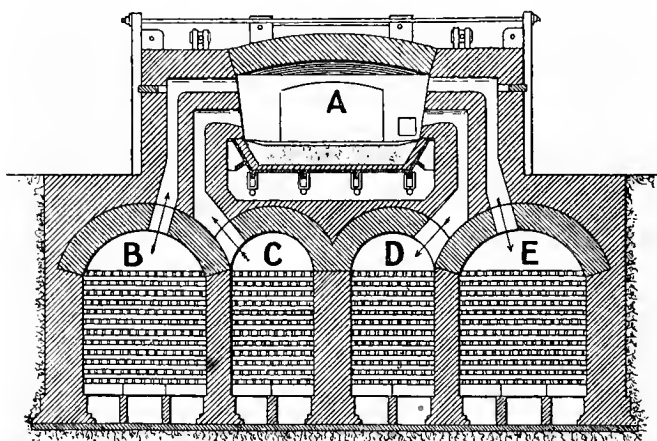


FIG. 11.—Siemens gas furnace.

combination of theory and practice he was able to effect economically many difficult operations, such, for instance, as the melting of steel and glass in open-hearth furnaces.

In gas furnaces, however, as in other subjects, the process of development could not be stayed, and we shall presently record various improvements which have been introduced in more recent times. But before saying more about furnaces proper it will be convenient to trace some of the more noteworthy developments in gas-producers. We have seen that Bischof and Siemens both made gas by drawing a current of air through an incandescent mass of fuel; but the production of gas by a chimney draught was slow and this led Siemens and others to try working their

producers with a blast of air. The rate of combustion was quickened; but the heat was also intensified, and this favoured the formation of clinker, which adhered to the brick lining of the producer and caused serious trouble. Siemens tried closing the ash-pit of his producer and forcing in air by means of a jet of steam acting as an injector; but it was not successful, as the stepped grate he used involved a comparatively shallow fire, and with this the decomposition of the steam and the reduction of the carbon dioxide were not properly effected. Various modifications of forced-draught producers with a steam jet were advocated from time to time, and for furnace work this type of producer is now used more than any other. Among others Tessié du Motay (1871) introduced the producer shown in Fig. 12, the leading feature of which was a solid hearth **A**, without grate of any kind. Air at pressure and steam were admitted through the channels **B**, **B**, of which there were several in the plan view; the fuel was introduced through the hopper **C**, and the gas outlet was at **D**.

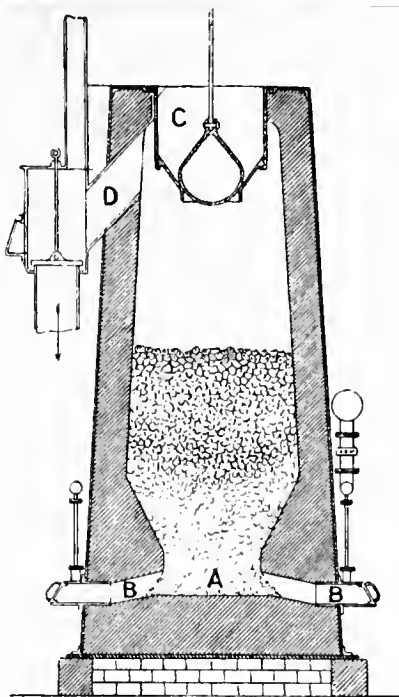


FIG. 12.—Tessié du Motay gas-producer.

This producer was extensively used in France and in the United States. In 1876 Brook and Wilson introduced the producer shown in Fig. 13; it also had a solid hearth **A**, and air was injected through the pipe **B** by a jet of steam at **C**; the fuel was introduced at **D**, and the gas passed into the circular flue or chamber **E**, and then through the outlet pipe **F**. This formed the basis of the well-known Wilson producer, which has been used successfully for furnace work in several countries, but has now been superseded by producers of more modern type. The

composition of the gas made in this producer with Durham coal was stated by Messrs. Pattinson and Stead to be as follows :—

Carbonic oxide	26·8 per cent. by volume.
Hydrogen	11·5 „ „
Marsh gas	1·4 „ „
Carbonic acid	4·0 „ „
Nitrogen	56·1 „ „

In the gas-producers now generally used for furnace work

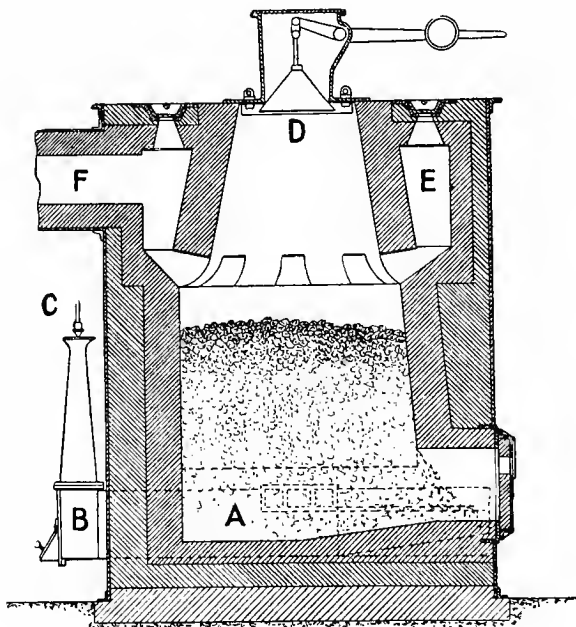


FIG. 13.—Brook and Wilson gas-producer.

numerous modifications have been made in the details of construction. Many kinds of firegrates are used ; some producers have rotating or moving grates of various kinds, and others have water-bottoms, to facilitate the removal of the ash and clinker ; some are rectangular, but most of them are cylindrical ; some have a slowly rotating grate or hearth, with scrapers for the automatic discharge of clinker and ash while working ; some have an automatic feed for the coal ; nearly all are worked with air injected by one or more jets of steam. The Morgan Construction Co. (U.S.A.) have a producer in which the chief feature

is a continuous automatic feeding device, consisting of an inclined, slowly rotating, water-cooled spout, by means of which the coal is fed at the rate required, and is distributed over the surface of the fire. But mere automatic feeding does not get over the difficulty of the caking of the coal when subjected to heat, and with bituminous coal there must nearly always be poking, whatever the system of feeding may be, to prevent hollows being formed.

In Fig. 14 we represent a producer of large size, made by Messrs. Ehrhardt and Sehmer of Saarbrücken. The most important feature in this is that the grate and ash-pan are independent of the body of the producer, and are rotated mechanically with a slow movement. In this way the lower part of the fuel column is kept moving, so that fresh surfaces are brought into contact with the currents of steam and air; the clinker and ash are also moved, and when they reach the rotating ash-pan the latter discharges them automatically. This type of producer is chiefly used for fuel containing a high percentage of ash, which usually produces a large amount of clinker. It will also be noticed that instead of the lower part of the body of the producer being lined with firebricks, in the usual way, it is cooled by a water jacket. This prevents the adherence of clinker to the sides of the producer, but the loss of heat and the consumption of water are considerable.

We visited a steel works in this country where there are numerous producers of various types, including some which had moving grates and water jackets, and it may be useful to give the conclusions of the manager and chemist in charge. They said that the water jacket of a producer about 10 feet internal diameter requires about 3500 gallons of water per hour, and that this is a serious drawback, especially where it must be run to waste. From the chemical and thermal efficiency points of view a water jacket is not desirable, but from the practical point of view it does prevent the adherence of clinker. The jacket of the first producer of this type which they worked had one water inlet and one outlet, but in later producers they had one inlet and three outlets and this was an improvement, as it gave quicker relief to the hot water and checked the formation of steam.

We found that the rotating grate moves the ash and clinker

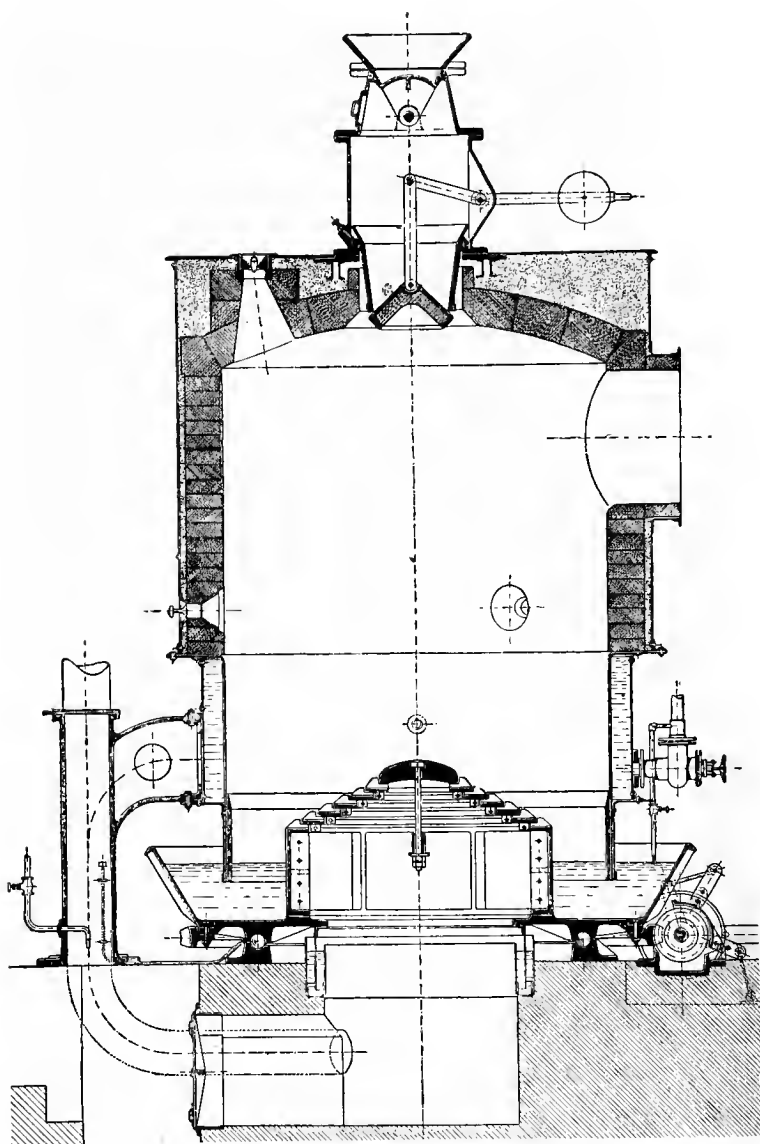


FIG. 14.—Ehrhardt and Sehmer gas-producer.

and the lower part of the fuel column, but not the upper fuel. With small coal it is desirable that all the fuel should be moved, as it often burns with hollows. With ordinary coal it is considered best to let it sink down vertically, unless it cakes, when it must be poked from the top. The labour of poking with this type of producer is about the same as with ordinary producers.

With these large producers it was considered important to have two independent supplies of steam and air, as the sectional area of the fuel column was so great. One supply of steam and air was for the fuel near the body of the producer, the steam being at a pressure of 25 to 50 lbs. per square inch (1.75 to 3.5 kilos per square centimeter); the other supply was for the middle of the fire, with a steam pressure of only 10 to 20 lbs. per square inch (0.7 to 1.4 kilos per square centimeter). There was a steam gauge for each supply, fixed on the top of the producer, so that the pressure could be regulated to suit the condition of the fire. The quantity of steam used was said to be 32 grams per cubic meter of gas, 2 lbs. per 1000 cubic feet. The temperature of saturation of the blast was about 40° C., sometimes lower, so that the quantity of steam used was probably between 0.1 and 0.2 of the weight of fuel consumed.

We will now describe a producer made by Messrs. R. D. Wood & Co. of Philadelphia, U.S.A. They introduced this in 1913, and they say they were led to do so owing to "the increasing shortage of natural gas and fuel oil, and consequent high cost of these fuels in many localities." They state that there are now many of these producers working regularly in America, and as the design is original and embodies several features of importance, it will be well to study it closely.

The shell or casing of the producer is divided by a water seal **A**, Fig. 15; the top of the producer, including the firebrick arch and gas outlet **B**, is fixed to a platform carried on girders, and is stationary, but the body of the producer **C** revolves, being kept in position by vertical and horizontal rollers **D**, Fig. 16. The conical bosh **E** is fixed at the top to the lower part of the revolving body **C**, and at the bottom it hangs free in a water seal in the circular trough **F**. The effect of this arrangement is that when the body of the producer rotates, the bed of fuel moves with it. The steam and air enter the fire through the stepped

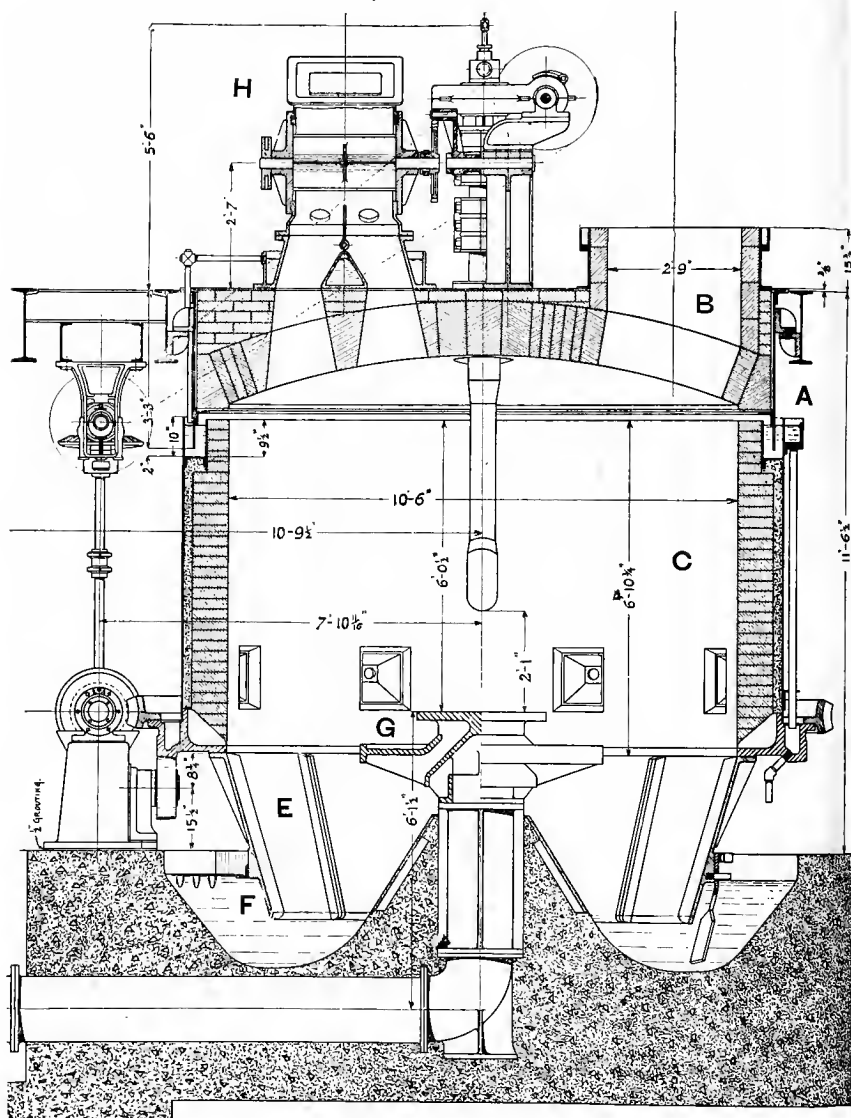


FIG. 15.—Wood & Co.'s "Automatic" Producer, vertical section.

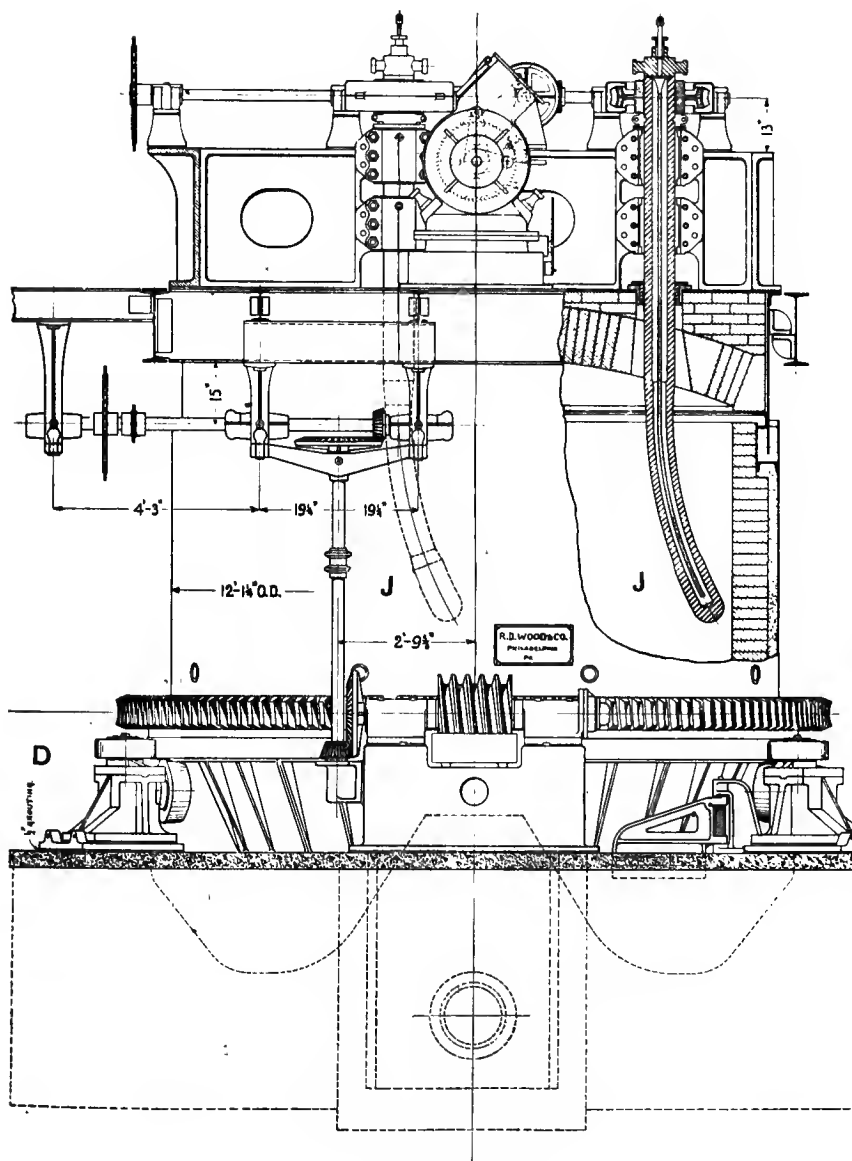


FIG. 16.—View showing rotating mechanism and hollow stirring bars.

hood **G**, the air blast being supplied by a turbo-fan-blower, with adjustments for proportioning the air and steam to suit the fuel used. The exhaust steam from the blower is usually sufficient to saturate the air to the extent required, and this arrangement

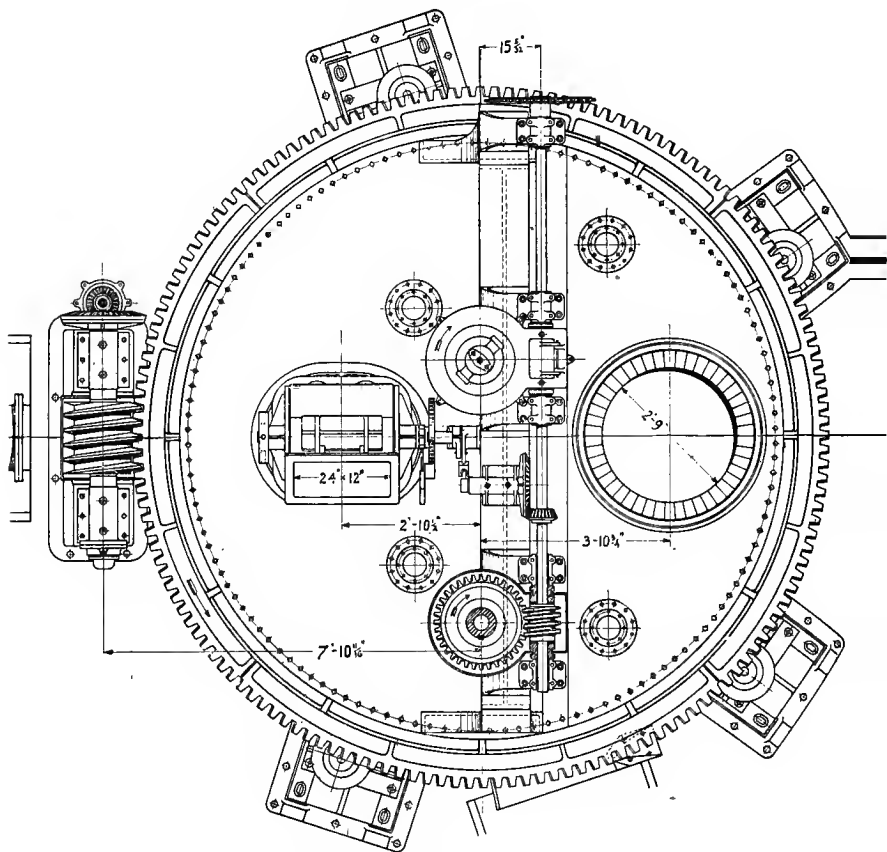


FIG. 17.—Gear for rotating body of producer and stirring bars.

has the further advantage that it is noiseless, which is certainly not the case with ordinary steam jet blowers.

The fuel is fed into the producer continuously (mechanically), the feeding apparatus **H** being on one side of the producer top; it follows that as the fuel column revolves with the body **C**, the coal fed through **H** is sprinkled over all the surface of the fire.

The rate of feeding the producer is regulated by a hand lever.

The column of fuel is agitated continuously by means of the two curved hollow stoking bars J J, Fig. 16, which are water cooled by means of copper tubes inside them. These stirring bars revolve on their own axes at such a speed that their lower

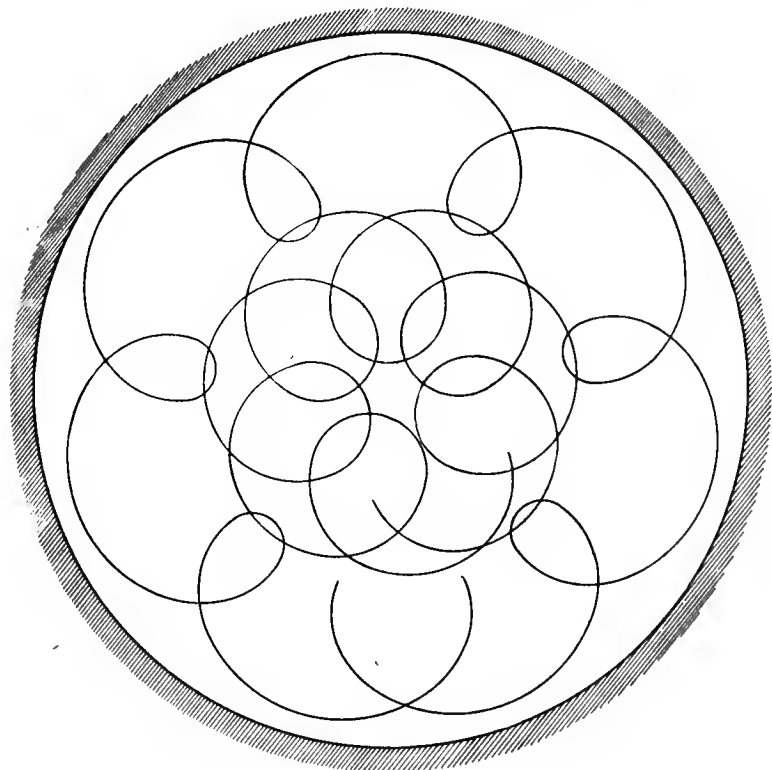


FIG. 18.—Paths described by two stirring bars.

ends describe a path as shown in Fig. 18. The moving of the fuel by rotation, and its agitation by the stirring bars, is said to prevent entirely the formation of blow-holes, and of course no manual poking is required as in ordinary producers. When a stirring bar has to be renewed it is only necessary to remove the bearing cap, without disturbing any other part of the mechanism.

To maintain the fuel column at a constant depth it is important to remove the ashes and clinker at the same rate as they are produced. To effect this there are two ash ploughs and two ash scrapers, which rotate with the bosh **E** in the water trough **F**; in this way the ash and clinker are carried to one point, and there a sweep discharges them into a pit or wagon.

The body of the producer and all its attachments are rotated by a large worm wheel and worm driven by gear, as shown in Fig. 17. The stirring bars are also worm driven, as shown in the same figure. .

The makers call this an "Automatic Producer," and this designation is not far from being correct; it feeds and distributes the coal mechanically, it moves the whole bed of fuel and stirs it mechanically, and it removes the ash and clinker mechanically. With this well-thought-out combination a producer 10 feet 6 ins. internal diameter is able to gasify as much as 50 tons of coal per 24 hours, over 2 tons per hour, and this is far ahead of any other producer with which we are acquainted.

In the practical working of gas-producers which are supplied with air or with steam and air for furnace work, the gas seldom contains less than 50, and sometimes as much as 65 per cent. of nitrogen. For many operations this inert gas is a distinct drawback (for reasons given on p. 104), and about 1874 Lowe (U.S.A.) made a new departure altogether and produced what is technically known as "water-gas."¹ His apparatus is shown in Fig. 19. It consisted of a producer **A**, and two superheating chambers **B** and **C**, filled with loose or chequered firebricks. The fire was built up with anthracite or coke on the grate **D**, and was blown up with air at pressure entering at **E**. The gas thus produced left through the outlet **F**, and at **G** it met a secondary supply of air (through the grating **H**), with which it was burnt; the flame and hot products of combustion passed downwards through the superheater **B** and upwards through **C**, and afterwards escaped as a waste product. In this way the brickwork in **B** and **C** became highly heated, and as soon as this was the case the two air-supplies were shut off, and steam at pressure was admitted at the top of **C**. It passed downward through **C** and upward through **B**, and then through **F** into the producer **A**, where it

¹ See Chapter I, p. 17.

was decomposed on passing through the mass of incandescent fuel. The solid fuel resting on the grate **D** was put in through the doorway **I**; but, in addition to this, powdered fuel was sometimes fed in automatically from the hopper **J** during the period when steam was being admitted. This powdered fuel was met by the currents of highly heated steam, and part of the steam

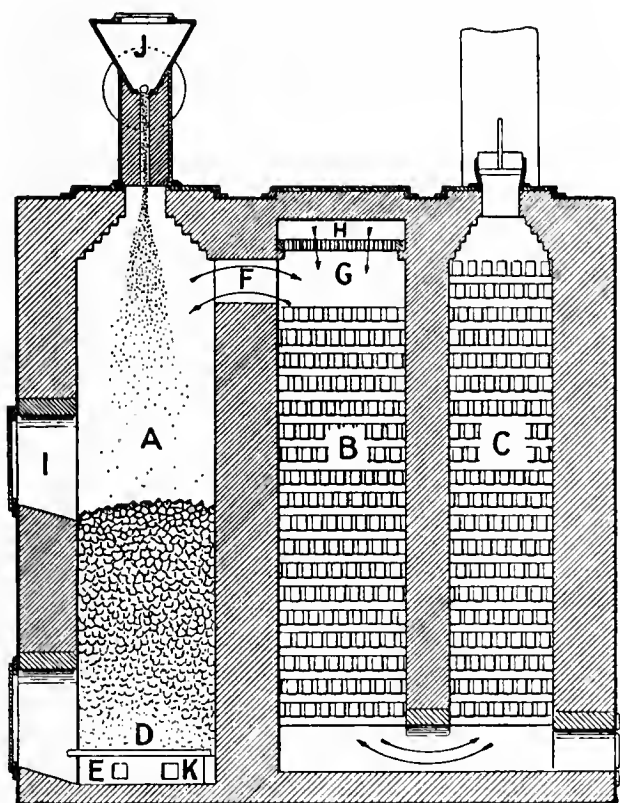


FIG. 19.—Lowe water-gas plant.

was then decomposed before it reached the incandescent mass. The other usual reactions occurred, and the gases formed left the producer at **K**. One effect of sending steam only into the producer was to lower the temperature of the fire, and after a few minutes it was necessary to stop the steam supply and turn on the air-blast again. The gases produced during the period

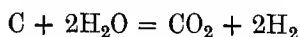
of blowing with air served to heat chambers **B** and **C**. The intermittent production of the water-gas is a drawback, and it is usual to pass the gas into one or more gasholders and to connect two or more producers to the latter, so that there may be a continuous flow of gas from the holder to the furnace, or wherever the gas is to be used. This adds considerably to the size and first cost of the plant. The heat efficiency is low, as the gases passing through the chambers **B** and **C** during the air-blow do not give up all their heat to the chequer brickwork, and they escape to the chimney stack at a comparatively high temperature, so that much of their heat is lost. The losses by radiation are greater than in gas-producers of the kinds previously considered in this chapter, as the loss of heat through the walls of the regenerator chambers must be added to the loss from the producer chamber itself; also when the gas is stored in a holder it loses its sensible heat before it is used.

The average composition of the gas is usually given as follows:—

Carbon monoxide	44 per cent. by volume.
Hydrogen	48 " "
Carbon dioxide	4 " "
Nitrogen	4 " "

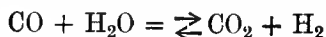
Allowance should, however, be made for the fact that the composition varies considerably between the times of starting and stopping each admission of steam. A further point to bear in mind is that at the end of the air-blast period the two superheating chambers **B** and **C** are filled with nitrogen and products of combustion, and when steam at pressure is introduced at the top of **C** the contents of **B** and **C** are driven backwards through the fire in **A**. This accounts in the main for the presence of nitrogen in the gas made during the steam-blast period.

To avoid an excessive proportion of carbon dioxide, a temperature of 1000° C. is necessary during the steam-blow. If the temperature falls much below this, there is a tendency for the reaction



to take place; also if some of the steam remains undecomposed

and leaves the fuel-column mixed with the water-gas, the reversible reaction



will take place to an extent depending on the temperature, as explained on pp. 58-60, so that some carbon dioxide will be formed as the gas cools.

Originally water-gas was intended chiefly for use in furnaces, but its intermittent production was a serious drawback, and it was seldom used for open-hearth operations. Its high calorific intensity was not an advantage for work of this kind, and the high temperature added greatly to the wear and tear of the furnace. Modern practice is therefore in favour of the ordinary producer, which can make gas continuously and without great fluctuations in its composition. Water-gas is, however, very useful for welding boiler tubes and similar work, and is more suitable for this purpose than ordinary producer gas, because its flame temperature is much higher. A recent development is the increasing use of water-gas as the starting-point in certain processes for the manufacture of hydrogen. But its chief use at the present time is as a basis for lighting-gas; it burns with a non-luminous blue flame, but when carburetted it gives an excellent light, hence the ordinary water-gas is often referred to as "blue water-gas," to distinguish it from the "carburetted water-gas" used for lighting. The lighting gas supplied to the public was at first made entirely by the distillation of cannel coal in gas-retorts; later other rich coals were also used, but owing to the increased demand for suitable coal, as the industry grew, many Companies have found it advantageous to manufacture carburetted water-gas of suitable heating and lighting power for a part or the whole of their requirements. The process of carburetting consists in introducing mineral oils into the blue water-gas as it leaves the producer at a very high temperature, and converting the oil vapours in superheating chambers into fixed gaseous products, which do not condense on cooling. The process is carried out in a modified type of the Lowe water-gas plant: a description of the process and plant would be beyond the scope of this work, but may be found in text-books on lighting-gas.

Messrs. Dellwik and Fleischer have devised a modified water-gas apparatus, in which the period of air-blow is greatly reduced.

The essential features of the process are that the layer of fuel is not as deep as in other types of water-gas producers, and a more rapid blast of air is used during the air-blow. The air is supplied at a relatively high pressure, and several air-inlets are used. With this method of working, little or no carbon monoxide is formed during the air-blow, but all the carbon then consumed is burned to carbon dioxide in the producer chamber; hence the fuel column is raised to the temperature necessary for the steam-blow much more rapidly than in the Lowe type of plant. The heat losses are therefore reduced, and the make of gas per hour is increased. The hot gases from the air-blow pass through regenerators as in the Lowe process, but there is no secondary supply of air, as the gases are not combustible. Professor Vivian Lewes, who has tested this apparatus, says:¹ "In the old 'European' process it was necessary to blow for nearly ten minutes to bring the fuel bed up to the right temperature, whilst the period during which the incandescence was sufficiently great to decompose the whole of the volume of steam used, limited steaming to four to five minutes, whereas in the Dellwik process the period of blowing rarely exceeds two minutes, and it is possible to steam for from seven to ten, according to the condition of the fuel." He gives the carbon dioxide as only 5 per cent., and explains that this is due to regulating the flow of steam so that "even at the extreme end of the run there shall be no excess of steam to oxidise the carbon monoxide to dioxide." He adds that samples of the gas taken during the process of making had the following compositions:—

	1	2	3
Hydrogen	52.43	50.09	52.76
Carbon monoxide	38.30	39.95	37.50
Carbon dioxide	4.73	5.38	4.08
Oxygen	0.74	1.22	0.46
Nitrogen	3.80	3.36	5.20

The average composition of the water-gas made in this type of plant, in a test carried out by Prof. W. A. Bone, F.R.S., is given in column 8 of Table I, p. 21. On the whole a considerable

¹ "Liquid and Gaseous Fuels," p. 230.

saving in fuel is effected compared with the type of water-gas plant in which air-gas is made alternately with water-gas. (See cols. 8 and 10, Table I., page 21.)

A more recent development is the water-gas plant founded on the patents of Messrs. Kramers and Aarts of Holland, and since modified by Mr. H. E. Smith. The original plant is shown in Fig. 20, and consisted of two producers, **A** and **B**, and two chequer-brick regenerators, **C** and **D**, connected at the top. There was a coke fire (5 to 6 feet deep) in each producer, an air blast was admitted at the bottom of each simultaneously, and the products of combustion (together with a secondary air supply admitted near the top of the producers, to complete the combustion) passed upwards through the regenerators **C** and **D**, and were then blown off through a valve **E** into a chimney **F**. In this way **C** and **D** were highly heated, and as soon as a sufficiently high temperature was attained the air

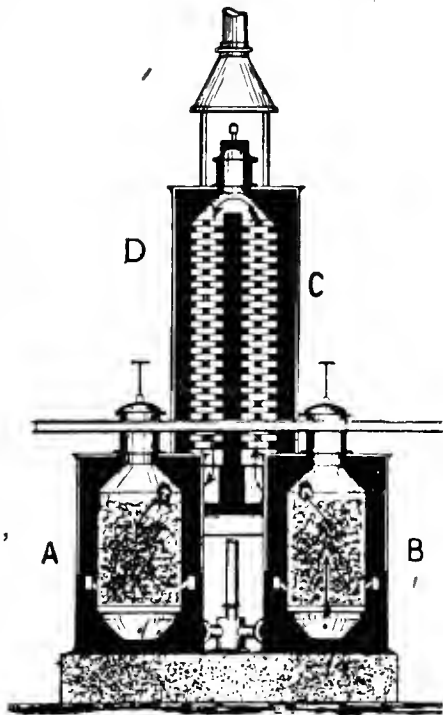


FIG. 20.—Kramers and Aarts water-gas plant.

and chimney valves were closed. Steam was then admitted to the base of one of the producers, and was decomposed on passing upwards through the fire; the resulting gases passed upwards through one regenerator, downwards through the other regenerator, and then downwards through the fire in the second producer, to an outlet leading to the gas main. After a few minutes the admission of steam was stopped, and the fires were blown up again with air, as in the first instance.

It will be noticed that the travel of the steam through the

incandescent carbon is double the length of the air travel, so that the plant had two important features—a comparatively shallow fuel bed for the air blast, and twice this depth of incandescent fuel for the steam. It was also claimed that with this method of operation the gas left the second producer at the hottest point of the fuel column, and that this prevented, or reduced to a minimum, the formation of carbon dioxide by the interaction of steam with the carbon monoxide in the gas. (See page 59.)

The gas made in this plant is used chiefly as a basis for town lighting gas, but it is also suitable for certain industrial processes, and at the works of Messrs. Clayton and Sons, Leeds, it is used on a fairly large scale for welding steel. Prof. Bone tested this plant, and we have extracted the following from his summary of results:—

1. The fuel was ordinary gas coke, containing 2·9 per cent. moisture. The dry coke contained: carbon 87·2 per cent., hydrogen 1·2 per cent., ash 7·3 per cent.
2. Mean composition of gas:—

Carbon dioxide . . .	3·75 per cent.
Carbon monoxide . . .	43·70 „
Hydrogen	45·10 „
Methane	0·50 „
Nitrogen	6·95 „
3. Mean calorific values per cub. ft. at 0° C. and 760 mm.: —
Gross 308·9 B.Th.U; Net 284·0 B.Th.U.
4. Yield of dry gas per lb. dry coke, 33 cub. ft. at 0° C. and 760 mm.
 „ „ „ carbon 37·84 „ „
5. Average duration of air-blow 70 seconds
 „ time required to operate valves . 12 „
 „ duration of steam run 308 „
 „ actual gas-making periods 47·4 minutes per hour.

The plant modified by Mr. H. E. Smith, and now made by Messrs. Perry & Co., Ltd., of London, is shown in Figs. 21 and 22. As before, there are two producers, **A** and **B**, but each has a vertical charging retort **C** and **D** above it, and these retorts are surrounded by regenerators of chequer brickwork **E** and **F**. At **G** and **H** there are secondary air inlets, and in addition to these there are ports or nostrils **J, J**, as shown in the Figs. The purpose of these will be presently explained. A single inlet for admitting a blast of air at pressure to the two producers is shown at **K**, near the bottom of Fig. 21.

A fire is kindled in each producer, and coke or a mixture of coal and coke is fed in through the retorts, **C** and **D**, until both are filled. When the fuel in **A** and **B** is at a good heat the air blast **K** is turned on, and acts on both the fires simultaneously, so that the two fuel beds are blown in parallel. During this blow the valves on the top of **C** and **D** are closed. The effect of this is that the resulting gases from **A** and **B** cannot go through **C** and **D**, and pass through the nostrils **J, J**, into the chequered regenerators **E** and **F**, where they are burnt by means of secondary air admitted through **G** and **H**. Finally, the products of combustion go through outlets at the top, leading to a stack, which discharges them into the air. In this way the fires in **A** and **B** are brought up to the temperature required, the regenerators are highly heated, and they in turn heat the retorts **C** and **D** and the fuel they contain; the fuel gradually works

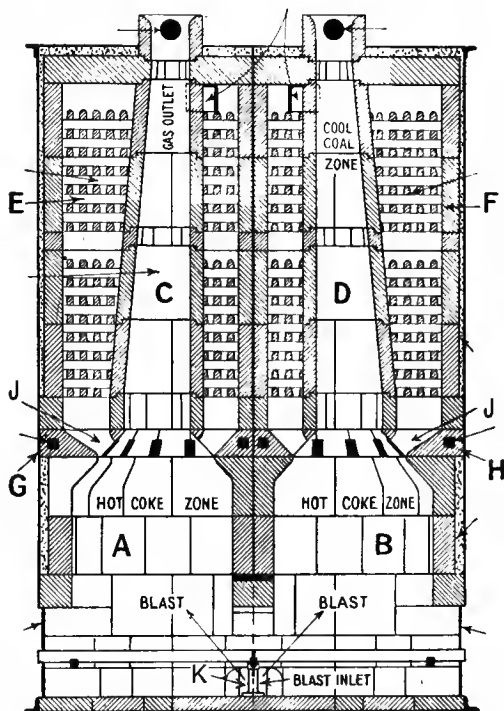


FIG. 21.—Vertical section of Kramers and Aarts' plant modified by H. E. Smith.

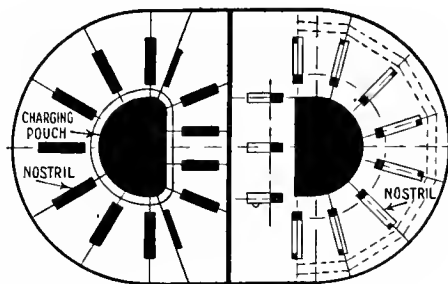


FIG. 22.—Transverse section.

its way down to **A** and **B**, so that it is almost incandescent when it reaches there. The air blast is now shut off, and the stack valves are closed; steam is then admitted at the top of one of the regenerators **E** or **F**. It passes down through the heated chequer work, and is highly superheated; it then passes downwards through the fire in one of the producers **A** or **B**, and is there decomposed; the resulting gases then pass upwards through the second producer, through the fuel in the retort, and finally escape into the gas main.

As the hot gas passes through the retort **C** or **D** it is automatically cleansed of dust and solid matter; at the same time it is cooled considerably, and carries with it any moisture given off from the fuel in the retort. The admission of steam lasts about six minutes; after this there is again an air-blow, which last about one minute. After the first blow the steam passes through the regenerator **E**, and the gases escape through the retort **D**; after the second blow the steam passes through the regenerator **F**, and the gases escape through the retort **C**, and so on.

The following is an analysis of gas made from coke in the modified plant:—

Carbon dioxide . . .	3.5 per cent.
Carbon monoxide . .	43.5 „
Hydrogen	47.3 „
Methane	1.25 „
Nitrogen	4.45 „

Calorific values per cub. ft. at 0° C. and 760 mm. (calculated):—

Gross 311.2 B.Th.U; Net 286.7 B.Th.U.

The makers state that with average coke the gas made in the two plants is approximately similar, but that with other fuels the modified plant gives a higher percentage of methane, and a lower percentage of nitrogen. They also state that with this plant they have succeeded in gasifying peat containing 40 per cent. of moisture.

Having discussed various types of producers used for furnace work, we will now revert to the furnaces themselves and consider briefly some of the improvements effected since the introduction of the Siemens system. One of the practical drawbacks in the Siemens regenerative furnace was that from defective

construction or from cracks caused by expansion there was sometimes a leak of air into the gas chambers; or sometimes, owing to defective valves or their bad manipulation, a mixture of hot air and gas was formed. Explosions more or less serious ensued, and it became necessary to modify the system. Siemens admitted that his cooling of the gas was objected to on the score of wasting heat which might be used in the furnace. He argued, however, that the cooling of this gas was not wasteful, as its final temperature in the furnace did not depend on its initial temperature. He considered that if the gas were cooled before it reached the regenerative chamber of the furnace the outgoing products of combustion would be cooled more thoroughly. He said,¹ "The only result, therefore, of working the furnace with gas of high temperature is to increase the heat of the waste gases passing off by the chimney flue."

Siemens heated both air and gas, but MM. Gaillard and Hailiot, M. Pousard, and others simplified and improved the arrangement by conveying the gas direct from the producer to the furnace without cooling it, and by heating only the air by the outgoing products of combustion. The Gaillard and Hailiot system of heating the air is shown in Figs. 23 and 24; in this the hot products of combustion from the furnace enter the air-heating arrangement at **A**, and flow through the horizontal passages **B, B**; then they pass away to the chimney flue **C**. The air for combustion of the gas in the furnace enters at **D**, and passes upwards through the perforated bricks shown in section in Fig. 24. In this way the air is highly heated by the waste products of combustion before it enters the combustion chamber through **E**. No unburnt gas can reach the air before the two meet in the combustion chamber, consequently there is no risk of explosion in any of the flues. Further than this, the flow of gas, air, and products of combustion is always in one direction, and the reversals of the Siemens system are dispensed with altogether. Many modifications of the Gaillard and Hailiot furnace have been introduced by engineers in this and other countries, but nearly all modern regenerative gas-heated furnaces (except for special purposes) follow the principle of heating the air only by the products of combustion, and of letting the currents

¹ Crookes and Röhrig, "Practical Treatise on Metallurgy," vol. iii. p. 537.

of gas, air, and products travel continuously in one direction. This not only simplifies the working of the furnace and materially

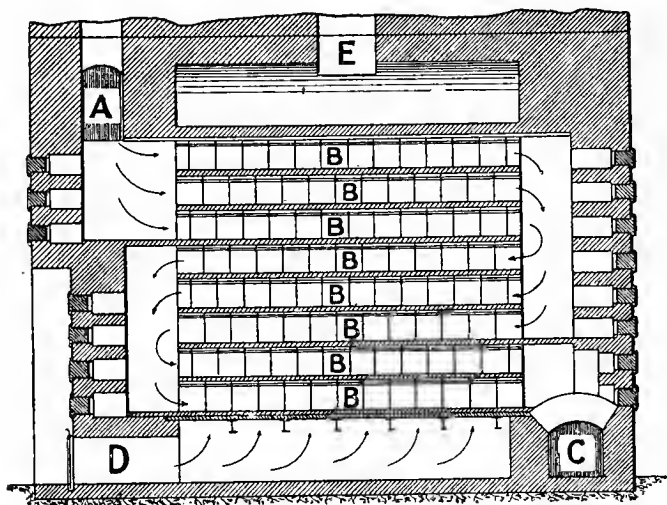


FIG. 23.—Gaillard and Haillet system of heating air—vertical section.

reduces the risk of explosions, but lessens also the cost of construction and the ground space required.

In some operations it is better to have a higher temperature at one end of the furnace than at the other, so that the material

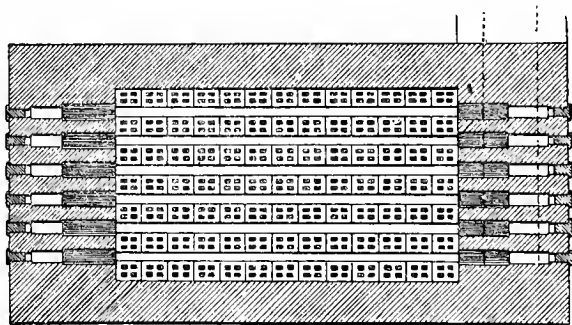


FIG. 24.—Gaillard and Haillet system of heating air—sectional plan.

put into the furnace may be gradually heated before it is subjected to the highest temperature required. For this purpose it is better to let the flame travel always in the same direction, and then by

regulating the admission of air it is possible to make the flame longer or shorter as required. In this way the character of the flame may also be varied to a considerable extent so as to have an oxidising or reducing action as may be desired, as already explained (p. 68).

In some furnaces, as in those for heating billets of iron or steel, annealing iron plates, etc., it is desirable that the temperature should be uniform throughout, and within certain limits this can be effected with the flame travelling always in one direction. In Figs. 25 and 26 we have shown a typical reverberatory furnace of this kind; the hot gas from the producer passes through the brick flue **B** and valve **C** to **D**, and it meets hot air at **E**; the mixture of gas and air passes through the chequered brickwork **F** and burns in the furnace **G**; the products of combustion pass through **H** into the flues **P, P**, which lead to a flue **I**, and thence to a chimney in any convenient position; the air for combustion is heated by passing through the flues **A, A**. A furnace of this design, with a floor 8 ft. long by 4 ft. wide, has been used for heating billets of steel before compressing them into the form of shells for projectiles.¹ In the same works there were other furnaces of the same size, used for the same purpose, but heated by ordinary fires. A competitive trial lasting twelve hours was made with the gas-fired furnace and one of the other furnaces. Each furnace had a separate gang of men and a separate hydraulic press; the competition was keen and the result was that the gas-heated furnace consumed 765 lbs. of coal, while the fire-heated furnace consumed 1276 lbs., a saving of 40 per cent. in favour of gas.

A good type of furnace for heating slabs, blooms, plates, etc., is the "Weardale," shown in Figs. 27 and 28. In this the mixture of gas and hot air enters the combustion chamber through ports in the crown, the flames burn downwards, and the heat is distributed evenly throughout the furnace. Figs. 29 and 30 represent a Weardale furnace as used for annealing malleable castings, etc.

If the furnace is long and if it is necessary to have equal heating throughout, it is sometimes best to reverse the direction of the flame periodically as in the early Siemens furnace. To give a

¹ *Proc. Inst. C.E.*, 1897, vol. cxxix. p. 221.

practical instance, we had to design a gas-heated furnace 20 ft. long by 12 ft. wide inside, for the purpose of heating armour plates to an even temperature throughout. Each plate was over

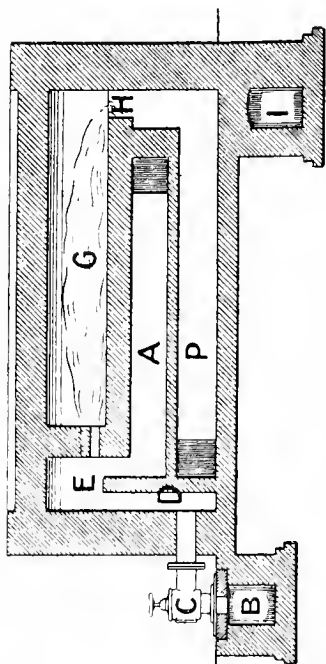


Fig. 26.--- Gas-heated reverberatory furnace—longitudinal section.

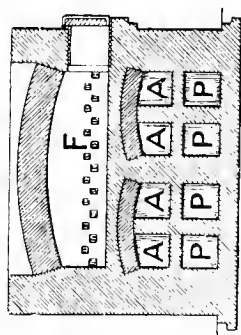


Fig. 25.—Gas-heated reverberatory furnace—transverse section.

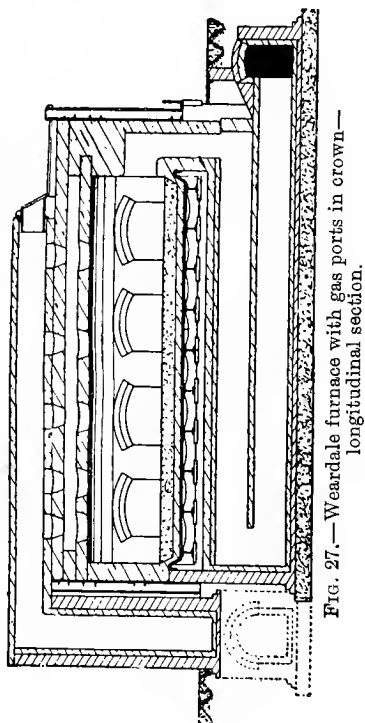


Fig. 27.—Weardale furnace with gas ports in crown—longitudinal section.

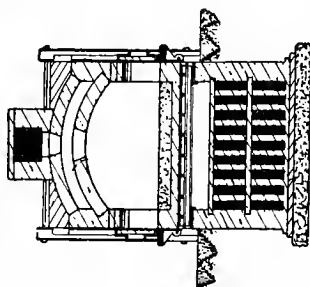


Fig. 28.—Weardale furnace with gas ports in crown—transverse section.

300 mm. (say 12 ins.) thick and weighed over 20 tons, and as it had already been shaped by costly processes it was important that there should be no distortion during the heating. Attempts

had previously been made with fires and had failed because some parts were over-heated while others were under-heated. In the gas furnace we reversed the flames as in the Siemens furnace at

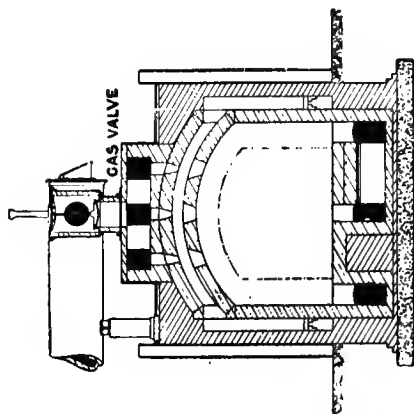


FIG. 30.—Weardale furnace for malleable castings—longitudinal section.

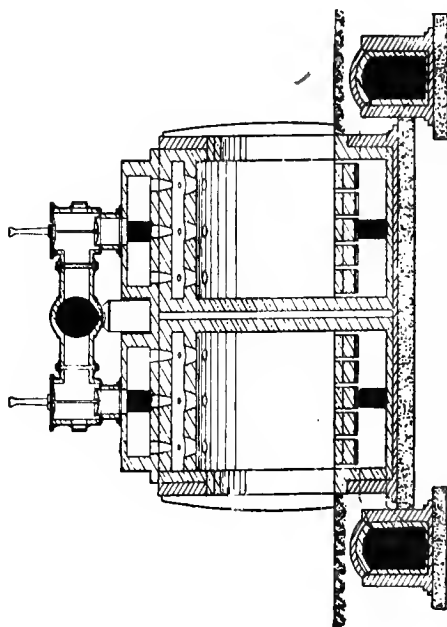


FIG. 29.—Weardale furnace for malleable castings—transverse section.

intervals of about 30 minutes, and we heated the air by the waste products of combustion; but we took the hot gas direct from the producers to the furnace and did not heat it further by

passing it through regenerative chambers. The result was satisfactory in every way, and it showed incontestably the superiority of heating by gas for work of this kind. Moreover, the average consumption of fuel in a month's work was only 185 kilos (407 lbs.) per ton of plates heated, including the heat losses during the discharging and recharging of the furnace after each heating and all other sources of loss.

In many operations, such as the annealing of glass or wire, the enamelling or glazing of various materials, it is necessary to heat the charge in the furnace gradually, then to heat it to a high temperature and maintain it at that heat, and afterwards to cool it gradually. It is usual to do this in an oven or chamber, and the brickwork of the oven, as well as the materials it contains, must be heated and cooled for each charge of materials treated. This necessarily involves a considerable loss of heat; and the wear and tear of the oven is also excessively great, owing to the frequent expansion and contraction of the brickwork and to its injury by hard firing to get up the maximum heat required. In some glass-works this is avoided, in connection with the annealing of large sheets, by using a long oven or furnace which is maintained at a moderate heat at the charging end and at the maximum heat in the middle. The discharging end is not heated. The glass to be annealed is mounted on a wagon, and this wagon is pushed or drawn through the oven from end to end at the speed required. In this way there is a gradual heating of the glass after it enters the oven; it is then highly heated, and afterwards it is allowed to cool gradually. We followed this principle in designing a continuous furnace for carbonising large blocks of material used in electrolytic works. Fig. 31 represents the cross-section of this furnace, and Fig. 32 a sectional plan. The blocks to be carbonised were packed in boxes **A, A**, and these were carried on a wagon with open framing which supported a floor of firebricks, so that the ironwork of the wagon was protected from excessive heat. On each side of the wagon there was an iron projection which dipped into the grooves **B, B** filled with sand, and cut off the connection between the upper and lower parts of the furnace; this protected the lower part of the wagon and ensured the passing of hot products of combustion through the upper part of the furnace only. The whole length of the furnace was kept full

of wagons; they entered through a door at **C** from a turntable **D**, and were pushed into and through the furnace by a hydraulic ram.

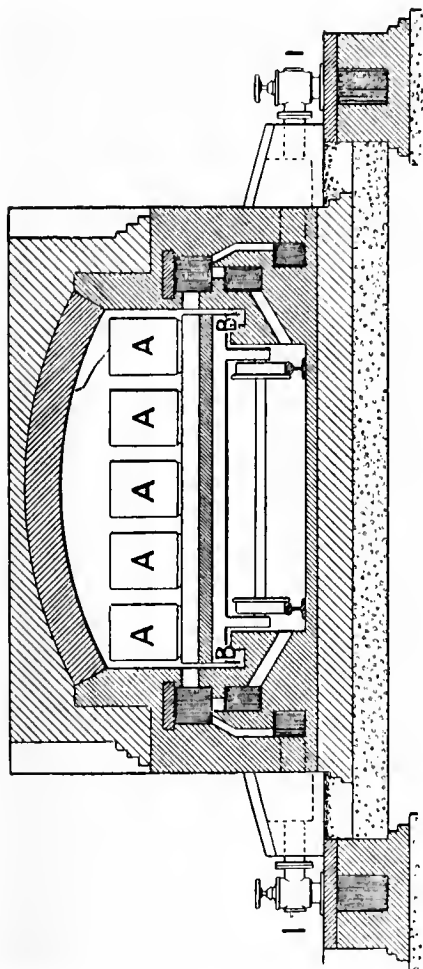


FIG. 31.—Continuous furnace—cross section.

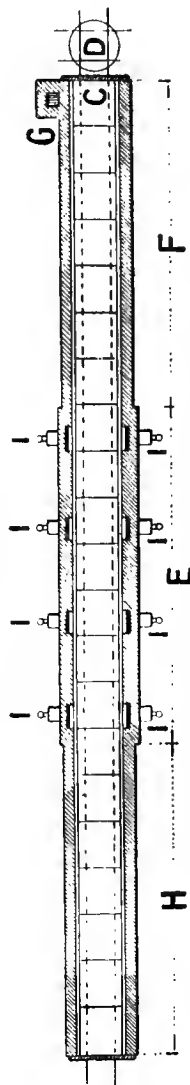


FIG. 32.—Continuous furnace—sectional plan (reduced scale).

Gas was burnt in the middle length of the furnace **E**, and the hot products of combustion passed through the length **F** to the

chimney **G**; the length **H** was used for cooling, and was not heated. Gas from the producer was admitted on each side of the furnace through the valves **I, I**; air entered at **C** and travelled along under the wagons until it reached the part **E**, when it passed up flues to burn with the gas; the air was heated by coming in contact with the hot bricks forming the floors of the wagons. The heating was continuous night and day, and the temperature in the length of furnace **E** was from 900° to 1000° C. (about 1650° to 1830° Fahr.). To maintain this heat uniformly and to carry on the process of carbonising, the consumption of local coal was only about 76 kilos (167 lbs.) per hour. Apart from the economy effected, the advantage of this system was that the material to be treated was gradually raised in temperature in **F** until it reached the maximum temperature in **E**; after this, its temperature was gradually lowered by passing through **H**. A modification of this gas-fired furnace has since been used for several manufacturing processes in which it is necessary to heat materials gradually, then to heat them highly, and afterwards to cool them gradually.

One case we dealt with was at a pottery in Staffordshire. There was a horizontal kiln, which was formerly heated by a large coal fire, for glazing porcelain cups, saucers, and plates; and instead of the fire we introduced producer gas. With the latter there was not only a saving in fuel, but the heat was more uniform, and there was no loss from under-firing or over-firing of the goods. This was considered of great importance, as a large proportion of them was spoiled when the kiln was fired in the usual way.

For high temperature furnaces it is desirable to have the gas as dry as possible when it enters the furnace, as the presence of moisture lowers the flame temperature. This is very important in melting steel, and for such work the quantity of moisture in the gas should not exceed 30 grams per cubic meter.¹ The whole of the steam which enters the producer should be decomposed in the producer, and none of it should pass through unchanged with the gas. In cases where the gas from the producer passes through coolers and scrubbers, the gas is saturated with water

¹ J. Hoffmann, International Congress at Düsseldorf, 1910. (*Iron and Coal Trades Review*, vol. 81, page 128.)

vapour at the outlet of the scrubbing plant, and the quantity of water vapour present in the gas depends on the temperature of the gas (see pages 122, 123), and will not be any greater if steam passes undecomposed through the fire. For high temperature furnaces it is also desirable (apart from fuel economy) to have a low percentage of CO_2 and a high percentage of CO in the gas, and this again means that the quantity of steam in the air blast should be no greater than is necessary to prevent an excessive amount of clinker being formed. For producers supplying ordinary gas-fired furnaces the temperature of saturation of the air blast usually varies from 45°C. to 55°C. , corresponding to about 200 to 400 grams per kilo (0.2 to 0.4 lb. per pound) of coal. These figures refer to producers using bituminous coal, working without recovery of ammonium sulphate. When anthracite is used it is generally necessary to use more steam to prevent an excessive amount of clinker being formed; the temperature of saturation of the air blast in a plant of the steam-jet type should be about $65\text{--}70^\circ \text{C.}$, corresponding to about 750 grams of steam per kilo (0.75 lb. per pound) of coal gasified.

The heating of steam-boilers may not belong strictly to furnace work, but as we have often been consulted on the subject and as we know that many are interested in it, we think it may be well to add a few words about it. Several attempts have been made to heat boilers with producer gas, and boilers can be heated in this way; but where gas is produced solely to serve one or more boilers the results are not encouraging from the point of view of fuel economy. In a boiler fired in the ordinary way the mass of incandescent fuel is within the boiler, and a large amount of heat is radiated from it; but when the fuel is converted into gas in a separate producer the incandescent fuel is away from the boiler proper. There is also a loss of heat in the process of conversion. These drawbacks are partly compensated for by less air being required, but in ordinary boilers of land or marine type, when the gas comes in contact with the comparatively cool metal surfaces of the boiler its temperature is lowered and the combustion is incomplete. In the practical working of the two systems the removal of the clinker is more difficult in a gas producer than in a boiler, and more labour is required. As an example, we may mention what we saw at a mill near Milan

some years ago. There were twenty-one large steam-boilers of the Cornish type, and four of them were heated with producer gas. With cheap Scotch coal the gas-fired boilers usually evaporated 7 kilos, but occasionally $7\frac{1}{2}$ kilos, of water per kilo of coal; the other boilers had mechanical stokers and were fired with Cardiff steam coal, and they evaporated ten kilos of water per kilo of coal, but this coal cost 5 francs per ton more than the Scotch coal. Apart from the question of labour, the general result was rather in favour of the ordinary firing; the cost of labour was a good deal higher for the gas firing. At a large steel-works in Cleveland, U.S.A., where there were many gas-producers in use, numerous experiments were made, and the general conclusion was that there was no saving in firing steam-boilers with gas. If there is any chance of success it would appear to be in the direction of combining the boiler and producer; some attempts have been made, but so far as we are aware they have not been entirely successful.

In this connection we welcome a new type of gas-fired boiler shown in Fig. 33. It was designed by Prof. W. A. Bone, F.R.S., and the late Mr. C. D. McCourt, and is known as the Bonecourt boiler. The superheater and the economiser can be dispensed with when not required. The leading feature of this boiler is that it has numerous longitudinal tubes surrounded by water, each tube having a separate gas flame, and inside each tube there is an iron packing piece, rather like a large screw thread in appearance. The latter quickens the mixing of the gas and air, and prevents gases passing along the middle of the tube without coming into contact with the surface to be heated; it also increases the length of flow for the gases. The gas and air and the products of combustion are drawn through the tubes by an exhauster, as shown in the Fig. The heat efficiency of this boiler is said to be about 90 per cent., and this statement is confirmed by some users of the boiler. There are various sizes and types of this boiler; the shell of the one illustrated is 6 ft. diameter by $18\frac{1}{2}$ ft. long, and this is said to be capable of evaporating 15,000 to 20,000 lbs. of steam per hour.

Instead of burning gas to heat the boiler the latter can be heated by the hot exhaust gases from a gas-engine, and in this way all or part of a factory or building can be heated by steam from the

boiler. At the same time the boiler acts as a silencer for the exhaust, so that an ordinary silencer can be dispensed with. A Bonecourt boiler has been working in this way for a long time

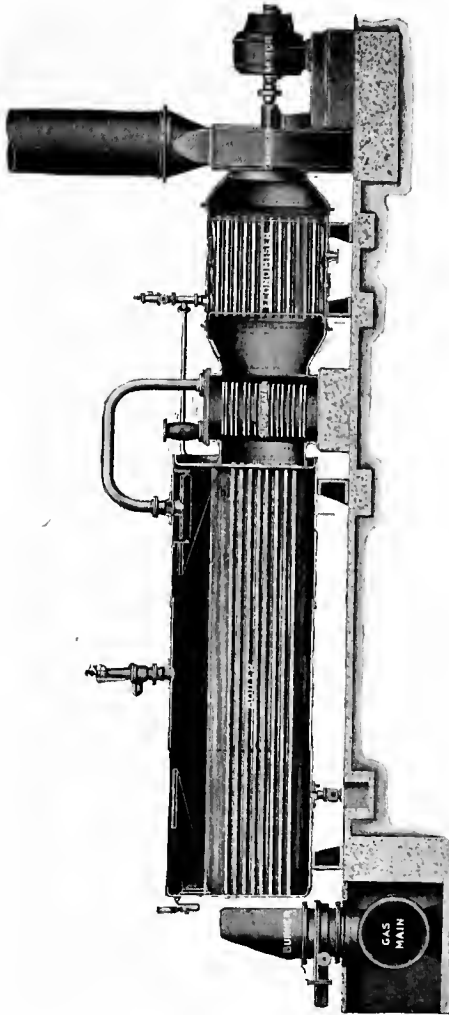


FIG. 33.—Bonecourt gas-fired steam-boiler.

at West Bromwich, near Birmingham, and the result has been so satisfactory that the owners of the factory have ordered a second boiler for similar use.

CHAPTER V

HEATING WORK (VARIOUS)

IN the previous chapter we have dealt with producer gas for furnaces and similar work in which large flames are required ; we will now consider its use for other kinds of work which require the use of burners and small flames. When burners and cocks are used it is essential that the gas should be clean, and it is obvious that it cannot be taken direct from the producer to the burners, or the latter would soon be clogged with troublesome deposits. In practice this usually means that the gas is passed through water and scrubbing material such as coke ; incidentally the gas is cooled to about the temperature of the surrounding air, and this not only means that the bulk of the sensible heat which the gas carries with it from the producer is lost, but that any condensable hydrocarbons which leave the producer in the form of tarry vapours are lost also.

When burners are used it is also important that the gas pressure at the burners should be constant, so that the heat given off by the flames may be kept uniform or varied at will by cocks on the supply pipes. For this reason the gas must be passed through a gasholder, or its pressure must be regulated in some equally efficient manner. As producer gas always contains a large proportion of nitrogen, and as its flame temperature is comparatively low, it is important not to use more air than is strictly necessary to ensure complete combustion. For this reason it is undesirable to use "atmospheric" burners when small jets of producer gas are required ; in such cases it is better to use plain burners with holes in them, usually not much under 2 to 3 mm. (say $\frac{1}{8}$ in.) diameter. When larger jets of gas are used atmospheric burners may be employed, or air at pressure may be mixed with the gas on its way to the burner ;

but in the latter case the adjustment of air to gas should be regulated carefully, to prevent the formation of an explosive mixture in the pipes. The advantage of forcing air into the gas is that an intimate mixture of gas and air is then formed, ready to burn quickly as soon as it is ignited. The flame is, therefore, shorter than it would be if it merely came in contact with the air surrounding its outer surface; and as a consequence of this a greater intensity of heat is produced, and the heat is concentrated on the object to be heated. For example, it is essential that blow-pipes should have air at pressure, and with producer gas of good quality it is best to use an air-pressure of 0.10 to 0.15 kilo per sq. cm. ($1\frac{1}{2}$ to 2 lbs. per square inch). This is a higher pressure than is generally used for ordinary town gas, and the probable explanation is that as the quantity of the weaker gas which must be burnt is much larger, and as the producer gas is largely diluted with nitrogen, a higher air-pressure is necessary to ensure a sufficient quantity being mixed with the gas before the latter is ignited. In all these cases it is manifestly important that the gas-pressure should be constant, so that the air-supply may be regulated to give the best effect. Owing to the comparatively low flame temperature of producer gas and to the liability of this temperature being still further reduced if the gas is wrongly used it is specially important that the best

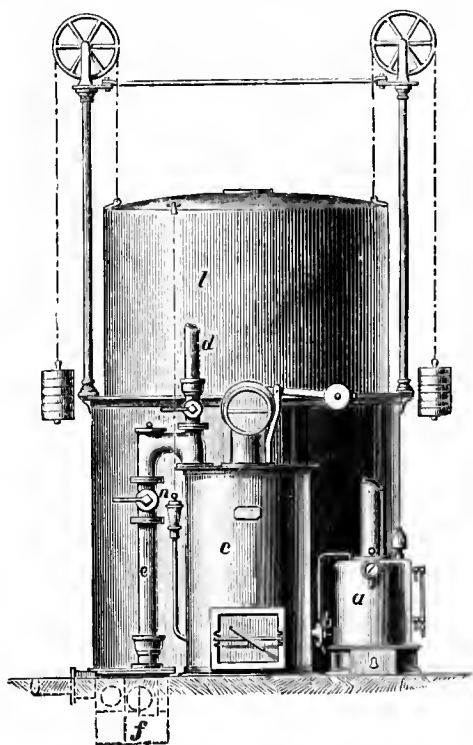


FIG. 34.—Early Dowson gas plant.

to ensure a sufficient quantity being mixed with the gas before the latter is ignited. In all these cases it is manifestly important that the gas-pressure should be constant, so that the air-supply may be regulated to give the best effect. Owing to the comparatively low flame temperature of producer gas and to the liability of this temperature being still further reduced if the gas is wrongly used it is specially important that the best

way of burning the gas in small quantities should be carefully considered in all cases.

For such work as we have referred to, the presence of a large proportion of nitrogen is a serious drawback ; in fact, all producer gas made with air only may be ruled out at once. It cannot be used with small burners, nor can other producer gas with a low percentage of hydrogen, because gas of this nature, when it is cool, has such an exceedingly low flame temperature. To get a high enough flame temperature and to get gas of sufficiently high

calorific power to be used with air at pressure it is necessary to keep the percentage of in-combustible gases as low as possible. It has been shown in Chapter I. that, apart from water-gas, the richest gas is obtained when the maximum quantity of steam is decomposed with the formation of carbon monoxide and hydrogen. When Mr. Dowson first took up the subject he endeavoured to carry this out in a practical way, and the apparatus he devised between 1878 and 1881 is shown in Figs. 34 and 35.

In these Figs. *a* represents the boiler with a coil of pipe inside in which steam was produced

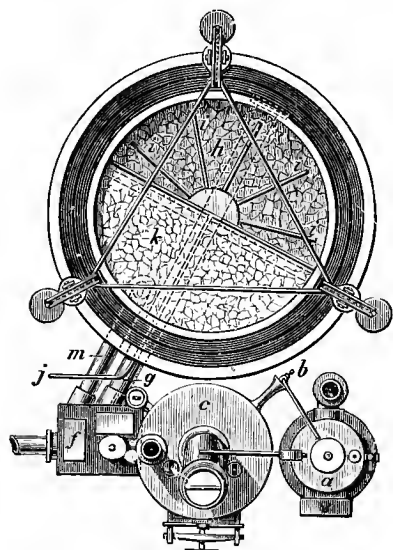


FIG. 35.—Early Dowson gas plant—sectional plan.

and superheated ; *b* is an air injector worked by a jet of steam at pressure from *a* ; *c* is the gas producer, with a chimney or waste-pipe *d*, and a down-pipe *e* ; *f* is a hydraulic box containing a water seal ; *g* is the inlet pipe and *m* the outlet pipe of the gasholder *l*. Inside the tank of the gasholder there is a cylindrical coke scrubber with a vertical partition down the middle ; the half *h* acted as a wet scrubber and had water-spray pipes *i*, *z*, and a water-feed *j* ; the other half of the scrubber, *k*, was dry. To govern automatically the production of gas to suit a varying rate of consumption a pipe

leading from the lower part of the gas-producer had a loose conical plug *n*, fitted into a suitable seating, and this plug was attached to a chain which was fixed to the top of the gasholder. It was so adjusted that when the gasholder was nearly full of gas the plug *n* was lifted, and allowed some of the steam and air to blow off, instead of all being passed through the fire. When the gasholder fell the plug *n* was closed, and gas was made at the maximum rate until the gasholder was full again.

The late Prof. William Foster, F.C.S., gave the following analysis of gas made in this apparatus :¹—

Hydrogen	18.73	per cent. by volume.
Marsh gas	0.31	” ”
Olefiant gas	0.31	” ”
Carbon monoxide . .	25.07	” ”
Carbon dioxide . . .	6.57	” ”
Oxygen	0.03	” ”
Nitrogen	48.98	” ”
Total	100.00	

The process of making the gas resembles in principle that adopted in some of the producers referred to in the preceding chapter ; but there was not only a producer but a complete set of apparatus for cooling and cleaning the gas, as well as a small gasholder. The gas was made from small anthracite coal, and special means were adopted for producing and *superheating* the steam required ; the thermal and other working conditions favourable to the necessary reactions in the producer were also carefully attended to. As a result there was a much higher percentage of hydrogen, and notwithstanding the cooling and cleaning of the gas and the consequent removal of the condensable hydrocarbons its calorific power (1432 calories per cubic meter or 161 B.Th.U per cubic foot) was higher than in any producer gas made before that date.

This apparatus with a modified boiler and superheater was shown working at the Smoke Abatement Exhibition (1881-1882), and was tested by Mr. D. K. Clark on behalf of the Committee,² who awarded the exhibitor a gold medal, and a special prize of

¹ *Proceedings Inst. C.E.*, 1882, vol. lxxiii. p. 320.

² Official Report of Smoke Abatement Committee, 1882.

fifty guineas given by the late Sir William Siemens for "The best method or arrangement for utilising fuel as a heating agent for domestic and industrial purposes, combining the utmost economy with freedom from smoke and noxious vapours." The steam producer and superheater consisted of a zig-zag coil of piping under which there was a special burner with numerous jets of gas which heated the coil. Water was sent into this coil under a pressure of 20 to 25 lbs. per square inch, so as to give the steam the pressure required to work the injector *b* and raise the gasholder. About one-third of the coil contained water, and the remainder steam, which was quite dry when it left the coil. The gas required for heating the coil was drawn from the gasholder. During a test lasting three hours and five minutes water was consumed at the rate of 7·8 lbs. per hour, and the consumption of gas for converting the water into superheated steam was at the rate of about 100 cub. ft. per hour. The gas was generated at the rate of 1175 cub. ft. per hour, after deducting the above allowance for making steam. Gas was made with anthracite, and the fuel consumption was reported to be at the rate of 12·13 lbs. per 1000 cub. ft. gross passed into the gasholder, and at the rate of 13·17 lbs. per 1000 cub. ft. net, after deducting the gas used for making the steam required.

One of the early installations carried out by Mr. Dowson was at the Gloucester (second) County Asylum in 1885, and from that date to the present time (1920), it has been used there regularly for all the cooking, baking bread, etc., for the staff and inmates, also for driving a gas-engine for pumping water, etc. At this place there is a large meter which registers all the gas consumed, except that used for the gas-engine which is served by a separate main. The Clerk of Works reported on the cost of production for the year ending March 31, 1895, as follows:—

	Cubic feet.
Gas produced (measured by meter)	22,211,700
Estimated quantity used for engine pumping three hours a day, at 3000 cub. ft. per hour (not registered) . . .	3,285,000
Total quantity produced . .	<u>25,496,700</u>

Details of material and labour used in the production of the above quantity of gas:—

	£	s.	d.
Anthracite coal, 124 tons 19 cwts. at 21s. 2d. a ton . .	132	4	10
One year's repairs to plant at 6d. a day	9	2	6
Gasman's wages, making gas only, at 21s. per week . .	54	12	0
	195	19	4

thus costing 1½d. per 1000 cub. ft., exclusive of slack used for the steam-boiler.

[Steam for the gas plant was generated in a small vertical boiler, and this boiler was fired with cinders, etc., from the various fires in the Asylum; no account of these was kept, as they were treated as waste for any other purpose. If fuel for the boiler were included, the cost of the gas would be about 2d. per 1000 cub. ft.]

The cooking and heating apparatus were tested by the architects, Messrs. Giles & Gough, and the following results are taken from their report to the Building Committee of the Asylum :—

Large roasting oven.

Initial temperature of oven, 57° Fahr.

Gas consumed, 60 cub. ft. to raise oven to 300° Fahr.

Time occupied, 9 minutes to raise oven to 300° Fahr.

Gas consumed at the rate of 250 cub. ft. per hour to maintain temperature of 300° Fahr.

Three coppers in scullery.

Filled in each 20 gallons of water at 57° Fahr.

Lighted gas 5.20 p.m.

Temperature, 150° 6.5 "

" 168° 6.20 "

" 190° 6.30 "

" 205° 6.40 "

" 212° 6.47 "

Gas consumed, 1400 cub. ft.

Result.—60 gallons boiled in 1½ hours, with consumption of 1400 cub. ft. of gas, requiring 19 lbs. of coal, and costing under 4½d., including wages.

They added, " With the gas system the coal consumption is about half that usually required for heating by coal fires."

To compare with this, it may be interesting to note that a thin steel copper of similar shape set in firebrick with a coal fire, as supplied to the War Office, was tested officially and gave the following results: 21 gallons of water at 58° Fahr. boiled in three-quarters of an hour, with a consumption of 15 lbs. of coal. This was the best type of copper fired with coal or coke.

Although the gas tests above referred to are not of recent

date, they are given, not only because they were made carefully under working conditions, but because gas of this kind made in more recent plants has about the same calorific power, and because there was a large meter to register all the gas consumed. It is seldom that this useful instrument forms part of the equipment of a heating gas installation.

In 1900 the gas plant at the Gloucester Asylum was extended, and in 1905 the Clerk of Works reported that the consumption of gas was then at the rate of about $36\frac{1}{2}$ million cub. ft. per annum. The following details were also given:—

Bakehouse.—The ovens were heated 74 hours a week, with a consumption of 131,600 cub. ft. of gas. The flour used = 27 sacks of 280 lbs. each.

Kitchen.—The average consumption of gas is as follows:—

6 a.m. to 9 a.m.,	at 4000 cub. ft. per hour	= 12,000 cub. ft.	
9 „ to 1 p.m.,	at 8000 „ „	= 32,000 „	
1 p.m. to 5 „	at 4000 „ „	= 16,000 „	
5 „ to 10 „	at 1000 „ „	= 5,000 „	

Total per day . . 65,000 „

Total per week . . 455,000 „

Another installation of a somewhat similar kind is at the Isolation Hospital of the Urban District Council of Walthamstow. It was started in 1900, and the gas is still used for a variety of purposes, including the heating of water for baths in the administrative block. There are also four independent blocks or pavilions for patients, and at each end of each of these blocks there is a gas-fired boiler of the geyser type, to provide hot water for the baths, lavatories, etc.

An interesting installation of this type of plant on a larger scale has worked for many years at the well-known cocoa factory of Messrs. Van Houten & Son at Weesp, in Holland. It is to be regretted that work at this important factory has now been stopped, but we continue to give an illustration of the plant in Fig. 36, as it shows the general arrangement adopted for a plant of considerable size. There were eight gas-producers, each capable of producing 453 c.m. (16,000 cub. ft.), or a total of 3625 c.m. (128,000 cub. ft.) per hour. The gas plant was outside the town, about a quarter of a mile from the factory, and the gas travelled through a main 2 ft. in diameter, which had to pass

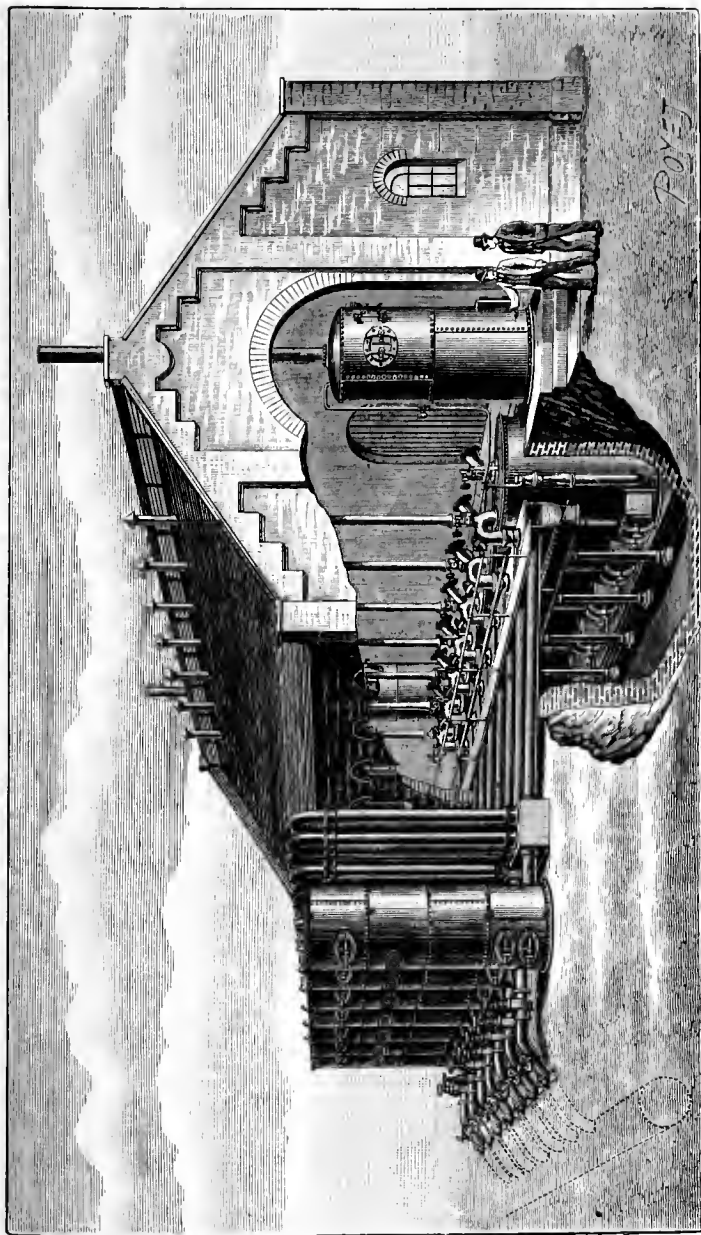


FIG. 86.—Dowson gas plant at Weesp, Holland.

under a canal, and the tank of the gasholder had to be carried on numerous timber piles as there was water near the surface of the ground. The gas was used chiefly for roasting cocoa beans, but also for soldering tin boxes, and for other heating work, as well as for heating stoves in several work rooms and offices. When the plant was started in 1885, the cost of anthracite was 16s. a ton, and careful tests showed that the calorific power of the gas was one-fourth that of town gas, and that its cost was $1\frac{3}{4}d.$ per 1000 cub. ft. (including fuel and wages). This would give 7d. for the equivalent of 1000 cub. ft. of town gas; but at the present price of fuel and wages the cost would be greater for the producer gas as well as for the town gas.

This gas is used in several other factories for roasting cocoa, coffee, and other food products. The following are the results of trials with two different samples of coffee :—

—	Trial No. 1.	Trial No. 2.
Speed of roaster (revolutions per minute)	58	58
Air pressure (pounds per square inch)	$4\frac{1}{2}$	$4\frac{1}{2}$
Gas alight (minutes)	$33\frac{1}{2}$	$34\frac{1}{2}$
Coffee in roaster (minutes)	$35\frac{1}{2}$	37
Producer gas consumed (cubic feet)	335	320
Weight of coffee roasted (pounds)	56	56

One great advantage of roasting by gas, compared with a coke fire, is that the heat can be better regulated; another is that the gas can be turned off at the critical moment, just when the roasting is done. It is well known that the roasting of coffee, for instance, is an operation of great nicety; if it is insufficiently roasted much of its aroma is lost. It is said that with gas-roasting the weight of finished coffee is 10 to 15 per cent. greater than with a coke fire.

The various kinds of heating work for which producer gas is used are too numerous to mention, but the following are some of those which have been dealt with :—

- Japanning and enamelling stoves.
- Cutting and finishing glass.
- Type-founding machines.
- Crucible furnaces.
- Varnish-making.
- Tailors' irons in clothing factories.

Laundry irons, calenders, etc.

Machines in boot factories.

Drying wood, for musical boxes, etc.

Gassing silk and cotton yarns.

Singeing textile fabrics.

Soldering biscuit and condensed milk tins, etc.

Brazing with blowpipes.

Small furnaces for hardening, tempering, annealing, etc. (At the Birmingham Small Arms Factory there are about forty of these furnaces in use.)

Expanding wheel rims and tyres.

Annealing cartridge cases, as at the Royal Arsenal, Woolwich.

Speaking generally, we have found that for heating work four volumes of the gas made in this type of plant are equivalent to one of ordinary town gas; but for blowpipes and some other special work it is best to allow more.

In connection with cooking and baking or the roasting of food materials by heat derived from the combustion of producer gas, it is well to consider whether any deleterious effect is caused by the contact of products of combustion with the food. Our opinion is that no harmful effect is produced, especially as there must be a fairly free and rapid escape of the products of combustion to ensure a sufficient in-draught of air to burn the gas in the oven or stove in which the food is cooked. The products of combustion of this gas consist chiefly of carbon dioxide and water-vapour, with a very small percentage of sulphurous or sulphuric acid. The accompanying nitrogen is a neutral body, and the mere traces of other gases are negligible. When producer gas is used, the products of combustion are similar in kind to those of town gas, although the proportions of carbon dioxide and water-vapour differ, and it has been well established by competent authorities that no deleterious effect is produced when ordinary town gas is used for cooking. As to the sulphur compounds, the sulphur does not exceed in amount that derived from ordinary town gas, provided the coal from which the producer gas is made does not contain more than about 0·5 per cent. of sulphur. It will be remembered that producer gas, as now ordinarily made for heating work, is merely washed and scrubbed. Except in special cases it is not purified chemically, as in the case of town gas; but purification, when necessary, presents no great difficulty. The water through which the

producer gas is passed takes up some of the sulphuretted hydrogen, but the total quantity of the latter which is in the gas is usually so small that it is neglected. If in certain cases it is considered desirable to remove the sulphuretted hydrogen this can be easily effected by passing the gas through a purifier containing iron oxide, as in town gasworks.

In some industrial processes, such for instance as japanning and enamelling, some of the constituents of the japan or enamel, which consist largely of coal-tar products, are injuriously affected by the sulphur compounds in the products of combustion of producer gas. These affect also the colours of certain metallic paints, *e.g.* the so-called "gold paint," which is made with copper and is readily tarnished by sulphuretted hydrogen. Without purifying the gas these troubles can be avoided by heating the stoves or ovens in such a way that the gases (burnt or unburnt) do not come in contact with the materials to be heated; or the gas can be purified as described above.

CHAPTER VI

ENGINE WORK

GAS-ENGINES were invented long ago, but the early ones were not successful ; in fact, they were not “ within the range of practical politics ” until Dr. Otto introduced his four-stroke cycle. His engine was patented in 1876, and it is since then that a real gas-engine trade has sprung up. The makers in Germany and in England were energetic and skilful ; and they not only achieved a remarkable success but prepared the way for numerous other makers, who adopted the Otto principle as soon as the master patent expired.

At first all gas-engines were worked with town lighting gas, and the conditions of working were almost ideal compared with steam power. The user of the engine needed no storage of fuel, no tall chimney ; and no ground space was required for a steam-boiler. There were no boiler repairs, no ashes to remove, no banking of fires and stand-by losses, no smoke nuisance ; and the engine could be started or stopped at a moment's notice. The attendance, and consequently the expenditure in wages, were nominal ; the only drawback was the price of the gas. An engine worked with costly gas was, in fact, analogous to an electric motor worked with current derived from zinc as the fuel. Still even with expensive town gas small gas-engines competed successfully with steam-engines and boilers ; but for 20 B.H.P. and upwards the working cost of a gas-engine with ordinary lighting gas was greater than that of steam power. A new field of enterprise was opened out when it was proved that a gas-engine could be worked successfully with semi-water-gas, because the low cost of the latter enabled the gas-engine of any size to beat the steam-engine in cost of working.

The first trial of a gas-engine with producer gas was in 1879, with a set of Dowson's gas plant ¹ (see Figs. 34 and 35, pp. 103, 104). His attention was drawn to the subject in 1878, while he was engaged in perfecting an apparatus for making cheap gas for heating purposes, and it occurred to him that it might be eminently suitable for gas-engines. The English makers of the Otto engine were sceptical as to the result, as they considered that no gas with a high percentage of nitrogen could succeed. They were, however, persuaded to make a trial at their works with a little engine developing about 3 B.H.P., and their adverse opinion was so far broken down that further trials were made in the following year. Mr. Dowson read his first paper on the subject at the York meeting of the British Association for the Advancement of Science (1881),² and he then showed a small Otto engine working with his gas plant. This same engine and plant were afterwards tested by Mr. D. K. Clark, at the Smoke Abatement Exhibition, on behalf of the Committee. He reported as follows ³ :—

Engine developed 4·41 I.H.P. and 3·26 B.H.P. when making 156 revolutions per minute.

Gas consumed per I.H.P.-hour, 110·34 cub. ft.

Gas consumed per B.H.P.-hour, 149·30 cub. ft.

Fuel consumed per I.H.P.-hour, 1·45 lb.

Fuel consumed per B.H.P.-hour, 1·97 lb.

For various reasons much better results can be obtained with engines of recent date, but at the time of these trials they were considered encouraging, and the figures are given now so that later results may be compared with them. Many improvements have been made in the construction and working of the gas plant since it was first introduced, but the average composition of the gas remains nearly the same, as will be seen from the following analyses by various chemists :—

¹ *Proceedings Inst. C.E.*, 1882, vol. lxxiii. p. 315.

² Report of Brit. Assoc., 1881.

³ Official Report of Smoke Abatement Committee, 1882, p. 113.

TABLE XIII.—COMPOSITION OF GAS (PER CENT. BY VOLUME).

Date.	B.H.P. of Producer.	Hydrogen.	Hydrocarbons.	Carbon monoxide.	Carbon dioxide.	Oxygen.	Nitrogen, etc.	Calories per cubic meter (higher value).	Calories per cubic meter (lower value). ¹	Cubic meters produced per kilo of anthracite consumed.	Authority.
1883	8	18.73	0.62	25.07	6.57	0.03	48.98	1420	1323	5.0	Prof. W. Foster, F.C.S.
1889	60	17.0	2.0	23.0	6.0	—	52.0	1420	1318	5.02	Mr. F. Uppenborn, Munich.
1890	40	16.67	—	27.5	8.40	0.90	46.73	1360	1279	4.74	Dr. C. Monaco, Turin.
1890	10	24.0	—	22.5	7.5	—	46.0	—	—	—	Dr. Langer, London.
1894	120	16.5	1.0	25.4	4.8	1.2	51.1	1384	1294	5.34	Prof. A. Witz, Lille.
1897	40	19.8	1.3	23.8	6.3	—	48.8	1463	1354	5.04	Mr. G. C. Jones, F.C.S.
1898	250	15.3	1.4	27.6	3.9	—	51.8	1451	1359	5.07	" " "
1898	300	17.5	2.1	26.5	4.4	—	49.5	1552	1446	4.88	" " "
Average		18.19	1.40	25.17	5.98	—	49.36	1432	1339	5.01	

It was thought that with a large producer, containing a great mass of fuel at a high temperature, the percentage of hydrogen might be increased without increasing that of the carbon dioxide. On comparing the first and the last two of the analyses in Table XIII. it will be seen that this supposition was not borne out; and it may be assumed that with anthracite of equally good quality the composition of the gas is about the same with a small producer as with a large one, provided the producers are properly proportioned and the other working conditions are as favourable for the one as for the other. In the trial of 1881 the consumption of semi-water-gas was fully five times as great per horsepower as would have been the case with ordinary town gas. By calculation, however, the calorific power of 1 c.m. of an average sample of the semi-water-gas was 1432 calories, or 161 B.Th.U. per cub. ft., while that of 1 c.m. of ordinary 16 candlepower town lighting gas was 5693 calories, or 639.9 B.Th.U. per cub. ft. Tests made with a calorimeter confirmed these figures approximately, and theoretically the comparative consumption of the two gases to get the same power in an engine was as 3.98 : 1. From this it was evident that as long as practice required fully 5 volumes to one the weaker gas was not being used to the best advantage. At the present time, the right treatment of semi-water-gas is

¹ Hydrocarbons reckoned as CH₄.

better understood, and many important modifications have been made in gas-engines, so that the heat efficiency of an engine working with this gas is equal to that of an engine working with ordinary town gas, and it is now necessary to use only about 4 volumes of good semi-water-gas for one of ordinary town gas. On this point, therefore, theory and practice are now fairly in accord.

The improvements referred to were due in large measure to the better understanding of the thermodynamic problems involved. At first the makers of gas-engines sought improvements almost exclusively in mechanical devices, and less attention than the subject deserved was given to the behaviour of different kinds of gas under the varying conditions of temperature and pressure which must necessarily prevail in the cylinder before and after each explosion. In this country it was Sir Dugald Clerk, F.R.S., who first thoroughly investigated the subject as a chemist and physicist, and his published writings have led to a better understanding of the somewhat complicated and difficult problems involved. With steam power, it is one thing to make steam in a boiler, it is another to make the best use of it in an engine; so with gas power, it is comparatively easy to make gas in a producer but to use it to advantage in an engine is another matter altogether. It will therefore be instructive to review briefly the changes made in the engine which have raised the efficiency of the combination, although the composition of the gas itself has not been appreciably altered.

The Otto engine tested in 1881 had a compression of only 35 lbs. per square inch, and a typical indicator diagram is given in Fig. 37. It was soon ascertained that a higher compression would be better, but at that time slide-valves were used to regulate the ignition as well as the admission of the charge, and a high compression would have caused excessive friction for the valves. For various reasons these troublesome valves were retained for several years, but when tube-igniters were adopted and slide-valves were abandoned a higher compression was used. In the diagram (Fig. 38) an attempt is made to represent approximately a charge of producer gas and air about to enter the compression space in the cylinder of an early Otto engine,

this space being filled with residual products of combustion from the previous charge, left in the cylinder at the end of the exhaust stroke. In this figure the inner cone represents the producer gas, and the outer cone represents air in the proportion of 2 volumes of air to 1 of gas. The dots indicate the combustible part, and

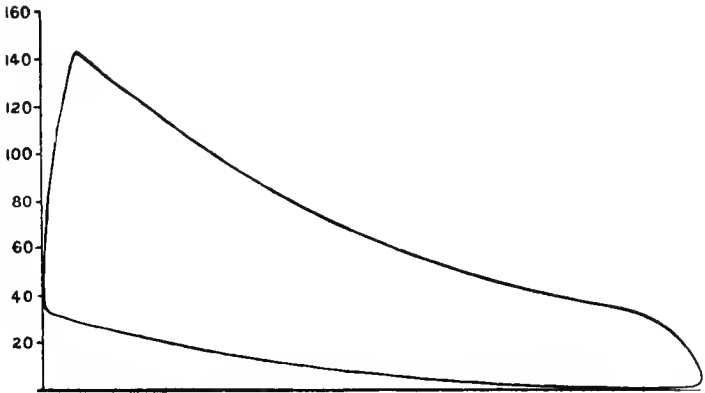


FIG. 37.—Typical indicator diagram with producer gas in 1881.

the crosses the incombustible part, of the producer gas, the latter being assumed to contain about 50 per cent. of combustible gases, the remainder being nitrogen and carbon dioxide. The circles show the oxygen in the air, and the crosses the nitrogen.

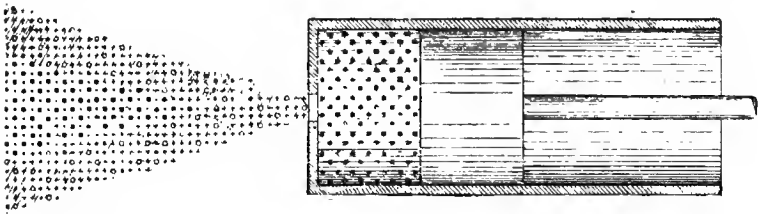
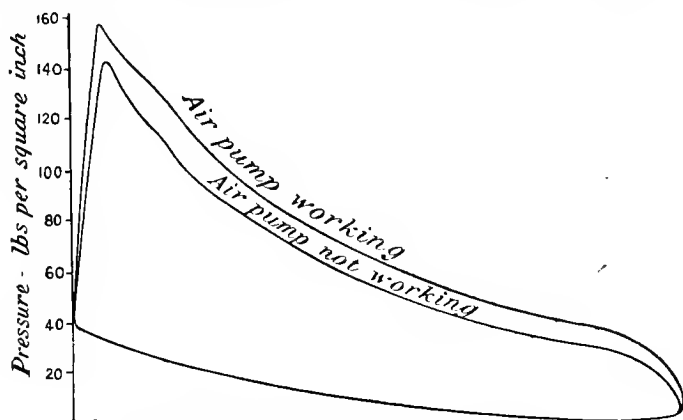


FIG. 38.—Diagram showing charge of producer gas and air about to enter cylinder of early Otto engine.

It is not possible to show in a diagram what actually occurred during the admission and compression of the charge, but the figure will assist the reader to realise the relative proportions of gas, air, and products of combustion which had to be mixed together. It will also serve to show how difficult it was for the

molecules of oxygen to reach the combustible gases, surrounded as they were with inert nitrogen and products of combustion. In the first place, before the charge entered the cylinder, it was as though there were two contending parties, four-fifths of one party (the atmospheric nitrogen) endeavouring to prevent the remaining fifth (oxygen) from joining half the members of the other party (the combustible gases), the other half of which was opposed to the union. When the charge of gas and air entered the cylinder it was mixed with a considerable volume of residual products, and the combination of the oxygen with the combustible gases was rendered still more difficult. Apart from



. FIG. 39.—Diagrams with and without air-pump.

these difficulties, there was the fact that carbon monoxide is slow to ignite compared with hydrogen. Hence more than half the combustible constituents of producer gas are rather slow to ignite. One fairly obvious improvement, so far as the gas was concerned, was to remove or scavenge out the residual products before admitting a new charge. To put this to a practical test the makers of the Otto engine, in 1881, fitted a small engine with a pump which delivered air into the compression space while the exhaust was open, so as to remove the products and displace them by air. The engine could work with or without the pump, and Fig. 39 shows two typical diagrams taken on the same day, with gas of the same quality. The smaller diagram represents the non-scavenging effect when the pump was not working, and

shows a mean pressure of 57·8 lbs. per square inch. The larger diagram superposed represents the effect after scavenging, when the pump was working, and shows a mean pressure of 68·5 lbs. per square inch, or an increase of $18\frac{1}{2}$ per cent. The fact that the exhaust products in the compression space were removed and displaced by air doubtless assisted the combustion of the gas; at the same time it allowed more gas to enter the cylinder so that there was a richer charge, and this to a large extent explains the increase in the mean pressure. In modern engines the compression space is much smaller in proportion to the volume of the cylinder than in the engine of 1881, and the increase of mean pressure due to scavenging is therefore not so great as in the example quoted. But apart from these considerations there is no doubt that it is especially advantageous for a comparatively weak gas, such as producer gas, not to be diluted with exhaust products. Against this improvement there was the extra friction due to the pump, and in the small engine of that date it was rather serious. Besides this, a further complication was introduced in the engine, and it added to the cost of construction, so that the makers were not in favour of the change. In the early Clerk engine the exhaust products were removed, and the inventor of it has always held that scavenging for producer gas is beneficial. Even the inventor of the Otto engine admitted that it was bad for a weak gas to be diluted with products of combustion. In the specification of a patent granted to Dr. Otto, dated January 4th, 1881, these words occur: "The products of combustion do not materially interfere with the combustion of the following charge if the gas employed is of a very inflammable character, such as coal-gas; but when gas of less inflammable character is used, such as carbonic oxide, it is of advantage to remove the said products more or less completely." Later, the manager of the German Otto Engine Works made a still greater admission, and in 1892 he wrote to Mr. Dowson as follows: "In all cases, and especially where weak gas is used, the expulsion of the products of combustion is an advantage; a larger quantity of heat will then be converted into work, and consequently the power developed by the engine will be increased."

Incidentally, scavenging has other advantages. For instance,

without scavenging the mixture of gas and air entering the cylinder is heated and expanded by the products of combustion from the previous explosion, so that the density and strength of each charge is somewhat diminished, a fact to which attention was called long ago by Profs. Ayrton and Perry.¹ Scavenging reduces the temperature of the explosive mixture during the suction stroke, and this not only increases the density of the charge but also tends to prevent pre-ignition. A further point is that if a weak charge enters the cylinder it may burn so slowly that part of the flame may remain in the compression chamber after the exhaust, and may ignite the succeeding charge during the suction stroke while the valves are open. This again would be impossible if all the hot products and flame were scavenged out, especially if a little air were admitted in front of the new charge.

Mr. Atkinson introduced an ingenious method of scavenging without a pump, but it entailed certain drawbacks. It is, however, generally recognised that if scavenging could be adopted without serious complication it would be an advantage, especially in large engines and in engines working with producer gas or other gases of low calorific power; but notwithstanding all the opinions in favour of scavenging, comparatively few engines are made with this provision. The majority of gas-engine makers consider that it is simplest and best to have a reduced compression space and a high compression without scavenging. In steam-engines the greatest care is taken to convert as much as possible of the heat energy of the working fluid into work, and undoubtedly the same should be done in a gas-engine which is to work with producer gas.

This discussion may be thought to be somewhat of a digression, as scavenging has not been generally adopted and therefore cannot have contributed to the improved efficiency of the majority of gas-engines working with producer gas. But the attention drawn to the subject has not been without its influence; indirectly, it has helped to bring about the adoption of a higher pressure for the compression of the charge, and this of itself has notably raised the heat efficiency of the engine, and has reduced the consumption of gas per H.P. In his James Forrest Lecture at

¹ "The Gas-engine Indicator Diagram," *Philosophical Magazine*, July, 1884.

the Institution of Civil Engineers (1904), Sir D. Clerk discussed this in detail, and as a general result he pointed out that in 1882 the heat converted into indicated work was only 16 per cent. of the total heat given to the engine, whereas in 1900 it had risen to fully 30 per cent.

Since 1881 the speed of gas-engines has been increased, and the tendency is to raise the speed rather than to lower it, especially for electrical work. Shorter intervals between the explosions, and therefore between the impulses, naturally lessen the variations in speed, and a quick-running engine is of smaller dimensions for a given power.

In the best engines of to-day about 30 per cent. of the total heat energy of the gas sent into the cylinder is lost by conduction through the walls of the cylinder. In 1882 this loss was about 50 per cent. On the other hand, the loss of heat through the exhaust has not been reduced; on the contrary, its tendency has been to rise, and it is now about 40 per cent. It is a striking fact that the exhaust of a gas-engine often leaves the cylinder at a pressure little under that of the steam pressure used in old times for driving a steam-engine. It is, however, reasonable to expect that in the process of evolution the gas-engine will be further modified and improved; indeed, what Sir D. Clerk has aptly termed its present "ratio of imperfection" may be considered as encouraging. If, notwithstanding its defects, it has done so well already, how much better will it be when these defects, or a considerable portion of them, have been remedied?

Numerous tests to determine the fuel consumption per H.P. have been made by well-known authorities, such as M. Mathot in Belgium¹; Prof. Witz in France²; Profs. Schottler,³ Meyer, and Slaby in Germany; Sir D. Clerk⁴ and Prof. Burstall in England. The general results show that when a steam-jet plant is used for making the gas a modern gas-engine of good design consumes about 450 grams (about 1 lb.) of fuel per B.H.P.-hour, including the fuel burnt in the boiler to raise the steam required. This is a great improvement on the fuel consumption of the first small engine worked with producer gas mentioned on p. 114, and this improvement is not due to any appreciable increase in the

¹ "Moteurs à Gaz."

² "Moteurs à Gaz." Paris.

³ "Die Gasmachine." Brunswick. ⁴ "The Gas and Oil Engine." Longmans.

calorific power of the gas, but to the various modifications and adjustments of the engine to which we have referred. A further reduction in the fuel consumption is effected when the steam is generated in the gas-producer or by the sensible heat of the gas after it has left the producer. This is dealt with in Chapter VII. on Suction Plants.

For engine work it is important that the temperature of the gas when it reaches the engine should be about the same as that of the atmosphere. This is desirable, because it renders the gas more dense so that a given volume contains a greater weight and yields a larger amount of heat energy, and consequently develops more power when it is exploded. For practical reasons too, it is objectionable to have moisture deposited from the gas in the pipes and passages near the engine, and to prevent this the gas should leave the plant at the atmospheric temperature. There will then be no further lowering of temperature accompanied by the condensation of a further portion of water-vapour from the gas. This is especially important now that magneto igniters have replaced tube igniters, as there is a tendency for moisture to collect on the terminals after the engine has been standing and is cool. If this occurs it gives trouble when the engine is to be started, as the current is short-circuited and the spark fails. This question of moisture is, however, not always understood; we therefore give a few explanations as to the cause of its presence and the best way of removing an excess.

We may assume that after passing through water or through wet coke in the scrubbers the gas will be saturated with moisture at whatever temperature it may be. As the gas at any given temperature contains sufficient water-vapour for saturation the quantity of water-vapour in the gas will be less at a lower temperature, and if the gas is further cooled any excess of water-vapour beyond that required for saturation at the lower temperature will be condensed. If, therefore, warm gas enters a cold engine, some of the water-vapour carried with it will be thrown out by condensation and will be deposited. A knowledge of the temperature of the gas in the pipe near the engine enables us to calculate the amount of water-vapour required to saturate the gas at that point, but it will not enable us to determine the amount of condensed water which may be held in suspension

over and above the amount of water present in the form of vapour. If we wish to determine the total content of water-vapour and of condensed moisture held in suspension it is necessary to pass some of the gas through a chemical absorbent, such as calcium chloride or concentrated sulphuric acid. To remove the condensed moisture from the gas before it reaches the engine it is best to pass the gas through a filter of sawdust or other suitable material. This will not affect the amount of uncondensed water-vapour in the gas, but it will to a great extent arrest the passage of condensed moisture held in suspension.

We have had to deal with a case where the temperature of the water used in the scrubbers was considerably lower than that of the surrounding air, and the temperature of the gas as it reached the engine was below that of the air, yet moisture was deposited in the cylinder of the engine and on the terminals of the igniter. It was evidently a case where condensed moisture was carried along by the gas, and the trouble was got over by passing the gas through a thick bed of sawdust.

Although the gas might not contain more water-vapour than is necessary for saturation, condensed moisture might be deposited at any point where there was a sudden reduction of pressure in the gas, because this sudden reduction of pressure would cause a slight lowering of temperature. It might be supposed that this would occur as the gas enters the cylinder on the suction stroke, when there is a lowering of pressure; but this is only momentary and does not give time for the deposition of moisture. Moreover, as soon as the gas enters the engine (after it has been working) it comes in contact with warm surfaces, which have a contrary effect. It may sometimes happen, when an engine has been standing and has been cooled by water colder than the gas, that when the latter comes in contact with the metal surfaces its temperature is lowered; there is then some deposition of condensed moisture.

The hot gas which leaves the producer can be cooled by passing it through pipes and coolers exposed to the air; but as the gas is usually consumed as quickly as it is made, and as its volume is considerable—say 2.1 to 2.25 c.m. (75 to 80 cub. ft.) per B.H.P.-hour—this process alone would be too slow, and the cooling apparatus would be too large and too costly. It is therefore

usual to pass the gas through a water-seal, and through one or more scrubbers containing wetted coke, as shown in Fig. 40.

In a well-designed plant worked with anthracite the quantity of water required for cooling and cleaning the gas is about 4.5 liters (1 gallon) per B.H.P.-hour. If worked with coke the quantity of water is about 6.7 liters (1.5 gallon). Sometimes, in order to reduce the first cost of the plant, smaller scrubbers are used than is desirable, and then the consumption of water is necessarily higher.

In a steam-jet plant the weight of steam decomposed is about 75 per cent. of the weight of anthracite or coke consumed in the producer. The total quantity of water required for the steam and for the cooling and cleaning of the gas may therefore be put at about 4.8 liters (1.06 gallon) per B.H.P.-hour for anthracite, and 7.0 liters (1.56 gallon) for coke. Water is also required for cooling the cylinder, etc., of the gas-engine, but this should not be debited to the gas plant; the quantity is, however, insignificant if there is a cooling tank with a flow and return from the cylinder.

Where water is scarce or costly a portion of the overflow from the scrubbers is sometimes collected and pumped into an overhead tank, a little

fresh water being mixed with it. It will not do to use overflow water several times without adding some fresh water, or it will become too acid. The acidity may, however, be neutralised by means of chalk or lime.

On referring to Table XIII., it will be seen that the gas contained an average of about 18 per cent. of hydrogen, with the

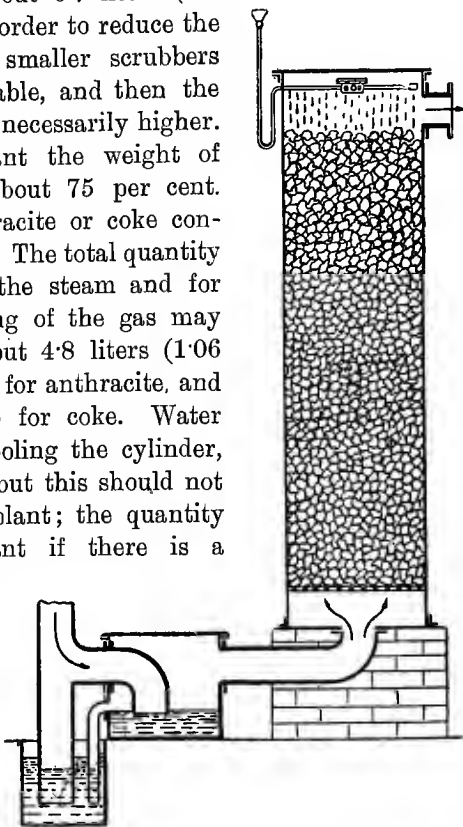


FIG. 40.—Hydraulic seal and coke scrubber.

accompaniment of an average of 6 per cent. of carbon dioxide, and it has sometimes been supposed that there can be no advantage in increasing the hydrogen if it involves a proportionate increase in the carbon dioxide. This question has already been dealt with in its theoretical aspects in Chapters I. and II., and it may be well to consider it briefly from the practical side. By way of example we may compare two of the samples of gas of which the composition is given in Table XIII. (p. 115) :—

	(1)	(2)
Hydrogen por cent. by volume	15·3	19·8
Hydrocarbons " "	1·4	1·3
Carbon monoxide. " "	27·6	23·8
Carbon dioxide " "	3·9	6·3
Nitrogen, etc. " "	51·8	48·8
Calorific power cal. per c.m.	1451	1463
" " B.Th.U. per cub. ft.	163·1	164·4

In the second case, the proportions of hydrogen and carbon dioxide are higher, but the proportions of carbon monoxide and nitrogen are lower; the calorific power is only slightly higher; and this is in accordance with our general experience.

At first sight there would appear to be little gain in raising the percentage of hydrogen, if there were a simultaneous rise in the carbon dioxide; but with a comparatively low compression in the cylinder (as was formerly the case) a certain increase of hydrogen assisted the ignition of the charge in the cylinder of the engine, the carbon monoxide being comparatively slow to ignite. An increase in hydrogen also led to a decrease in nitrogen. This consideration is of less importance now that the pressure of compression has been raised, as the ignition is satisfactory when there is not more than 15 per cent. of hydrogen in the gas, or even less. There is, however, a further point to consider in connection with hydrogen, namely, its bearing on the question of pre-ignition. We have seen that the heat efficiency of an engine is raised by an increase in the pressure of compression, but that the compression which can be used in practice is limited by the necessity of avoiding pre-ignition. When a gas is compressed, as in a gas-engine cylinder, its temperature is raised

considerably, but it is essential that the temperature of compression should be less than the ignition temperature of the charge. Exact data are wanting for the ignition temperature of mixtures of various gases with air, but Sir D. Clerk says, "It is known in a general way that gases which contain a large proportion of hydrogen are ignited at a comparatively low temperature," and that "compression can be carried very much farther with weak gas of the producer type, such as blast-furnace gas, than with very inflammable gases, such as town gas or natural gas."

It should also be remembered that it is not so much the percentage of hydrogen in the gas which is important as the percentage of hydrogen in the charge of gas and air introduced into the cylinder; so that a town gas containing 50 per cent. of hydrogen may be no more liable to pre-ignition than a producer gas containing 15 per cent., although these figures seem at first sight to indicate that it would. The town gas would be mixed in the engine cylinder with about 7 times its volume of air, so that the mixture would contain about 6 per cent. of hydrogen. The producer gas, requiring, say, 1.2 volumes of air, would give a mixture containing about seven per cent. of hydrogen, so that there is little to choose between the two cases. If, however, we take two examples of producer gas, one containing 15 per cent. of carbon monoxide and 25 per cent. of hydrogen, the other containing 25 per cent. of carbon monoxide and 15 per cent. of hydrogen, the quantity of air required for combustion is the same in each case. Therefore in the cylinder of the engine there will be 25 parts of hydrogen in the first case and only 15 parts in the second, and the possibility of pre-ignition would arise at a lower compression pressure in the former case.

It is true that when gases are fired in the cylinder of an engine hydrogen explodes more readily than carbon monoxide, and its combustion during the explosion is more complete; but the heat lost in the exhaust is increased, owing to the latent heat of the steam produced. On the other hand, carbon monoxide explodes less readily, and with weak mixtures its complete combustion is less certain; but there is no loss from latent heat.

Whatever the composition of the producer gas may be it is desirable that there should be a good igniter. The old-fashioned slide-valves with ignition ports were certainly troublesome, and

the ignition tubes afterwards used were much more satisfactory ; moreover, they could be heated by a jet of producer gas, so that an installation could be entirely independent of town gas, and an engine could be worked in places where there was no town gas at all. Since about 1903 magneto igniters have found favour, and, as we shall see later, they are essential for suction plants in places where there is no town gas with which to heat a tube igniter. The great point about the ignition is that it should be prompt and sure, especially for a comparatively weak gas such as producer gas. It has now become the practice with large engine-cylinders to ignite the charge at more than one point. The explosion requires an appreciable time to travel through the combustion chamber of the engine, especially with the comparatively weak charges and low compression pressures used in large engines, and the arrangement of two magnetos and sparking plugs to each cylinder not only improves the efficiency of the engine by shortening the period of combustion, but it also makes the ignition more reliable.

In Chapter XV. we shall deal fully with the fuels suitable for producer gas for various purposes, and Chapter IX. will be devoted to the production of gas from bituminous coal for engine work. For gas power, anthracite or coke is generally used for plants up to about 200 B.H.P., and for larger sizes in places where the cost of bituminous coal is not much less than that of the other fuels. From the practical point of view we may say generally that anthracite is rather better to work with than coke of average quality. Both give about the same heat efficiency ; but there is usually more ash in the coke, and consequently there is more trouble with clinker. Also the yield of gas may be taken at about 10 to 20 per cent. less with coke than with anthracite ; consequently, from 10 to 20 per cent. more coke must be used for a given output. It also takes rather longer to get the gas plant in working order for making good gas when coke is used. It follows, therefore, that when the two fuels cost about the same it is better to use anthracite, but that when coke is cheaper it is better to use it, provided it is well carbonised and does not contain more than 10 to 12 per cent. of ash.

In connection with the subject of gas power there is an

interesting invention of Mr. H. A. Humphrey, M. Inst. C.E., which is probably destined to have an important future. We refer to the Humphrey Pump, which employs the principle of internal combustion for pumping liquids. It can be worked with producer or other gas, and independent tests show that the thermodynamic cycle on which the pump works has a greater efficiency than the Otto cycle. There are no moving parts except the mushroom valves, and the use of a flywheel is not necessary since the movements to and fro in the cylinder of a column of water forming part of the water pumped effect the

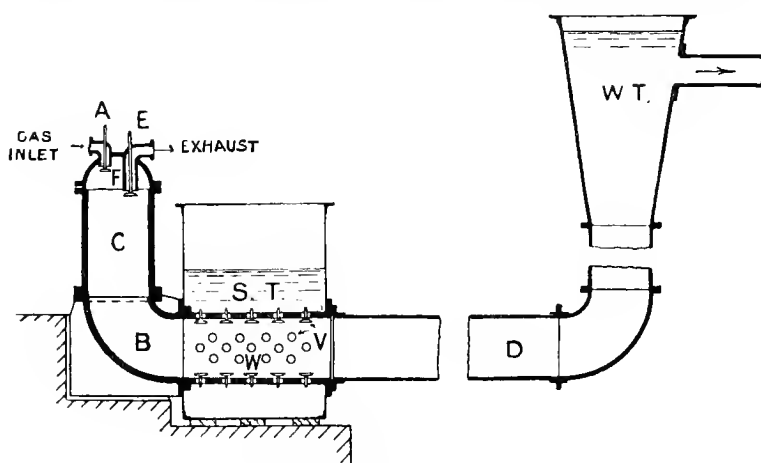


FIG. 41.—Humphrey pump.

actions of exhaust, suction, and compression in the intervals between the pumping strokes. The water column, which also acts as a piston, has four unequal strokes, such as theory requires when expansion is carried to atmospheric pressure. These strokes are—a long stroke during combustion and expansion, another long stroke during exhaust, a shorter stroke during suction, and a still shorter stroke during compression. There is no valve across the discharge pipe at any point, so that the water has a free passage from the explosion chamber to the water tower at a higher level.

Fig. 41 shows a pump with water tower, etc., complete, the pump proper being built up from three main castings. **C** is

the combustion chamber, connected by means of the bend **B** to the water valve chamber **W** and the discharge pipe **D**, which leads to the water tower **WT**. The suction tank **ST** embraces the valve box chamber, so that there is a free access of water to all the water valves **V**. These water valves are plain mushroom valves, opening inwards, and held on their seats by light springs. In the top of the combustion chamber are fitted a gas inlet valve **A** and an exhaust valve **E**. A simple interlocking gear is arranged between these two valves, so that when the valve **A** closes it locks itself shut and releases the valve **E**, and when the valve **E** closes it locks itself shut and releases the valve **A**. Consequently, each time that suction occurs in the chamber **C** the valve **A** opens and the valve **E** is closed; when the exhaust occurs the valve **E** opens and the valve **A** is closed.

A charge of gas and air is compressed in the top of chamber **C** and is fired by a sparking plug which projects through the top casting. All the valves are shut when the explosion occurs, and the increase in pressure drives the water downwards in the pump and sets the whole column of water in the discharge pipe in motion, and when the expanding gases reach atmospheric pressure the column of water may be moving at, say, 6 feet per second. The motion of this column of water cannot be suddenly arrested, hence the pressure in **C** tends to fall below that of the atmosphere; the exhaust valve **E** opens, as well as the water valves **V**. Water rushes in through the water valves mostly to follow the moving column in the pipe **D**, but partly to rise in the chamber **C** in an effort to reach the same level inside the chamber as exists in the suction tank. When the kinetic energy of the moving column has expended itself by forcing water into the water tower, it comes to rest, and, there being nothing to prevent a return flow, the column starts to move back towards the pump and gains velocity until the water reaches the level of the exhaust valve, which it shuts by impact. A certain quantity of burnt products is now imprisoned in the cushion space **F**, and the energy of the moving column is expended in compressing this gas cushion to a greater pressure than that due to the static head of the water in the water tower **WT**. Hence a second outward movement of the column results, and when the water in **F** reaches the level of valve **E** the pressure in the space **F** is

again atmospheric, and further movement of the water opens valve **A** against a light spring and a fresh charge of gas and air is drawn in. Once more the column of water returns under the water tower pressure and compresses the charge of gas and air, which is then ignited to start a fresh cycle of operations.

The only moving parts (the valves) open and shut under slight changes in pressure, and are all on their seats when the explosion occurs; consequently there is no shock, and the pump works quietly and smoothly.

It is said that the fuel consumption of the Humphrey Pumps, for a given horse-power in the water lifted, is less than with any other type of pump, whether driven by gas or steam, and this statement is confirmed by independent tests made with a small pump by Prof. W. C. Unwin, F.R.S. After careful investigation, the Metropolitan Water Board, under the advice of their Chief Engineer, Mr. W. B. Bryan, M. Inst. C.E., adopted this system on a large scale for their pumping station at Chingford, in Essex. Official tests of this remarkable installation were made in June, 1913, and the following is a general summary of the results¹:—

The pumping plant consists of five Humphrey internal combustion pumps working on producer gas, the gas being supplied by four Dowson pressure producers gasifying anthracite coal. Four of the pumps were each to be capable of delivering 40 million gallons of water per day of 24 hours, or 27,780 gallons per minute, and the remaining pump was to deliver half this quantity, the water being raised in all cases to a height of 25 to 30 feet. Three of the gas-producers were each to be capable of gasifying 370 lbs. of anthracite per hour, and the remaining producer 138 lbs. per hour.

Before the pumps were tested each gas-producer was tested separately during six hours to ascertain for each producer the quantity and heat value of the gas made per pound of anthracite consumed. The height of the fire was measured at the beginning of each test, and maintained approximately constant, and in all cases the level at the end of the trial was the same as at the start. Coal was fed into the producer about every 15 minutes, and the gas made was measured through a rotary gas meter,

¹ *Engineering*, December 19th, 1913.

and was burnt. The meter was calibrated before and after each test against the fall of a gasholder. Each half-hour the calorific value of the gas was measured by a Junkers calorimeter, and simultaneous analyses of the gas were made. Ordinary anthracite of good quality was used, its calorific value being given as 14,600 B.Th.U per pound (8100 calories per kilo).

The results of these tests are given in Table XIV.:—

TABLE XIV.—PRODUCER GAS TESTS, JUNE, 1918.

Producer Number	1	2	3	4
Date	June 9.	June 5.	June 2.	June 10.
Duration of test hrs.	6	6	6	6
Anthracite used during test . . lbs.	2031	2024	2002	854
Anthracite used per hour . . . lbs.	338·5	337·3	333·6	142·3
Temperature of gas deg. Cent.	17·1	20·5	21·0	17·1
Pressure of gas ins. mercury	30·35	29·97	30·2	29·96
Gas made at 60° Fahr. and 30 ins. "				
cub. ft.	166,389	166,736	171,244	67,140
Gas made per pound of coal . . cub. ft.	81·9	82·4	85·5	78·6
Gas made per hour cub. ft.	27,732	27,789	28,540	11,190
Average calorific value, B.Th.U. per cub. ft. :—				
Higher value	157·9	155·1	155·7	156·4
Lower value	147·4	145·0	145·9	146·8
Average analysis of gas, per cent. by volume	CO ₂	5·7	5·8	5·8
	O ₂	0·2	0·4	0·5
	CO	24·3	24·8	25·2
	H ₂	19·5	19·5	18·3
	CH ₄	1·8	1·5	1·3
Average boiler pressure . . lbs. per sq. in.	54·7	55·7	50·5	54·7
Weight of coke used in boiler . . lbs.	303	279	319	88

A summary of the Humphrey Pump tests, which were afterwards made, is given in Table XV. :—

TABLE XV.—SUMMARY OF RESULTS OF HUMPHREY PUMP TESTS.

Pump Number	1	2	3	4	5
Number of tests made	6	6	6	6	6
Average duration of tests minutes	9.27	8.95	8.37	9.67	10.0
Lift in feet.	30.01	30.24	30.06	32.6	30.24
Water pumped . . . gallons per minute	33,407	32,773	33,047	32,663	18,116
Pump H.P. developed	308.9	300.4	301.1	322.7	166.0
Gas used per minute at 60° Fahr. and 30 ins. mercury cub. ft.	395.4	393.3	391.5	400.1	191.6
Calorific (lower) value of gas, B.Th.U. per cub. ft.	145.7	146.4	146.2	142.2	138.1
Average thermal efficiency per cent. .	22.39	22.19	22.33	24.07	26.63
Anthracite used per P.H.P. hour . lbs.	0.946	0.957	0.949	0.881	0.796

The Contractors guaranteed, under heavy penalties, that the consumption of anthracite should not exceed 1.1 lb. per water H.P.-hour, and the Chief Engineer was able to report officially that the average fuel consumption of the four large pumps was only 0.931 lb. per water H.P. per hour. The small pump, rated at 20 million gallons per day, gave a still lower average of only 0.8 lb., the general average of all the five pumps being 0.904 lb. of anthracite per water H.P.-hour. He further reported that each of the large pumps which was specified to lift 40 million gallons per day gave an actual average of 47.5 million gallons per day, and the small pump which was to lift 20 million gallons actually raised 26.1 million gallons per day. These results are believed to be unprecedented. The heat efficiency of the gas-producers was given as over 82 per cent., and the pumps converted into work 23.5 per cent. of the heat of the gas they consumed, so that 19.3 per cent. of the heat energy of the fuel was converted into useful work.

After a lapse of some months the Chief Engineer reported that the endurance tests provided for in the contract had been fulfilled satisfactorily.

CHAPTER VII

SUCTION PLANTS

WE have seen that in some of the early gas-producers used for furnace work air was drawn into the producer by suction, instead of being forced in under pressure, as in producers of later date. In recent years the idea of working the producer by suction, instead of by air at pressure, has been reverted to, chiefly in connection with gas-engines. As early as 1862 Dr. Jacques Arbos, of Barcelona, patented a combination of gas plant and gas-engine in which the latter drew gas direct from the producer. It was not a very practical arrangement, and the charge of gas and air was not compressed before ignition, but it deserves to be mentioned as one of the early suction plants devised. The first to give effect to this idea in a practical way in a compression engine was M. Léon Bénier, of Paris. His first patent was in 1891, and he afterwards took out others; the gas plant shown in Fig. 42 represents what he first used for practical work (1894) in conjunction with the special engine shown in Fig. 43. In the former figure, **A** is the gas-producer; **B** the feeding hopper; **C** a revolving grate containing water; **D** a chamber to receive steam produced in **C**; **D'** is a chamber open at the bottom to receive steam from **D** and allow it to expand to atmospheric pressure; **E** the air inlet; **E'** a passage for steam from chamber **D'**; **F** a mixing chamber for steam and air at atmospheric pressure; **G** the inner casing of gas-producer; **H** an annular space for steam and air to pass from **F** to the bottom of fire, the steam and air being heated on the way; **I, I** an annular space for hot gas from the producer; **J** a cylinder with water inside; **K** an inner cylinder, of which the lower end is dipped in water in **J** so as to form a washer for the gas, with an overflow leading to the tank **L**; **N** a chamber to receive gas, with outlet **O** at the top.

The engine had a suction pump by the side of the motor cylinder, as shown in Fig 43, and this pump was connected by a pipe with the outlet **O** in Fig. 42. As soon as the fire was lighted it was blown up with a hand-power fan, and when the gas was good enough to work the engine, the latter was started. The pump on the engine then drew gas from the producer and

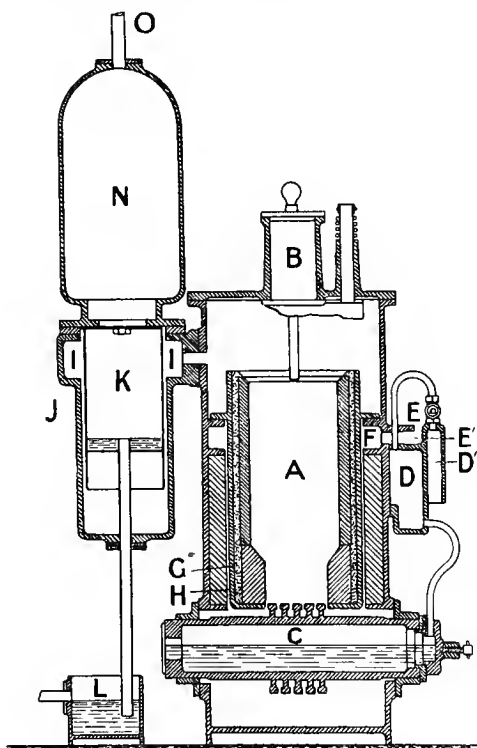


FIG. 42.—Bénier early suction plant.

forced it into the motor cylinder. This suction of gas from the producer lowered the pressure in the latter, and as a consequence air from the outside (at atmospheric pressure) flowed in through the inlet **E**. The steam or water-vapour formed in **C** mixed with the air before the latter entered the fuel column, and both steam and air were drawn together into the fire. By suitable adjustments, the volume of air drawn in varied with the rate at which gas was consumed in the engine; in other words, the

rate of producing the gas was governed automatically by the engine itself, and both the gasholder and the independent boiler were dispensed with altogether. As this plant and those of which it is the type work by suction they are now generally known as *suction plants*, to distinguish them from pressure plants worked by air at pressure.

Prof. Aimé Witz, of Lille, tested M. Bénier's combination of gas plant and engine, made to serve about 15 B.H.P. The first

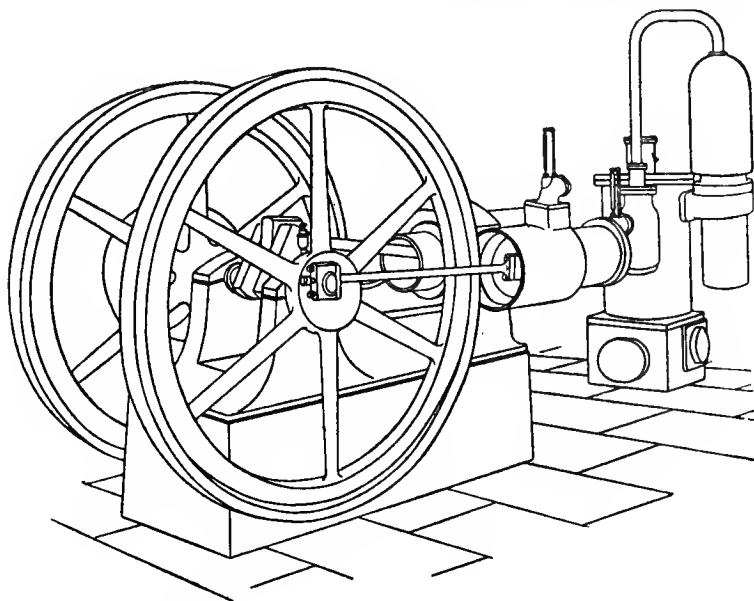


FIG. 43.—Bénier gas-engine and suction plant.

trial¹ was with English anthracite of good quality, and the calorific power of the gas was 1149 calories per cubic meter, or 129 B.Th.U. per cubic foot, higher value. The engine developed 27.6 I.H.P., but only 14.59 B.H.P.; while the consumption of anthracite was 714 grams, or 1.57 lbs. per B.H.P.-hour. A second trial was made with ordinary gas coke in the producer, and the calorific power of the gas was then as low as 1035 calories per cubic meter, or 116 B.Th.U. per cubic foot. The engine developed

¹ "Moteurs à Gaz," vol. iii. p. 186; *Encyc. Brit.*, 10th edition, vol. xxviii. p. 606.

14.7 B.H.P., and the consumption of coke was 752 grams, or 1.66 lbs. per B.H.P.-hour. These results were with a full load on the engine, and it is probable that the gas would have been still weaker if the load had been much reduced, as the temperature of the fuel most favourable for making the gas would probably not have been maintained.

At that date (1895) the consumption of fuel in a pressure plant, *i.e.* the consumption of anthracite in the producer and of coal or coke in the boiler, was guaranteed by different makers not to exceed a total of 450 to 500 grams (1 to 1.1 lb.) per B.H.P.-hour. There was, therefore, a considerable loss of fuel by using the suction plant of that date, notwithstanding the fact that it required no independent boiler, while the amount of fuel consumed in the boiler of the pressure plant usually represented from one-sixth to one-fifth of the total fuel consumed. The gas was poor in quality compared with that made in a pressure plant, and there were other drawbacks ; but the idea was an ingenious one, and it was seen that the working of a gas plant by suction in combination with an engine would have distinct advantages if the practical details could be worked out in a satisfactory manner.

Several engineers gave their attention to the subject, and the next step of importance was to do away with the pump on the engine and to use the suction of the engine itself, *i.e.* the suction caused by the outstroke of the piston in the motor cylinder, to draw gas from the gas plant. This reduced appreciably the loss from engine friction. Various methods have been devised for producing the steam required and for removing the clinker formed in the producer, as the arrangements adopted by M. Bénier were not satisfactory. He himself recognised this, and his more recent apparatus showed several modifications and improvements in this respect. The production of the steam required to make gas of good quality and to keep the temperature of the fire low enough to prevent the formation of an excessive amount of clinker presents many difficulties. Some makers have a water-vapouriser inside the producer, sometimes near the bottom of the fire, but more often near the top ; and they heat it by the fire or by the hot gas which leaves the fire. In some cases both these sources of heat are used. On the other hand,

some makers prefer to have the vapouriser outside the producer and to heat it by the sensible heat of the gas after it has left the producer. The latter system has the advantage of cooling the gas more, but the amount of steam raised is less than in the other systems, and there is the risk that the gas will not always be hot enough to make the full quantity required. This not only affects the percentage of hydrogen, etc., in the gas, but has an important bearing on the formation of clinker. It is, in fact, essential that there should be a sufficiency of steam; yet this point does not always receive the attention it deserves.

The steam is produced at atmospheric pressure, and to avoid losses by condensation when it mixes with the air drawn into the producer the steam, or the mixture of steam and air, is sometimes superheated by passing it through a chamber heated by the fire in the lower part of the producer. Another method adopted is to heat the air supply to the producer by causing it to be drawn through a jacketed space surrounding the body of the producer or the gas outlet pipe. The heating of the air supply by waste heat from the producer has further important advantages; a certain quantity of heat which would otherwise be lost is carried back to the producer, so that more steam can be decomposed and the efficiency of the process improved; when the producer is working at a small output, and the temperature of the fire tends to become too low (*see* p. 168), the hot air-supply assists in maintaining the working temperature; and further, the producer starting all cold is sooner brought into its normal working condition.

So long as the temperature of the mixture of steam and air entering the fire is below 100° C. the quantity of steam or water vapour in the mixture is limited, not by the quantity produced in the vapouriser, but by the temperature of the mixture; for at temperatures below 100° C. the air can only carry a certain proportion of water vapour (*see* p. 322). The air current may at times carry with it water in suspension in the form of small drops, formed by the condensation of any excess of steam from the vapouriser, beyond the amount required for saturation (*see* pp. 122, 123), but this should be avoided as far as possible, since the introduction of liquid water (or wet steam) into the fire is not favourable to the production of good gas. The diagram, Fig. 44, based on

the figures given in Table XLIV., shows the weight of water vapour in one kilo of saturated air at different temperatures. In a small or moderate-sized producer working with anthracite or coke, the amount of steam used in the producer should be from 0.75 to 1.0 kilo per kilo of fuel, or about 16 to 21 per cent. by weight of the saturated air. It will be seen from the diagram that the temperature of the air should be from 65° to 70° C. (say 150° to 160° F.) in order that it may carry a sufficient quantity

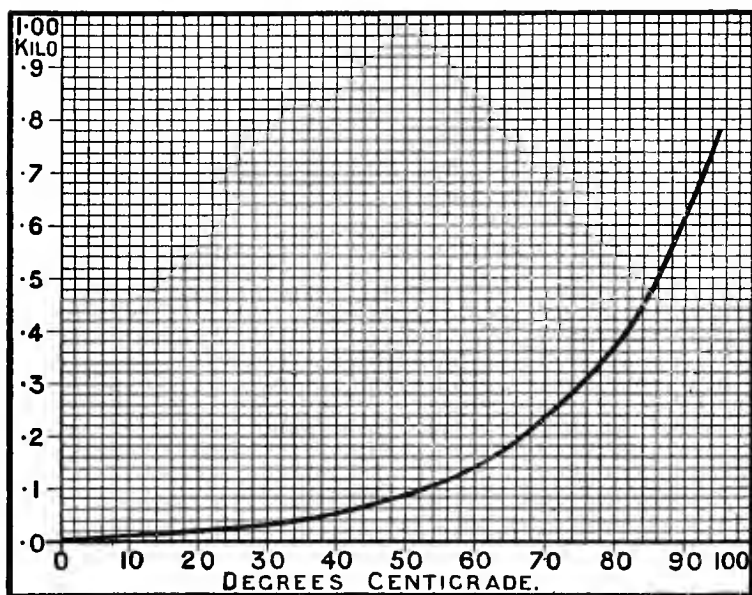


FIG. 44.—Weight of water vapour in 1 kilo. of saturated air.

of water-vapour. It is therefore important that the producer should be designed so that the mixture of steam and air is heated at least to this temperature before entering the fire, and so that this temperature is reached as soon as possible after starting. The increased tendency to clinkering when a heated air-blast is used may be counteracted by using sufficient steam, and when the air is heated in any of the ways described it is of course all the more important that a sufficient quantity of steam be used with it.

Apart from producing a sufficient quantity of steam when the

maximum volume of gas is required, there is the further necessity for regulating the quantity of steam drawn into the fire when the load on the engine is variable. It has been supposed that when less gas is produced, *i.e.* when less air is drawn into the fire, the lowering of temperature which follows causes less steam to be produced, and that in this way the quantity of steam produced is proportional to the quantity of gas required. This is only partly true, as actually the temperature of the fire does not vary as quickly as the load on the engine may vary, and although there may be a considerable fall in the load, there is usually heat enough in the fire to produce more steam than is then desirable. If this excess of steam continues, it not only causes an excess of carbon dioxide to be formed, but it damps down the fire. Then, when the load is increased suddenly, the temperature of the fire is not high enough to give effect to the necessary reactions, and the gas is not good enough to develop the power required. Some makers of suction plants try to get over this difficulty by having regulating valves worked by the engine, by means of which the admission of steam to the fire is governed by the engine. Some merely allow a vent in the vapouriser for the excess of steam to escape when the load is reduced, some make no special provision at all; while Mr. Dowson and others have used the suction of the engine to draw water into the vapouriser in very small quantities, just enough at each suction stroke to give the steam required for the quantity of gas to be consumed. This has answered well, and as a result the engine governs not only the admission of air to the producer but also the admission of water to be converted into steam. This can only be done provided the vapouriser flashes the water into steam; if the vapouriser holds a body of water, as in a boiler, steam is given off continuously, and although there might be a governing of the feed-water the quantity of steam produced would not be governed.

We cannot emphasise too strongly the importance of providing steam enough, and of regulating the quantity to suit all the variations in the volume of gas produced.

While suction plants were of comparatively recent date few complete tests of them had been published, and when Sir D. Clerk was preparing his James Forrest Lecture for the Institution of Civil Engineers in April, 1904, he was anxious to know the

actual heat efficiency of a suction plant. Mr. Dowson therefore placed at his disposal two plants of this type, one for 30 B.H.P., the other for 40 B.H.P., as shown in Figs. 45 and 46, and both were rigorously tested on his behalf by Mr. M. A. Adam, B.Sc.¹

In Fig. 45, **A** is the grate on which the fuel rests; **B** is the container holding a store of fuel which is admitted through the

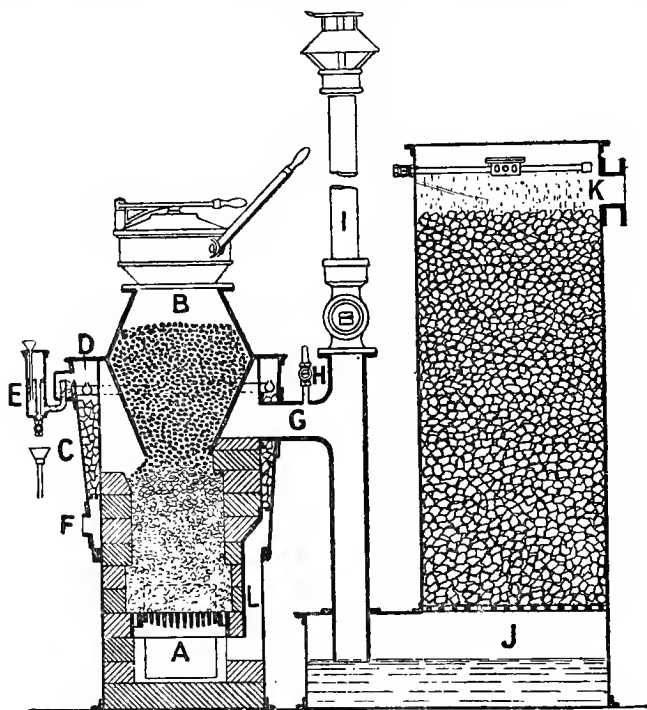


FIG. 45.—Dowson suction plant (30 B.H.P.) tested by Mr. Adam.

hopper and valve at the top; **C** is a chamber filled with loose pieces of firebrick; **D** is a circular pipe with holes in the top, which receives water from the feed-pot **E**; this feed-pot has a continuous supply and a constant level overflow, and it forms one limb of a **U**-tube, the other limb being in the vapouriser. Normally the water is just at the level of the open end of the **U**-tube in the vapouriser, and when the sucking action of the engine occurs a small quantity of water overflows; the supply of

¹ *Proc. Inst. C.E.*, 1904, vol. clviii. p. 320.

water to the vapouriser is thus in proportion to the number of working strokes made by the engine. **F** is the air inlet, and **G** the gas outlet, with test-cock at **H**; **I** is a chimney or waste pipe; **J** is a coke scrubber with water-seal at the bottom; **K** is the gas outlet. There was also a small hand-power fan (not shown in the figure) for blowing up the fire at the start. When the plant is to be worked, a little oily waste and some wood are put on the grate **A**, and the producer is filled with anthracite or coke in small pieces. The feeding hopper is then closed, and the cock on the waste-pipe **I** is opened; the fire is then lighted, through a door on the level of grate **A**; the fan is set in motion, and the products are in the first instance allowed to escape through the pipe **I**. The water-supply is turned on, and as soon as gas will burn well at the test-cock **H**, it is ready for use in the engine; the cock on the waste pipe **I** is then closed, and gas is blown off through another waste pipe near the engine until good gas from the producer reaches the gas-cock on the engine. The fan is then stopped and the engine is started. From this time the engine itself draws in the air required for the producer, as well as the water to be vapourised in the chamber **C**, the mixture of steam and air passing downwards from **C**, through **L** to the underside of the grate **A**.

In Fig. 46 similar reference letters are given to the various parts of the apparatus, but it will be noticed that the details of construction, especially of the vapouriser, etc., are somewhat different. The process of making the gas is, however, the same in both the plants.

The fuel used in Mr. Adam's trials was the ordinary commercial quality of anthracite peas from one of the well-known collieries in South Wales, as used regularly at the works of the makers of the gas plants.

On each occasion the plant was worked fully eight consecutive hours, the producer being started cold. Samples of the anthracite were taken by Mr. Adam, and were analysed by Mr. Bertram Blount, F.I.C. Gas for sampling was drawn off continuously by an aspirator during the whole of the tests, and samples were taken every half-hour by Mr. Horatio Ballantyne, F.I.C., and were afterwards analysed by him. In the 30 H.P. trial, half-hourly determinations of the calorific power of the gas were

also made by Mr. Adam with a Junkers calorimeter. All the thermometers used were corrected by thermometers standardised at Kew, and every precaution was taken to avoid the possibility of error.

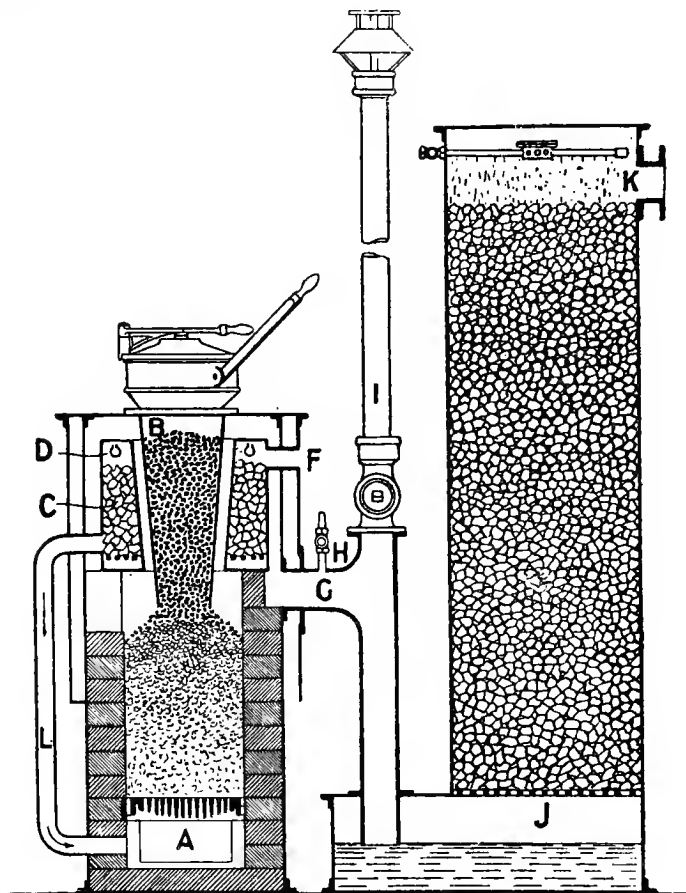


FIG. 46.—Dowson suction plant (40 B.H.P.) tested by Mr. Adam.

To start the fire in each producer the small hand-power fan already described was used, and in about ten minutes after lighting the fire the gas was good enough to start a gas-engine, as shown by a flame at the test-cock *H*. As soon as the gas was good enough the hand-power blower was stopped and a power-driven suction fan was started to draw the gas steadily from the

producer. This was taken to represent fairly the action of an engine under constant load drawing gas from the producer, a fan being used instead of a gas-engine so that the gas might be measured and tested accurately. The gas was delivered by the fan under pressure through a new large dry meter into a gas-holder; it then passed out through a pipe and was burnt. A diagrammatic view of the testing apparatus used is shown in Fig. 47. In this **A** is the gas-meter; **B** the suction fan; **C** the gasholder; **D** a shut-off valve; **E** the gas outlet; **F** a branch tube conveying gas to the sampling apparatus **G**, in which **H** is the

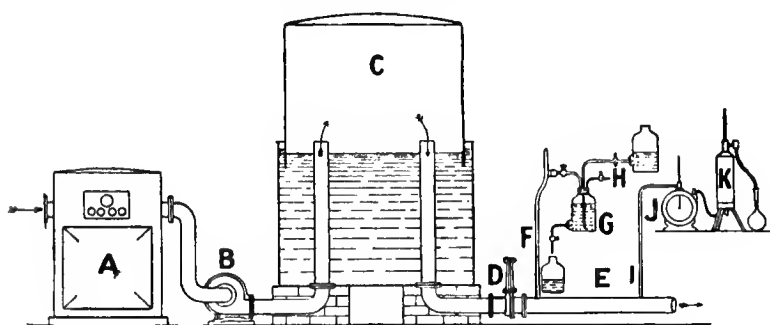


FIG 47.—Diagram of testing apparatus.

outlet for drawing off samples; **I** is another branch tube conveying gas to the testing meter **J** and calorimeter **K**.

The heat efficiency of each plant was taken in two ways. In the first the whole test from start to finish was included, *i.e.* a start was made with the producer and other apparatus all cold. In the second the test began after the plant had worked two hours, so as to determine the heat efficiency of a plant working continuously after it had been fairly started. For this test the fuel was made up to a definite level at the end of the first two hours, and again at the end of eight hours, so that the fuel actually consumed during the last six hours could be ascertained, after making due allowance for the clinker and ash found in the producer. The general results are given in the following tables, XVI. and XVII., which are based on a table compiled by Mr. Adam: —¹

¹ *Proc. Inst. C.E.*, 1904, vol. clviii, p. 322.

TABLE XVI.—TRIAL OF 30 B.H.P. SUCTION PLANT WORKING WITH ANTHRACITE.

	FUEL.					GAS.						
	Calorific value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.	Calorific value.		Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Heat efficiency.	
	Calories per kilo.	Per cent.	Per cent.	Kilos.	Calories.	Per cent. by volume.	By calculation.	By Junker calorimeter.	Cubic meters.	Calories.	Per cent.	Per cent.
Whole run—cold start.	7955	3·37	3·975	109·48	870,950	H 15·2 CH ₄ 1·2 CO 21·0 CO ₂ 8·2 O 0·2 N 54·2	Higher 1225 Lower 1139	1243 —	531·90	652,000	70	75
Last six hours—hot start.	7955	3·37	3·975	71·94	572,280	H 15·60 CH ₄ 1·21 CO 21·05 CO ₂ 8·41 O 0·20 N 53·53	Higher 1240 Lower 1152	1243 —	382·88	474,600	77	83

TABLE XVII.—TRIAL OF 40 B.H.P. SUCTION PLANT WORKING WITH ANTHRACITE.

	FUEL.					GAS.						
	Calorific value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.	Calorific value.		Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Heat efficiency.	
	Calories per kilo.	Per cent.	Per cent.	Kilos.	Calories.	Per cent. by volume.	By calculation.	By Junker calorimeter.	Cubic meters.	Calories.	Per cent.	Per cent.
Whole run—cold start.	7715	3·60	8·76	111·25	853,250	H 15·59 CH ₄ 1·31 CO 19·05 CO ₂ 5·93 O 0·79 N 57·33	Higher 1180 Lower 1091	— —	619·82	731,000	79	85
Last six hours—hot start.	7715	3·60	8·76	81·65	629,900	H 15·64 CH ₄ 1·16 CO 20·13 CO ₂ 6·09 O 0·74 N 56·24	Higher 1204 Lower 1117	— —	473·29	570,000	84	90

NOTE.—The above results in British weights and measures, as well as those of Table XVIII. are given in Tables XXV., XXVI., and XXVII. in Appendix A.

In his report Mr. Adam explained that, "For the sake of convenience of comparison, the efficiencies on the lower heating value¹ are given in addition, but it should be remembered that the loss through condensation of the steam produced by the burning of the hydrogen of the gas is, in reality, a gas-engine loss, and not a producer loss, so that the efficiency on the higher heating value is the true heat efficiency."²

It will be seen that the heat efficiency of the 30 B.H.P. plant was 75 per cent. for the whole eight hours' run with a cold start, and 83 per cent. for the six hours' run with a hot start. For the 40 B.H.P. plant it was 85 per cent. with a cold start, and 90 per cent. with a hot start. We are not able to explain precisely why the heat efficiency of the 30 H.P. plant was lower than that of the 40 H.P. plant. Under the mixed conditions which prevail when gas is being made it is hardly possible to measure all the heat losses in detail; but it may be fairly assumed that the principal cause of the lower efficiency of the smaller apparatus was that it had greater cooling surfaces in proportion to the body of fire in the producer and to the volume of gas produced. In the 40 H.P. plant the cooling surfaces were relatively smaller. As a general result the heat efficiencies of these two small plants were certainly satisfactory, and do not leave much room for improvement.

It may be added that during these tests the following quantities of water were used:—

For the vapouriser of 30 B.H.P. plant, about 20 lbs. per hour.

"	"	40	"	"	30	"	,
For the scrubber of 30	"	"	"	"	380	"	,
"	"	40	,	"	400	"	"

The rise of temperature of the scrubber water at the overflow was about 40° C. or 72° F.

¹ See p. 297.

² A Committee appointed by the Institution of Civil Engineers to consider and report on the standards of efficiency of internal combustion engines, state in their report that it is preferable to use the lower calorific value of a gaseous fuel in calculating the thermal efficiency of an engine (*Proc. Inst. C.E.*, vol. clxii. part iv. page 319). If this recommendation be followed, the thermal efficiency of a gas-producer for engine work should be reckoned on the lower calorific value of the gas, whilst for heating work the higher calorific value is used. We have, therefore, given both the higher and lower calorific values of the gas wherever possible.

It was then arranged that Mr. Larter should make a similar test with small gas-coke in the producer, instead of anthracite. This test was begun the day after Mr. Adam's tests were finished, and precisely the same 40 H.P. gas plant and the same testing apparatus were used, without any modification whatever. Samples of the coke were analysed by Mr. Blount, and during the whole of the run the same method of sampling the gas was employed as in the anthracite tests, also the calorific value of the gas was calculated from the analyses and was determined by the calorimeter.

TABLE XVIII.—TRIAL OF 40 B.H.P. SUCTION PLANT WITH COKE.

	FUEL.					GAS.						
	Calorific value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.	Calorific value.		Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Heat efficiency.	
							By calculation.	By Junker calorimeter.			Lower value.	Higher value.
	Calories. per kilo.	Per cent.	Per cent.	Kilos.	Calories.	Per cent. by volume.	Calories per cubic meter.	Cubic meters.	Calories.	Per cent.	Per cent.	
Whole run—cold start.	6932	—	11.37	125.28	868,400	H 12.0 CH ₄ 0.4 CO 25.5 CO ₂ 5.3 O 0.65 N 56.15	Higher 1186 Lower 1089	1189 —	616.88	731,700	80	84
Last six hours—hot start.	6932	—	11.37	94.85	657,500	H 13.2 CH ₄ 0.35 CO 25.3 CO ₂ 5.4 O 0.6 N 55.15	Higher 1212 Lower 1144	1218 —	482.86	585,200	84	89

In the trial with coke the following quantities of water were used :—

For the vapouriser, about 25 lbs. per hour.

For the scrubber, „ 600 „ „

With these results before us, we are able to compare closely some points of interest connected with the use of coke and anthracite respectively, and we have summarised them in Table XIX.

chiefly because the gas was poor in hydrogen. This will be readily understood by a glance at the following diagrams (Figs. 48, 49, and 50), in which we have shown the variations in the com-

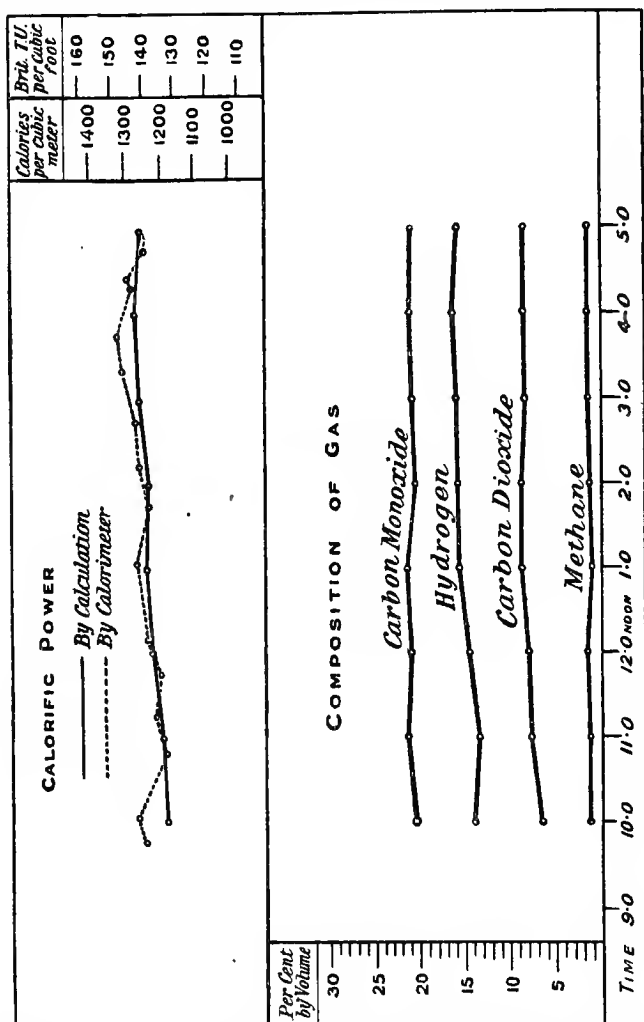


Fig. 48.—30 B.H.P. suction plant—trial with anthracite.

position and calorific power of the gas at different hours during the trials. It is noteworthy that when the producer has reached the normal working condition the composition of the gas and its calorific power are remarkably constant.

It should, however, be understood that although the gas made at the beginning of the trials (before the producer had been thoroughly heated) was of low calorific power, it required less air

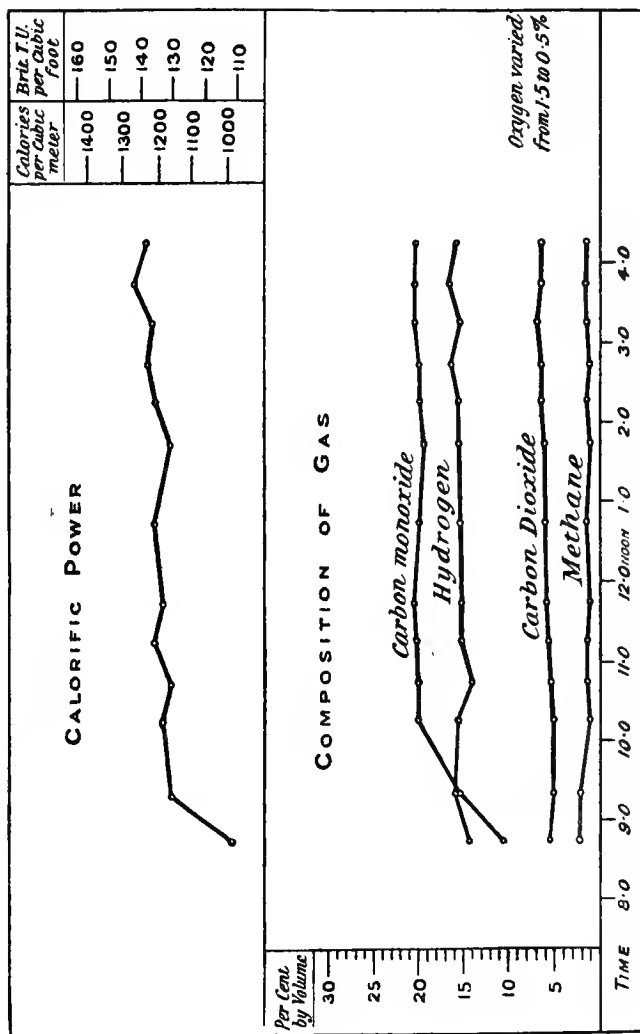


FIG. 49.—10 B.H.P. suction plant—trial with anthracite.

for its complete combustion. A larger volume of the gas could therefore be used in an engine cylinder of given size, and the power which the engine could develop would not be appreciably reduced.

If, for instance, the heat energy contained in one unit volume (cubic meter or cubic foot) of a mixture of the gas mentioned in column 5 of Table XIX., with air in the proportion theoretically

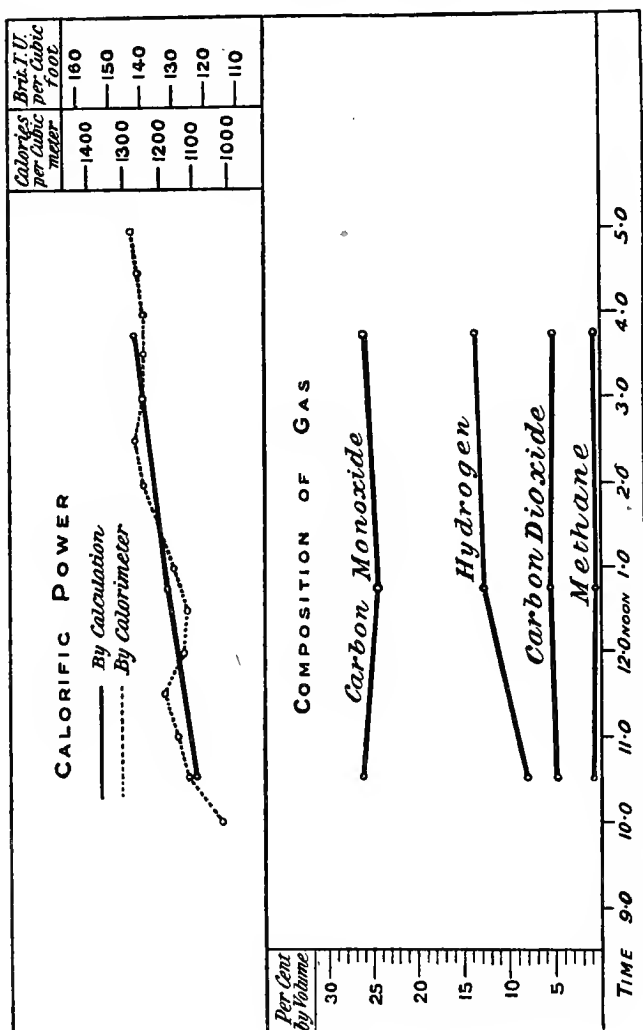


FIG. 50.—40 B.H.P. suction plant—trial with coke.

required for its combustion be taken as 100, the heat energy contained in one unit volume of similar mixtures of the other gases with air, would be 99, 99, 99, 99, and 102 respectively. Approximately,

therefore, the powers which could be obtained in the same engine with these six gases would be in the proportions of 99, 99, 99, 99, and 102. Practically, therefore, a gas-engine will give the same maximum power with any of these different qualities of gas.

If we compare the figures of the "hot start," *i.e.* for the last 6 hours of the run, it will be seen that the coke gas is slightly richer, and contains a higher total percentage of combustible gases. But the yield of gas per kilo of fuel consumed is considerably lower, and this is due to the poorer nature of the fuel, the coke containing 11.37 per cent. of ash, while the anthracite contained 8.76 per cent. The coke, also, had practically no volatile constituents which would enrich the gas, whereas the gas made from anthracite was considerably enriched in this way.

Before we leave this branch of the subject it will be interesting to compare the gas made in a pressure plant with that made in a suction plant. For this purpose we have taken the results obtained by Mr. Adam with the 40 B.H.P. suction plant, and those obtained in a careful trial of a 40 B.H.P. steam-jet pressure plant of the Dowson type. We have also given the average results of seven different pressure plants of this type of various sizes ranging from 8 to 300 H.P.¹ All the plants referred to were worked with anthracite, and the comparative results are given in Table XX.

From this it appears that the calorific power of the pressure gas is approximately 20 per cent. higher than that of the suction gas. In the latter the percentages of hydrogen and carbon monoxide are lower, while the percentage of nitrogen is higher, and less air is required for the combustion of the suction than of the pressure gas; but after allowing for this it will be seen that (approximately) an engine which will develop 100 I.H.P. with the pressure gas will only give 92 I.H.P. with suction gas, a decrease in the maximum power of the engine of 8 per cent. On the other hand, the heat efficiency of a complete pressure-gas plant with an independent boiler would necessarily be lower than that of a suction plant which produces its own steam without an independent boiler. If the steam for the pressure plant were raised by the sensible heat of the gas produced, as is sometimes done, we should not have to take into account the separate fuel

¹ See *Proc. Inst. C.E.*, 1901, vol. cxliv. p. 282.

TABLE XX.—COMPARISON OF SUCTION AND PRESSURE PLANTS.

	Suction plant, 40 B.H.P. (hot start).	Pressure plant, 40 B.H.P. (hot start).	Pressure plant. Average of seven plants (hot start).
<i>Composition of gas (per cent. by volume)—</i>			
Hydrogen	15.64	19.8	17.36
Methane	1.16	1.3	1.20
Carbon monoxide	20.13	23.8	25.55
Carbon dioxide	6.09	6.3	5.77
Oxygen	0.74	—	0.30
Nitrogen	56.24	48.8	49.82
Total combustible gases .	36.93	44.9	44.11
<i>Calorific value—</i>			
Calories per cubic meter—			
(higher scale)	1204	1463	1432
(lower scale).	1117	1354	1336
B.Th.U. per cubic foot—			
(higher scale)	135.3	164.4	161.0
(lower scale).	125.5	152.2	150.2
<i>Air required for combustion of</i> <i>unit volume</i>	0.927	1.162	1.122
<i>Yield of gas—</i>			
Cubic meters per kilo of fuel consumed in producer . . . }	5.80	5.04	5.01
Cubic feet per ton of fuel con- sumed in producer . . . }	208,000	181,000	180,000
<i>Heat of combustion (lower value)</i> <i>of one cubic meter of an ex-</i> <i>plosive mixture containing</i> <i>gas and air in the propor-</i> <i>tions required theoretically</i> <i>for combustion . calories</i>			
	580	626	630
<i>Approximate power given by an</i> <i>engine which will give 100</i> <i>H.P. with the gas of column 3</i>			
	92	99	100

consumption of the boiler in calculating the heat efficiency, and the figures show that the heat efficiencies of the two plants (pressure and suction) would then be nearly alike. We may therefore assume that the heat liberated by the exothermic reactions is recovered in each case to about the same extent by the endothermic reactions.

A suction plant has manifest practical advantages—it costs less, it is more simple to work, and requires much less labour and less fuel; but the gas made in it is not so strong as in the older form of pressure plant, and in some cases this advantage of the latter is important.

In June, 1906, as many as twelve different suction plants and

engines of about 15 to 20 B.H.P. each were tested at Derby, on behalf of the Royal Agricultural Society of England. The chief object of these trials was to determine—as far as circumstances permitted—whether suction plants could be relied on for agricultural and estate purposes, bearing in mind that they would have to be worked by unskilled labourers. The consumption of fuel and water was also noted, and a full report of the trials was drawn up by Captain H. R. Sankey, R.E., who was one of the Judges. He thus summarises the results (p. 41):—

“From these trials it can be deduced that the following fuel and water consumptions may be expected with a good suction producer plant when working continuously at the loads specified and under the best conditions:—

ANTHRACITE.

Full load : 1·1 lb. per B.H.P.-hour, including fuel needed for starting and for banking during the night.

Half load : 1·6 lb. per B.H.P.-hour, including coal for starting.

Water : 1 gallon per B.H.P.-hour at full load, and $\frac{3}{4}$ gallon at half load.

COKE.

Full load : 1·3 lb. per B.H.P.-hour, including fuel needed for starting.

Water : $1\frac{1}{2}$ gallons per B.H.P.-hour at full load.”

On p. 55 he says : “It is evident from the results of the trials that many of the suction gas-producer plants submitted for trial were quite satisfactory. There can be no reasonable doubt that with due care any of them would give satisfaction if employed for agricultural work as an ‘estate’ engine.”

We will now give some typical examples of the numerous suction plants which are made in this and other countries. Fig. 51 represents the plant made by M. Delassue, of Paris; the vapouriser is below and around the lower part of the fire, and the admission of steam to the fire is governed by a valve actuated by the engine, so that steam is admitted during the suction stroke only, any excess being allowed to escape into the air. In this way it is claimed that the quantity of steam converted into gas is always in the proportion required by the

engine under any variation of load. The firebox at the bottom of the producer has an opening to admit the air required, and

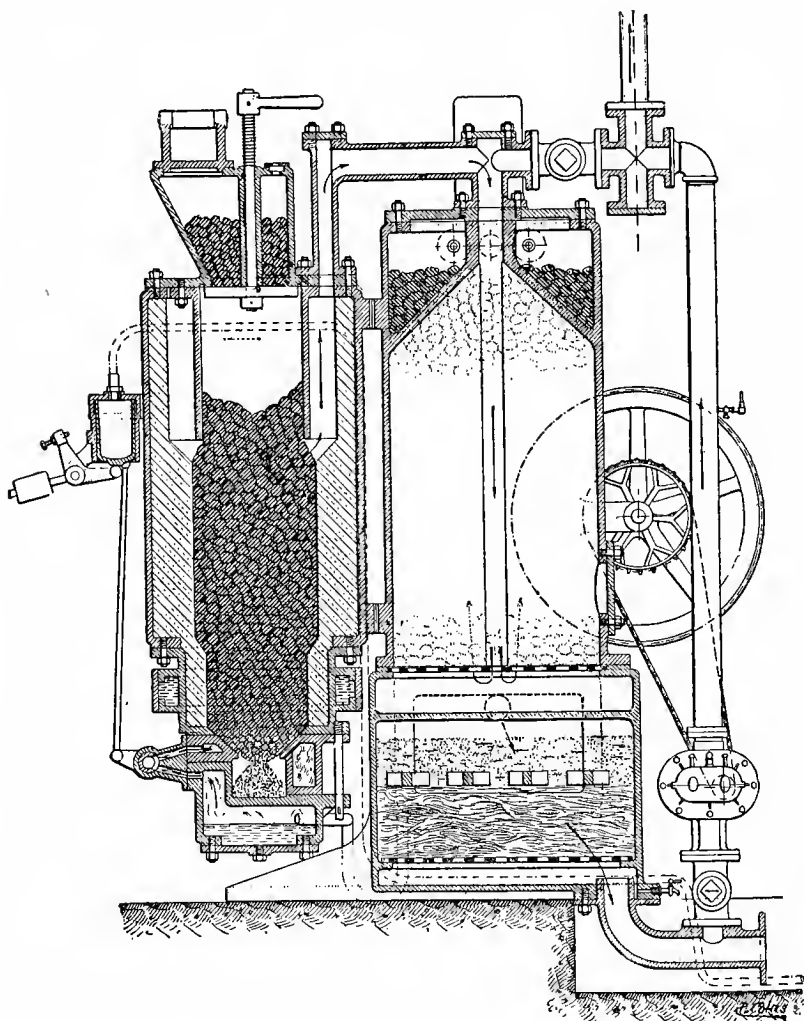


FIG. 51.—Delassue suction plant.

there is a suction fan on the outlet of the plant to draw up the fire at starting, instead of the usual blower. When the gas is good enough to serve the engine, it passes down a central pipe in

the coke scrubber, then upwards through coke, and finally through sawdust in the base of the scrubber, to the outlet.

In Fig. 52 we represent the plant made by MM. Fétu-Defize, of Liège, Belgium; in this, **A** is the producer, **B** a scrubber, and **P** a washer. The fuel is introduced through the feeding hopper

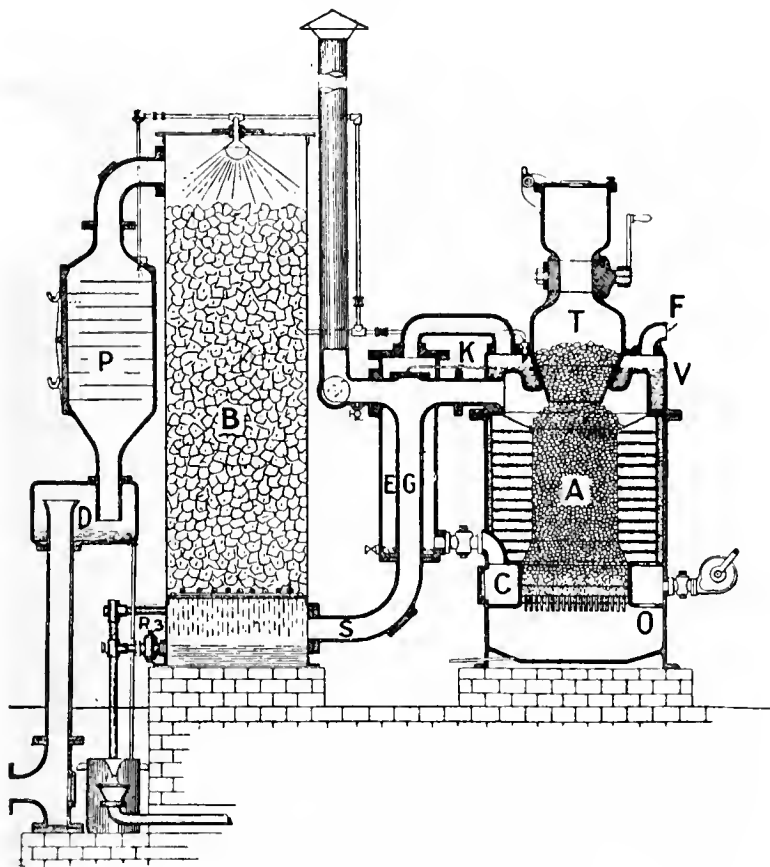
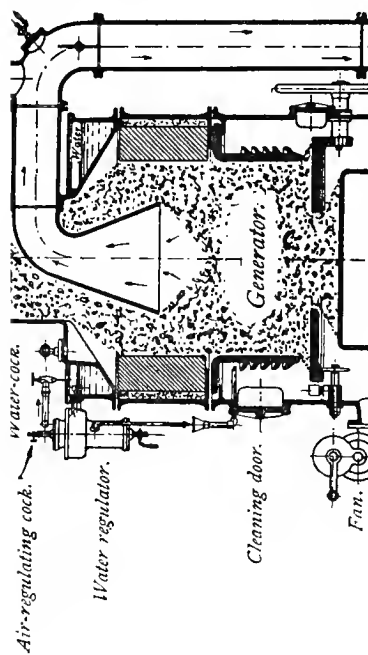
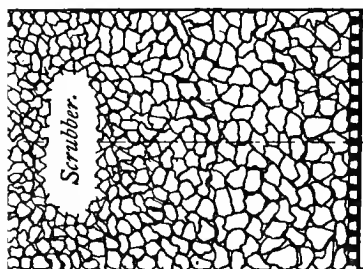


FIG. 52.—Fétu-Defize suction plant.

T; the vapouriser **V** is at the top of the producer. When the engine takes gas, it draws in air at **F**, and this air mixes with the steam in the vapouriser; the mixture of steam and air then passes through the chamber **E**, and is heated by contact with the pipe **G**, through which the hot gas passes. The steam and air afterwards

PRODUCER GAS

Gas outlet



pass through the chamber **C**, which surrounds the lower part of the fire, and are then discharged through **O** into the space under the firegrate. The gas from the producer passes through **G** into the scrubber **B**, and then through the washer **P**. No provision other than the escape of steam at **F** is made for regulating the proportion of steam for varying loads.

Fig. 53 shows the plant made by Mr. A. Bollinckx of Huyssinghen, Belgium. The vapouriser is in the lower part of the producer and consists of a circular casting with gills or channels running round the outside of it. The feed-water passes into a chamber near the top of the producer, and from there it overflows into the channels surrounding the vapouriser. Although the fire is in contact with the vapouriser it is said that the latter is not overheated because of the water and evaporation on the outside of it, also no clinker adheres to it. The fuel rests partly on a fixed hearth and partly on a rotating table, and the ash and clinker fall into a water trough at the bottom, when the table is turned. There are doors facing the outside of the vapouriser so that the channels can be scraped and cleaned when required, and this can be done while the plant is working. The gas escapes through a central funnel and outlet pipe to the scrubber.

In Fig. 54 we show the suction plant now made by Messrs. Crossley Brothers, Ltd., of Manchester. In this **A** is the gas-producer, **B** the steam raiser, **C** the scrubber, **D** the feeding hopper, **E** the water regulator, **F** poking holes, and **G** an open-hearth stepped grate. The steam raiser **B** consists of a series of gilled pipes fed with water, and heated on the outside by hot gas from the producer. The steam thus produced passes through a pipe round the fire in the lower part of the producer, and enters the fire through suitable holes. The admission of water **B** is carefully regulated by the system of piping **E**, a small vacuum chamber being connected by a pipe to the gas outlet of the producer, so that when the engine takes a charge of gas the suction allows water to enter **B**. The fire in the producer is blown up by a suction fan near the engine instead of the more usual pressure fan near the producer.

Fig. 55 represents the latest design of the makers of the Dowson suction plant for powers of 100 B.H.P. and upwards. The producer has an open hearth, so that clinker and ash can

be removed while the plant is working. The vapouriser is inside the top of the producer, and is an annular chamber of which the sides and bottom are made of mild steel; the top or cover of the vapouriser consists of cast-iron segmental plates

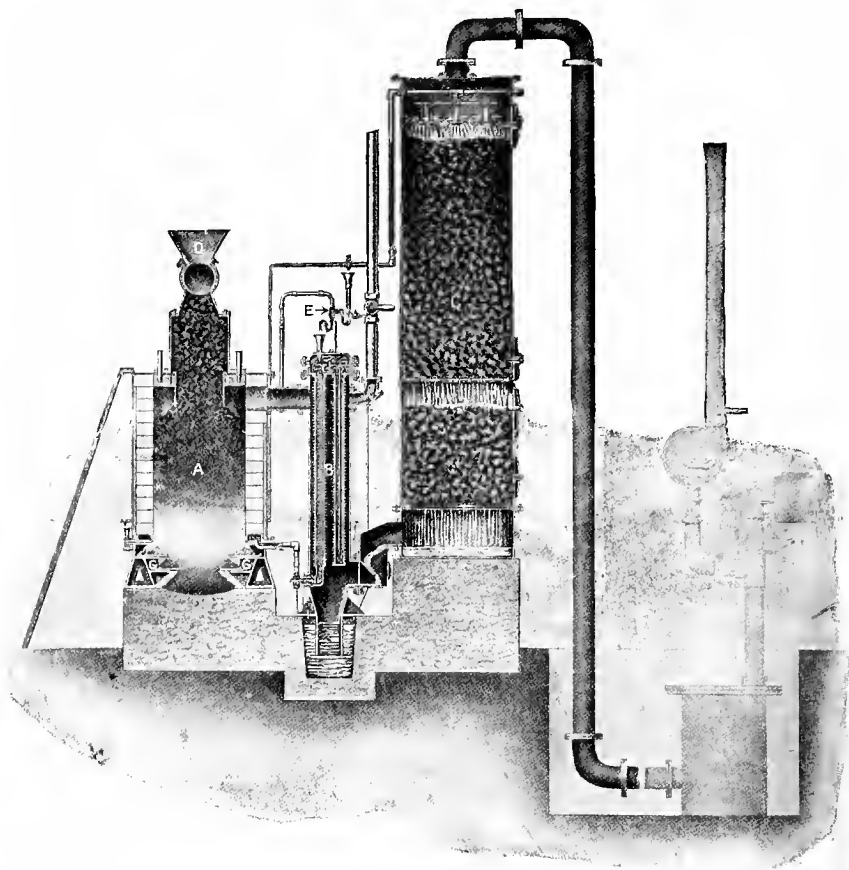


FIG. 54.—Crossley suction plant.

which are clamped down, so that there is easy access to the inside of the vapouriser to remove deposits of lime, etc. The water supply to the vapouriser is constant, with a visible overflow to ensure the water level inside being always the same. A steam pipe is taken from the vapouriser through the gas outlet pipe of the producer, and is then connected to a distributing ring of

pipe, just under the bottom of the firebrick lining. This ring has holes in it which allow steam to escape through them; steam is drawn into the fire when the engine sucks, and when there is no suction the steam escapes into the surrounding air. In this way the engine governs the admission of steam as well as air to the fire.

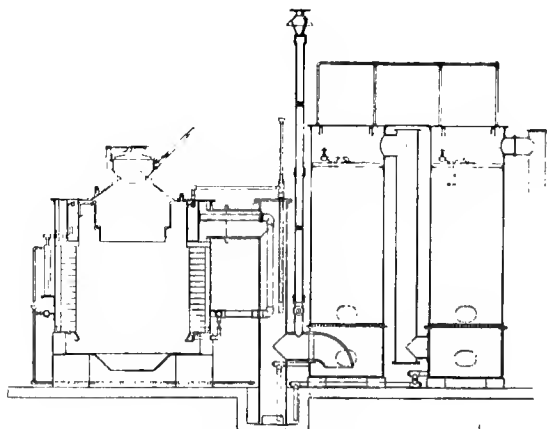


FIG. 55.—Dowson suction plant for 100 B.H.P. and upwards.

With a pressure plant a closed hearth for the producer is of course necessary, but for suction plants the leading makers have given up the closed hearth. They use instead a water-bottom, or preferably some form of open hearth. In this way the bottom of the fire can be cleaned and clinkers removed, without stopping the plant or affecting the quality of the gas; with this means of keeping the fire in good working order the composition of the gas is more uniform. When necessary it is not only possible, with an open hearth or water-bottom, to run the plant for several months without a stop, but it is also possible to use coal of inferior quality, as the clinker can be more easily removed.

CHAPTER VIII

SUCTION PLANTS (CONTINUED)

WHEN suction plants were first introduced, several makers of gas-engines feared that the increased suction in the cylinder would seriously reduce the maximum power developed by the engine, compared with that obtained with gas at pressure from a gasholder. Some makers estimated this loss in maximum power at 20 to 25 per cent., and although this was an exaggeration the fact remains that there is a loss, and it will be well to consider what actually occurs. In the first place, we should remember that the suction in the cylinder, to draw in the required volume of gas and air, is distinct from the additional suction required to draw air into the producer and gas through the plant and mains. In the next place, we should remember that when gas at pressure is used it passes through an elastic gas-bag, which to a certain extent keeps up a gas pressure during the suction stroke, and that when a suction plant is used the gas is never above the atmospheric pressure. In the one case we have a head of gas at pressure to draw from; in the other no head of gas, and the pressure in the gas main falls below atmospheric as soon as the engine begins to draw in its charge.

There are various systems of governing a gas-engine. In this country the usual system is the "hit-and-miss" (*tout ou rien*), in which the gas only is governed, the quality of the mixture of gas and air admitted being constant, while the charge is admitted at intervals to suit the varying load. On the continent the almost invariable practice is to admit gas at every cycle, but to govern the quantity of the mixture of gas and air admitted, the quality being constant. There is good in both these systems, the chief advantage of the throttling system being that there is a more even turning moment. It would, however, be beyond the scope of this work to discuss this interesting question in

detail, but especially in connection with suction plants we should consider the loss of power caused by the suction of air when the gas-valve is closed during the governing stroke in engines using the hit-and-miss system. This does not affect the maximum power of the engine, but it is a practical question of importance because it does affect every governing stroke, and in average work an engine is usually working at about one-third less than its maximum output. This does not occur in the throttling system of governing where a working charge is drawn in at every suction stroke. The losses of power so far referred to are the direct losses due to fluid friction; they occur with both pressure and suction working, but may be greater in the latter than in the former case: they are considered in detail later in this chapter. The principal loss of power arises in an indirect manner, and as this is the most important we discuss it first.

For the purpose of comparison we will assume that the gas from a suction plant has the same calorific power as the gas from a pressure plant, also that the gas and air supplies on the engine are regulated to give the best explosive mixture obtainable. The charge then drawn into the cylinder will have the same composition, and the difference to be considered will be the *amount* of the charge in each case. Usually the admission valves close a little after the piston has completed its outstroke, but they do not remain open long enough for any portion of the charge to be expelled at the beginning of the compression stroke. Therefore in each case the same *volume* of charge is drawn in, viz. that equal to the volume swept out by the piston. In both cases the pressure of the charge is below that of the atmosphere while the admission valve is open; but in the case of gas from a suction plant this pressure is lower than when the gas is supplied at pressure, and therefore the *quantity* or weight of the charge is less. We shall not be far wrong in assuming that in a modern gas-engine the pressure in the cylinder falls to $1\frac{1}{2}$ lbs. per square inch below atmospheric pressure during the suction stroke, when gas at pressure and air are being drawn in.¹ But to compare the quantities of gas drawn in we should know the pressures at the *end* of the suction stroke when the cylinder is full. According to Sir D. Clerk,² when pressure gas is used and when the valves

¹ See p. 164. ² "The Gas Engine," 1902 edition, p. 308 and Fig. 125.

are properly set the pressure at the end of the suction stroke rises to that of the atmosphere. In some early experiments with a 40 B.H.P. engine working with a suction plant the pressure in the cylinder was about $1\frac{1}{2}$ lbs. below atmospheric at the end of the suction stroke, as shown in Fig. 56. This pressure was, therefore, 13·2 lbs. per square inch, compared with 14·7 lbs. per square inch for pressure gas. The weights or quantities of explosive mixture would be in the same ratio, and the maximum power of the engine—confining our attention to this cause only—was $\frac{13\cdot2}{14\cdot7}$, or 90 per cent. of its maximum power when working with gas at pressure. In a well-designed plant and engine, however, the pressure in the cylinder at the end of the suction stroke should not be more than 0·5 lb. per square inch below atmospheric; the maximum power would then be $\frac{14\cdot2}{14\cdot7} = 96\cdot6$ per cent. of the maximum power of the same engine working with gas at pressure.

When an engine is working with pressure gas from a gas-bag and gasholder it is probable that the pressure on the supply side of the gas-cock on the engine does not fall to more than 3 ins. of water below atmospheric during the suction stroke; but we have seen that the pressure in the cylinder during the suction stroke falls to $1\frac{1}{2}$ lbs., or about 42 ins. of water, below that of the atmosphere. This shows that however plentiful the supply of gas may be, the piston moves forward so quickly that there must be a considerable wire-drawing until near the end of the stroke. In the case of working with suction gas, as in Fig. 56, the suction on the supply side of the gas-cock was $11\frac{1}{2}$ ins. of water, and it might be expected that the pressure in the cylinder during the suction stroke would fall much more than when pressure gas was used. Actually the pressure shown on the diagram by the upper of the two suction lines, which represents the drawing in of a working charge, is not more than 2 lbs. below the atmospheric. At the end of the suction stroke, which for the moment is the important point to consider, the piston moves comparatively slowly as the crank approaches the horizontal position, and with pressure gas (having a pressure equal to a few inches of water) the gas continues to flow into

the cylinder, and the pressure in the latter rises practically to atmospheric, as stated above. With suction gas, although Fig. 56 shows a slight rise of pressure (from 2 lbs. to $1\frac{1}{2}$ lbs. below atmospheric) at the end of the suction stroke when the piston is moving more slowly, the pressure does not rise to the same extent as with pressure gas. The reason for this is that there is only the reduced pressure in the cylinder to draw the gas through the producer, scrubber, etc., and gas valve, instead of there being gas at pressure on the inlet of the gas-cock, as in the other case. It should also be noted that the higher the speed of the engine the greater will be the loss of power from this cause; and that the gas and air valves should therefore be held open as long as possible after the out centre has been

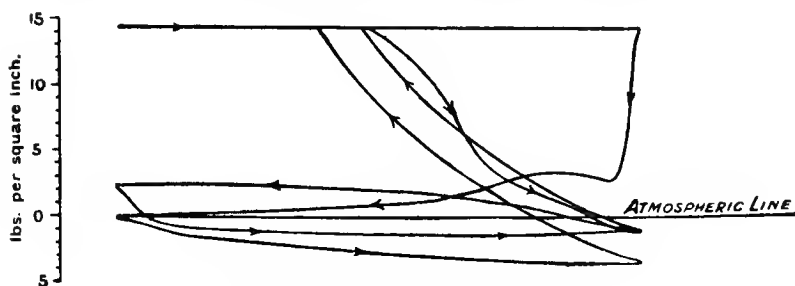


FIG. 56.—Suction diagram (light spring).

reached, without risking the expulsion of gas at the beginning of the compression stroke.

With these facts in view it is clearly important to reduce the resistances in the gas plant to a minimum; the connecting pipes between the engine and plant should be fully large, and with as few bends as possible; and it is also desirable to have an enlarged pipe or gas-box close to the engine so that there may be a reserve of gas to draw from. In this way the fall of pressure in the gas main is reduced; and what is now usually termed an expansion box takes the place of the gas-bag used for pressure gas. This expansion box can also be used to catch any condensed moisture from the gas, if the main leading to it has a fall in that direction.

To reduce the suction it is usual to place the engine tolerably near the gas plant; but provided the main is direct and of ample

size it is quite satisfactory if the engine is 50 ft. from the plant. With a well-designed plant the suction near the engine will then be from 8 to 10 ins. of water or even less. If the distance is greater than 50 ft. special care should be taken to avoid friction in the pipe. We have had to deal with a case where the engine was about 150 ft. from the plant, and yet the gas suction in the expansion-box near the engine was only 11 ins. of water. Where two or more engines are to be served by one suction plant, or where there are two engines and two plants and the sets are to be interchangeable so that either plant can serve either engine, a special arrangement of piping and shut-off valves should be adopted. The chief consideration should be to avoid complications and excessive friction; the number of valves and bends should be minimised. In some cases it is best to have a suction fan between the engines and gas plant, so as to draw gas from the latter and deliver it at pressure to the engines.

To complete our comparison of working with pressure or suction gas we will now revert to the engine itself and refer briefly to the subject of fluid friction. When an engine works with a suction plant there is obviously a direct loss due to the action of the piston as a suction pump, and it is often supposed that this is the chief loss when working with suction gas. The engine is its own pump, and this necessarily involves loss of power; but actually this loss is a small one, and is not nearly as great as the other losses which have to be taken account of. Taking Sir D. Clerk's statement¹ that when pressure gas is used the pressure in the cylinder during the suction stroke falls to $1\frac{1}{2}$ lbs. below the atmospheric, we can compare this with Fig. 56, which shows that with suction gas the pressure in the cylinder falls to 2 lbs. below atmospheric. In the latter case, the work done by the engine as a pump, over and above the similar work which it would do when supplied with gas from a gasholder and a gas-bag, is equal to $0\cdot5$ lb. \times piston area \times stroke \times number of power strokes. This loss is greatest when the engine is working with a full load, and taking the case of an engine developing a maximum of about 40 B.H.P. (with producer gas), the cylinder may be taken as 13 ins. diameter, the stroke 20 ins. and the number of revolutions per minute 170. The loss of

¹ *Journal of Soc. Arts*, 1905, vol. liii.

power due to this extra half-pound suction will then be $0.5 \times 132.7 \times \frac{20}{12} \times 85 \times \frac{1}{33.300} =$ about 0.3 H.P. From this cause alone the maximum indicated horse-power will therefore be reduced by only 0.3, compared with that obtained with gas at pressure.

With engines governed by throttling the mixture of gas and air, there is no difference in the fluid friction losses with pressure and suction gas when working below full load, but with hit-and-miss governing there is an indirect loss due to the fact that the air inlet to the engine must be smaller for suction than for pressure gas, so that the negative work of the idle stroke is increased. When the engine is not fully loaded and the governor allows the gas valve to remain shut, air alone is drawn into the cylinder on the suction stroke; and when this occurs the pressure in the cylinder behind the piston is always lower than when both gas and air are admitted. The reason of this is that on the governing stroke the whole contents of the cylinder are drawn through one opening (the air inlet), instead of through two openings (the gas and air inlets). This occurs with suction or pressure gas, but when suction gas is used the suction in the cylinder is greater, and consequently the air inlet must be smaller, if the proportions of gas and air drawn in for the useful cycles are to be the same in both cases. It follows, therefore, that the loss of power by fluid friction on the idle cycles is greater when working with suction than with pressure gas.

In Fig. 56 the lowest line of all represents the suction stroke when the gas valve remains closed; this shows a pressure of $5\frac{1}{2}$ lbs. per square inch below atmospheric during more than half the stroke, and the average for the whole stroke is about 4 lbs. per square inch. If we assume that with pressure gas the average would be 3 lbs. per square inch, with suction gas it would be one pound more, and on this basis the extra loss of power would be about half a horse-power for the 40 H.P. engine when the engine is running light, but we believe that rather better results have been obtained. In comparing the power obtainable in the same engine worked with a pressure plant or with a suction plant we have sought to emphasise rather than to minimise the differences between the two systems, so that attention may be drawn to certain directions in which

improvements may be sought. The respective merits of suction and pressure plants for engine work are now fairly well understood, and the high compressions used and other mechanical improvements in the engines have made the combination of engine and suction plant deservedly popular.

Hitherto we have dealt more particularly with engines and suction plants working under full load, and we should now consider what occurs with light and variable loads. We have seen that in a suction plant the *quantity* of gas produced is regulated exactly by the action of the engine, as there is a draught of air and steam through the producer every time that gas is admitted to the engine. If the latter is of the Otto type, when there is a full load the gas valve opens at every fourth stroke ; but when there is a light load the valve is opened less frequently, and consequently there are longer intervals between the intakes of air which are drawn through the producer. It is therefore important to consider how this varying quantity of air affects the condition of the fire and the composition of the gas, especially in view of the fact that in many installations the load may vary within wide limits.

Some gas-producers are better than others, but it is safe to say that none make gas of equal calorific power at all rates of production. They may make gas good enough to drive engines with varying loads, but as our object should be to improve in all directions possible it is worth while to examine this branch of the subject more closely. Speaking generally, the best gas will be produced when the producer is worked uniformly at its maximum, or nearly its maximum capacity ; at any rate of production considerably less than the maximum the calorific power of the gas will be lower. To illustrate this, we will take the case of a 40 B.H.P. engine working with a full load, and with no load at all. We made this test with ordinary gas-coke in the producer ; and although somewhat better results can now be obtained, those we give will serve as an illustration. The full-load test was made when the fire was in good working order, and the no-load test began by throwing off the load and the belt, while the engine continued to run. The latter test lasted three-quarters of an hour. The following table gives analyses which represent the average composition of the gas in each test :—

TABLE XXI.—COMPOSITION OF GAS WITH FULL LOAD AND NO LOAD ON ENGINE.

	Per cent. by volume.	
	At full load.	At no load.
Carbon monoxide	27·65	22·4
Hydrogen	9·85	7·0
Carbon dioxide	3·8	4·9
Oxygen.	0·3	0·5
Nitrogen, etc.	58·4	65·2
	100 0	100·0
	Calorific power (lower value).	
Calories per cubic meter . . .	1099	865
B.Th.U. per cubic foot . . .	123·5	97·1

A further useful illustration is afforded by the trials made at Derby, referred to on p. 153. To test the working of the different suction plants at widely different loads they were run for two hours with no load immediately after starting up in cold producers, then for one hour at full load, another hour with no load, and for further successive periods of one hour each at one-quarter, one-half, and full loads. We made use of this opportunity to collect samples and analyse the gas made in a 20 B.H.P. Dowson plant under these varying conditions, and we give the results in the following table:—

TABLE XXII.—COMPOSITION (PER CENT. BY VOLUME) OF GAS MADE WITH ANTHRACITE UNDER DIFFERENT LOADS IN 20 B.H.P. DOWSON SUCTION PLANT AT DERBY.

								Calorific power (lower value).	
Conditions.		CO.	H ₂ .	CH ₄ .	CO ₂ .	O ₂ .	N ₂ .	B.Th.U. per cubic foot.	Calories per cubic meter.
1	First hour, no load. .	10·2	11·06	2·75	11·2	0·1	64·7	93·6	833
2	Second hour, no load .	12·45	12·16	2·0	10·1	—	63·3	96·9	863·
3	Third hour, full load .	22·25	15·9	1·96	5·25	0·1	54·65	141·5	1259
4	Fourth hour, no load .	18·3	13·6	1·2	9·05	0·3	57·55	114·0	1015
5	Fifth hour, $\frac{1}{2}$ load . .	20·0	11·8	0·75	8·35	0 1	59·06	110·3	981
6	Sixth hour, $\frac{1}{4}$ load . .	20·9	14·0	0 7	7·7	—	56·7	119·2	1061
7	Seventh hour, full load	21·5	14·5	1·2	7·6	—	55·2	127·5	1135

It will be seen that the difference in the composition of the

gas is that it contains smaller percentages of carbon monoxide and hydrogen, and larger percentages of carbon dioxide and nitrogen during the no-load periods, and it is noteworthy that while the gas made with no load on the engine, immediately after starting in a cold producer, has a low calorific power and does not materially improve while the producer continues to work without load, yet after the producer has worked for a time at full load, has become thoroughly heated up, and contains a good depth of bright fire, it gives gas of considerably higher calorific power than before when the load is again removed. The explanation of this is mainly a question of temperature. At full-load the intermittent draughts of air through the fire follow one another in quick succession, and the fuel is maintained at a high temperature ; when there is no load there are comparatively long intervals between the in-takes of gas, so that in the producer there are short sharp suction of air with intervals between them during which the temperature of the hot fuel falls. After the producer has been working for a little time at full load, the depth of bright fire is sufficient to make good gas during each of these periods of suction, and the temperature does not at once fall off, so that the producer continues to make fairly good gas for a considerable time after the load has been removed.

If the producer were worked by the continuous suction of a fan instead of by the intermittent suction of an engine the effect during the no-load period would not be quite the same. With a fan there would be a steady draught of the volume of air required, and there would be a shallow zone of fire near the grate, which would be maintained at a sufficiently high temperature to make good gas ; and gas of good quality would be produced as long as this hot zone was sufficiently deep in relation to the size of the fuel. If the air for the producer were drawn in by an engine without load a greater depth of fuel would be heated by reason of the more rapid draught of air through the fire ; but a good deal of heat would be dissipated before the next suction. This points to the importance of maintaining the temperature of the fire as high as possible when the producer is worked at a reduced load by the suction of an engine ; and a step in this direction is to reduce the quantity of steam proportionally to the volume of air drawn in. This was done approximately during the no-load test above

referred to (Table XXI.), but frequently no attempt is made to vary the proportion of steam. If the production of steam is continuous while the in-draught of air is intermittent it follows that after each interval there must be an excess of steam mixed with the air, unless some way of regulating the production or admission of the steam is adopted. If there is too much steam during the light loads this of itself lowers the temperature of the fire and adds to the trouble caused by the small amount of air drawn in. If the air is heated before it reaches the fire, this also will assist to maintain the temperature required.

It is well known that after an engine has been working under a light load for some time with a suction plant there is a risk of stoppage if the full load is put on suddenly. Moreover, when this occurs it is not uncommon to attribute the stoppage to an insufficient supply of gas. This is incorrect, as the volume of gas necessarily varies directly in proportion to the load on the engine ; it is the *quality* of the gas which is wrong, and the explanation of this fact is not far to seek. During the light load the temperature of the fire has fallen, and for a few moments after the full load has been put on there is too little hot fire, and what there is is not hot enough, to effect the necessary chemical reactions. The chief defects are that there is too little hydrogen, and that too little of the carbon dioxide is reduced to the monoxide. The remedy is to put on the full load more gradually, and to check the admission of air to the cylinder, so that the engine may be kept running at full speed in spite of the weakness of the gas ; the fire in the producer will then recover rapidly, and there will soon be a full supply of gas of good quality. These changes are clearly shown in the series of indicator diagrams shown in Figs. 57-63, the adjustments of the gas and air supplies to the engine being unaltered throughout the tests, so that the variations in the mean pressures were due to variations only in the quality of the gas. The engine and suction plant were worked without a load for seventy minutes, and then the full load was suddenly applied, with the following results :—

Fig.	Time.	Mean pressure of indicator diagram— pounds per square inch.
—	2.50 p.m. load off	
57	3.5 " "	76
58	3.15 " "	74
59	3.25 " "	74
60	3.45 " "	73.5
61	4.0 " full load on	decreasing
62		increasing
63		84.5

The diagrams shown in Figs. 61, 62, and 63 were taken in succession, immediately after putting on the full load: while

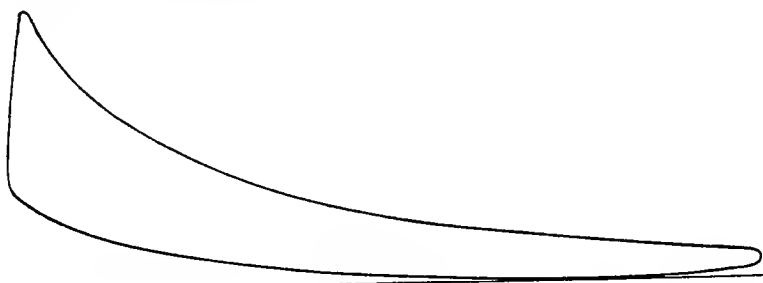


FIG. 57.

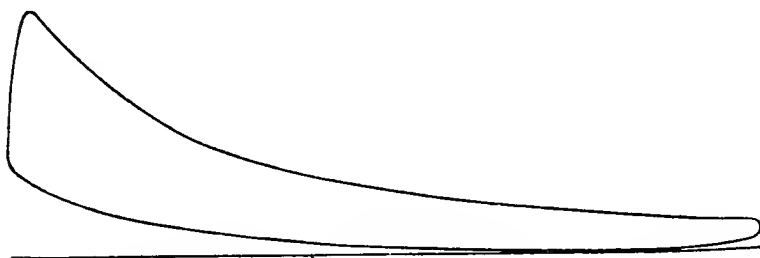


FIG. 58.



FIG. 59.

Fig. 61 was being taken the explosions became weaker and weaker ;
while Fig. 62 was being taken they became stronger and stronger ;

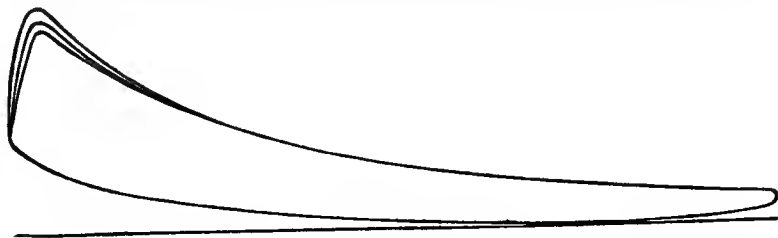


FIG. 60.



FIG. 61.

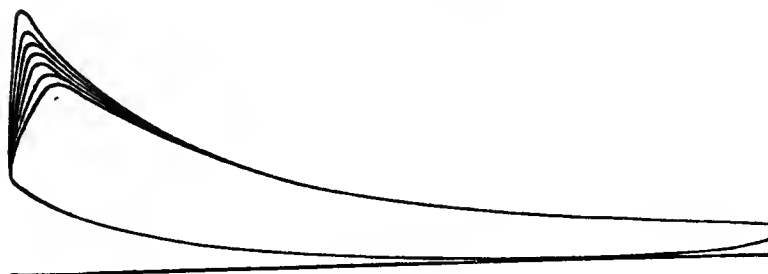


FIG. 62.

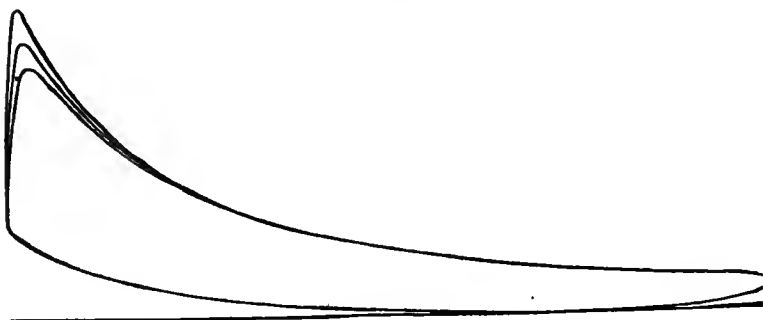


FIG. 63.

and when Fig. 63 was taken the fire in the producer had regained its normal condition, and the explosions were regular and good.

The explanation seems clear. While there was no load on the engine the temperature of the fire was reduced, and the heat required to make the gas existed only in the lower part of the producer near the grate. When the brake was suddenly applied to the engine it at once began to draw in more gas; and consequently more steam and air were drawn into the producer fire. But the fire was not hot enough, nor was there a sufficient depth of hot fuel to complete the reactions. Not all the steam was decomposed, and too little of the carbon dioxide was reduced. The effect would be similar to that of blowing up a rather dull and shallow fire with air saturated with moisture. Until the increased draught had time to produce a good depth of bright fire there would necessarily be a deterioration in the quality of the gas. As bearing on this question we may mention another test we made. On this occasion gas was made with anthracite and the engine was run without a load. The brake was then suddenly applied and in a short time the engine stopped. Immediately after it stopped, a sample of gas was drawn from the main near the engine, and on analysis it showed the following composition:—

Carbon monoxide	16.2	per cent. by volume.
Hydrogen	11.9	” ”
Methane	0.25	” ”
Carbon dioxide	9.4	” ”
Oxygen	0.9	” ”
Nitrogen	61.35	” ”
	<hr/>	
	100.00	
	<hr/>	

The lower calorific value was only 824 calories per cubic meter, or 92.5 B.Th.U. per cubic foot.

By way of illustration, we have thought it best to take the extreme case of an engine running for some time without a load, the full load being then suddenly applied. This would seldom occur in ordinary practice, and the variations would not be so noticeable under the ordinary variations of load; but the principle holds good, and we cannot but emphasise the importance of maintaining, as far as possible, a sufficient depth of fuel at a

sufficiently high temperature for whatever variation of load may be put on the engine. Assuming that the producer is properly designed, there should be no difficulty in fulfilling these conditions under a full load or any intermediate load down to half load or less.

During the Derby trials with anthracite we took numerous samples of the gas made in the 20 B.H.P. Dowson plant, and the following represent the average analyses (per cent. by volume) for full and half loads:—

TABLE XXIII.—COMPOSITION (PER CENT. BY VOLUME) OF GAS MADE WITH ANTHRACITE AT FULL LOAD AND HALF LOAD IN 20 B.H.P. DOWSON SUCTION PLANT AT DERBY.

	Full load.	Half load.
Carbon monoxide	21·95	18·9
Hydrogen	13·85	14·05
Methane	1·55	1·60
Carbon dioxide	7·2	8·05
Oxygen	0·1	0·05
Nitrogen, etc.	55·35	57·35
	100·0	100·0
	Calorific power (lower value).	
Calories per cubic meter	1181 0	1078·0
B.Th.U. per cubic foot	132·8	121·2

It will be seen that at half load there is less CO and more CO₂ and N, owing to the lower temperature in the producer. Consequently the gas is weaker, but it is satisfactory to note that the difference is not great between full load and half load.

There are many engines and suction plants which are working well with smaller loads, but if the gas were analysed it would probably be found to be not of the same quality as it is with the full load, for the reasons already stated. When all or a considerable part of the load is thrown off after working with a full load the quality of the gas will at first be good, because at first there will be more steam than before in proportion to the air drawn in, and the fire will be deep enough and hot enough to decompose it; but this effect will last for a short time only. There is no

difficulty in working a suction plant with a steady load which is only a small fraction of its maximum; the difficulty arises only when the load is increased suddenly. We are aware that several devices have been tried to get over the difficulty; we need not discuss them here as we are merely dealing with the principles involved, and doubtless sooner or later means will be found for doing all that is necessary.

An important feature with a suction plant is the small amount of labour it requires, and the readiness with which gas can be made. With plants up to about 100 B.H.P., the engine can be started in 15 to 20 minutes after lighting the fire in the producer; and not much longer time is needed for larger plants. The producer is then left full of fuel, and the attendant need put on more only at long intervals. In the Report on the Derby trials, Captain Sankey says that, taking a broad view of the results, "a suction gas plant can be started and the full load put on in about 25 minutes from the time of laying the fire, and in 20 minutes from starting the fan if the fire is banked." It has been a matter of surprise that the engine can be started so soon after lighting the fire, and it has been noticed that if the engine is not started promptly the gas is no better when the fire is blown up for a much longer time. The probable explanation is that the wood with which the fire is lighted and the mass of new fuel in the producer soon yield rich hydrocarbon gases; but after a certain time these are exhausted, and then producer gas of the ordinary kind is made.

. After the engine has been started, if the adjustments of air and gas are right, it should continue to work with a constant or varying load, and as long as it works it should regulate automatically the quantity of steam and air drawn into the fire. In this way it will govern the rate of producing the gas to suit its own varying consumption.

CHAPTER IX

GAS FROM BITUMINOUS COAL FOR ENGINE WORK

WHEN Mr. Dowson introduced his gas plant for engine work (1879),¹ the largest gas-engine then made developed under 20 B.H.P., and for various reasons several years elapsed before engines of 50 and 100 B.H.P. came into use. As the fuel consumption was not much over 450 grams (1 lb.) per B.H.P.-hour, the total amount of fuel required was comparatively small, and the mere cost of the fuel per ton was less important than the certainty of having a clean gas free from tar. He therefore worked with anthracite or coke, as these fuels gave much less trouble than bituminous coal, and it is still the general practice to use these fuels, not only for small powers, but also for large powers where bituminous coal costs nearly as much as small anthracite or small gas-coke. In cases, however, where an appreciable saving can be effected by using bituminous coal it is certainly better to use it, provided that the gas can be made clean and suitable. The general aspect of the question has, in fact, altered considerably during the last few years. Many gas-engines of 1500 to 2000 B.H.P. each are now working satisfactorily, and there is no doubt that gas power has a recognised position, even for large powers. It is generally believed that its extension in the near future will be very considerable. It is true that many of the large gas-engines are working with blast furnace gas; but many are also working with producer gas, and it is all-important that there should be gas plants which can convert the cheapest kinds of fuel into gas suitable for large gas-engines. Moreover, for large powers the use of bituminous coal has an important bearing on the competition of gas power with steam power, because in places where steam coal can be bought at a

¹ See Chapter VI., p. 114.

much lower price than anthracite or coke, the saving in weight by using either of the latter in a gas plant might be more than counterbalanced by the lower price of the steam coal used for firing boilers.

The problem is a difficult one, as the gas must be free from tar, or it will foul and clog the valves and gas passages of the engine. There is nothing new in making gas from bituminous coal; this has been done from the first for furnace work—in fact, it is an advantage to have hydrocarbon vapours mixed with the gas when it enters the furnace, because they add appreciably to the heat of combustion. But for engine work there must be no condensable hydrocarbons with the gas when it reaches the engine.

The late Dr. Ludwig Mond was the first to attack this difficult question on a full working scale; but it is interesting to note that what he first attempted was the production of gas for furnaces and the recovery of ammonium sulphate as a by-product: the working of engines with this gas followed afterwards. Nevertheless, we are indebted to him for the introduction of an ingenious and interesting gas plant which has many excellent features. The Mond producer is shown in Fig. 64, and it will be seen that it has a water bottom for drawing out the ashes and clinker; there are also sloping firebars at the base of the producer suitably arranged for poking the fire. The body of the producer is lined internally with firebricks, and outside the body there is an outer casing. The producer is worked with a blast of air from a blower, mixed with a large excess of steam—about $2\frac{1}{2}$ kilos of the latter for each kilo of coal converted into gas; the steam and air pass through the annular space between the body and the outer casing, and thence through the firebars. The chief object of this large excess of steam is to keep down the temperature of the fire, and by doing this a twofold effect is produced. In the first place, it prevents the destruction of the ammonia gas (NH_3); in the next place, it checks the formation of clinker, and thus facilitates the continuous working of the producer. It is said that only half a kilo of steam is decomposed for each kilo of fuel gasified, so that when the gas leaves the producer it is accompanied by a large amount of steam. To reduce the loss on this account, as well as to assist the process,

the hot gas and steam are made to give up some of their heat to the air which is driven into the producer. This is effected by means of a tubular regenerator, the hot gas from the producer passing in one direction through an inner series of pipes, while

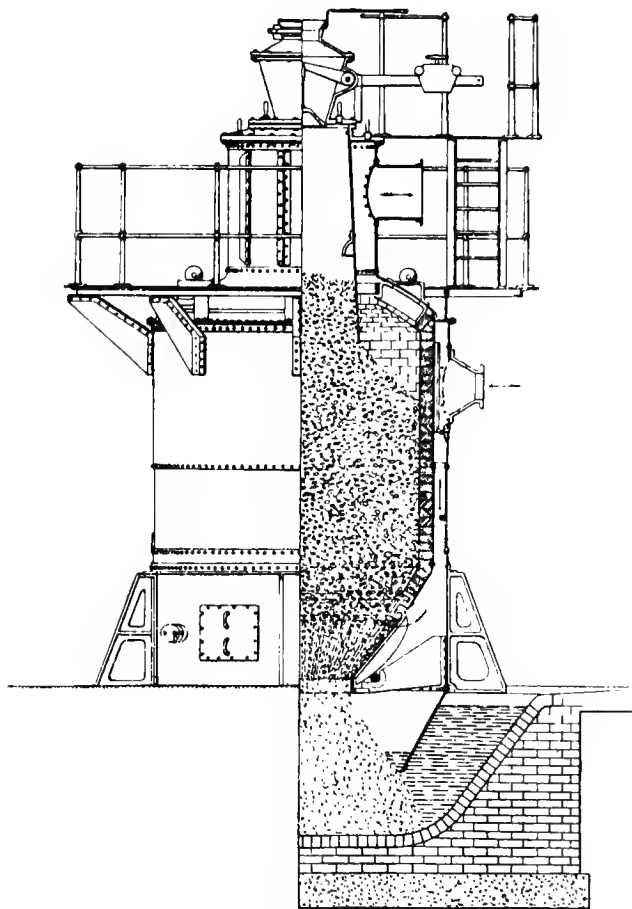


FIG. 64.—Mond gas-producer.

the hot air and steam from an air-heating tower pass in the opposite direction through an annular enclosure round the gas main. The steam and air are further heated by passing round the producer itself, as described above. After leaving the

regenerator, the gas and undecomposed steam pass through a washer and are cooled down to about 90° C. (194° Fahr.); here the gas takes up a further quantity of water vapour by evaporation. The gas then goes upwards through a lead-lined tower packed with tiles, and meets a current of acid liquor (circulated by pumps) containing sulphate of ammonia with about 4 per cent. excess of free sulphuric acid. Combination of the ammonia of the gas with the free acid takes place, so that more ammonium sulphate is formed, and when the gas has been freed from ammonia it is passed through a cooling tower, in which it meets cold water; after this it is ready for use. There is a third tower (called the air-heating tower) in which the hot water from the cooling tower descends, meeting the supply of cold air which is on its way to the regenerator and so heating it and saturating it with water vapour. The regenerative system has been skilfully applied, and the general outcome of the process is that from 70 to 90 lbs. of ammonium sulphate are recovered per ton of coal gasified. The amount of sulphate produced and the composition of the gas depend a good deal on the composition of the coal, especially as to the percentage of nitrogen it contains. In a paper by Mr. W. L. Case,¹ the following are given as the averages of several analyses of the gas produced in the Mond plant, with and without the recovery system:—

TABLE XXIV.—AVERAGE COMPOSITION OF GAS MADE IN MOND PLANT.

	With recovery of ammonia.	Without recovery of ammonia.
Hydrogen per cent. by vol.	24·3	27·5
Methane „ „	2·0	2·0
Carbon monoxide „ „	13·8	11·0
Carbon dioxide „ „	13·9	16·5
Nitrogen, etc. „ „	46·0	43·0
	100·0	100·0
Total combustible gases „ „	40·1	40·5
Calories per cubic meter at 0° C. and 760 mm. (higher value)	1361·0	1375·0
„ „ „ „ (lower „ „)	1223·0	1222·0
B.Th.U. „ per cubic foot „ „ (higher „ „)	153·0	154·6
„ „ „ „ (lower „ „)	137·4	137·3

¹ *Journal Soc. Chemical Industry*, 1905, vol. xxiv. p. 596.

Mr. Case further states that the coal used in both cases was slack, giving the following average analysis:—

Moisture at 100° C. (212° F.)	8·6 per cent.
Volatile matter (excluding carbon)	18·29 „
Total carbon	62·69 „
Ash	10·42 „

For further details of tests made with this interesting plant, we cannot do better than refer to papers read by the Mond Company's engineer, Mr. H. A. Humphrey, M. Inst. C.E.¹

One of the disadvantages of using bituminous coal with a large excess of steam is that a rather complicated and costly regenerative plant is necessary; another is that the high percentage of hydrogen adds to the risk of pre-ignitions in an engine if the compression is raised to the point required for its highest efficiency. The gas has, however, been proved to be suitable for engine work, and many engines are working well with it. The South Staffordshire Mond Gas Company have a large plant for the distribution of this producer gas; and Fig. 65, reproduced from a photograph, gives a general view of the plant in question. It was started with 8 producers, each capable of gasifying about 20 tons of coal per day, together with duplicate ammonia recovery, gas washing and cooling apparatus; also the necessary boilers, machinery, pumps and compressors. More recently four more producers have been added, each to gasify about 30 tons per day. The plant has been laid out so that it can eventually be extended to 32 producers, and Parliamentary powers have been obtained for distributing the gas over an area of 120 square miles. The scheme was a bold one, not only from a financial but also from an engineering point of view, and the results obtained are interesting. The total length of mains laid is about 37½ miles; the trunk mains which leave the central station are 914 mm. (3 ft.) diameter, and the distributing mains are of various sizes; the large mains are made of steel, and are coated first with asphalt, then with canvas, and finally with a second coat of asphalt, the thickness of the coating being about 6 mm. altogether. Owing to the high specific gravity of the gas (0·8 if air = 1), the long distances it has to be conveyed, and the necessity of keeping the sizes of the mains within practical

¹ *Proc. Inst. C.E.*, 1897, vol. cxxix. p. 190; 1913, vol. excii. p. 1; *Proc. Inst. M.E.*, 1901, p. 41.



FIG. 65.—Gas Plant of the South Staffordshire Mond Gas Company.

limits, the gas is forced through the mains at a pressure of about 0.42 kilo per square centimeter, or about 6 lbs. per square inch. For this purpose gas compressors are used, and they are shown in Fig. 66. Each set has two steam cylinders 457 mm. (18 ins.) diameter, working with steam at a pressure of 8.4 kilos per square centimeter, or 120 lbs. per square inch; and two gas-compressing cylinders 1016 mm. (40 ins.) diameter, with a stroke of 1067 mm. (42 ins.). Each compressor is capable of delivering 266 c.m. or 9400 cubic feet of gas per minute, at the pressure mentioned above, and for this output it requires about 240 B.H.P. The exhaust steam from the compressors is used in the gas-producer. A reducing valve is supplied for each consumer, so that the pressure at which he takes the gas into his works or premises can be regulated; for ordinary work it is usually from 1 in. to 3 ins. water gauge; but for high temperature furnace work (1300° C.) and upwards the gas is delivered at a pressure of 3.5 lbs. per square inch (0.25 kilo per square centimeter) and upwards. To measure the gas consumed there is a small rotary meter (the principle of which somewhat resembles that of an anemometer for measuring air), which is said to be fairly accurate. Special joints have been adopted for the mains, because it is not only important to prevent waste of gas, but to prevent leaks—on account of the carbon monoxide in the gas.

The total gas made in 1919 was 4,351,760,100 cubic feet, and the total gas sold during that period was 3,898,120,600 cubic feet. The residuals produced were ammonium sulphate 1279 tons, and tar 3143 tons; the nett value of these was £19,115. The revenue account for 1919 was as follows:—

<i>Receipts.</i>		<i>Expenditure.</i>	
Sale of gas	£130,609	Manufacturing costs, including fuel, salaries, wages, repairs, and maintenance, etc. . .	£119,370
Rent of meters, etc. . . .	1,020	Distribution costs, including salaries, wages, materials, repairs, maintenance and renewal of mains, repairs of meters and experimental work	9,026
Residual products	19,115	Rents, rates, taxes and insurance	3,122
Rents and fees	176	Management, including salaries, Directors' and other fees and general expenses . .	3,545
Total	<u>£150,920</u>	Total	<u>£135,063</u>

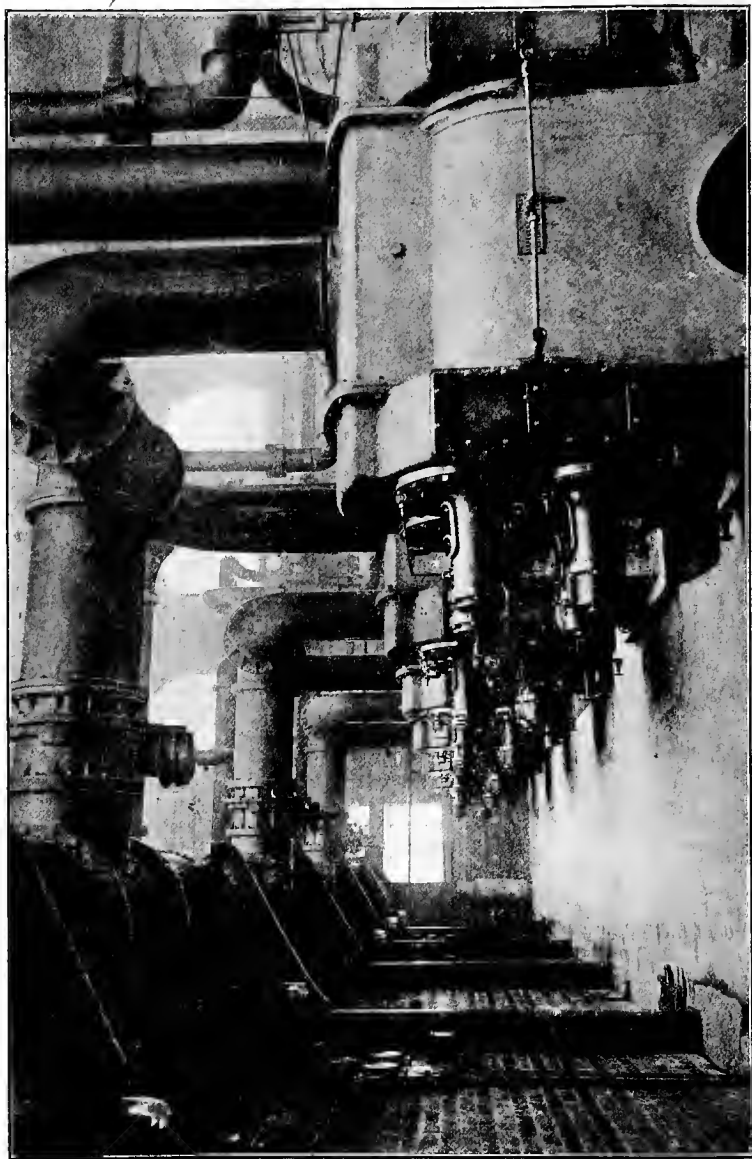


FIG. 66.—Gas compressors for forcing gas through mains.

This shows a gross profit of £15,857 for the year, but the total capital expenditure to the end of 1919 was £548,030, so that the profit was under three per cent. on the capital outlay. Early in 1920 there were 161 consumers, and the consumption of gas in February of that year was 391,292,100 cubic feet, the inquiries for gas being then greater than could be served by the plant. Before the war the prices charged for gas were from 1½ to 2¾ pence per 1000 cubic feet for gas-engines, and from 1½ to 2 pence per 1000 cubic feet for heating work; the latter includes furnaces for reheating, annealing and melting, also various operations in factories. At present the cost of coal, labour, etc., is so high that it has been necessary to raise the selling prices of the gas to 8·8 pence to 10 pence per 1000 cubic feet for engines, and 8·8 pence to 9·3 pence per 1000 cubic feet for heating work.

As an engineering problem, it has been shown that producer gas suitable for driving gas-engines and for heating furnaces, etc., can be made from bituminous coal on a large scale of working, and that it can be distributed through miles of piping. But as a commercial proposition for other places it is clear that every endeavour should be made to keep down the capital outlay. The cost of large special mains for a gas of low calorific value must alone always be a serious item to face where the length of the mains is considerable. The late Dr. Mond and his associates have done valuable pioneer work in proving what can be accomplished, and others will doubtless profit by the experience gained.

The ammonia recovery plant in this system is somewhat complicated and is costly, and we believe it is not recommended for smaller powers than 2000 B.H.P., especially as the labour and other costs are now so high; moreover, it is desirable that the plant should work night and day without a stop. It is, therefore, beyond the reach of the large number of manufacturers and others who require about 500 to 800 B.H.P., and for cases of this kind the Mond plant is constructed without apparatus for the recovery of ammonia.

An exhaustive series of experiments was carried out in 1906 and 1908 by Professor W. A. Bone, F.R.S., and Mr. R. V. Wheeler,¹ with Mond producers at the iron and steel works of Messrs.

¹ *Journal of the Iron and Steel Institute*, 1907 (1), p. 126; 1903, (3), p. 206.

Monks, Hall & Co., Ltd., Warrington, in order to ascertain the effect of varying the proportions of air and steam in the blast. The producers were 10 feet in internal diameter, and each was rated to gasify 16 cwt. of coal per hour. The plant consisted of two producers and the usual superheaters and washers, but it was worked without recovery of ammonia, and the air-heating tower was not used. Part of the gas was used in various furnaces, and part was passed through sawdust scrubbers and used for driving two gas-engines, of 650 H.P. and 250 H.P. respectively. Each trial lasted over a full working week, and during that time the furnaces and gas-engines were worked day and night under normal conditions. The first set of tests was made with two producers working with an average output of one-half, and a maximum output of three-quarters, of the rated capacity. The depth of fire was 7 feet. The proportion of steam in the blast was varied each week by changing the saturation temperature of the blast in five equal steps from 60° C. (140° F.) to 80° C. (176 F.), the quantity of steam in the blast varying from 0.45 lb. to 1.55 lbs. per lb. of coal gasified. In the later tests, one producer was used alone, working at 85 per cent. of its rated capacity during the night shift, and at 47 per cent. overload during the day. The depth of fuel was only 3 feet 6 inches, and the saturation temperature of the blast was varied week by week in five equal stages from 60° C. (140° F.) to 45° C. (113° F.), the quantity of steam in the blast varying from 0.45 lb. to 0.2 lb. per lb. of coal gasified.

The bituminous coal used during the trials was a Lancashire coal known as "Collins' green washed beans," screened over a 1-inch mesh, and containing 3 to 7 per cent. moisture. The analyses of the dried coal showed the average composition and calorific power as follows:—

	First series of trials.	Second series of trials.
Carbon, per cent.	78.41	77.60
Hydrogen „	5.51	5.35
Nitrogen „	1.39	not determined
Sulphur „	0.83	1.25
Oxygen (by difference), per cent.	10.03	not determined
Ash, per cent.	3.83	4.60
Calorific power, higher value:—		
Calories per kilo	7711	7739
B.Th.U. per lb.	13880	13930

	First series of trials.	Second series of trials.
Calorific power, lower value :—		
Calories per kilo	7411	7450
B.Th.U. per lb.	13340	13410

The principal results obtained are summarised in Table XXV., and the authors draw the following conclusions :—

- (1) Increasing the saturation temperature of the blast above 65° C. (149° F.) reduced the calorific value of the gas. The gas became less suitable for furnace work owing to the replacement of part of the carbon monoxide by hydrogen.
- (2) Increasing the saturation temperature of the blast above 60° C. (140° F.) decreased the thermal efficiency, and 20 per cent. of the steam and upwards passed through the producer unchanged.
- (3) The producers could not be worked satisfactorily with a saturation temperature as low as 45° C. (113° F.) on account of the ash fusing on the fire bars, but the thermal efficiency was practically the same with saturation temperatures from 50° C. (122° F.) to 60° C. (140° F.), and the gas was of suitable quality both for furnaces and for driving engines. These saturation temperatures corresponded to 0·21 to 0·45 lb. of steam in the blast per lb. of coal gasified. When the saturation temperature of the blast was 60° C. (140° F.), 75 per cent. of the steam was decomposed; at 50° C. (122° F.) and 55° C. (131° F.), the whole of the steam was decomposed.
- (4) For maximum ammonia recovery, the steam saturation temperature should be as high as is consistent with the production of combustible gas, but if ammonia recovery be considered in conjunction with the suitability of the gas for furnace purposes and the thermal efficiency of the process, the best saturation temperature for the blast is 65°–70° C. (149°–158° F.). If ammonia recovery is not taken into account, the best results can be obtained with saturation temperatures from 50° C. to 60° C. (122° F. to 140° F.).
- (5) A depth of fuel of 3 feet 6 inches was sufficient to permit

of a high rate of gasification, with nearly complete decomposition of the steam, and to reduce the amount of carbon dioxide in the gas to 5 per cent. or less.

We may point out, however, that a comparison of the results obtained in the two trials made with a saturation temperature of 60° C. (140° F.), in the one case with the fire 7 feet deep and working below the full capacity of the producer, in the other case with the fire 3 feet 6 inches deep and working at nearly 50 per cent. overload during the dayshifts, shows that only 76 per cent. of the steam was decomposed in the latter case as compared with 87 per cent. in the former; the quality of the gas was correspondingly inferior, the yield of gas less, and the thermal efficiency of the process lower.

TABLE XXV.—BONE AND WHEELER'S EXPERIMENTS ON THE USE OF STEAM.

Depth of fire	FIRST SERIES. 7 feet.					SECOND SERIES. 3 feet 6 inches.			
	80° C. 176° F.	75° C. 167° F.	70° C. 158° F.	65° C. 149° F.	60° C. 140° F.	60° C. 140° F.	55° C. 131° F.	50° C. 122° F.	45° C. 113° F.
Saturation temperature of the blast									
Steam added to blast, lbs. per lb. of coal	1.55	1.10	0.80	0.65	0.45	0.45	0.32	0.21	0.2
Weight of steam decomposed, lbs. per lb. of coal	0.62	0.57	0.49	0.44	0.39	0.34	0.32	0.21	0.2
Percentage of steam decomposed	40.0	52.0	61.0	80.0	87.0	76.0	100	100	100
Composition of gas, per cent. by volume—									
Carbon monoxide	16.05	18.35	21.70	25.40	27.30	27.30	28.10	30.60	31.60
Hydrogen	22.85	21.80	19.65	18.30	16.60	15.50	15.45	12.35	11.60
Methane	3.50	3.35	3.40	3.40	3.35	3.05	3.00	3.00	3.05
Carbon dioxide	13.26	11.65	9.15	6.95	5.25	5.10	4.40	2.50	2.35
Nitrogen	44.55	44.85	46.10	45.90	47.50	49.05	49.05	51.55	51.40
Total combustible gases	42.2	43.50	44.75	47.10	47.25	45.85	46.6	45.95	46.2
Calorific power of the gas, higher value—									
Calories per cubic meter	1508.5	1531	1580	1650	1652	1590	1609	1589	1602
B.Th.U. per cubic foot	169.5	172.0	177.5	185.4	185.6	178.7	180.8	178.5	180.0
Calorific power of the gas, lower value—									
Calories per cubic meter	1373	1400	1453	1531	1540	1485	1605	1501	1517
B.Th.U. per cubic foot	154.3	157.3	163.3	172.0	173.0	166.9	169.1	168.7	170.6
Yield of gas, measured at 0° C. and 760 mm.—									
Cubic meters per kilo of fuel	4.11	4.06	3.94	3.64	3.85	3.76	3.70	3.69	3.73
Cubic feet per ton of fuel	147,560	145,800	141,450	134,400	138,250	135,000	132,700	132,500	133,700

In a Wilson bituminous plant, made by the Horsehay Company, the tar is removed chiefly by cooling, care being taken not to let the gas come in contact with water until it has been cooled. Several methods have been proposed for converting the

tarry vapours into fixed gases by passing them through a zone of incandescent fuel in the producer itself. In some cases (*e.g.* in the Whitfield producer) tarry vapours are drawn off from the upper part of the producer as the fuel becomes gradually heated by the fire below, and are made to enter the producer again at a lower level where combustion is taking place, but this has not been successful. In others, again, an attempt is made to arrange the grate, the feeding hopper, and the gas outlet so that the tarry vapours distilled off from the raw fuel must pass through heated fuel before they reach the gas outlet, while the fuel itself must become coked before it reaches the zone where combustion is taking place. In producers of these types the conversion of the tarry vapours into fixed gas is not complete, and there is a certain quantity of tar in the gas, which must be removed by scrubbing.

Another method of fixing the tarry vapours is to work the producer with a down-draught instead of an up-draught. The principle is to free the raw fuel from tarry vapours, and compel the latter to traverse the whole depth of the fire, so that they may be converted into fixed gases. It is not easy to carry this out effectually in practice, owing to the difficulty of maintaining a suitable temperature; if the temperature of the fire is too low some of the tarry vapours are not decomposed.

The principle of working a producer downwards was tried so long ago as 1866 (for furnace work) by Howson, of Middlesborough.¹ He used air at pressure, forced in by a steam-jet injector, but in 1905 M. Deschamps, of Paris, worked a producer with bituminous coal downwards by suction from a fan or gas-engine, and this combination has several practical advantages. The producer can be permanently open at the top, and there is no smoke given off while coal is being put in, as the suction draws all the smoke downwards through the fire. With many plants worked by pressure the smoke nuisance is a serious one. With downward working there is no difficulty in poking down through the fuel, and this is a great advantage in any plant in which bituminous coal is used, as the fire has a tendency to burn in hollows, and away from the red-hot brick lining of the producer, especially if the coal is of a caking kind. With downward working the clinker difficulties are also considerably reduced. Having

¹ *Proc. Inst. C.E.*, 1886, vol. lxxxiv. pp. 42, 68.

mentioned these advantages, we must point out some drawbacks which this system involves. It is difficult to burn the fuel completely, and usually there is an accumulation of small carbon in the form of coke, mixed with clinker and ash, in the lower part of the producer. This is not only wasteful, but the fine coke and ash choke the interstices through which the currents of gas have to pass, and add considerably to the resistance which the suction of the fan or engine has to overcome. This in turn affects the quality of the gas produced, because the currents of air are not then distributed evenly through the fire, and where late combustion of the fuel occurs the carbon dioxide is not reduced.

To avoid these and other difficulties Mr. Dowson introduced

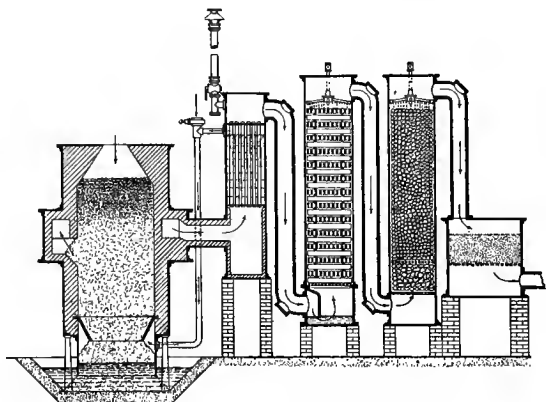


FIG. 67.—Dowson bituminous gas plant.

the plant shown in Fig 67. The special feature of the producer is that it is double-acting, *i.e.* air is drawn in through the top, and steam and air through the bottom of the fuel column. The producer is open at the top, and coal is put in there, but there is no escape of smoke or gas, as there is a draught inwards caused by the suction of the engine, or by an exhaust fan. The upper part of the fire burns downwards. The hydrocarbons are distilled off and various useful reactions occur; the coke which remains sinks down gradually into the lower part of the producer where it meets an upward current of steam and air, and is there converted into ordinary producer gas. The mixture of gases leaves the producer through an outlet about halfway between the

top and the bottom. When working with bituminous coal containing as much as 30 to 35 per cent. of volatile matter, or with lignite and some other varieties of fuel, there is practically no tar; it is disposed of in the producer, and no mechanical or other tar extractor is required. The producer has a water-bottom, so that clinker and ash can be drawn out while the plant is working. After leaving the producer the hot gas passes through a tubular vapouriser, to cool the gas and raise the steam required for making the gas. It then passes through a water seal and through a wood-grid scrubber, a coke scrubber, and a sawdust scrubber, to remove dust, soot, etc. This bituminous plant can be worked by the suction of an engine; when the gas is to be passed into a gasholder for distribution to several engines, or to heating apparatus, there is an exhaustor to draw gas from the plant and deliver it into a holder.

A plant of this type for 500 H.P. was started in October, 1908, at the works of Messrs. Kenrick and Sons of West Bromwich, and in October, 1909, they started a second plant of this type for 700 H.P.; the two plants served 13 gas-engines which were previously worked with anthracite pressure gas. The gas made had the following average composition:—

Carbon monoxide	23.9	per cent. by volume.
Carbon dioxide	7.2	„ „
Hydrogen	16.0	„ „
Methane	1.0	„ „
Nitrogen	51.9	„ „

Calorific power of gas:—

Higher scale	1317	cal. per c.m.;	148.0	B.Th.U. per cub. ft.
Lower scale	1230	„ „	138.2	„ „

From this it will be seen that the calorific power of the gas was about the same as that of gas made with anthracite in an ordinary suction plant. The fuel used at West Bromwich had usually the following composition:—

Fixed carbon	55	per cent.
Volatile matter (other than moisture)	30	„
Moisture	8	„
Ash	7	„

Calorific value 7440 calories per kilo, or 13,400 B.Th.U. per lb.

On an average of several months the consumption of

bituminous coal was about the same as with anthracite, namely, about 1 lb. per I.H.P.-hour including all stand-by, cleaning and starting losses. The gas was said to be as clean as the anthracite gas previously used, so that the engine valves were cleaned only once in about three months. Recently this plant was altered so as to work as a recovery plant.

There are other plants of this type in use, and we may mention one at Burham, Kent, belonging to the Associated Portland Cement Manufacturers, Ltd., as it was carefully tested by their engineer and their chemist. There are three sets of plant, each to serve 325 B.H.P., and each set is approximately like Fig. 67. They were started in October, 1912, for driving engines to generate electricity, and the Chief Engineer, Mr. C. Percy Taylor, M. Inst. C.E., has recently reported that, "From that time until now [1920] two of the three producers have been working continuously [night and day], each gasifying about 300 lbs. of coal per hour. Our general experience has been that with coal containing not more than ten per cent. of ash the plants are satisfactory to operate, and it is not necessary to draw the fire except after a period of about 18 months for the purpose of renewing parts of the firebrick lining." He also states that the average consumption of coal of pre-war quality was 1·7 lb. per kilowatt-hour, and that with coal of the present day quality the calorific power of the gas is somewhat reduced, and the average consumption of coal is 1·9 lb. per kilowatt-hour.

When this plant was started, tests made during a run of eight hours showed that the gas had the following average composition:—

Carbon monoxide	23·8	per cent. by volume.
Carbon dioxide	4·6	" "
Hydrogen	11·1	" "
Methane	2·2	" "
Nitrogen (by difference) . .	58·2	" "

Calorific power of gas (calculated):—

Higher scale . .	1278 cal. per c.m.;	143·6 B.Th.U. per cub. ft.
Lower scale . .	1203 " "	135·2 " "

At first it was thought that plants of this type might not be suitable for small powers, but a 30 H.P. suction plant of this kind was worked regularly for about eight months, by way of

experiment, and it gave no more trouble than an ordinary suction plant working with anthracite or coke. The engine valves were not cleaned for five months.

MM. Fichet & Heurtey of Paris have worked on somewhat similar lines, and we have seen a plant of theirs working well with semi-bituminous coal containing 11·5 per cent. of volatile matter. We have not seen one working with bituminous coal containing 30 to 35 per cent. of volatile matter, such as we have to deal with in this country.

More recently Messrs Crossley Bros. have adapted their suction plant, shown in Fig. 54 (p. 158), to work with non-caking bituminous coal; and with their open hearth they claim that they can work satisfactorily with coal containing a high percentage of ash, owing to the ease with which the lower part of the fire can be stirred and the clinker and ash removed. The chief additions they have made to their ordinary suction plant are a scrubber with cascades of water, and a high speed rotary fan of special construction (see Fig. 68). The latter is placed between the cascade scrubber and the ordinary coke scrubber.

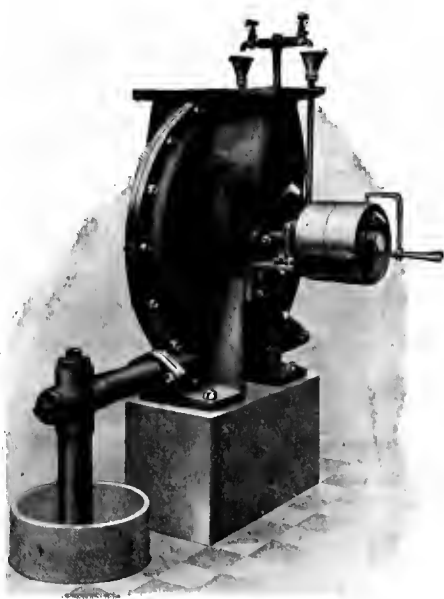


FIG 68.—Crossley centrifugal tar extractor.

MM. Boutillier et Cie. have a producer in which the raw fuel is forced into the bottom of the fire by means of a screw feed, and as the producer is worked with an up-draught from a blower the tarry vapours distilled off at the bottom ascend through the incandescent fuel above. An incidental advantage of this

arrangement is that although there is an up-draught the depth of the fire can always be the same, provided the fuel is regulated to suit the rate of consumption, which varies when the load on the engine varies. We have seen a plant of this type working well with semi-bituminous (*demi-gras*) Belgian coal containing 12 to 13 per cent. of volatile matter.

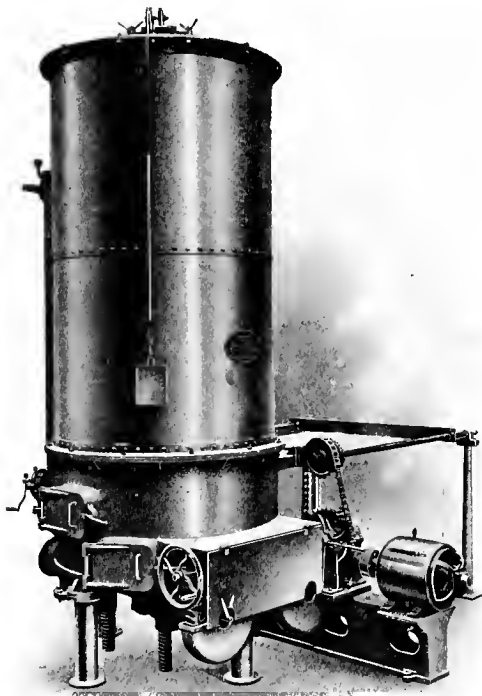


FIG. 69.—Farnham gas-producer for bituminous coal.

The plant devised by Mr. R. V. Farnham¹ of Linwood, near Paisley, shown in Fig. 69, makes use of the same principle of feeding the raw fuel at the bottom of an up-draught producer, but the system of feeding the fuel differs from that of MM. Bontillier et Cie., and the plant has other features which are

¹ Paper read by Mr. Farnham at Inst. of Engineers & Shipbuilders in Scotland, 1916.

interesting. The fuel is fed at intervals through a door at the bottom of the producer, underneath the fuel column, the grate being lowered and a horizontal perforated sliding plate being pushed in, to hold up the column of fuel above.

Steel rams are coupled to the grate, so that the latter can be raised or lowered when required. For a 100 B.H.P. plant there is a 3 B.H.P. electric motor to operate the sliding plate and the grate. The main steam raiser consists of numerous gills or ribs cast on the outside of the gas outlet pipe, which has a casing round it. The air supply is pre-heated to about 350° F. (177° C.) by drawing it through an enclosure (not shown) over the top cover of the producer. The outlet from this enclosure is connected to the top of the enclosure where the steam is raised, and the mixture of steam and air passes downwards through the latter enclosure to the bottom of the producer. In order to get steam when the fire in the producer is started, water is sprayed from one or more nozzles, and distributed over the underside of the grate and adjacent metal parts. The gases are drawn upwards through the fuel column, and very little cleaning is required after they leave the producer.

The method of working the producer is as follows: Ordinary gas coke is fed on the grate, when at its lowest position, through an opening formed by a hinged door on the top of the producer; this charge of coke is brought up to the level of the gas outlet. The engine is then run from one to two hours (according to the load) with gas made from coke only. After this the grate is raised about 10 inches, to the level of the sliding plate; the latter is then driven across the fire, between the bottom of the fuel and the top of the grate. The grate is then lowered again to its lowest position, and bituminous coal is put in through the door opening on to the grate. When this space is closely packed with coal, the sliding plate is withdrawn, allowing the incandescent fuel above to gradually settle on the fresh fuel. When a further charge of fresh fuel is required the grate is raised, compressing the fuel above it, and the operations described are repeated. The application of pressure to the incandescent fuel is considered important, as it closes interstices and makes the fuel column dense and compact, so that no poking is necessary. To prevent change in the composition of the gas due to loss of steam while

the bottom of the producer is opened for charging, the fresh coal is moistened with water, before it is put in the producer. It is claimed that the pre-heating of the air supply in the enclosure on the top of the producer prevents condensation of the steam on the cold wet fuel. For the 250 and 500 B.H.P. sizes of plant the sliding plates are made double, with a circulation of water between them, to keep them cool and straight.

One of the early plants worked by the suction of a 100 B.H.P. engine was tested in 1910 by Sir D. Clerk, and he stated that "the operation of charging did not in any way affect the quality of the gas, as shown by the running of the engine. I determined this fact by taking indicator diagrams, three minutes before charging, during charging, and three minutes after charging. The power continued to be developed quite uniformly. No variation occurred." He also stated that, "at the end of the trial [48 hours under load] I had the gas inlet valve of the engine withdrawn, and found no tar worth mentioning. The thin film of matter adhering to the valve was scraped off, and weighed less than one ounce." During this trial the total fuel consumed was 6573 lbs., of which about $21\frac{1}{2}$ per cent. was coke. The bituminous slack used contained 34 per cent. of volatile matter, and had a calorific value of about 10,710 B.Th.U., and allowing for the coke Sir D. Clerk estimated that "the calorific value of one pound of the total fuel amounts to about 10,260 B.Th.U." He further stated that the total fuel consumed was 1.36 per B.H.P.-hour, including starting and stand-by losses.

Seven representative analyses of the gas made in this plant are given in Mr. Farnham's paper, and they show the following average composition :—

Carbon monoxide	17.1 per cent.
Hydrogen	11.3 "
Methane	5.1 "
Carbon dioxide	6.5 "
Oxygen	0.1 "
Nitrogen	59.9 "

It will be noted that the percentage of hydrogen is low, while that of methane is exceptionally high; the nitrogen is also high. A further point to note, is that the average quantity of water converted into steam is under 0.21 lb. per pound of coal gasified;

this is much less than is usual with other bituminous plants. The average temperature of the gas leaving the producer is stated to be 1075° F. (580° C.); this is high for engine work.

In this plant the clinker and ash cannot be removed while the plant is working; when fresh fuel is pushed up from the bottom it drives the clinker and ash upwards as well, so that a large accumulation of incombustible material takes place in the producer. After some days' work it is therefore necessary to stop the plant and remove the entire contents of the producer; the ash content of the fuel determines the length of time the producer can make suitable gas. As an example, after 12·8 tons had been gasified the plant was stopped, and 1200 pounds of clinker, etc., were removed. After the producer has been emptied it is re-charged with coke, and a new start is made, as above described.

Another system which has been tried is a modification of the water-gas process described in Chapter IV., and the plant is known as the Loomis-Pettibone plant (U.S.A.). In this there are two producers, through which air is drawn downwards by an exhaustor, and after passing through scrubbers, etc., the producer gas thus formed is sent into a gasholder. At intervals the air supply to one of the producers is closed, and steam is admitted at the bottom. A mixture of producer and water gas is then formed, and this is sent into the gasholder to mix with the producer gas already there. As the process is intermittent and variable it is necessary to mix the gases in a gasholder to get something like an average result. Mr. Nisbet Latta says:¹ "The best result or efficiency of gas obtained from this process for power purposes is found with the gas approximating 105 B.Th.U. in value, this usually representing about 5 per cent. of water gas to 95 per cent. of producer gas in the total mixture."

It will be seen that many different processes and many types of plant are being tried with bituminous coal for making gas which is suitable for engine work. When anthracite or coke is to be used the choice lies between working by pressure or by suction, according to the requirements of each case; and when once this choice has been made the principles to be followed in

¹ "American Producer Gas Practice," p. 114.

the construction and working of the plant are well defined. But for the present the methods of working with bituminous coal are to a certain extent tentative, and it cannot be said that any of the plants now used are as simple and as free from trouble as those working with anthracite or coke. The use of bituminous coal is, in fact, beset with difficulties, and it is encouraging that so much has been accomplished in the comparatively short time during which serious attempts have been made to work with this class of fuel. In course of time the best lines to follow will doubtless be discovered.

Speaking generally, badly caking coals are not suitable for gas-producers, and this is specially the case when the gas is to be used for engines. If the coal cakes there are often hollows in the fire instead of its being uniformly close and dense, and the air currents are not well distributed and are not brought properly into contact with the hot fuel, so that inferior gas is made. It involves a good deal of poking, and even with non-caking bituminous coals the fire should be poked occasionally, especially with producers of larger size, to ensure the gas being of uniform quality.

It is a great step forward to be able to use bituminous coal for gas-engines, but a still further development is taking place at the present time. Owing to the restricted output of coal, the difficulty of getting a regular supply, its excessively high price, and the serious rise in the cost of wages and materials, great endeavours are now being made to make suitable producer gas with other kinds of fuel. For a long time attempts have been made to work with peat, in this and other countries, and we have dealt with this separately in Chapter X.; but when coal was plentiful, and its price was low, there was not the same inducement to deal with other fuels as there is now. At the present time gas is not only being made with peat, but also with wood refuse such as chips, shavings, and sawdust. It is also made with spent tan, olive refuse, rice husks, cotton seed or cake, locomotive smoke-box char, and various other waste products. Messrs. Crossley have been foremost in dealing with this subject, and have already established a good record; other firms are also doing well, and now that the war is over, and more time can be given to this very important development, there is every

reason to believe that many substitutes for coal will be used extensively.

Fortunately good and clean gas can be made with these waste materials without complicating the gas plant. The general practice is to use a suction plant, to modify the producer, and to have a centrifugal washer or tar extractor as in most bituminous coal plants.

CHAPTER X

PRODUCER GAS FROM PEAT

THE possibility of using peat as a profitable source of power has long been in the minds of chemists and engineers; they thought it was possible, but they did not know what to do to make it a commercial success. Moreover, when coal was cheap, it was more difficult for peat to compete favourably. At the present time, however, there are reasonable grounds for supposing that a practical solution of the problem has been found, and since the war a great impetus has been given to the subject, owing to the serious rise in the cost of coal, and the difficulty of getting it in sufficient quantities. There is in fact a demand everywhere for some good substitute for coal, not only because of its cost, but so that we may be more independent of strikes and industrial crises.

For many years the subject has been approached in various ways; some advocates have tried to do too much, and their schemes have failed; some have sunk capital, or have induced others to do so, to develop processes which could not succeed commercially. What has really put new life into the subject is the fact that gas-engines are now working successfully with producer gas made directly from peat.

The chief obstacle to the more extensive use of peat in gas-producers has been the cost of digging, drying, and transport, and it has seldom been commercially profitable to use peat for this purpose except in the immediate neighbourhood of the bogs, or where there is water carriage at a low cost. After a bog has been drained the peat often contains as much as 85 to 90 per cent. of water, and for domestic and other uses the moisture has to be brought down to 20–30 per cent. This is usually done by standing it in heaps or stacks in the open air, and it is not only a slow process, but it is dependent on the weather. But this amount of drying is not necessary when the peat is to be used in a gas-producer; we shall presently give instances of peat

being used successfully which contains 45 per cent. of moisture, and for gas-power purposes the question seems to be resolving itself into one of cutting the peat and reducing the percentage of moisture from 85 or 90 per cent. down to 40-50 per cent.

Attempts have been made to get rid of a large proportion of the water by compressing the peat in powerful presses, but none have succeeded, and there appears to be little likelihood of success, because of the slimy hydro-cellulose which prevents the extraction of water, and because of the excessive cost of working. A more promising system was introduced by Dr. Ekenberg, who subjected the peat to a temperature of 150° C. (318° F.) in order to decompose the cellulose, and then removed water by compression, so as to bring down the moisture to about 35 per cent. But this again involves a considerable addition to the working cost, and although it may be useful for certain purposes it is unnecessary for a gas-producer of suitable type. Our own opinion is that when working on a fairly large scale the peat should be either dug by hand or by mechanical means, according to the situation, nature of bog, prevailing weather, etc.; and that it should be conveyed to drying sheds heated by the exhaust from the gas-engines (assuming that they are near the bog), in order to reduce the moisture to the percentage required. Such a system would utilise a large proportion of the waste heat of the exhaust, and at the same time it would make the whole system of working more uniform, and less dependent on weather.

Messrs. Crossley Bros. carried out tests with a 90 H.P. suction producer and 75 H.P. gas-engine driving dynamos, cranes, blower, crusher mill, and other foundry appliances at their works at Openshaw. The plant included a coke scrubber for cooling and washing the gas, their special centrifugal tar-extractor shown in Fig. 68, p. 191, and a sawdust scrubber. The peat had the following composition:—

TABLE XXVI.—COMPOSITION OF PEAT.

	As received.	Calculated as dry peat.
Moisture	37·0 per cent.	—
Ash	1·0 "	1·6 per cent.
Volatile matter	37·2 "	59·0 "
Fixed carbon	24·8 "	39·4 "

The following are some typical analyses of the gas taken indiscriminately with the plant working at various loads :—

TABLE XXVII.—TYPICAL ANALYSES OF GAS MADE FROM PEAT IN CROSSLEY SUCTION PLANT.

	1	2	3	4	5
Carbon monoxide	27·4	25·8	28·5	26·9	25·2
Hydrogen	12·3	10·3	9·4	11·8	9·9
Methane	3·7	3·5	3·4	3·3	2·9
Carbon dioxide	8·0	8·3	5·1	7·0	7·6
Nitrogen and oxygen	48·6	52·1	53·6	51·0	54·4
Calorific power (lower value)—					
Calories per cubic meter	1477	1362	1406	1415	1282
B.Th.U. per cubic foot	166	153	158	159	144

The following analyses of gas sampled under special conditions are also of interest :—

TABLE XXVIII.—ANALYSES OF GAS FROM PEAT UNDER SPECIAL CONDITIONS.

	10 minutes after restarting after 16 hours stand-by.	After running for 1 hour at 15 B.H.P.	After increas- ing load from 15 to 110 B.H.P.	After running 1 hour at 110 B.H.P.
Carbon monoxide	24·3	20·4	26·1	29·5
Hydrogen	11·0	12·6	9·1	10·0
Methane	3·5	3·6	3·5	1·8
Carbon dioxide	8·9	11·0	8·0	5·4
Nitrogen and oxygen	52·3	52·4	53·3	53·3
Calorific power (lower value)—				
Calories per cubic meter	1326	1264	1335	1317
B.Th.U. per cubic foot	149	142	150	148

When a recovery plant is used the principal by-product (as with bituminous coal) is ammonium sulphate, and the method of recovery is the same. The watery liquor condensed from the gas can also be worked up for the recovery of methyl alcohol and acetic acid, and wagon-grease can be made from the tar. The amount of ammonium sulphate which can be obtained depends on the amount of nitrogen in the peat, the theoretical maximum yield being nearly five times the weight of nitrogen. Actually about 60 per cent. of this can be obtained. Messrs. Crossley Bros., in trials made at Openshaw, using peat containing 2·2 per cent. of nitrogen, recovered 140 lbs. of sulphate per ton of peat.

In 1910 the Power Gas Corporation, Ltd., erected a full-sized recovery plant in Norfolk for the purpose of determining the yield of ammonium sulphate obtainable from peat, and the maximum amount of moisture in the peat with which good producer gas could be made. Numerous tests were made on a practical scale, and the general result showed that, theoretically, dry peat containing 2·3 per cent. nitrogen yielded from 180 to 200 lbs. (80 to 90 kilos) of ammonium sulphate per ton of peat (theoretically dry) gasified; also that the water content of the peat fed into the producer should not exceed 40 per cent. when the gas produced is to be used for engine or heating work.

The methods adopted in Sweden, Norway, Denmark, Germany, Holland, and Ireland were carefully investigated and reported on in detail by the Department of Mines, Canada, in the interest of the peat industry of that country. All who are interested in the various ways of procuring and treating peat will do well to study this Report.¹ In several European countries increased attention is being given to the peat industry, and some of their Governments offer special inducements to promote its development. Thus we learn from the official Report just referred to that in Sweden considerable sums of money have been voted by Parliament, from which loans on liberal terms are made to peat manufacturers. We also learn that before the war "Russia had the largest peat industry in the world, with some 1300 machine peat plants in operation," several of which were owned and worked by the Government. Special inducements were offered to peat manufacturers, and a fund was provided from which they could obtain loans on easy terms. In Holland the production of peat fuel was over one million tons a year, and the Report states that "the worked-out peat bogs are excellent for agricultural purposes, and annually about 1000 acres of such land are gained."

In Sweden there is little coal but any amount of peat, and encouraged by the action of the Government, Messrs. Körting Bros. of Hanover, for several years before the war had suction plants working in Sweden with peat for an aggregate of over 2000 H.P. These included two sets of plant, each for 150 H.P., for an electric light and power station at Skabersjö, and although

¹ "Peat and Lignite: their Manufacture and Uses in Europe." Department of Mines, Ottawa, Canada, 1908.

the generating station was three miles from the town, the charge for current for power purposes was the equivalent of only one farthing per unit. Messrs. Körting give the following average composition for gas made from peat in their producers:—

TABLE XXIX.—AVERAGE COMPOSITION OF GAS FROM PEAT IN KÖRTING SUCTION PLANTS.

Carbon monoxide	15 per cent.
Hydrogen	10 "
Methane	4 "
Carbon dioxide	14 "
Nitrogen	57 "
Calorific power (lower value)—	
Calories per cubic meter	1050
B.Th.U. per cubic foot	118

In Italy the Power Gas Corporation, Ltd., established a recovery plant to work with peat at Orentano. There are five gas-producers, each with washing, cooling, absorbing, and scrubbing plant. About one-third of the gas is used for driving gas-engines, one-third for raising steam for driving the plant, and the remaining third for drying the peat in special ovens, this drying being assisted by the exhausts from the gas-engines. The peat fed into the producers contains about 30 per cent. moisture, and one ton of theoretically dry peat yields 70,000 cub. ft. (2,000 c.m.) of gas of the following composition:—

TABLE XXX.—COMPOSITION OF GAS IN RECOVERY PLANT AT ORENTANO.

Carbon monoxide	10·6 per cent.
Hydrogen	22·0 "
Methane	4·0 "
Carbon dioxide	20·5 "
Nitrogen	42·9 "
Calorific power (lower value)—	
Calories per cubic meter	1157
B.Th.U. per cubic foot	180

There is a power station which has six gas-engines each of 350 H.P., coupled direct to 5,000-volt alternators, the current being transmitted to Pontedera, a distance of about ten miles, and used there for lighting the town and for power purposes. The peat is dug out of the bog where the plant is situate, and

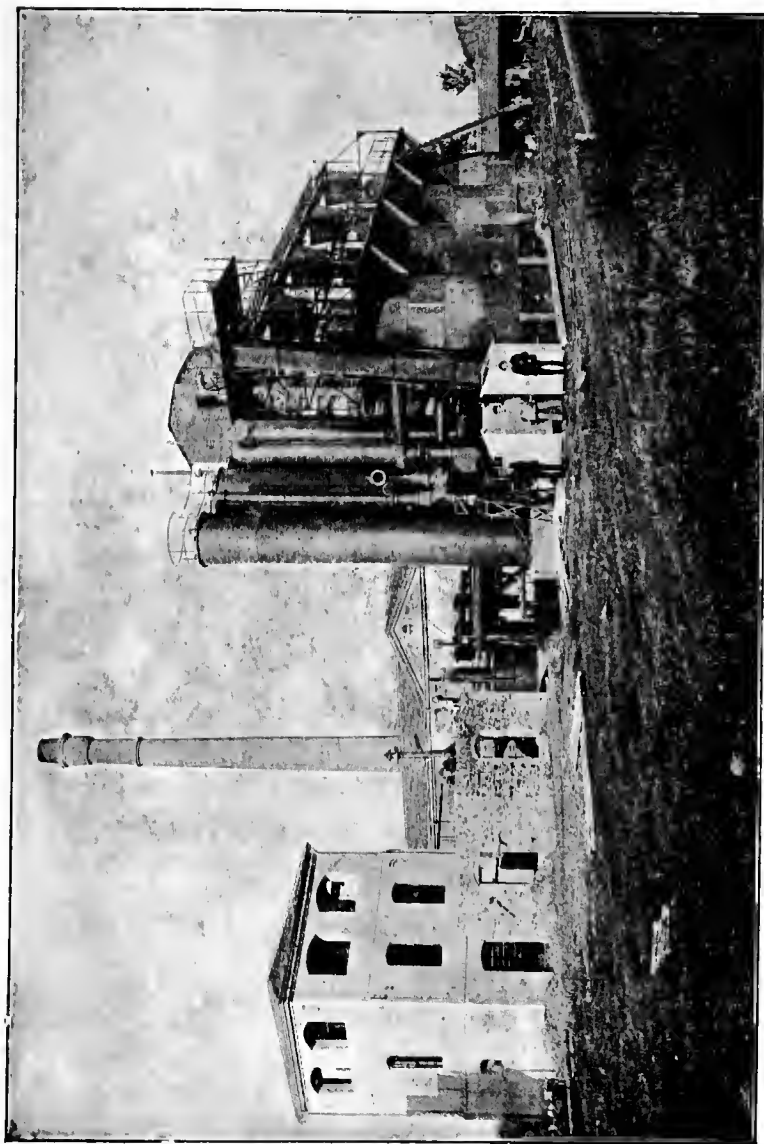


FIG. 70.—Power Gas Corporation recovery plant working with peat at Orentano, Italy.

theoretically dry it contains 2 per cent. of nitrogen; the yield of ammonium sulphate is about 130 lbs. (59 kilos) per ton gasified.

The same Corporation also erected a large recovery plant with eight producers, etc., at Codigoro in Italy, this plant being used chiefly for the recovery of ammonium sulphate. After the bog is drained the raw peat contains only 66 per cent. moisture, an unusually low figure. The general design of the plant resembles that at Orentano, but it does not include a final scrubbing of the gas, as the latter is used for heating steam boilers for driving turbines. The peat (theoretically dry) contains 2·3 per cent. of nitrogen, and yields 160 to 180 lbs. (70 to 80 kilos) ammonium sulphate per ton (theoretically dry) gasified. The peat from the bog is dried in ovens, and some of it is made into briquettes before being fed into the producers. The fuel as used contains only 10 per cent. of moisture. We are informed that the Orentano and Codigoro plants have both worked very satisfactorily, but we have no actual figures of the economic results.

A branch of the same Company erected a recovery plant to work with peat on a bog about 25 miles from Osnabrück in Hanover. According to Dr. Carl Duisberg¹ (1912) the gas is used for an electric power station of 3000 H.P., and from 2500 to 2600 cubic meters of gas with a heat value of 1000 to 1300 calories per cubic meter (112·4 to 146 B.Th.U. per cubic foot) are obtained from 1000 kilos (2200 lbs.) of peat free from moisture. This gas, he said, "represented energy equal to 1000 H.P. hours, equal to 700 kilowatt hours, after deducting the heat and power used for working the plant. In addition 35 kilos (77 lbs.) of ammonium sulphate were produced from the above quantity of peat, which contained one per cent. of nitrogen." This quantity of ammonium sulphate represents the recovery of over 75 per cent. of the nitrogen present in the peat.

In 1912 the Dutch Government started a Crossley suction plant for 50 H.P. working with peat at the Penal Settlement of Veenhuizen. It is stated officially² that a test during six hours

¹ Prof. G. T. Morgan, D.Sc., F.R.S., *Journal of Department of Agriculture, etc., Ireland*, October, 1915.

² *L'emploi de la Tourbe pour la force électrique dans les Etablissements de travail de l'Etat à Veenhuizen.—Imprimerie de la prison de la Haye.*

at full load showed a consumption of 1·5 kilo (3·3 lbs.) per B.H.P. hour, with peat containing 52 per cent. of moisture. It is further stated that the firing of steam boilers is not satisfactory with peat, and that the use of peat for domestic purposes is constantly diminishing, owing to the greater use of closed stoves heated with anthracite. This is regretted, as the removal of peat exposes a soil suitable for agriculture, and this diminution in the use of peat is checking the increase in cultivated land. Converting the peat into gas is therefore welcomed for several reasons, and it is believed that the success at Veenhuizen will lead to an increase in the use of peat in other parts of the Pays Bas.

These foreign installations are interesting and instructive, as they have established the fact that peat can be used successfully for power purposes in a suction plant, or in a recovery plant; but the fact that there is a peat-gas plant working in our own kingdom will probably help the subject more in this country than the examples given from abroad. Seeing is believing. We refer to a 400 H.P. Crossley plant, with two producers and two sets of scrubbers, etc., each for 200 H.P., which was started in 1911 at Portadown, Ireland. This is at the weaving factory of Mr. Hamilton Robb, whose enterprise in making a trial on a thoroughly practical scale of working is greatly to be commended. For his sake as well as for the advancement of the subject generally we are glad to add that it has proved to be a commercial success. The plant is of the kind described at the end of Chap. IX., with a centrifugal tar extractor, but the producers have not open hearths, as in more recent plants.

The peat used comes from a bog about ten miles from the factory, and is brought by canal boats to the gas plant; when dug the peat contains from 85 to 90 per cent. of moisture, and after being air-dried the peat blocks are fed into the producers. The quality of the gas is said to be as good as that made from anthracite, which was previously used, and the tar extractor and scrubbers clean the gas satisfactorily. The weight of tar recovered is said to be about 5 per cent. of the weight of peat consumed. The consumption of air-dried peat is about 2·5 lbs. per B.H.P. hour.

We have seen that there are various ways of dealing with

peat as a source of power, and the following appear to be the most practical :—

- A.—The conversion of peat into gas in a suction plant, at the place where gas power is required, without reference to by-products except tar.
- B.—The conversion of peat into gas in a recovery plant for serving gas-engines, and for obtaining ammonium sulphate and other by-products, at the place where the power is required.
- C.—The conversion of peat into gas for driving gas-engines, with or without recovery, at or near the peat bog, and the conversion of the mechanical power obtained into electrical power to be conveyed where it is required.

Project A.—This plant would be of the Veenhuizen or Portadown type; no other could well be used economically for small or moderate powers. For this to succeed peat must be within easy reach of the factory or where the power is required. Railway transport, with cartage to and from the railway stations, will in most cases be too costly, but carriage by water (as at Portadown), direct from the bog to the factory, will do quite well. The peat should be air-dried for a short period, not only because it is better for the producer, but because the carriage of many tons of excessive moisture in the peat would be a direct loss. In such a moist climate as there is in Ireland there are few months in the year when peat can be sufficiently air-dried, and this must be provided for by storage.

There will be some tar from the gas plant, from which various commercial products can be obtained, but until there is a sufficient number of these installations working regularly, it will probably not be worth while for distillers or manufacturing chemists to put down special plant to treat the tar for its various constituents.

Project B.—This plant would have to be on a larger scale of working, say a minimum of 1500 H.P. or probably more, and it should work continuously night and day. Heavier labour charges than for a simple suction plant would also have to be considered. The same remarks as to the supply of peat will apply to this type of plant as in *Project A*, but with even greater importance, as the

quantity of peat to be transported will be much greater. The capital outlay for a plant of this type will be considerable.

Project C.—If this plant is without recovery it would probably follow the lines of *Project A*, with the addition of the necessary electrical plant. If there is a recovery plant it would be on the lines of *Project B*, with the addition of electrical plant. This *Project C* would be ideal so far as the supply of peat is concerned, as there would be no transport to pay for, but compared with *Projects A* and *B* there would be the additional cost of producing and transmitting electrical energy. On pp. 202, 204, we have described two installations of this type using recovery plant (Orentaro and Osnabrück) which can be cited as practical examples. Plants of this type are more ambitious than the others, but that is no bar to their being adopted if the capital outlay required is forthcoming.

We have spoken in general terms of the recovery of ammonium sulphate and “other by-products,” and all who are interested in this branch of the subject should read the instructive article by Prof. Gilbert T. Morgan on the subject.¹ He points out that “The importance of increasing the output of ammonium sulphate from peat lies in the circumstance that this salt can displace sodium nitrate as a nitrogenous manure, thus rendering the nitrate available for the manufacture of explosives and other chemical products.” As to the tar from a peat-gas producer, he says that in experiments he made, in conjunction with Mr. G. E. Scharff, the tar contained about 29 per cent. of water, and yielded on distillation 50 per cent. of volatile oils. At the end of his interesting article Prof. Morgan gives the following summary:—

“1. Peat has long been employed as a domestic fuel. Its industrialisation could be most efficiently brought about by gasifying it in gas-producers, as this procedure would render feasible the recovery of several valuable by-products.

“2. The combined nitrogen of the peat can be commercially recovered in the form of ammonium sulphate. This valuable fertiliser, together with the peat ash containing potash and phosphoric acid, could be restored to the land from which the peat has been taken.

¹ See footnote on p. 204.

"3. Peat tar, another by-product, can be fractionated into the following useful materials: refined pitch and tar, candle wax, lubricating and burning oils, and very powerful disinfectants, greatly exceeding carbolic acid in germicidal strength.

"4. The aqueous distillate from the producer contains methyl alcohol, acetone, pyridine bases, and crude acetic acid, all of which are capable of recovery and utilisation.

"The economical utilisation of peat in the generation of gaseous fuel, even without recovery of by-products, is to-day an accomplished fact. It can scarcely be doubted that, with efficient chemical control, a larger plant of sufficient capacity to deal rationally with the ammonia, tar, and other products of the destructive distillation of peat, would lead to still greater economies in the employment of this important combustibile."

This subject, like many others, has been checked by the war, and since then industrial troubles and restrictions have to a great extent prevented the undertaking of new enterprises. The labour cost of winning the peat has gone up, but so has the cost of coal with which it has to compete, and so long as the relative cost of peat is low there will doubtless be a large field of operations for this class of fuel. At the same time engineers will do well to give special attention to the simplest and best means of getting peat from the bog, and of reducing the moisture down to 40-50 per cent.; their object should be not only to reduce the working cost, but to make the system as little dependent as possible on labour and weather conditions.

CHAPTER XI

GAS TRACTION ON ROADS

WHEN petrol cost about sixpence a gallon, or less, as it did a few years ago, there was no great inducement to find a substitute for it for driving motor lorries and other road vehicles. But during the war and since, there has not only been a great increase in the use of vehicles of this kind but the cost of petrol has risen seriously. Moreover, there is every reason to expect that our chief source of supply (the United States of America) will be restricted to a considerable extent, as an enormous increase has taken place in the use of petrol-driven vehicles in that country, while at the same time there is a threatened diminution in the output of petrol. It is in fact expected that soon America will not be able to export this or any other oil in large quantities, as nearly all that can be produced there will be required for home consumption.

There are of course other sources of supply, but wherever it comes from the cost of petrol as a working fuel will always be higher than that of producer gas, and this consideration and the desire to use a fuel which is derived from our own country have led several makers of gas plants and others to consider seriously the question of driving motor lorries with some modified form of suction plant. An ordinary stationary plant of this type will not do, as it occupies too much space, it is too heavy, and it requires a considerable quantity of water for cooling and cleaning the gas. The requirements for road service are in several respects special, and some are rather difficult to fulfil, but we see no good reason for supposing that they cannot be met satisfactorily. We are not able at present to record a complete success, but we do know that several practical attempts on roads, and in congested traffic, have been made, that the general

conditions of working are now understood, and that special designs of plant based on this experience are now under trial.

In some respects the road plant is more easy to contrive than the stationary plant. In the stationary engine there would be one cylinder, the engine speed would be from 150 to 200 revolutions per minute, and if the engine were working at full load, on the usual Otto cycle, air would be drawn through the fire in the producer at every fourth stroke, with a considerable velocity. If the engine were working at less than full load, the suction of air would be at still longer intervals. On the other hand, for the same H.P., the road-car engine would have four or more cylinders of small dimensions, one sucking after the other. The speed of the engine would probably be 800 or more revolutions per minute. The practical effect would be that there would always be one suction acting, and the gas would flow at a greatly reduced velocity compared with the single-cylinder stationary engine. So far as the fire in the producer is concerned, it would be equivalent to a continuously working small suction fan, and this makes it more easy to maintain a uniform temperature in the gas-producer. It also facilitates the cooling and cleaning of the gas as the flow of gas at any given period is reduced, and small dry scrubbers, cleaning-boxes, or filters are found to be sufficient. Moreover, the travelling of the vehicle through the air helps materially to cool the apparatus and piping through which the gas passes. No water need be used except for the steam required in the producer.

Another point in favour of the road plant is that for the greater part of the time the engine is running on a comparatively light load; the full power of the engine is only exerted at starting and when running up hill. On the other hand, a stationary engine may have to work for long periods under a full or nearly full load. For road work, therefore, the producer need not be rated at the maximum H.P. of the engine; it will be sufficient to rate it at the H.P. normally required, and to work it with an overload during the short periods when the engine is under full load. For this reason, and on account of the steady or continuous suction effect of the small multi-cylinder engine, the sectional area and the depth of the fire can be less than in a stationary plant, without causing the velocity of the gases passing through

the fire to be as high as with the intermittent suction from a single-cylinder engine of the same power. Also the firebrick lining of the producer can be thinner, as the loss of heat through it is unimportant in view of the great saving which can be effected in working cost compared with petrol and its substitutes or with steam power or coal gas. The general result of what has been said is that the dimensions and weight of the gas-producer can be very considerably reduced for a road plant, and the space occupied by ordinary wet scrubbers and their weight can be almost eliminated.

As to working with a shallow fuel bed there is no objection in principle, provided the depth of incandescent fuel is sufficient to make good gas. It has been pointed out in Chapter III. that the depth of hot fuel necessary to make good gas depends on the size and nature of the fuel, and on the velocity of the gases passing through it. We have worked a fairly large producer of the pressure type with a bed of anthracite peas only 9 to 12 ins. deep, and we found that good gas was made, although the draught of air was sufficient to keep the upper surface of the fuel in a state of agitation, resembling in appearance the rapid boiling of water. In a stationary plant one reason for using a considerably deeper fuel bed than the minimum required for making good gas is to ensure a sufficient depth of fuel in the event of there being an excessive accumulation of ash and clinker; another reason is that allowance must be made for the fluctuations in the rate of consumption caused by varying loads; again, with a deep fire, the fuel need only be replenished at long intervals, and this saves labour; also the gas is usually more uniform in quality, and a margin is provided for lack of attention by the workman in charge. The steady draught produced by the small high-speed multi-cylinder lorry engine should make it possible to obtain good gas with a shallower fire than would be desirable with a single-cylinder stationary engine giving the same power. Also the jolting of the lorry on the road will tend to keep the pieces of fuel closely packed, so as to make it impossible for the gas to find any path through the fuel bed without coming in contact with incandescent fuel. On the other hand, if the depth of the fuel bed is only just sufficient to make good gas, it is necessary to feed fresh fuel and to remove the ash

continuously by mechanical means, in order to avoid any reduction in the effective depth of hot fuel. This adds complications in the design of a small plant, and it is difficult to adjust the fuel feed automatically to the varying consumption, as the engine may be running at the same speed with the throttle in any position, or with the clutch disengaged. If the amount of fuel delivered into the producer is in proportion to the revolutions of the engine, there will be too much on the fire when the lorry is frequently slowed or stopped in crowded traffic, or there will be too little on the fire when the engine is fully loaded, as when running up a long hill. Whatever depth may be found desirable for a constant load, it would seem to be best to provide a greater normal depth, so that there may be some reserve for fluctuations, in case the mechanical feed does not respond exactly. It is, however, a matter to be decided on the results of ordinary everyday working, whether the balance of practical advantage lies with a very thin fuel bed and mechanical feed, or with a depth of fuel which will provide a good margin for variation, and which will render a constant feed and frequent removal of ash unnecessary.

Among the first to experiment with a motor vehicle driven by producer gas was Mr. J. W. Parker. He tells us that between 1901 and 1903 he ran something like 1000 miles, at first with a small $2\frac{1}{2}$ H.P. car, and afterwards with a 25 H.P. car carrying several passengers. The gross weight of the latter car loaded was $5\frac{1}{2}$ tons, and in a test run of 35 miles the consumption of Scotch anthracite was said to be $1\frac{1}{8}$ lb. per ton-mile. After this the subject was dropped, chiefly owing to the cost of petrol (with which he had to compete) being only $5\frac{1}{2}d.$ per gallon. In 1916 he made a fresh start with a new design of gas plant, which he says was more simple than the one he first worked with; and incidentally he mentions that he abandoned automatic feeding of the producer, which he had found to be troublesome and unnecessary.

Mr. Parker is now associated with Mr. H. W. Bamber of London, and we have recently seen the plant they have experimented with. The producer is of the ordinary suction type, but it is smaller and lighter than for a stationary engine of the same power. It has a special grate, in the middle of which is a hollow

circular casting with holes at intervals round the circumference, which acts as a vapouriser, the water fed into it being regulated by a float. The internal diameter of the producer is about 10 ins., and the height from the grate to the gas outlet is only 12 ins.; above this there is a fuel container. The producer with lining and accessories weighs about 112 lbs. (50 kilos). The gas is cleaned by passing through a small dust trap on the producer outlet, and it is cooled by passing through a good length of piping 3 ins. in diameter, which runs round underneath the body of the lorry.

The engine experimented with was not made for gas, it was an old petrol engine converted, of about 20 H.P. with four cylinders. The weight of the lorry and load was six tons. The fuel used was gas coke of good quality, in pieces which would pass through a mesh of $\frac{3}{4}$ of an inch; the depth of fire varied from 10 to 12 ins. Mr. Bamber states that test runs of 75 to 80 miles were made on several occasions and gave consistent results, the average total consumption of fuel being equal to about 2 lbs. per car-mile.

The gas plant is mounted on a little platform built out low down on the left-hand side, near the end of the driver's seat; it does not project beyond the side of the lorry, nor does it encroach on the driver's seat. The only useful space occupied for the gas plant is that used for storing fuel, and for a water tank to supply the producer. After the engine has been started no attention is given to the fire until the lorry has run from 30 to 40 miles; the engine is then stopped and the producer is filled again with coke. In a trial at which we were present the lorry was driven for an hour through crowded streets in Westminster, South Kensington, Earl's Court, Shepherd's Bush, etc., and no attention was given to the producer. The driver has a special cock for adjusting the air-supply to the engine, in case the quality of the gas varies, but he had no occasion to alter it. We were favourably impressed with the simplicity of the arrangement and the small amount of attention required; we also saw that a sufficient depth of fire can be obtained without making the producer large or heavy, and that a simple type of producer, following the usual practice for stationary engines, but lighter in construction and smaller, will do all that is required for a motor lorry.

In November, 1917 (during the war), an Inter-Departmental Committee was appointed to report on the employment of gas as a source of power, especially in motor vehicles, in substitution for petrol and petroleum products. This Committee issued an interesting report¹ (1919) dealing with various branches of the subject, including Portable Suction Gas Producers. They examined and tested several portable suction gas systems, and they state that the difficulties to be overcome before any such system can be held to be adapted for road transport service include the following :—

1. Length of time required to start from cold.
2. Regulation of fuel-feed, water-feed, and fire state.
3. Loss of power with existing types of engines.
4. Lack of cleanliness.
5. Scrubbing of the gas.

On the other hand they consider that the advantages of such portable plants in their application to road transport service include the following :—

1. Lowest known fuel cost.
2. Large radius of action without recourse to compression or the use of gas containers.
3. Use of home-produced solid fuel.
4. Low cost of upkeep.

The Committee further state :—

“The evidence which has been placed before us indicates that an average performance of 1·8 ton-miles per pound of coke, or 2·2 ton-miles per pound of anthracite, will be obtainable from any one of the systems A, B, and C, provided that the coke contains not more than 12 per cent. of ash and 6 per cent. of moisture, or the anthracite not more than 5 per cent. of ash, that the fuel is free from dust, and that the size of the pieces is such that they will all pass through a one-inch ring.

“The foregoing performances will yield the undermentioned average fuel consumptions and costs, if coke be taken at 45s. per ton, and anthracite at 55s. per ton :—

Coke . . . 0·55 lb. per ton-mile, and 0·133*d.* per ton-mile.

Anthracite . 0·45 lb. „ „ 0·133*d.* „ „

“Taking the average road performance on suction gas at the mean figure of one ton-mile per 0·5 lb. of solid fuel, and assuming the average cost of such fuel at 50s. per ton, each penny expended on the fuel yields in work 7·5 ton-miles.

¹ “Report of the Inter-Departmental Committee on the employment of gas as a source of power,” etc. Published by H.M. Stationery Office, 1919.

- “Taking the average road performance on petrol at 40 ton-miles per gallon, and the average cost of such fuel at 2s. 6d. per gallon, each penny expended on petrol yields in work 1·33 ton-miles.
- “It thus appears, solely on a fuel comparison basis, that the propulsion of motor vehicles on common roads may be accomplished on the portable suction gas system at costs which on the average are equivalent to petrol at not more than 5·1d. per gallon. On the average one cwt. of coke or anthracite so used will do the same work on the road as 5·6 gallons of petrol used in an ordinary internal combustion engine.”

These conclusions show clearly that if the gas plant engineer can meet satisfactorily the requirements of road service, an important saving can be effected in working cost. The case is even stronger now (1920) than it was when the Committee reported, as the price of petrol is much higher than it was then. At the same time a great development is taking place in the use of motor lorries in this country, and the Government are advocating their use to relieve the railways. There is therefore an increasing demand for petrol or some suitable substitute.

The Committee state, “There can be no question that automatic stoking and discharge of the fuel-body contribute in a marked degree to uniformity of both production and quality of the gas, whilst correlation between the rate of feed of water and solid fuel and the rate of demand for combustible gas by the engine is of admitted importance and apparent novelty.” In principle the automatic feeding of fuel and the automatic discharge of ash doubtless favour uniformity of production and quality of gas, but, as we have already pointed out, this cannot be done without rather complicated mechanical devices, which in themselves are not only troublesome but are attended with a certain amount of risk. For lorry work the power required cannot well exceed a maximum of 50 H.P., and will usually be less; therefore the gas plant will necessarily be small, and we feel sure that it should be of the simplest kind possible, and that all complications should be avoided, unless it can be proved that they cannot be dispensed with for road service. We can hardly imagine any one suggesting automatic feeding and stirring of the fire in a steam lorry; the fire is made up at the start and then left for a considerable time, and it has yet to be proved that the same cannot be done with a small gas-producer of the same power.

As regards the three systems, A, B, and C, referred to in the Committee's report, we may mention that A was put forward by the British Westinghouse Co., who have since given up this class of work; C was the system of Mr. H. W. Bamber, which we have already described; B was the system of Col. D. J. Smith, O.B.E., who described it fully in a paper read by him at the Institution of Automobile Engineers in January, 1920. The plant has a producer of special construction, and the hot gas from this passes through a dry scrubber, and then through piping leading to the engine. The scrubber has one large vertical pipe surrounded by water, and the hot gas from the producer passes downwards through this pipe, it then passes upwards through a series of small vertical pipes, then downwards through another series of small pipes, and finally it flows upwards through a large pipe, and from this the gas passes through piping to the engine. In this way the gas is cleaned and cooled without coming in contact with water, and there are cleaning boxes and covers over the ends of all the pipes, so that the dust, etc., deposited can be removed easily and quickly. The water which is heated by the first gas pipe above mentioned passes to a vapouriser, which forms the top of the producer; air is drawn through the vapouriser and mixes with water vapour, but the admission of air is controlled by a throttle which is connected to the throttle on the engine, so that when the engine-throttle is opened the throttle on the air inlet of the vapouriser is partially closed. This regulation of the steam and air supply to the producer is considered important, in order to maintain the right proportion of air to steam; leaving only the quantity of the mixture to vary according to the volume of gas required. The total weight of a plant to serve 50 B.H.P. is said to be 2 cwts. (100 kilos).

The producer has mechanical devices for feeding the fuel, for moving the grate frequently, and for discharging the ash, all connected together and worked automatically by power from the engine. Each part is adjustable, and can be worked independently by hand if required. The diameter of the fire chamber in the producer is about 12 ins., and its depth is about the same, and Col. Smith advises that the actual depth of fuel should not exceed 6 ins. To work in this way, he says, it is essential

to have a regular feed of fuel in small measured quantities, and to have a continuous agitation of the whole fuel bed, in order that no channels or holes may be formed in the fire. We have already discussed the question of working with a shallow fire, but we did not have in view such a little depth as 6 ins., as advocated by Col. Smith. If he is right he is fully entitled to the credit of working a producer in a new way ; from long association, and for the reasons we have given, we favour a deeper fire than he recommends, but we are open to conviction if it can be shown that his system of working is better for its special purpose. There is, however, one point to which we think it right to call attention. So long as there is a depth of 6 ins. of incandescent fuel in the producer, in small pieces, the gas may be of good quality, but if the feeding is imperfectly done, or if from any cause the fire is not deep enough to burn all the air drawn in by the suction of the engine, the excess of air will burn part of the gas in the producer. If this occurs the gas which passes to the engine will be diluted with combustion products, and the power will be reduced.

We have not thought it worth while to make a close comparison between a gas-driven lorry and a steam lorry, for if the combination of a suction plant and gas-engine can work as well as an engine driven with petrol, it follows that the gas power can also compete favourably with steam power, which consumes not less than five or six times more fuel than the gas power. Assuming that a suitable gas plant is devised for the special requirements of road service, the whole question will resolve itself into one of economy in working cost. The labour cost with a suction plant will be about the same as with steam power, but the former will have to carry much less dead weight of fuel and much less water.

CHAPTER XII

GAS PROPULSION OF VESSELS

THE propulsion of vessels in water is somewhat analogous to traction on roads, but the conditions of working are of course very dissimilar, and call for some special notice. In this country there are not so many rivers and inland waters as there are in many other countries, where steamboats run considerable distances ; but there are sufficient waterways to make it rather surprising that so little use has been made of gas power for propulsion. In Europe suction-gas plants on boats have been in use for several years—in Belgium, Germany, and Holland ; and in the United States of America there is a still greater use of them, owing to the considerable saving effected by using gas made from anthracite or coke instead of petrol.

On fairly smooth water passenger and freight boats, tugs and lighters, use suction plants which resemble those used on land in their leading characteristics ; but some special modifications and precautions are necessary. Obviously the general arrangement must be as compact as possible ; it is also desirable to keep down the weight and dimensions, but this is not so essential as with a road vehicle. Fortunately there can be no lack of water for the steam required, or for cooling and scrubbing the gas, and salt water can be used when necessary. The floor on which the producer is placed should be fireproof, and there should be a bulkhead or partition between the engine and gas plant, to prevent ashes and dust getting to the engine. There should be no bunks or sleeping accommodation in the rooms where the engine and gas plant are worked.

We have referred more particularly to vessels on canals, rivers, estuaries, and lakes, because much less has been done on the open sea. The chief reason for this is that so long as a

special fuel like anthracite or coke is necessary to make the gas with, it is considered too risky and impracticable to let a boat depend on a fuel which cannot be obtained at any ordinary stopping-place. It would not do to lose the cargo space which would be required to stow enough of the special fuel for the home as well as the outward voyage. Now that suction plants on land can be worked with non-caking bituminous coal, there seems to be no reason why it should not be used equally well for marine work; the saving in working cost compared with steam power would be considerable.

Among the first, if not the first (1904), to design a special engine and suction plant to propel small vessels was the late Herr Emil Capitaine, of Frankfort. He ran several boats on the Rhine and elsewhere, but he was unable to deal with large sizes, owing to the power not being reversible, clutch gears and reversing propellers being considered unsuitable for powers above 300 H.P. The fuel he used was anthracite.

The next important experiment (1907) was the fitting up of H.M.S. *Rattler*, a training ship on the Clyde, with gas power. This was done at the instigation of Sir William Beardmore, who for a long time has been a keen advocate of gas power, and who has probably the largest producer-gas installation in this country for engine and furnace work. The engine was designed and built at his works in Glasgow, and it replaced triple-expansion steam-engines. The gas-engine had five cylinders, each developing 100 B.H.P.; the power was reversed by means of a hydraulic clutch and gear. The gas-producer was worked with anthracite, and had no special features of importance except that the steam required was raised by the exhaust from the engine, and in doing this the exhaust was silenced. After leaving the producer the gas was cooled by water in a vertical pipe, and then passed through a centrifugal fan to dry it. This vessel worked satisfactorily for a considerable time and made many cruises, but from the point of view of adopting gas power generally for marine work it was only partially successful, because it was necessary to use anthracite as the fuel, and because the hydraulic clutch used for reversing was not considered satisfactory for large powers. In the light of what has since been accomplished on land with bituminous coal, it seems probable that this class of

coal would now give as good results as were obtained with anthracite.

In 1909 Prof. Föttinger, one of the engineers of the Vulcan Engineering Works at Stettin, brought out his hydraulic transformer, which was intended originally for reducing the high speed of steam turbines to the comparatively slow speed of propeller shafts; with this he also claimed to be able to reverse the power of engines of large size. Messrs. A. C. & M. Holzapfel, of Newcastle-on-Tyne,¹ acquired the British patent rights for the Föttinger transformer, and proceeded to build an experimental sea-going vessel of 300 to 400 tons, to test gas power and to try the hydraulic transformer, also to find out by practical experience what arrangements would be best for large sea-going vessels. The vessel was built as a coaster on commercial lines, but unfortunately, it was considered best to work the gas plant with anthracite until the above tests of engines and transformer had been completed, and there are no trials with bituminous coal to record.

The engine had six cylinders, and was designed to run at 450 revolutions per minute. As to the transformer, Mr. Holzapfel says that, "Roughly speaking, it consists of two centrifugal pumps driven by a main shaft attached to the gas-engine, and two turbines—one for going ahead and one for going astern—mounted on a secondary shaft. Either of these centrifugal pumps delivers water into its turbine, according to the movement of a lever. By a simple movement of this lever from forward to aft, the revolutions of the propeller can be instantly changed from full speed ahead to full speed astern. While the lever stands in the middle there is no load on the engine, and the propeller remains stationary." He adds: "Altogether the transformer has done its work in an entirely satisfactory manner."

The vessel had her trials in April, 1911, and afterwards she made the following trips with the cargo indicated:—

Tyne to London, 242 tons of coke.

London to Llanelly, 330 tons of scrap iron.

Llanelly to London, 330 tons of lime.

¹ "Gas Power for Ship Propulsion," by A. C. Holzapfel. Inst. of Naval Architects, March, 1912.

London to Cork, 330 tons of wood and cement.
Cork to Newhaven, 251 tons of oats.
Guernsey to London, 340 tons of granite.
London to Tyne, 340 tons of chalk.
Seaham to Morlaix, 331 tons of coal.
Guernsey to Weymouth, 331 tons of granite.

The consumption of anthracite during these runs is stated to have been from 25 to 35 cwt. (1250 to 1750 kilos) per 24 hours, "about one-half that of steamers of similar power."

Various troubles were experienced with the gas plant, partly owing to the scrubbers, but chiefly owing to the arrangement of the gas plant and engine. The coke in the scrubbers became pulverised, and choked the outlet so that water rose into the producers and put out the fires; earthenware pipes were afterwards put in the scrubbers instead of coke, and the connecting pipes were altered. We think that Messrs. Beardmore & Co.'s arrangements on board the *Rattler*, especially for cooling and cleaning the gas, would have avoided these troubles. The engine worked fairly well, but gave less power than was expected. The vibration was "not inconsiderable." These were the principal troubles mentioned in Mr. Holzapfel's interesting paper, and we have thought it best to repeat them, as they show that with present experience they are not likely to recur. The really serious drawback for sea-going is the want of a thoroughly trustworthy gas plant to work with almost any kind of bituminous coal. Mr. Holzapfel rightly says that it is "absolutely essential in a large vessel to use bituminous coal, as anthracite is not readily obtainable at many foreign coaling ports." Also the cost of anthracite is usually much greater than that of bituminous coal.

In Holland the Machinefabriek Drakenburgh, of Utrecht, have fitted several small cargo vessels with gas power for the coasting trade of Great Britain and the Continent. The first was the *Zee-meew*, of 630 tons deadweight (see Fig. 71), which was in regular service from 1910 to 1915, chiefly between Rotterdam and Harwich. She was then taken by the Germans and partly dismantled, but has now been restored to the owners and is being refitted for service. A sister vessel, the *Zeearend* (with gas power), was also trading regularly for some time, but in

1918 came in contact with a floating mine and was wrecked. The same makers have fitted similar gas-engines and gas plants to the *Wilhelmina*, *Wageningen*, *Brandaris*, *Quo Vadis*, and *Rynveer*; all are from 500 to 700 tons deadweight.

Speaking generally, the gas-producers used in these vessels have no special features, except that they have water-jackets instead of firebrick linings; they are all worked with anthracite, and the consumption is said to be about 350 grams (0.77 lb.)



FIG. 71.—The *Zeemeeuw* worked by gas-power.

per H.P.-hour. In all cases the engines and gas plant are in the stern of the vessel, the gas plant being on the poop deck and the engines below the plant. The propeller is driven by a friction clutch, and the makers say that they find this satisfactory up to 300 H.P., but not beyond. Each vessel has two vertical engines of about 150 H.P. each, with four cylinders; the engines make about 300 revolutions per minute, and are reversible, so that they can be worked forwards or backwards. This important operation is effected in the following way: On the top of each cylinder there is an inlet for a mixture of gas and air, and an outlet for the exhaust gases, as shown in section in Fig. 72, and by reversing a lever the outlets of all the cylinders become inlets for gas and air, and all the inlets become outlets for the exhaust

gases. The engine is started by compressed air from a receiver, and is afterwards worked by the suction of gas and air in the usual way; when the engine is reversed it is again started by compressed air, as in the first instance. It is said that the complete reversal and restarting are effected in about 5 to 7 seconds. There is a small auxiliary oil-engine to charge receivers with compressed air before the first start of the main engine, and when the latter is running with gas it works a separate air compressor (when required) so as to keep the receivers charged for manœuvring the vessel, etc.

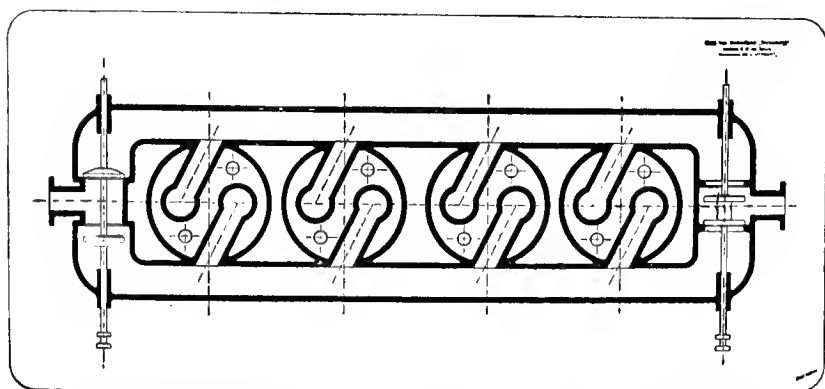


FIG. 72.—Section through inlet and exhaust pipes on top of cylinders.

In the United States Mr. A. L. Galusha, now the engineer of the Gas Producer and Engineering Corporation, New York, has for several years given special attention to the subject of gas power for propelling vessels, and he says that his marine gas plant, shown in Fig. 73, is now working in several different countries. In principle the producer is of ordinary type, but it is said to be lighter than usual. The feeding hopper stands on four inclined pipes, which distribute the fuel evenly, although the boat may be rolling or pitching at an awkward angle. There is a rocking grate, but no vapouriser, as the steam required is raised without boiler or vapouriser. A short length of the exhaust pipe next to the engine is jacketed with water, and a piece of $\frac{1}{4}$ -in. pipe (with regulating valve) leads from the jacket to the exhaust pipe beyond the jacket; through this small

pipe a trickle of hot water from the jacket is sent into the exhaust pipe, and most of it is there converted into steam. About ten feet from the water inlet a steam dome is fixed to the

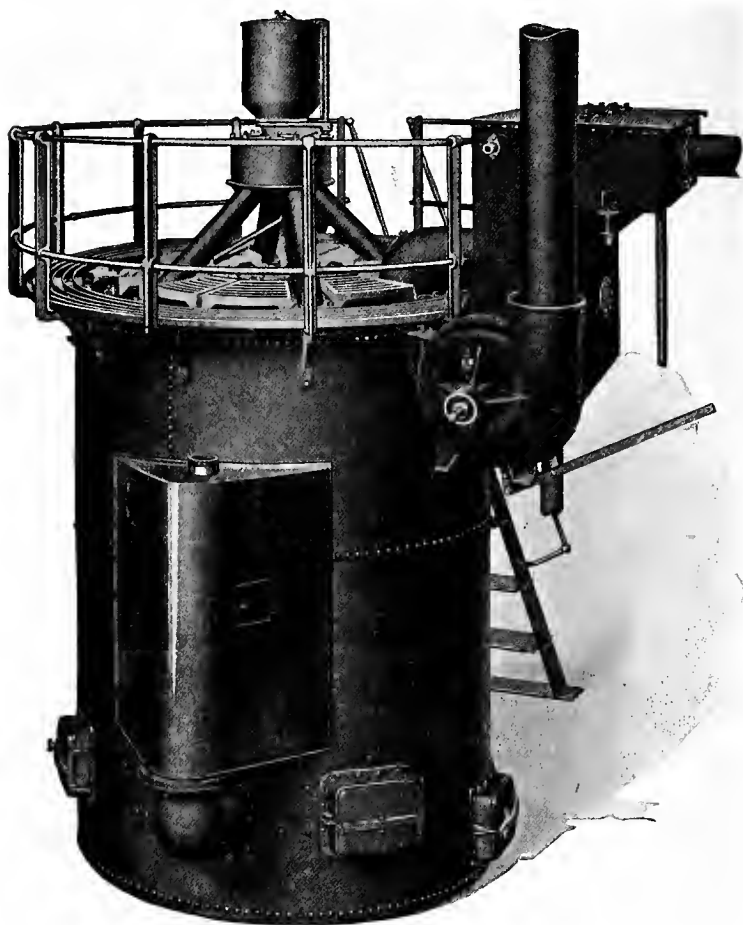


FIG. 73.—Galusha producer and scrubber for marine work.

upper side of the exhaust pipe, and steam and some of the exhaust gases collect in this, leaving a little water and the remainder of the exhaust gases in the exhaust pipe. From the top of the dome there is a small pipe which runs to the air

inlet near the bottom of the producer, and the pressure in the exhaust pipe makes steam flow to this air supply. It is claimed that the amount of steam sent to the producer depends on the pressure in the exhaust pipe, the pressure being adjusted by a slide which reduces the sectional area of the exhaust pipe beyond the dome (after the producer and engine have worked together a short time); the pressure of the steam then varies automatically with the rise and fall of pressure in the exhaust pipe, so that after an explosion in the engine, when more gas is required, more steam is sent to the producer. A certain amount of the exhaust gases no doubt passes with the steam to the air inlet of the producer, and the effect of such an addition to the blast is to increase the proportion of nitrogen in the gas. The nitrogen in the exhaust gases passes unchanged through the producer, whilst the carbon dioxide is converted in the producer to carbon monoxide. The addition of exhaust gases to the blast of the producer has been advocated by some designers, but it is only an incidental feature in the Galusha system. Salt or impure water can be used in this system, and the admission of water and the raising of steam in the exhaust pipe silence the exhaust.

Another novel feature is the exceedingly small size of the scrubber shown at the back of Fig. 73; there is only one pipe bend between it and the top of the producer, and after passing through this diminutive scrubber the gas goes direct from the outlet of the scrubber to the engine. The small rectangular chamber next the producer is packed with refractory material, and is plentifully supplied with water from a pump; the projection at the top contains a series of vertical perforated plates, to trap dust or other impurities, so that when the gas reaches the engine it may be clean and dry. In some cases the gas from the producer is passed through a vertical cooling pipe before it enters the scrubber.

An interesting development has been the application of gas power (as an auxiliary) to a four-masted schooner, 185 feet long by 37 feet beam; with a deadweight of 1400 tons her draught is about 18 feet. She is fitted with a six-cylinder Wolverine gas engine, rated at about 200 B.H.P. The gas plant is of the Galusha type, and the only floor space required is for the producer, the little scrubber being overhead. With

gas power alone (without sails) the schooner makes from five to six knots per hour in still water. No fresh water is required, as the gas is washed with salt water, the inside of the scrubber being coated to prevent rust. Every part of the plant drains dry, so that in case it does not work, when there is a favourable wind, there is no water pocket which can freeze or give trouble.

This schooner has been doing active service since June, 1919, and in the autumn of that year she crossed the Atlantic to Liverpool, and from there she re-crossed to Halifax, Nova Scotia. This is the first record of gas power being used for such a long sea voyage, and is a noteworthy event. It happens that this occurred exactly 100 years after the sailing of the first vessel with steam power across the Atlantic—also from America. The gas was made with American anthracite on the outward trip, and with Welsh anthracite on the return; the consumption was 48 tons for 28 days. There was one man for each watch to work the gas plant, the engine, and all the power plant machinery, pumps, etc. The cost of working the gas power was considered so low that the plant was kept going nearly all the voyage. Against head winds it took 28 days to make the trip to Liverpool, and as a comparison it may be mentioned that a sister vessel (without gas power) started two weeks before the other, and was 48 days making the same trip. This schooner has been four times across the Atlantic Ocean, using gas power, and is now engaged in carrying timber from New Brunswick, Canada, to New York. She is one of a fleet of over sixty sailing vessels belonging to the Gorton-Pews Shipping Co.; some of the vessels have auxiliary power, and it is found that the profits realised by these vessels are considerably greater than those earned by the vessels without auxiliary power. In consequence of this all the Company's new vessels are being equipped with auxiliary gas power. Apart from the general saving in time and working cost, no tugs are required.

It will be noticed that we are still without practical trials of gas power with bituminous coal for marine work, but Mr. Galusha says that he has a tar extractor which will make working with this class of fuel a certainty, and we trust that an opportunity will be found to make a thorough test with bituminous coal, so that this important question may be proved to the satisfaction of ship-owners and others concerned.

CHAPTER XIII

STAND-BY LOSSES

CLOSE attention is usually given to the consumption of fuel per horse-power-hour while a gas plant is serving an engine, sometimes to the thousandth of a pound, and it is not a little remarkable that account is seldom taken of the consumption of fuel while a producer is standing with a fire in it. It is exceedingly low compared with that of a steam-boiler under like conditions. So long ago as 1886 Mr. Dowson made an interesting test with a small set of his plant, capable of serving a maximum of about 30 B.H.P.¹ The gas-producer and the little boiler which gave it the steam required were placed on a weighing-machine, as shown in Fig. 74. The outlet pipe from the producer had a loose water joint perfectly free, so that the weighing-machine could go up or down while gas was made continuously and conveyed to the engine. The chief object of this arrangement was to determine accurately not only the total consumption of fuel and water, but the weight of these materials converted into mechanical work at stated times. A separate test was made to determine the stand-by loss in the producer after the engine was stopped. The fire in the little boiler was raked at the end of the day's run, as was usual in ordinary work, and the gas-producer, with an anthracite fire in it, was allowed to stand eighteen hours; during that time the actual loss of fuel was only 18 lbs., or 1 lb. per hour. The plant stood in an open yard without shelter of any kind, and the test was made in the month of November when the day temperature was about 7° C. (45° F.). It was doubtless lower during the night.

In 1893 Messrs. Crossley of Openshaw, who were using a Dowson gas-producer for about 250 H.P., reported that on January

¹ *Proc. Inst. C.E.*, 1893, vol. cxii. p. 88.

20th the working of the producer was stopped at 8 p.m., and that it was started again at 5 a.m. the next day. The waste of fuel during this stoppage was at the rate of 5.1 lbs. per hour. On January 21st (Saturday), the producer was stopped at 2 p.m., and was started again at 7 a.m. on the 23rd (Monday); the waste was at the rate of 3.9 lbs. per hour. In all these tests a slight current of air was allowed to pass through the producer during the stand-by hours to keep the fire alight, and as this current was not constant the waste of fuel necessarily varied

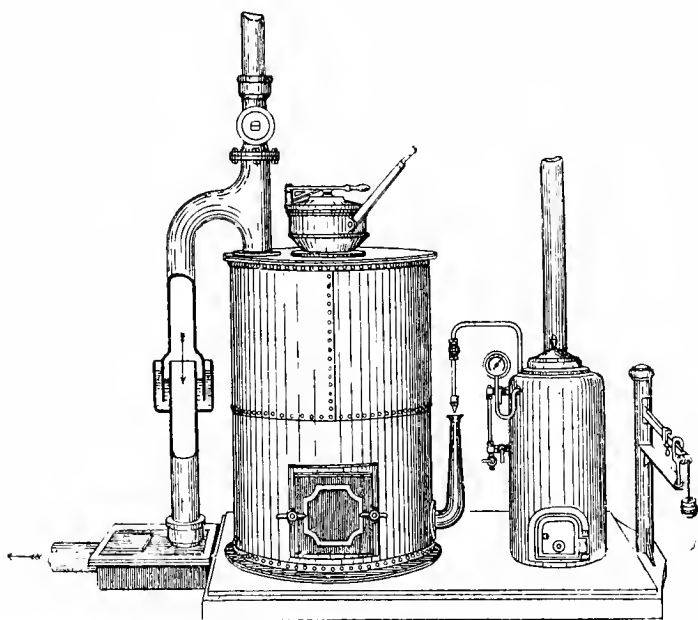


FIG. 74.—Gas-producer on weighing-machine.

somewhat, but the periods of standing were long, so that the averages are trustworthy.

Being anxious to compare these results with the stand-by losses of steam boilers, Mr. Dowson consulted the late Mr. Bryan Donkin in 1898, and the latter made some special tests with a Lancashire boiler at his works. He reported that the boiler had about 580 square feet of heating surface, that it was carefully set in brickwork in the usual way, and that it would evaporate economically (from cold) 250 to 300 gallons of water

per hour. The two fires of the boiler were banked about 5.30 p.m., and the fireman came again at 5 a.m. the next morning to make up the fires. When the two fires of the boiler were banked, the fireman put on each fire about 3 cwts. of small coal, making 672 lbs. in all. Mr. Donkin estimated that 150 lbs. of this coal were actually consumed during the night, but he did not know to what extent the remaining 522 lbs. were affected by being subjected to heat for several hours. He added that during the stand-by hours the brickwork was cooled considerably, and that when the fires were made up in the morning the brickwork was heated again at the expense of additional fuel.

Later (1904) Mr. Dowson interested several engineers in the subject, and they were good enough to have special tests made for him. The following are the results they gave:—

Leicester.—At this place there is a gas plant which serves gas-engines for the electric lighting of the railway-station and goods yard, and Mr. Deeley, the locomotive superintendent of the Midland Railway, wrote as follows:—

“A twenty-four hours’ trial has been made at Leicester, and it is found that the amount of coal required to leave the generator [100 B.H.P.] in the same state at the end of the twenty-four hours as it was at the beginning, was 51 lbs., or 2.1 lbs. per hour, and at the end of this period gas was passed into the gasholder (ready for use) in ten minutes. A steam-boiler of the same horse-power, under the same conditions, requires 14 lbs. of coal per hour to maintain its pressure ready for immediate use.”

Birmingham.—Mr. Henry Lea, M.Inst.C.E., had a special test made of a Lancashire boiler 28 ft. long by 7 ft. 6 ins. diameter, with two flues each 3 ft. diameter. He reported that the evaporative power in full work was 8000 to 9000 lbs. of water per hour. The consumption of Cannock screened coal in the boiler while standing twelve hours was about 4 cwts. During this time the steam pressure fell from 120 lbs. to 90 lbs., and it was not raised again to 120 lbs. The consumption while standing was 37.5 lbs. per hour.

Chelmsford.—Colonel R. E. B. Crompton, M.Inst.C.E., sent the following report from one of his staff:—

“Although we have never made a special test for the particular purpose in question, we have found that to keep up one of our

hand-fired Babcock & Wilcox boilers hot and ready for steam at short notice, during a period of about ten hours, required about 6 cwts. of hard steam coal or thereabouts. Under the above conditions, the boiler would be coupled to the main steam range, *i.e.* not isolated. The rating of the boiler is 4200 lbs. per hour, and the coal used is Shipley Best Hards.

"I called at the Chelmsford Electric Light Co.'s station, to see if I could obtain any figures on the subject, as they practically always have one boiler banked up during the day, and they tell me that they use about 3 cwts. on a similar boiler to ours, but with chain-grate stoker; and under similar conditions, during about ten hours, it took another 3 cwts. to make the boiler begin to generate steam. The coal used in this case would be Shipley peas."

In both these cases the consumption was 67 lbs. per standing hour.

London.—Sir Alexander Kennedy, M.Inst.C.E., wrote: "What I have repeatedly measured is the proportion borne by the coal actually used at a generating station, in boilers of which the stop-valves are closed, to the total coal used in the same time in the station. I have found that during the heavy hours of working in an electric lighting station, *i.e.* from 3 to 11 p.m., this proportion is about $2\frac{1}{2}$ per cent. Measured over the whole twenty-four hours' load in one case, I found it to amount to 7·2 per cent. for a fortnight; in another case 7·8 per cent. At other times over forty-eight or seventy-two hours I have found it to average 10 per cent. All these higher figures are for cases where a very large number of boilers have to be kept or got ready for a very short peak."

This information is interesting in itself, but it does not enable us to arrive at the stand-by loss of an individual boiler.

Newport (Mon.).—Mr. H. Collings Bishop, the borough electrical engineer, made two special tests, and reported as follows:—

Trial No. 1.—With two Babcock & Wilcox boilers of 500 H.P. each, the consumption of Welsh coal (colliery screenings) during five hours standing was 1800 lbs. The steam pressure at the beginning of the test was 120 lbs.; it dropped to 80 lbs. during the test, and was raised to 120 lbs. at the finish. The consumption of coal was about 180 lbs. per boiler per hour.

Trial No. 2.—The same two boilers at a week end while standing twenty-nine hours consumed 6500 lbs. of coal. The steam pressure at the start was 120 lbs.; it fell to 50 lbs., and was raised to 120 lbs. at the finish. The consumption of coal was about 112 lbs. per boiler per hour.

Rugby.—Messrs. Willans & Robinson also made a special test with a Niclaussé type of boiler, capable of evaporating 8000 lbs. of water per hour; its dimensions were 13 ft. × 10 ft. × 10 ft. They gave the consumption of Midland large coal as 600 lbs. while standing twelve hours, the full steam pressure and water-level being maintained throughout the trial. This consumption was equal to 50 lbs. per standing hour.

London.—Mr. F. A. Wilkinson, electrical engineer, had a special test made with a Lancashire boiler (Galloway) 30 ft. long by 9 ft. diameter, with a grate area of 47·5 sq. ft. This boiler was one of a battery; on one side there was a similar boiler doing regular work, and on the other side a similar boiler which had been shut down for some months. The fires were cleaned just before the start and again at the end of the test. There was a Musgrave superheater at the end of the boiler, and the valve between the range of boilers and the superheater was closed. There was a slight leakage at the deadweight valve throughout the test, and a certain amount of water escaped through the trap which drains the superheater connections. The water in the gauge glass fell $\frac{3}{4}$ in. during the trial. The consumption of coal during twelve hours standing was 537 lbs. = 44·7 lbs. per hour.

Smallheath.—At this place there was a large gas plant in the works of the Birmingham Small Arms Co. One set of 250 B.H.P. was tested by Mr. Henry Lea, their consulting engineer, during five consecutive days. The consumption of anthracite peas during the stand-by hours was at the average rate of 4·5 lbs. per hour.

Limerick.—The corporation of Limerick had a gas plant for the electric light station, and when the consulting engineer, Mr. J. Enright, tested the plant it was found that the stand-by loss in a 225 B.H.P. producer was at the rate of 4·8 lbs. per hour.

Walthamstow.—There was a large gas power installation at this place (over 3000 B.H.P.) for the electric lighting and tramway

service, and Mr. F. A. Wilkinson, the electrical engineer in charge, wrote: "I have made some tests on the gas generators installed at these works to ascertain the actual consumption of anthracite in a gas generator when standing with a fire in it, and when gas was not being made. A 375 B.H.P. generator was standing forty-eight hours, and the total weight of coal consumed was 84 lbs." This is equal to only 1·8 lbs. per hour.

We give a *résumé* of these results in the following table, and may explain that for estimating the [†]maximum horse-power of the boilers we have allowed 20 lbs. of water per horse-power-hour.

TABLE XXXI.—CONSUMPTION OF FUEL IN STAND-BY HOURS.

Steam Power.

Type of boiler.	Max. H.P. of boiler.	Coal consumed per standing hour.	Authority.
1. Various	100	14·0 lbs.	{ Mr. Deeley, Loco.-Supt. Mid-land Railway. Mr. H. Lea.
2. Lancashire	450	¹ 37·5 "	
3. Babcock and Wilcox	210	67·0 "	Col. R. E. B. Crompton.
4. " "	210	67·0 "	
5. " "	500	180·0 "	Mr. H. Collings Bishop.
6. " "	500	112·0 "	
7. Niclaussé	400	50·0 "	Messrs. Willans and Robinson. Mr. F. A. Wilkinson.
8. Lancashire	400	44·7 "	
Average		342	71·5 lbs.

TABLE XXXII.—CONSUMPTION OF FUEL IN STAND-BY HOURS.

Gas Power.

Locality.	Max. H.P. of producer.	Coal consumed per standing hour.	Authority.
1. Openshaw	250	5·1 lbs.	Messrs. Crossley Bros., Ltd.
2. "	250	3·9 "	
3. Leicester	100	2·1 "	Mr. "Deeley "Midland" Rlwy.).
4. Smallheath	250	4·5 "	
5. Limerick	225	3·8 "	Mr. J. Enright. Mr. F. A. Wilkinson.
6. Walthamstow	375	1·8 "	
Average		242	3·5 lbs.

¹ Exclusive of raising the steam pressure from 90 to 120 lbs.

In this table we have not included the small 30 B.H.P. producer referred to on p. 227, as all the other producers are much larger, and its small consumption might be thought to lower the general average unduly. But without considering mere fractions of a pound it is clear that the stand-by loss in a gas-producer is trifling compared with that of a steam-boiler of any type; and the explanation is not far to seek. For a given horse-power the producer is much smaller, and has far less radiating surface than a boiler; it has no water in it to be heated, and it can be worked up to its maximum production in about fifteen minutes, after standing almost any length of time. With a boiler, except in the vertical or portable type, there is a large amount of external brickwork to be heated, and there is a considerable quantity of water, even in the tubular type. When the boiler is standing, the water and the brickwork lose heat, and not only more time but more fuel is required to make up this loss than in the case of a gas-producer. Doubtless the heat-efficiency of a good boiler is high when it is working to nearly its full capacity, but the reverse is the case when it is standing; in factories and electric lighting and power stations, where the plant is usually standing a long time, this question is deserving of close attention.

By way of illustration, let us take the case of a gas plant and engine for 200 B.H.P., and of a boiler and steam-engine of the same power, each working at its maximum for eight hours and standing sixteen hours. For the gas power we will assume a fuel consumption of 1 lb. per B.H.P.-hour while the plant is working, and 3·8 lbs. per hour when standing, as at Limerick. For the steam power we will assume a fuel consumption of 2·5 lbs. per B.H.P.-hour while the plant is working, and 67 lbs. per hour when standing, as at Chelmsford. We then have the following comparative results:—

$$\begin{array}{rcl}
 \text{Gas power : } 200 \text{ H.P.} \times 1 \text{ lb.} \times 8 \text{ hours} & = & 1600 \text{ lbs.} \\
 & 3\cdot8 \text{ lbs.} \times 16 \text{ hours} & = \quad 61 \text{ ,,} \\
 \text{Total} \quad . \quad . & & \underline{1661} \text{ ,,}
 \end{array}$$

$$\begin{array}{rcl}
 \text{Steam power : } 200 \text{ H.P.} \times 2\cdot5 \text{ lbs.} \times 8 \text{ hours} & = & 4000 \text{ lbs.} \\
 & 67 \text{ lbs.} \times 16 \text{ hours} & = 1072 \text{ ,,} \\
 \text{Total} \quad . \quad . & & \underline{5072} \text{ ,,}
 \end{array}$$

On this basis, with steam power the stand-by loss of the boiler

is over 20 per cent. of the total fuel consumed in twenty-four hours; whereas with gas power the stand-by loss of the gas-producer is under 4 per cent. of the total fuel consumed in twenty-four hours.

If we were to take the case of a plant for 500 B.H.P. the result would be still more striking. For the gas power we will assume a fuel consumption of 1 lb. per B.H.P.-hour while the plant is working, and as much as 5 lbs. per hour when standing. For the steam power we will assume a fuel consumption of 2.5 lbs. per B.H.P.-hour while the plant is working, and 112 lbs. per hour when standing, taking the lower consumption of the two 500 H.P. boilers tested by Mr. Bishop. We then have the following results:—

$$\begin{array}{rcl}
 \text{Gas power: } 500 \text{ H.P.} \times 1 \text{ lb.} \times 8 \text{ hours} & = & 4000 \text{ lbs.} \\
 & 5 \text{ lbs.} \times 16 \text{ hours} & = \quad 80 \text{ „} \\
 \text{Total} & . & . \quad \underline{4080} \text{ „}
 \end{array}$$

$$\begin{array}{rcl}
 \text{Steam power: } 500 \text{ H.P.} \times 2.5 \text{ lbs.} \times 8 \text{ hours} & = & 10,000 \text{ lbs.} \\
 & 112 \text{ lbs.} \times 16 \text{ hours} & = \quad 1,792 \text{ „} \\
 \text{Total} & . & . \quad \underline{11,792} \text{ „}
 \end{array}$$

On this basis, with steam power the stand-by loss of the boiler is about 15 per cent. of the total fuel consumed in twenty-four hours; whereas with gas power the stand-by loss of the gas-producer is under 2 per cent. of the total fuel consumed in twenty-four hours, although the consumption during the eight working hours is only 4000 lbs., compared with 10,000 lbs. for steam power. If we take the percentage of the stand-by loss on the fuel consumed during the working hours, in each case, we have the following results:—

	200 B.H.P.		500 B.H.P.
Steam power	26.8 per cent.	. .	17.9 per cent.
Gas power	3.8 „	. .	2.0 „

CHAPTER XIV

COMPARISON OF GAS AND STEAM POWER

It would be beyond the scope of this little work on producer gas to enter minutely into questions affecting the gas-engine only; but the subject of gas power cannot be considered without taking account of the heat efficiency, not only of the gas-plant but of the gas-engine also. The two are connected inseparably, as in the case of the steam-engine and boiler. We propose, therefore, to consider briefly the combined heat efficiency of a gas plant and gas-engine, and to compare it with that of a boiler and steam-engine of the same power.

For this purpose we have constructed the diagrams shown in Figs. 75, 76, 77 and 78. The first two refer to steam and gas power plants each of a size suitable for 250 B.H.P.; the other two refer to plants suitable for 40 B.H.P. each. In each the base of the diagram represents the number of heat units (calories or B.Th.U.) in the fuel consumed to produce the same amount of useful work, viz. the equivalent of 100 heat units.

In determining the heat efficiencies of steam-boilers we have consulted the late Mr. Bryan Donkin's work on the "Heat Efficiency of Steam-Boilers" (1898). He gives the result of a large number of careful tests, and from these we get the following averages:—

TABLE XXXIII.—HEAT EFFICIENCIES OF STEAM-BOILERS.

Description of boiler.	Number of boilers tested.	Average heat efficiency per cent.
Water tube (Babcock and Wilcox type) .	16	61·2
Lancashire	161	63·4
Water tube (various)	27	67·5
Cornish	37	67·6
Marine	32	69·0
Locomotive and Portable	36	72·4

We have also the authority of Sir Alexander Kennedy for saying that the actual heat efficiencies of steam-boilers vary from 50 to 80 per cent. He said,¹ "The 50 per cent. is the result of every-day careless working, the 80 per cent. the result of thoroughly good working with real care." For the 250 B.H.P. steam plant (Fig. 75) we have taken 80 per cent. as the heat efficiency of

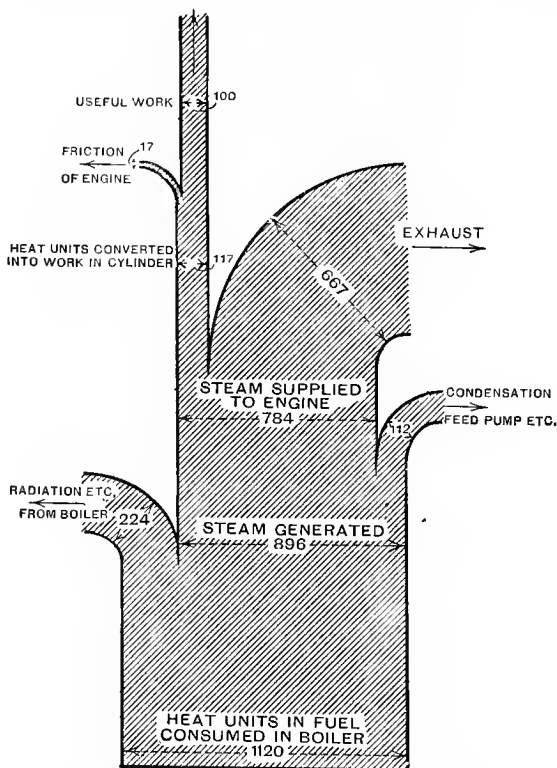


FIG. 75.—Steam power—heat efficiency diagram 250 B.H.P.

the boiler; and for the 40 B.H.P. size (Fig. 77) we have taken 75 per cent., although Mr. Donkin's averages show that in practice the efficiencies obtained are much lower than those we have assumed. For the heat lost by condensation in steam pipes, the driving of feed pumps and other usual losses, we have taken 10 per cent. of the total heat in Fig. 75, and 5 per cent. in

¹ Royal Inst. Lecture, 1893.

Fig. 77. For the 250 B.H.P. steam-engine (Fig. 75), we have assumed a heat efficiency of 15 per cent., *i.e.* 15 per cent. of the heat supplied to the cylinder is assumed to be converted into *indicated* work; for the smaller steam-engine (Fig. 77) we have assumed a heat efficiency of 10 per cent. For all the diagrams (steam and gas) we have assumed that the friction of the engine, *i.e.* the difference between the indicated horsepower and the brake horsepower, is 15 per cent. of the indicated horsepower.

For the 250 B.H.P. gas-power diagram (Fig. 76) we have assumed that the gas plant is of the steam-jet pressure type, and that including the small boiler its heat efficiency is 80 per cent.; but if we had taken a plant of the suction type without an independent boiler, it would have been more correct to assume a heat efficiency of 85 per cent. For the 40 B.H.P. gas-power diagram (Fig. 78) we have assumed that the gas plant is of the suction type, and that its heat efficiency is 85 per cent., although 90 per cent. has already been attained for this size of plant

(*vide ante*, p. 145). The loss of heat in converting the solid fuel into gas is therefore assumed to be 20 per cent. of the total heat of combustion of the fuel in the case of Fig. 76, and 15 per cent. in Fig. 78. With the gas plant there are no losses from condensation or other causes beyond those included in the 20 and 15 per cent. just referred to. For the gas-engines we have assumed a heat efficiency of 28 per

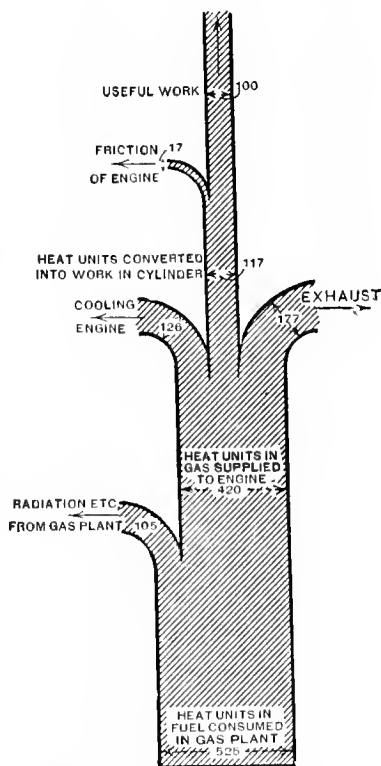


FIG. 76.—Gas power—heat efficiency diagram 250 B.H.P.

cent.; and of the 72 per cent. loss in the engines we have apportioned 30 per cent. to the cooling, and 42 per cent. to the exhaust.¹

These diagrams show at a glance the chief sources of waste in the two systems; and although they can only be estimated approximately, and although they vary in different cases, the

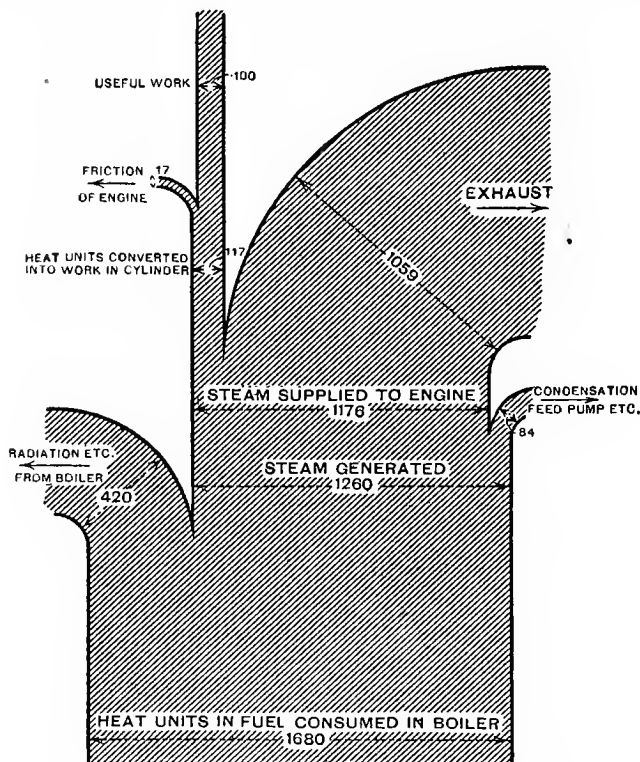


FIG. 77.—Steam power—heat efficiency diagram 40 B.H.P.

figures correspond with fuel consumptions per B.H.P.-hour which are in accord with practical results for gas power, and the figures for steam power are probably considerably better than are usually obtained with the sizes of installation considered. The figures correspond approximately with the following consumptions of fuel of average quality :—

¹ James Forrest Lecture, *Proc. Inst. C.E.*, 1904, vol. clviii. p. 283.

900 grams (2 lbs.)	per B.H.P.-hour	for 250 B.H.P. steam power.	
450 grams (1 lb.)	"	"	gas power (pressure plant).
1350 grams (3 lbs.)	"	40 B.H.P. steam power.	
400 grams (0.9 lb.)	"	"	gas power (suction plant).

Taking the 250 B.H.P. size, we see in Fig. 75 that of 1120 heat units in the fuel consumed in the boiler 224 are lost in ashes, radiation, flue gases, etc.; that there are 896 units in steam generated, and that 112 units in this steam are lost by condensation in pipes, feed pump, etc. The steam supplied to the engine contains 784 heat units, but of these 667 are lost in the exhaust, so that only 117 are converted into indicated work in the engine, and from this 17 have to be deducted for the friction of the latter.

In Fig. 76 we see that of 525 heat units in the fuel consumed in the gas plant 105 are lost in ashes, radiation, cooling of gas, etc.; that there are 420 units in the gas supplied to the engine, and that of these 177 are lost in the exhaust, and 126 in cooling. As in Fig. 75, there are 117 units converted into indicated work in the engine, and of these 17 are deducted for friction.

In the 40 B.H.P. size, it will be seen in Fig. 77 that, starting with 1680 heat units in the fuel consumed in the boiler, 420 are lost in ashes, radiation, flue gases, etc.; that there are 1260 units in the steam generated, of which 84 are lost by condensation in pipes, feed pump, etc. The steam supplied to the engine contains 1176 units of heat, but of these no less than 1059 are lost in the exhaust.

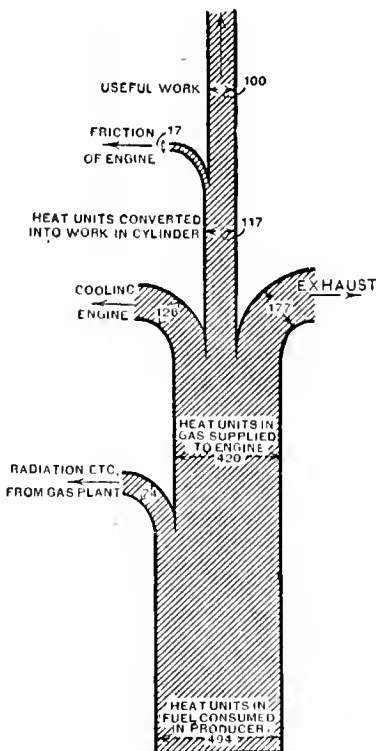


FIG. 78.—Gas power—heat efficiency diagram 40 B.H.P.

In Fig 78 we see that of 494 heat units in the fuel consumed in the gas-producer 74 are lost in ashes, radiation, cooling of gas, etc.; that there are 420 units in the gas supplied to the engine, and that the remaining losses are similar to those in Fig. 76.

On the above bases the general result is that for the 250 B.H.P. size, in order to obtain 100 heat units in useful work with steam power, there must be 1120 heat units in the fuel consumed in the boiler; whereas with gas power there need only be 525 units in the fuel consumed in the plant. This shows a saving in fuel of 53 per cent. in favour of the gas plant. The result is still more striking in the case of the 40 B.H.P. size, as there must be 1680 units in the fuel consumed for steam power compared with 494 units for gas power. This is a saving of 70 per cent. in favour of the gas plant. These figures do not include any allowance for stand-by losses, although we should have preferred to give them if possible. We know what they are for gas plants of the sizes considered, but we do not know exactly what they would be for steam plants of the same powers; we may, however, safely conclude from the figures given in Tables XXXI. and XXXII. (p. 232) that they would be considerably greater for steam power than for gas power.

These diagrams not only help us to compare the heat efficiency of gas power with that of steam power, but they bring home to us the fact that even with a modern gas-engine there are very serious heat losses; and it may be well to consider what are its possibilities in the future compared with those of the steam-engine. It is generally conceded that theoretically the heat efficiency of the latter cannot exceed 30 per cent., and that there is no likelihood of attaining this in practice. On the other hand, the actual heat efficiency of a gas-engine has already reached the theoretical best of the steam-engine. Of still greater importance is the fact that theoretically it is possible for the gas-engine to have a much higher efficiency; what that efficiency may be cannot be precisely stated, but all authorities are agreed that there is still a large margin for practical improvements; and it is only reasonable to suppose that in the course of time the present great losses in cooling the engine, and in the exhaust, will be appreciably reduced. We have given an

instance (p. 101) of a Bonecourt tubular boiler heated by the exhaust gases from a gas-engine.

The above diagrams represent the heat efficiencies when the engines are working at full or nearly full load; and we should consider what would occur with a three-quarter or a half load. It is well known that the heat efficiency of a steam-engine falls as the load diminishes, owing to the heat losses being greater in proportion to the useful work done; and this also occurs with a gas-engine. The lowering of the heat efficiency with reduced loads may not be in precisely the same proportion for gas-engines as for steam-engines, but approximately it may be assumed that the comparison we have made in the above figures will hold good, in about the same proportion, for three-quarter or half loads as for a full load. As regards the heat efficiencies of the gas-producing plant and the steam-boiler, they are not so susceptible of change as those of the engines; their principle of working is altogether different. Actually the heat efficiency of a gas plant or of a steam-boiler is about the same at a three-quarter as at the maximum output; at half load there will be some lowering of the efficiency, but it will be about the same for the gas-producer as for the steam-boiler, so that on this account also our comparison will be in about the same proportion as for the full load. The figures and diagrams given above refer to typical gas-producers using anthracite or coke as fuel, but similar results may be stated for bituminous coal and other fuels.

In 1904-1905 the United States Geological Survey¹ made a large number of careful and elaborate tests at St. Louis, to determine the relative value of different kinds of coal for firing steam-boilers, and for making producer gas suitable for driving gas-engines. They had a complete steam-power plant, and a complete gas-power plant, for generating electricity, and Table XXXIV. gives their comparative summary of the leading results:—

¹ Report on the operations of the Coal Testing Plant of the U.S. Geological Survey, Washington Government Printing Office, 1906.

TABLE XXXIV.—COMPARATIVE SUMMARY OF LEADING RESULTS OF COAL TESTS MADE IN BOILER TRIALS AND IN GAS-PRODUCER TRIALS.

Coal.	Duration of trial in—		Total dry coal consumed per hour by— ^a		Dry coal burned per square foot of grate surface per hour in—		Water evapo- rated from and at 212° F. per pound of dry coal in boiler plant.	B.Th.U. per pound of dry coal used in—		Electrical horse-power delivered to switch-board trials of—		Total dry coal per electrical horse-power per hour used by— ^a	
	Boiler plant.	Gas-producer plant.	Boiler plant.	Gas-producer plant.	Boiler plant.	Gas-producer plant.		Boiler plant.	Gas-producer plant.	Boiler plant.	Gas-producer plant.	Boiler plant.	Gas-producer plant.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Hours.	Hours.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Alabama No. 2	10-02	43-00	874	328-7	21-54	7-78	8-55	12,555	13,365	213-7	200-6	4-08	1-64
Colorado No. 1	9-97	30-00	722	341-7	17-80	7-56	7-21	12,577	12,245	149-1	200-2	4-84	1-71
Illinois No. 3	10-13	30-00	861	356-7	21-23	8-41	8-04	12,857	13,041	198-1	199-6	4-84	1-79
Illinois No. 4	10-02	30-00	938	348-5	23-13	7-96	7-27	12,459	12,834	195-4	198-4	4-80	1-76
Indiana No. 1	9-93	29-67	908	384-8	22-39	9-08	8-45	13,377	13,037	220-0	199-9	4-13	1-93
Indiana No. 2	10-13	7-00	832	312-0	20-51	7-13	8-02	12,452	12,953	191-0	201-0	4-35	1-55
Indian Territory No. 1	9-75	31-00	778	374-0	19-17	8-95	8-64	12,834	13,455	192-3	204-0	4-04	1-88
Kentucky No. 3	10-07	30-00	882	381-2	21-75	8-92	8-27	13,036	13,226	208-9	200-5	4-22	1-91
Missouri No. 2	9-98	4-33	1014	339-6	25-00	7-96	7-08	11,500	11,882	205-6	198-6	4-93	1-71
West Virginia No. 1	9-98	24-00	768	315-6	18-94	7-36	8-95	14,198	14,396	196-7	200-4	3-90	1-57
West Virginia No. 4	10-00	9-00	770	258-2	18-98	5-96	9-65	14,002	14,202	212-5	199-7	3-62	1-29
West Virginia No. 9	10-00	6-33	721	320-1	17-78	7-60	10-09	14,616	14,580	208-2	201-0	3-46	1-59
West Virginia No. 12	10-13	30-00	719	300-5	17-68	6-92	9-90	15,170	14,825	203-6	199-8	3-53	1-50
Wyoming No. 2	9-95	30-00	1075	416-5	26-51	9-50	5-92	10,897	10,656	182-0	201-2	5-90	2-07

^a In gas-producer plant this includes the coal consumed in the producer and the coal equivalent of the steam used in operating the producer.

^b Gas-producer hopper leaked during these tests.

The steam plant consisted of two Heine water-tube boilers, each for 210 H.P., and a simple non-condensing engine of the Corliss type requiring 26.3 lbs. of steam per hour per H.P. developed. The engine was belted to the dynamo, and the mechanical efficiency of this combination was 81 per cent.

The gas plant was of the steam-jet pressure type, rated at 250 H.P., and consisted of a Taylor producer with rotating hearth, coke scrubber, centrifugal tar extractor, purifier, gas-holder, and meter. The engine was a three-cylinder Westinghouse, driving (by belt) a Westinghouse dynamo.

There were 78 boiler tests, and the Report states that a small number of the tests were not satisfactory, owing either to accident or to special qualities of the coals, but that fully 70 trials were regarded as satisfactory and complete in all details. It is also remarked that "the objects of these tests is to compare the steaming value of the various coals when burned under ordinarily favourable conditions. It is probable that somewhat higher efficiencies might, after a careful study, be obtained with any of the coals tested if it were possible to adapt the grate area and the baffling to the evident requirements of the several coals. On the other hand, it is doubtless true that, with the facilities available for knowing the existing conditions of any test, the coals were burned with more economy than is secured under the average boiler."

There were 24 gas-plant tests, and it is particularly interesting to note that four of them were with lignite, and that all these four produced gas of better quality than could be obtained from high-grade bituminous coals. Moreover, the Report says that "one ton of lignite used in a gas-producer plant will yield as much power as the best Pennsylvania or West Virginia bituminous coals used under boilers." It was also noted that as coals declined in value when measured by their steam-raising power, they increased in value comparatively as a fuel for the gas-producer.

It is interesting to observe that in all these 24 tests the fuel used contained a high percentage of volatile matter, ranging from about 19 per cent. (the lowest) to 39.6 per cent. (the highest), and giving an average of about 30 per cent. At the date of these trials comparatively little had been accomplished with bituminous

coals for gas-engine work, and it is creditable that useful results were obtained in these tests with 24 varieties of fuel. A simple up-draught producer, such as the one used, distils off a large quantity of condensable hydrocarbons from the fresh fuel put on the top of the fire, and apart from the trouble with tar, etc., which this causes, there is a considerable heat loss per pound of fuel consumed. It is also probable that some of the coals would have yielded better gas if they had been dealt with in some of the modern types of plant we have described in Chapter IX. With the boiler tests there was long experience to fall back on, but with the gas tests there was little or no experience, not even a rehearsal with some of the fuels used. It was also a drawback, as mentioned in the Report, that the setting of the ignition of the gas in the engine could not be altered while the engine was running, and that in consequence of this there was in some cases an excessive consumption of gas. It is therefore reasonable to expect that if some of the fuels were tested again with a modern gas plant and modern gas-engine, the results would be even better than in Table XXXIV.

The Report says: "In considering the possible increase in efficiency of the boiler trials, if a compound engine were substituted for the simple engine used, the fact should not be overlooked that a corresponding increase in the efficiency of the gas-producer trials may be brought about under more favourable conditions. The gas-engine is passing through a transition period. In the larger sizes the vertical single-acting engine is being replaced by the horizontal double-acting. Other changes and improvements are constantly being made which tend to do for the gas-engine what compounding and tripling the expansions have already done for the steam-engine." A general conclusion is that "the power producing efficiency of a number of bituminous coals, when converted into gas and used in the gas-engine, is $2\frac{1}{2}$ times what it is when used under boilers in the production of steam power."

An important feature connected with gas power is that the producer gas, if it has been cooled and scrubbed, can be conveyed any reasonable distance in pipes without appreciable change or deterioration. If the gas is properly cooled and cleaned in the gas plant there is nothing which can be condensed

except water-vapour, and if any of this is thrown down and drained away in the pipes, it is advantageous so far as the gas is concerned. In Chapter IX. we have referred specially to the distribution of producer gas under a high pressure in an extended district; but for the ordinary distribution of such gas in a factory or power station the pressure of the gas in the mains need not exceed that of a column of water 40 to 50 mm. high (say $1\frac{1}{2}$ to 2 ins.). As an example, this pressure was not exceeded in the installation in Holland, illustrated on p. 109, although the gas plant was about 500 meters from the factory. With such a low pressure it is easy to provide against leaks from the distributing pipes.

For gas power there is no advantage in having a higher gas pressure near the engine than that stated above; but with steam power the conditions are altogether different. With the steam-engine it is essential that the working fluid should be at high pressure when it enters the cylinder; and the steam in the pipes between the boiler and the engine cannot be at a lower pressure than the initial pressure required in the cylinder. Actually the boiler pressure is usually about 5 lbs. higher than the pressure of the steam when it reaches the engine, where the boiler and engine are not far apart. If the pressure in the pipes is only 3 to 6 atmospheres (45 to 90 lbs. per square inch) it is from 800 to 1600 times greater than that of the gas from a pressure plant; in practice the steam pressure used is sometimes as high as 9 or 10 atmospheres. The conveyance of steam at these pressures is troublesome on account of leaks, but its most serious drawback is the loss from condensation, especially if the distance it has to travel is great. In large works and in shipyards the loss from condensation alone doubles or trebles the consumption of fuel required in the boiler; moreover it is often difficult to get steam to a distant engine at the pressure required, and as the steam loses heat in the pipes a further difficulty is experienced in removing the condensed moisture from it. With gas there is no such loss, because it enters the cylinder cold, and only when the gas is in the cylinder are high temperatures and pressures developed.

When steam power is used in a mill or factory one large engine is often placed near the boiler-house to minimise the loss

from condensation in the steam pipes. If the machines to be driven are far from the engine there must necessarily be an extensive system of shafting to transmit the power, and this is not only costly, but it absorbs a great deal of power. With gas power there may be several engines if it is more convenient or advantageous to subdivide the power, and there need be only one light shaft for each engine.

A further practical question is the cost of repairs and maintenance. Speaking with many years' experience, we can say that the following may be taken as a fair allowance at pre-war prices for the repairs and maintenance (exclusive of painting) of a well-designed gas plant:—

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

We will not attempt to estimate the repairs and maintenance of boilers for steam power, but there cannot be any doubt that on the same scale of working these charges are much greater.

With a steam-jet pressure plant the cost of wages is about the same as for a steam plant of the same horse-power ; but with a suction plant the cost of wages is much less. The consumption of water is also considerably less for gas than for steam power.

CHAPTER XV

FUEL

A GREAT variety of fuels can be used for making producer gas, the particular kind selected depending on the type of producer, the purpose for which the gas is to be used, and the sources of supply which are available, as well as upon considerations of price.

In this country, for furnace work the majority of producers are fired with bituminous or semi-bituminous coal; on the Continent brown coal or lignite is largely used, and in some cases peat. There are also cases where, owing to special local circumstances, wood is used as the fuel, and in this and other countries wood refuse is now being used extensively.

When the gas is to be used in small burners for heating work or when it is to be used for driving gas-engines, it is often simplest and best to use anthracite or coke; but in some localities these are too costly for use on a large scale. As a matter of fact, for several years nearly all plants for powers of 100 B.H.P. or less, and many plants for much larger powers, were worked with anthracite or coke, as there was then little or no trouble with tar and less labour was required than with the early bituminous plants. At the present time, however, producers capable of making gas from bituminous coal, suitable for engines of all sizes, are being used (see Chapter IX.), but the greater number of small plants are still made for anthracite or coke. For large plants working with bituminous coal, when the ammonia is to be recovered it is essential that the coal should contain a high percentage of nitrogen.

The principal constituents of each of the natural fuels mentioned above are the elements carbon, hydrogen, and oxygen; but

the proportions in which they are present vary considerably in the different classes of fuel. Usually there are also small quantities of nitrogen and sulphur; and there are varying quantities of ash (consisting of the mineral constituents of the fuel), which is left as an incombustible residue when the fuel is burnt. Both the quantity and composition of the ash are very different, even in different specimens of the same class of fuel; and in considering the average composition of the different kinds of fuel it is best to deal with the combustible matter only, or, in other words, to reckon the percentages on the weight of fuel considered as dry and free from ash. In round numbers, the average composition of the different fuels used for making producer gas is indicated in Table XXXV., where that of cellulose is also given for comparison.

TABLE XXXV.—AVERAGE COMPOSITION OF FUELS.

	Composition of fuel, reckoned as dry and free from ash. ¹				Fuel allowed to dry in air.	
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Moisture.	Ash.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Anthracite . .	95.0	2.5	2.5	Traces.	1 to 8	2.0 to 15
Common coal .	82.0	5.0	12.0	1.0	2 to 8	2.0 to 30
Brown coal . .	70.0	5.0	24.5	0.5	10 to 30	1.0 to 50
Peat	59.0	6.0	32.5	0.5	20 to 35	1.0 to 50
Wood	50.0	6.0	43.0	1.0	10 to 20	0.5 to 4
Cellulose . .	44.4	6.2	49.4	—	—	—

The deposits of coal with which we are familiar have been formed from the *débris* of plant life by the combined influence of pressure, heat, and moisture, extended over an enormous period of time. Brown coal, lignite, and peat have been formed in a similar manner, but the changes are not so far advanced.

The chief constituent of vegetable fibre is *cellulose*, a substance consisting of carbon, hydrogen, and oxygen in the proportions indicated in Table XXXV. Young fibre consists almost entirely of cellulose, but during the life of the plant about half of this is changed into *lignine*, a substance containing more carbon and less

¹ "Fuel and Water," Schwackhöfer and Browne, p. 41.

hydrogen and oxygen than cellulose. It is probable that the wood-fibre consisting of lignine and cellulose is gradually decomposed by natural decay, with the formation of water, carbon dioxide, and methane. As a result of this, the proportion of carbon increases and the proportions of hydrogen and oxygen (more particularly the latter) decrease. The ultimate product of these changes is probably graphite, which consists of almost pure carbon; and intermediate between this and wood we have the different classes of fuel which have occupied longer or shorter periods of time in their formation. Thus peat is of more recent formation than coal, and it has not lost the fibrous structure characteristic of the material from which it has been formed. It contains about 15 per cent. more carbon than cellulose. Brown coal contains about 10 per cent. more carbon than peat; it is of older formation, though sometimes the signs of its vegetable origin can be observed. Common coal and anthracite are the products of still further change, and the latter approximates in its composition to pure carbon.

In a sense, therefore, these fuels are the products of successive steps in the slow decomposition of vegetable matter, and it is often difficult to draw a sharp dividing line between them. It must be remembered, however, that they are derived from very different forms of plant life, and that the conditions under which the decomposition has taken place may have been very different in the various cases.

All these fuels, when heated under conditions which prevent the access of air, lose nearly the whole of their oxygen and hydrogen as well as a part of their carbon, and leave a residue consisting almost wholly of carbon and ash. This process is carried out commercially with wood, peat and common coal, and the carbonaceous residues which are obtained are known as wood-charcoal, peat-charcoal and coke respectively. The last is frequently employed in gas-producers and must be added to the list of fuels with which we have to deal.

Wood.—Different kinds of wood, when dry, have approximately the same chemical composition; but the specific gravity varies considerably. The average figures for several kinds of wood are given in Table XXXVI.

The amount of moisture held by the wood is very variable;

it is greatest in freshly felled timber, and is greater in young wood than in old. It depends also upon the season in which the tree is felled, and may vary from 25 to 60 per cent. If the bark is removed and the wood left in the open air much of this water will evaporate, and the quantity held by the wood will eventually be reduced to 10 or 20 per cent. The wood is then said to be "air-dried."

TABLE XXXVI.—AVERAGE COMPOSITION OF DRY WOOD.

	Specific gravity.		Moisture in freshly felled wood per cent.	Ash in undried wood per cent.	Composition of organic matter per cent.		
	Freshly felled.	Dry.			Carbon.	Hydrogen.	Oxygen and nitrogen.
Oak . . .	0·973	0·785	35·4	1·65	50·0	6·1	43·9
Beech . . .	0·980	0·721	39·7	1·06	49·5	6·1	44·4
Pine . . .	0·908	0·613	39·7	1·04	50·7	6·2	43·1
Fir . . .	0·894	0·600	37·1	1·02	50·9	6·3	42·8
Birch . . .	0·919	0·664	30·8	0·85	49·6	6·3	44·1
Willow . . .	0·785	0·461	26·0	2·00	50·6	6·3	43·1
Elm . . .	0·909	0·619	44·5	—	50·2	6·4	43·4
Ash . . .	0·852	0·692	28·7	—	—	—	—
Poplar . . .	0·857	0·472	51·8	—	50·6	6·3	43·1

The calorific power of air-dried wood is from 3000 to 3500 calories per kilo (4500 to 6300 B.Th.U. per pound), according to the amount of moisture it contains. When free from moisture, the calorific power would not be more than 4000 calories per kilo (7200 B.Th.U. per pound). Formerly wood was not considered suitable for use in gas-producers on account of its bulk and comparatively low calorific power; but wood refuse, such as chips, shavings, sawdust, bark, etc., is now used extensively in suction plants. See Chap. IX. p. 196. On account of the large quantity of volatile products formed when wood is heated, and the comparatively small amount of non-volatile carbonaceous residue, it can only be successfully employed in special producers.

Wood-charcoal.—This substance is usually obtained by the following process:—Wood is stacked in large heaps, which are covered with earth and charcoal dust to prevent access of air; suitable draught holes are made and the wood is ignited, the

draught of air being regulated so that sufficient heat is generated to drive off the volatile matter from the wood, leaving unburnt carbon in the form of wood-charcoal. The yield of charcoal by this method is from 20 to 25 per cent. of the weight of wood employed. The volatile matter which is expelled includes the gases carbon dioxide, carbon monoxide, hydrogen and methane, together with tarry vapours and an aqueous distillate (pyroligneous acid) from which methyl alcohol, acetone and acetic acid can be obtained. When the product sought is charcoal the process described above is used and the volatile products are wasted; but wood is also carbonised in order to obtain the methyl alcohol, acetone and acetic acid, and in this case the heating is carried out in retorts in which the charcoal remains as a by-product of the process. In some instances the mixture of gases which is obtained by heating wood in retorts has been used as an illuminant, under the name of wood-gas.

Wood-charcoal retains the shape of the original pieces of wood; these, however, suffer a shrinkage in bulk of 30 to 40 per cent. It is very porous and extremely light, the specific gravity ranging from 0.17 to 0.24. The chemical composition of wood charcoal varies between the following limits:¹—

Carbon	85 to 90 per cent.
Hydrogen	1 to 2 „
Oxygen	2 to 4 „
Ash	2 to 5 „
Moisture	2 to 10 „

Its average calorific power is 7000 calories per kilo, or 12,600 B.Th.U. per pound. Its calorific power is therefore nearly as high as that of anthracite, and it contains little or no volatile matter; it is extremely porous and reacts readily with gases; and the ash which it contains is small in amount and does not easily fuse into clinker. In most of the European countries charcoal is too costly to compete with anthracite or coke in gas-producers; but the reverse is the case in countries where wood is abundant and the other fuels are costly.

From the Argentine we have learnt that a suction plant was tested carefully with anthracite and wood-charcoal, and that the

¹ "Fuel and Water," Schwachhöfer and Browne, p. 50.

weight of fuel consumed in each case was the same, whilst the cost of the charcoal was 8 dollars per ton against 13 dollars for anthracite.

From New Zealand we have received a useful report, from which we give the following extracts: "The charcoal should be hard, any kind of wood will do provided the charcoal is made in the right way: we are using mixed wood. Up-country it is much cheaper than coke, but apart from this the gas made from charcoal is better, and it is easier to start the engine. When the producer is standing with a fire in it very little air will keep it alight for several days."

From Australia we have received the following results of tests made with charcoal:—

	Full load.	Two-thirds load.
Consumption per B.H.P.-hour	0.846 lb.	0.938 lb.
„ „ K.W.-hour	1.33 „	1.62 „

Peat.—As might be expected in view of its comparatively recent origin, peat is found at the surface of the earth, and the beds of peat are not covered with other and more recent strata, as is the case with the different kinds of coal.

The peat bogs or mosses, as they are called, vary in depth from only a few feet up to 20 or 30 feet. They rest on a subsoil which, either from its impervious character or from its position below the standing water-level, keeps them always more or less saturated with water.

The chief deposits of peat in the United Kingdom are to be found in Ireland, where the area of thick peat-beds (20 to 30 feet in depth) is estimated at about 2500 square miles; besides these there are some 2000 square miles of shallow deposits. In England there are large tracts of good peat; it is also found in considerable quantities, and is extensively used, in many European countries and in Canada and the United States of America.

The physical characteristics of peat vary considerably according to the locality and the extent to which decomposition has proceeded. Some kinds of peat are extremely fibrous and contain

twigs of practically unchanged wood. Other varieties are comparatively dense and are almost without structure. When dried in air the specific gravity of peat (determined by weighing it in water) is from 0.15 to 1.0, the fibrous peat being very light. The low specific gravity given by fibrous peat is not the true value, for the peat holds a considerable quantity of air, even when it is immersed in water. If the test piece be left in water for several days, the apparent specific gravity rises. Thus the specific gravity of a sample of dense peat from Norway increased in six days from 0.90 to 1.23; while that of a sample of prepared peat increased in the same time from 1.17 to 1.31. The specific gravity of prepared peat is sometimes as high as 1.4; it is not easily broken, but is sufficiently brittle to be powdered under the hammer.

The quantity of ash in air-dried peat may range from 1 to 50 per cent. The best kinds of peat have only 1 to 2 per cent. of ash, but many varieties must be considered unfit for use as fuel on account of the large proportion of ash which they contain.

The following may be taken roughly as the composition of air-dried peat of good quality: ¹—

Carbon	50 to 60 per cent.
Hydrogen	5 to 6 "
Oxygen	30 to 35 "
Nitrogen	1 to 2 "
Ash	5 to 10 "
Moisture	10 to 20 "

The calorific power of good air-dried peat varies from 3500 to 5000 calories per kilo (6300 to 9000 B.Th.U. per pound). Prepared peat has a somewhat higher calorific value, viz. 4000 to 5500 calories per kilo, or 7200 to 10,000 B.Th.U. per pound.

When heated without free access of air peat can be carbonised, leaving a residue of peat-charcoal, the yield being about one-third of the weight of the air-dried peat. The volatile matter given off during the process contains a great deal of steam, the quantity being somewhat greater than the amount of uncombined moisture in the peat; there is also a considerable quantity of gas containing carbon dioxide, carbon monoxide, and methane, which will burn with a luminous flame; and there are condensable tarry vapours

¹ "Fuel and Water," Schwackhöfer and Browne, p. 64.

which have a very offensive odour. In consequence of the large amount of moisture and other volatile substances (compared with the non-volatile or fixed carbon), peat, like wood, is not as suitable as coal or coke for use in ordinary gas-producers, but we have shown in Chap. X. that good results can be obtained with peat when it is properly treated. When the gas is to be used in furnaces the tar need not be allowed to condense if the furnace is near the producer, and it then serves to enrich the gas. Peat contains very little sulphur and would therefore be of great use as fuel in certain metallurgical operations if it were otherwise suitable. For example, in iron-smelting the fuel should contain as little sulphur as possible, in order that the metal may not be contaminated. Peat direct from the bog would not give the required heat, and peat-charcoal is too friable to support the weight of ore and fuel above it; but air-dried peat can be used in gas-producers, and the gas made with it can be used for smelting. This system has been adopted in Sweden, and with it a very pure iron is obtained.

Brown Coal or Lignite.—This fuel is intermediate in composition between peat and common coal. It is not found to any extent in the United Kingdom, but there are extensive deposits on the Continent, chiefly in Austria and Germany, and it is much used. There are also large deposits in the United States of America and in Canada. Strictly speaking, lignite is a variety of brown coal, but the two terms are often used indiscriminately. The composition of different varieties of brown coal varies within wide limits, some kinds approaching more nearly to peat, while others resemble common coal in their chemical composition, as shown by the following table:—

TABLE XXXVII.—COMPOSITION OF BROWN COALS.

	Composition per cent. (fuel free from ash and moisture).		
	Carbon.	Hydrogen.	Oxygen and nitrogen.
Peat	59	6·0	33·0
Brown coals—			
Lignite	60	5·5	34·5
Common brown coal . .	70	5·0	25·0
Pitch coal	75	5·5	19·5
Common coal	82	5·0	13·0

The amount of nitrogen in brown coal is usually less than 1 per cent.; in many places brown coal contains about 0.5 per cent. of sulphur, but in other localities it has as much as 2 per cent., or even more.

In its natural state brown coal usually contains from 30 to 40 per cent. of moisture; before use it is dried by exposure to air, and the proportion of moisture is thus reduced to 10 or 20 per cent. The amount of ash in brown coal should not be greater than 10 per cent., and it may be as low as 2 per cent.; but in some cases the quantity of ash is excessive, reaching as much as 50 per cent.

The calorific power varies from 4000 to 6000 calories per kilo (7200 to 10,800 B.Th.U. per pound).

On the Continent brown coal is used as a fuel for industrial purposes, and also to some extent for the production of illuminating gas by heating it in retorts. In this process tar and ammoniacal liquor are obtained, but neither these nor the gas itself are as valuable as the gas and products obtained from common coal. Some varieties yield a coke which can be used in the production of iron. *Lignite*, which is the form of brown coal most nearly allied to peat, contains very little bituminous matter, and before the war it was coming into favour in Germany for the manufacture of producer gas. In Chap. XIV. p. 241, we have described a large number of tests made with many varieties of fuel by the United States Geological Survey. These included four lignites from different localities, and they all yielded better producer gas for engine work than could be obtained with high-grade bituminous coal.

Common Coal.—There are many different varieties of coal, and they merge one into another so that no rigid classification according to their chemical composition is possible. For practical purposes they are divided roughly according to their behaviour on heating. Certain kinds of coal give very little smoke or flame, and their volatile matter contains practically no condensable hydrocarbons. These coals are known as anthracite, and as they are of special importance in connection with producer gas they are dealt with later in a separate section. Ordinary coal, on heating, yields considerable quantities of gas and tar, which are the products of decomposition of the bituminous matter in the

coal: such coals are said to be semi-bituminous or bituminous, according to the amount of their volatile constituents. Roughly speaking, the amounts of volatile matter in coal (reckoned as dry and free from ash) are as follows:—

Anthracite	4 to 10 per cent.
Semi-bituminous coal	10 to 20 „
Bituminous coal	20 to 40 „

Cannel coal is a variety intermediate in composition between lignite and bituminous coal, and it is specially valued for the production of illuminating gas. The amount of volatile matter in lignites and in cannel coal varies from 40 to 55 per cent.

The behaviour of coal on heating also serves as the basis of the division of bituminous coals into *caking* and *non-caking* varieties. Caking coals are those which on heating fuse or soften. After the volatile matter has been driven off no trace of the original form of the coal is left; the residue of coke has an open cellular structure and is hard and resistant to crushing. Non-caking coals do not fuse or soften when heated; the residue either retains the shape of the original pieces of coal, or crumbles and is of little value as a fuel on this account.

Caking and non-caking coals are very similar in chemical composition. Their composition and specific gravity are shown in the following Table¹:—

TABLE XXXVIII.—COMPARISON OF CAKING AND NON-CAKING COALS.

	Specific gravity.	Composition (per cent.) of coal, dry and free from ash.				
		Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.
Caking coals. . .	1.25 to 1.35	80 to 90	4.5 to 6	5 to 13	1 to 2.5	0.5 to 2.5
Non-caking coals	1.25 to 1.40	70 to 85	4.5 to 6	10 to 18	1 to 2.0	0.5 to 1.5

The non-caking varieties of bituminous coal contain more volatile matter than the caking coals, and yield less coke when heated in retorts. They are not used for the manufacture of lighting-gas, but are more suitable than caking coals for use in gas-producers. Caking coals soften on heating, and in a gas-producer this leads to the formation of hollows in the fire; the

¹ "Gas Manufacture," Butterfield, p. 8.

gases then pass through the producer without coming thoroughly into contact with the heated fuel, and the producer gas is of inferior quality. For this reason caking coals are seldom used for producer gas, and if they are used special precautions must be taken to break up the fused masses of coal, in order to prevent the fire from becoming hollow.

The proportion of ash in good coal usually varies from 1 to 8 per cent., but it is not an uncommon thing to find samples containing as much as 20 per cent. of ash. The calorific power varies from 7500 to 8500 calories per kilo (13,500 to 15,300 B.Th.U. per pound).

Coke.—Coke is the non-volatile residue left when bituminous coal is heated without the admission of air for combustion. Large quantities of it are made as a by-product in the manufacture of lighting-gas. The gas-coal is heated in retorts and almost the whole of the volatile matter in it is driven off, the coke left in the retorts being about 60 per cent. of the weight of the coal; so that about 5 tons of "gas-coke" are produced for every million cubic feet of lighting-gas made. A part of this coke is often used at the gasworks for the manufacture of water-gas in gas-producers, this gas being afterwards carburetted and mixed with the ordinary lighting-gas made in retorts.

The composition of a good gas-coke is approximately as follows :—

Carbon	89·6 per cent.
Hydrogen	0·4 „
Oxygen and nitrogen	2·0 „
Ash	8·0 „

A coke of this composition would have a calorific power of about 7300 calories per kilo (about 13,000 B.Th.U. per pound).

Gas-coke, however, varies considerably in its composition, and care should be exercised in choosing a suitable source of supply when the coke is to be used for making producer gas. Generally the coal used in gasworks is selected with a view to its gas-making properties, and if the coal is rich in ash the coke obtained from it will also contain a high proportion of ash. It is obvious that on the average coke must contain a higher percentage of ash than coal, since it contains all the ash originally in the coal, but is itself equal to only about 60 per cent. of the total weight of

the coal. Thus a coal containing 6 per cent. of ash would yield a coke containing about 10 per cent. Where a part of the coke is to be used in the gasworks for making water-gas it is probable that some attention is paid to this point in selecting the coal used in the retorts, and the gas-coke will not then contain more than 10 per cent. of ash. Gas-coke is often met with, however, containing as much as 15 or 20 per cent. of ash. When gas-coke is used in a producer, without special apparatus for removing tar from the gas, it should be well carbonised, and should not be mixed with small pieces of unburnt coal, as often happens in gasworks.

Large quantities of coke are also produced in coke ovens, the object in this case being to obtain a coke suitable for iron smelting and other metallurgical processes. Gas-coke is too light and porous for this purpose, it is also too impure. A hard dense coke can be obtained if the carbonisation is carried out more gradually, as is the case in coke ovens; and in order to obtain a coke comparatively free from sulphur and ash such as is required by the iron-master the coal used is selected with this object in view, and if the proportion of ash is high the coal is washed to remove the mineral matter (chiefly shale and pyrites) before it is carbonised.

A typical analysis of oven-coke, as it is called, is as follows:¹—

Carbon	93·15 per cent.
Hydrogen	0·72 „
Nitrogen	1·28 „
Oxygen	0·90 „
Ash	3·95 „

The calorific power of this sample would be about 7700 calories per kilo, or 13,900 B.Th.U. per pound.

Oven-coke is better than gas-coke for use in gas-producers, because it contains less ash and less sulphur; it has a higher calorific power and yields a smaller proportion of dust in handling. Gas-coke is, however, more often used, as it can generally be obtained from a local source and is cheaper than oven-coke.

Anthracite.—Great Britain and the United States have by far

¹ “Chemistry for Engineers and Manufacturers,” Blount and Bloxam, vol. ii. p. 93.

the most important output, but there are also anthracite pits in Belgium, France, Germany, Japan, Russia, and Spain. Anthracite is said to be found also in South America (Brazil and Chili) ; and it is believed that there are extensive deposits in China, but they have not yet been opened up. In Great Britain anthracite is found in South Wales, the main field being partly in Glamorganshire, partly in Carmarthenshire, and partly in Brecknockshire, extending from the Neath Valley in the east to Carmarthen Bay in the west, a distance of some 25 miles. There are about forty-four collieries working seams varying in thickness from 6 to 0·5 meters (18 ft. to 18 ins.). Some of it is used for burning lime, hop-drying, malting, domestic stoves, etc., but since the introduction of producer gas for engines and heating work the anthracite trade has changed considerably, and in the opinion of several pit-owners the sale of anthracite for producer gas will eventually be greater than for any other purpose. The shipments abroad from Swansea for producer gas alone are extensive and increasing.

The anthracite and semi-bituminous varieties of coal are often found near together, and merge into one another. Anthracite is hard and dense, and has a conchoidal fracture ; it has been defined as " the ultimate product of the conversion of vegetable matter into coal." Its average composition is given in Table XXXV., p. 248, but its quality varies considerably because so many veins are worked, each having its own peculiarity. There are also several sizes produced at the principal pits, to suit various requirements ; and these sizes are sold at different prices. It is, therefore, important for the user of a gas-plant to know the size and quality of anthracite he should buy ; and, apart from the question of price, he will find that the best size for his producer will chiefly depend on the design and the mode of working the latter.

When Mr. Dowson first introduced his gas-plant little attention was given in this country to the sizing of anthracite, except for close stoves of the American type. These required " nuts," which would pass through screens having round holes from 38 to 50 mm. (1½ ins. to 2 ins.) diameter, and as they were exported chiefly to France and Germany they were usually called French and German nuts. He began by using these in his gas-producers, and for plants of large size he used " cobbles," which are larger

than nuts. In the production of these sizes a considerable proportion of small coal was formed, and for this there was little or no sale; as the use of producer gas extended, this comparatively unsaleable product became a serious consideration, and tended to raise the price of the nuts. Mr. Dowson, therefore, modified his producer so that a smaller size of anthracite called "peas" could be used, and this reduced the price of the fuel for the producer by five to six shillings a ton. The use of producer gas has greatly increased since then, and there are now numerous makers of gas-plants. The quantity of small anthracite required to keep pace with the demand is at times greater than that produced in the sizing of "nuts." This has led the principal collieries to give closer attention to the sizing of the coal, but they often find it difficult to make each size in the proportion required for a varying demand. When the coal reaches the pit mouth so much of the "large" as is not required of that size is broken and passed over a series of screens with different-sized openings, and usually the following sizes of anthracite are produced:—

Large—will not pass through a 5-in. (127-mm.) opening.

Cobbles—have passed through 5 ins., but will not pass through $2\frac{1}{2}$ to 3 ins. (63 to 76 mm.) square.

Nuts (French)—have passed through $2\frac{1}{8}$ ins. (54 mm.) diameter, but will not pass through $1\frac{3}{4}$ ins. (44 mm.) diameter.

Nuts (German)—have passed through $1\frac{3}{4}$ ins. (44 mm.) diameter, but will not pass through $\frac{3}{4}$ in. (19 mm.) or 1 in. (25 mm.) square.

Peas or Beans—have passed through $\frac{3}{4}$ in. (19 mm.) or 1 in. (25 mm.) square, but will not pass through $\frac{3}{8}$ in. (9 mm.) square.

Duff (residue)—have passed through $\frac{3}{8}$ in. square.

The demand for the various sizes varies considerably at different seasons and at different times; the crushers are therefore made adjustable, so that when required they can be opened or closed to produce a higher or lower percentage of "large." Other manipulations are resorted to, but the difficulty remains of avoiding waste in producing the sizes required for a varying demand. Even in the best-managed collieries the actual waste

in coal too small for use is about 10 per cent. of the total output, sometimes more, and this loss is covered by a higher price being charged to the consumer.

In a gas-producer it is important to make as little clinker as possible, and for this reason it is usual to specify anthracite which has a low percentage of ash. The best anthracites contain about 2 to 3 per cent. of ash, but many contain from 5 to 7 per cent., and all these can be used in a suitable producer. If there is more than 7 per cent. of ash special care should be taken to avoid trouble with clinker. The mere percentage of ash is, however, not a precise indication of the suitability of the anthracite; it is only an approximation to it. It is important to take into account the fusibility of the ash; this depends upon its composition, especially as to the amounts of basic substances present (oxides of iron, calcium, aluminium, etc.) in relation to the amount of silica. Speaking generally, these oxides will combine under the influence of a high temperature with the silica in the ash or in the refractory lining of the producer. The compounds thus formed (silicates) will be more or less fusible according to their composition; the silicate of aluminium fuses only at very high temperature, while that of iron is fused with comparative ease.

If the incombustible residue remains in the condition of ash, or if it is partially fused, forming loose pieces of clinker, it can be easily removed from the producer; but there is always a tendency for the basic constituents of the residue to combine with the siliceous matter and to form fusible silicates which adhere tenaciously to the brick lining, and in time adherent slag or clinker will block the fire. Its removal is attended with difficulty, and the best practical method of dealing with the trouble, when circumstances make it desirable to employ a fuel of this character, is to reduce the temperature in the lower part of the fire by passing through it an excess of steam.

When the producer is of the pressure type and is worked with a jet of steam it is easy to give an excess of the latter, but in a producer of the suction type it is not so easy. In some suction gas-producers there is not enough steam to give the best gas, and this favours an excessively high temperature in the fire, and the formation of a troublesome amount of clinker. There have

been cases where complaints have been made of the quality of the anthracite, when in reality it was good but there was too little steam. The open hearth has met this difficulty to a great extent, but it is still important that the designers of gas-producers should give close attention to the right use of the fuel on which the working of the plant depends.

Another question of importance is the proportion of coal-dust which may be present with the large pieces, and indirectly this also bears on the question of clinker, as when there is much dust with the coal there is generally a larger proportion of impurities. *Primâ facie* one might suppose that if a large lump of coal were broken into pieces of any size there would be the same proportion of impurities in a given weight of any size, including the coal-dust. But actually the case is not quite so simple; not all the coal is in large lumps when it reaches the pit's mouth, and there is necessarily a mixture of various sizes, including some roofing and other impurities. The "large" which is removed for sale usually represents something like a fourth of the total, so that a larger proportion of impurities is left in the remaining three-fourths. Then, as the coal is broken and passes over screens of various sizes for different uses, the "small" remaining contains a still larger proportion of impurities. At several pits this has led to the washing of the "peas" used for gas-producers, but this adds to the cost of production.

The following analyses are instructive, as they show the difference in composition of good qualities of anthracite in the "large" size, and of "peas" produced from the same class of coal:—

TABLE XXXIX.—COMPOSITION OF ANTHRACITE (LARGE AND PEAS).

	Large size.			Peas.		
	Carbon.	Volatile matter.	Ash.	Carbon.	Volatile matter.	Ash.
No. 1	92.73	6.06	0.76	90.0*	5.1	2.5
„ 2	92.53	5.57	1.15	90.2*	5.6	4.2
„ 3	91.95	5.67	1.55	89.4*	5.5	3.9
„ 4	91.37	6.06	1.97	90.1	5.5	4.4

* These peas were washed.

These analyses show that in the "peas" there was an average decrease of 2.22 per cent. in the carbon, and an average increase of 2.39 per cent. in the ash. These samples are better than the average sold, and frequently the percentage of ash in "peas" is as high as 7 per cent.—sometimes higher. We have, however, already explained that the composition of the ash, especially the percentage of iron, is even more important for gas-producer work than the mere percentage of ash in the coal. It is for this reason that some of the lower grades of anthracite are suitable, for although they contain a high percentage of ash, the latter contains little or no iron, and little clinker is formed. From the buyer's point of view it would clearly be better to be without dust, if he has to pay as much for it as for "peas" or "nuts," as the carriage per ton will be the same whatever the quality may be. Some makers of gas-plants even advise their clients to buy "nuts," although they cost much more than "peas;" but if the producer is rightly designed there should be no more waste with "peas" than with "nuts," and we have reason to believe that the time is approaching when it will be possible to use all the small produced, including a large proportion of the vast heaps of "duff" and waste now accumulating at the principal collieries. In any case it will benefit all concerned and help to develop the use of gas power if makers of plants seek to use the lowest grades of anthracite, because the output is large and the price is lower than that of the picked coal.

When gas made from anthracite was first introduced on the Continent "nuts," such as were burnt in American stoves, were used in the gas-producer. Later "peas" were adopted, but the voyage, and especially the trans-shipments, caused an appreciable loss from dust. In France, Germany, and Italy this has led to the importation of anthracite from South Wales in large sizes, and to its being broken and sized at depôts after its arrival. This is especially desirable with the softer kinds of anthracite, which are more friable: we have known of a shipment of "peas" containing over 30 per cent. of dust on arrival.

Another matter of importance is the presence of volatile matter in anthracite, because it often gives rise to tarry and other troublesome products in the gas which are not always provided for in an anthracite gas-plant. This varies considerably in

different qualities of coal, but in Welsh anthracite it varies from about 4 to 10 per cent. Many anthracites, probably all, yield more or less tarry matter when distilled in the absence of air. In a gas-producer air comes in contact with the fuel in the lower part of the fire, and there should be no free oxygen in the upper part of the producer; but a large proportion of the fuel in this upper part is sufficiently heated to distil off any volatile matter without contact with air. The nature of the volatile matter is, however, of importance as well as the amount: as an exceptional case we may mention an anthracite containing only 6·2 per cent. of volatile matter, which nevertheless made the producer gas decidedly tarry. On heating a sample of this coal (out of contact with air), it gave off small quantities of tarry vapour such as would come from a bituminous fuel. On the other hand, we have used anthracite containing as much as 6 or 10 per cent. of volatile matter which did not make the gas tarry. It is probable that in all producers worked with anthracite there is a slight yield of tarry matter; but its extent will be influenced by the nature of the volatile matter in the anthracite and the temperature to which it is subjected in the upper part of the producer.

We have spoken chiefly of anthracite from South Wales because this is the chief source of supply in Europe, but there is also a fairly good supply in Scotland. The anthracite there is usually sold in two sizes, *singles* and *doubles*. The latter are used chiefly for stoves, and the former for gas-producers. There is a higher percentage of ash in Scotch anthracite than in the best kinds from South Wales; but at trials made in 1905, on behalf of the Highland Society (at their Agricultural Show), it was proved that with a gas-engine and suction plant fired with Scotch anthracite the actual consumption was under 1 lb. per B.H.P.-hour, even when working on such a small scale as 10 to 20 B.H.P. Some anthracite pits have been opened in the South of Ireland, and the quality of coal is said to be promising.

In Belgium and France the anthracite usually contains more ash and more volatile matter than the anthracite from South Wales; in many cases it should properly be classed as semi-bituminous coal. In France the best anthracite is obtained in the Departments of the Nord and of the Pas de Calais; in the

former the Compagnie des Mines d'Anzin have very extensive workings, and to meet the varying requirements of their customers they have given close attention to the sizing of their anthracite. They have now adopted the following elaborate classification, the figures given being the diameters of round holes in the screens through which the coal is passed :—

Schlamms—residues from the washers.

Poussiers—2, 4, 8, and 10 mm.

Greneux—2 to 5, 2 to 7, 5 to 7, 4 to 8 mm.

Grains—5 to 13, 7 to 13 mm.

Grenus—10 to 20, 13 to 20, 20 to 30 mm.

Braisettes—30 to 55, 45 to 55, 55 to 80 mm.

Petite gailletterie—70 to 120, 80 to 120 mm.

Grosse gailletterie—pieces above 120 mm.

Gros—size prepared by hand.

Besides these there are several other grades, depending on whether the coal is or is not riddled and washed free from dust. The average calorific power of this anthracite is said to be from 7500 to 7700 calories per kilo, or 13,500 to 13,860 B.Th.U. per pound.

CHAPTER XVI

ANALYSIS OF FUEL AND OF PRODUCER GAS

Analysis of Fuel.—The chemical analysis of fuel consists either of the ultimate analysis, *i.e.* the determination of the proportions of carbon, hydrogen (chemically combined), oxygen, nitrogen, sulphur, ash, and moisture; or of the proximate analysis, which consists of the determination of fixed carbon, volatile matter, ash, and moisture.

For industrial purposes the ultimate chemical analysis is seldom required. The character of a fuel and its suitability for a particular purpose can be judged from the results of the proximate analysis, and when a fuel is to be used in gas-producers it is usually sufficient to know the results of the proximate analysis, together with the percentage of sulphur in the fuel and the calorific power. Methods for the ultimate analysis of fuel are described in text-books on quantitative analysis and need not be repeated here. The methods described below for the proximate analysis of fuel are those recommended by a Committee of the American Chemical Society.¹

Sampling.—In making an analysis in the laboratory only a very small quantity of the fuel is actually tested, and it is of the utmost importance that the sampling and subsequent preparation of the fuel should be carried out in such a way that the small quantity which is tested truly represents the average of the whole bulk. The method which is recommended in testing a consignment of coal is as follows :—

Shovelfuls of coal are taken at regular intervals during the unloading of the truck. The coal thus taken is placed on a close floor and is broken till there are no pieces larger than about

¹ "Report of the Committee on Coal Analysis," *Journal of the American Chemical Society*, 1899, vol. xxi. pp. 1116-1192.

75 mm. or 3 in. cube. It is then well mixed and divided roughly into four equal parts; opposite quarters are rejected and the remaining half of the coal is broken to a smaller size. This process is repeated until the sample is reduced to about 1 kilo in weight and consists of pieces about 5 mm. cube. It is then sealed up in an air-tight jar and kept for analysis. To avoid alteration in the percentage of moisture in the coal these operations should be carried out as quickly as possible.

To prepare the sample for analysis the process of quartering is continued until a sample weighing about 100 grams or $\frac{1}{4}$ lb. is obtained, and this is ground as quickly as possible to a coarse powder in a suitable mill. An ordinary coffee-mill answers well for this purpose. A portion of this coarsely ground sample is at once transferred to a tightly stoppered bottle and kept for the determination of moisture.

About 15 grams or $\frac{1}{2}$ oz. of the remainder of the powdered sample is ground moderately fine in an iron or porcelain mortar, and is kept in a stoppered bottle for use in the other determinations.

Moisture.—The percentage of moisture is determined by drying one gram of the coal in an open porcelain crucible, either by heating it for one hour in an oven kept at 104° to 107° C. (219° to 224° F.), or by exposing it for twenty-four hours over concentrated sulphuric acid in a vacuum desiccator. The latter method is the more accurate; the former gives a slightly lower result, but is sufficiently accurate in view of the fact that some slight alteration in the percentage of moisture probably takes place during sampling.

The percentage of moisture should be determined in both the coarsely ground and the finely powdered samples. Generally some moisture will have been lost during the process of grinding in the mortar, and all the results obtained in which the finely powdered sample has been used must therefore be corrected. Suppose the results of an analysis are as follows:—

	Coarsely ground.	Finely powdered.
Moisture	3.26 per cent.	1.30 per cent.
Ash	—	12.55 „

The percentage of moisture in the coal is 3.26; the percentage of ash was determined in the finely powdered sample which contains only 1.30 per cent. of moisture, and the necessary correction is easily made:—

100 grams of the coarsely ground sample with the true percentage of moisture contain $(100 - 3.26)$ grams of dry coal; 100 grams of the finely powdered sample contain $(100 - 1.30)$ grams of dry coal of which 12.55 grams are ash.

The percentage of ash in the coarsely ground coal is the weight of ash in $(100 - 3.26)$ grams of dry coal,

$$\text{or } 12.55 \times \frac{100 - 3.26}{100 - 1.30} = 12.30 \text{ per cent.}$$

Thus the percentages of ash or of volatile matter found by analysis of the finely powdered sample must be multiplied by a factor which is equal to:—

$$\frac{100 - \text{percentage of moisture in coarsely ground sample}}{100 - \text{percentage of moisture in finely powdered sample}}$$

Volatile Matter, other than Moisture (Volatile Combustible Matter).—This is determined by heating the coal under certain specified conditions. The residue which is left is not entirely free from hydrogen, and by prolonged heating at very high temperatures more volatile matter can be expelled. The complete expulsion of the hydrogen can only be attained at temperatures which are too high to be practically used in the analysis. Consequently it is necessary to specify certain arbitrary conditions for the heating, which will give comparative results with different samples of coal. The following is the procedure recommended by the Committee:—

One gram of the finely powdered coal is placed in a platinum crucible weighing 20 to 30 grams, and having a tightly fitting cover. The crucible is heated over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle with the bottom 6 to 8 cms. above the top of the burner. The flame should be 20 cms. high when the crucible is removed, and the determination should be made in a place free from draughts. The upper surface of the cover should remain clear, but the under surface should remain covered with carbon.

The loss in weight gives the percentage of volatile matter and moisture, and the percentage of moisture in the powdered sample

must be deducted from this. There is no mechanical loss of coal during the heating, even with samples rich in volatile matter.

Ash.—The portion of powdered coal which has been used for the determination of moisture is heated in the open crucible until all carbon is burnt away. The weight of the residue in the crucible gives the quantity of ash left by the combustion of the powdered sample.

Fixed Carbon.—This is calculated as the difference between 100 and the sum of the percentages of moisture, volatile matter, and ash. The sulphur in the fuel is included partly in the volatile matter and partly in the ash, and is therefore not taken into account in calculating the percentage of fixed carbon by difference.

When sulphur is present as pyrites (iron sulphide, FeS_2) the amount of ash left on burning the coal is less than the amount of mineral matter in the coal, because the sulphur in the pyrites burns away and is replaced by three-eighths of its weight of oxygen, the pyrites being converted to iron oxide. The value of the fixed carbon is therefore not given accurately as the difference required to make up 100 per cent. For ordinary purposes the fixed carbon is calculated as described above, but if the results of the proximate analysis are used for calculating the calorific power it is better to take the corrected value for the fixed carbon. This is less than the amount required to make up the 100 per cent. by five-eighths of the weight of sulphur present as pyrites. For this purpose the total sulphur in the fuel is determined as described below, and it is sufficiently accurate to assume that all of this is in combination as pyrites.

Sulphur.—The total percentage of sulphur in the fuel is determined by Eschka's method as follows:—1 gram of the finely powdered coal is thoroughly mixed with 1 gram of light magnesium oxide and 0.5 gram of dry sodium carbonate in a thin platinum dish of about 75 to 100 c.c. capacity. The dish is gently heated over a spirit lamp, the heat being raised very gradually until the carbon is burned away. (Gas must not be used for the heating on account of the sulphur which it contains.) The sulphur in the coal is thus oxidised, and is fixed by the sodium carbonate and magnesium oxide. The mass is transferred to a beaker and the dish is rinsed with about 50 c.c. of water ;

15 c.c. of saturated bromine water are added and the liquid is boiled for five minutes, allowed to settle, and then decanted through a filter. The residue is twice extracted with boiling water and then washed on the filter. The filtrate now contains all the sulphur in the form of sulphate; it is acidified with hydrochloric acid and boiled till free from bromine. The sulphate is then estimated in the usual way as barium sulphate.

When the coal tested contains much pyrites or calcium sulphate, the residue of magnesium oxide should be dissolved in hydrochloric acid and tested for the presence of sulphate.

Calorific Power.—The methods for determining the calorific power of coals are described in the next chapter.

Analysis of Producer Gas.—The chemical analysis of producer gas consists in the determination of the proportions by volume of carbon dioxide, oxygen, carbon monoxide, hydrogen, methane, and in certain cases ethylene (C_2H_4). The difference required to make up 100 per cent. is assumed to be nitrogen. The weight of sulphur in a given volume of the gas is also sometimes determined. In the volumetric analysis the gases containing sulphur are not separately determined, and are included with the carbon dioxide. Their volume is, however, very small.

There are many forms of apparatus which can be used for this analysis, and for some of the constituent gases alternative methods of analysis are available. For full detailed information on the whole subject, the reader is referred to text-books on Gas Analysis. We will confine ourselves here to the description of a method of analysis which has been found very convenient in practice.

The method of collecting the sample for analysis depends upon the object of the test. If it be required to determine the composition of the gas at any particular time the sample may be transferred direct from the gas main to the sampling tube. The latter may conveniently be of the form shown in Fig. 79. The bulb **A** has a capacity of about 120 c.c.; the lower end terminates in a tube 7 mm. in diameter; a similar tube at the other end of the bulb terminates in a short tube **B** of capillary bore. A short piece of rubber tubing with a pinch-cock is connected to each end of the sampling tube. The capillary end of the tube is connected

to the gas supply and the gas is blown through the bulb for a sufficient time to remove all the air; the pinch-cocks are tightly closed and the sample is at once taken to the laboratory and analysed. The sample may also be drawn into the tube by displacement of water. For this purpose the tube is completely filled with water which has been saturated with the gas; the capillary end **B** is connected to the gas supply and the pinch-cock opened. By opening the pinch-cock on the lower end the water is allowed to run out, and its place is taken by gas from the main. A small quantity of water is left in the lower end of the tube; after the cocks have been closed and the tube disconnected from the gas main it is inverted in order to allow a little of the water to enter the capillary. On returning the tube to the vertical position the gas is confined between two short columns of saturated water, so that it can be kept for a short time without undergoing any alteration in composition by diffusion through the rubber. If the sample cannot be analysed soon after it is collected, the ends of the rubber tubing should be closed by short pieces of glass rod, and the whole of the rubber covered with paraffin wax. The amount of water which has been left in the tube should be as small as is consistent with avoiding contact of the gas with the rubber. With these precautions the sample may be stored for one or two days if necessary.



FIG. 79.—Gas-sampling tube.

The object of analysing producer gas is more often to ascertain the average composition during a period of one or two hours, and for this purpose the above method of sampling is obviously unsuitable. The apparatus shown in Fig. 80 is very convenient for regular sampling, when it can be set up permanently in a convenient spot. The sample is collected in the aspirator **E**, which has a capacity of 5 liters. A capillary tube **K**, provided with a cock **D**, connects the aspirator with the gas main **J**. The aspirator is filled with saturated water from the bottle **G** by means of the glass tube **H** leading to the bottom of the aspirator; the air or

previous sample of the gas which may have been in the aspirator escapes through the cock **B**. The aspirator having been completely filled with water, cocks **A** and **B** are closed and **D** is opened. Water is now allowed to drip at the cock **C**, the rate being adjusted so that the aspirator will be rather more than half emptied at the end of the period during which the sample

is to be collected. The sample of gas thus slowly collects above the water in the aspirator, and as the producer gas is continually passing the point **F** where it is drawn into the capillary tube, the sample obtained represents an average of the whole of the gas passing through the main. The water should escape from the aspirator approximately at a constant rate, and to secure this the cock **C** should be well below the bottom of the aspirator, so that the alteration in the head of water will make very little difference to the rate of flow.

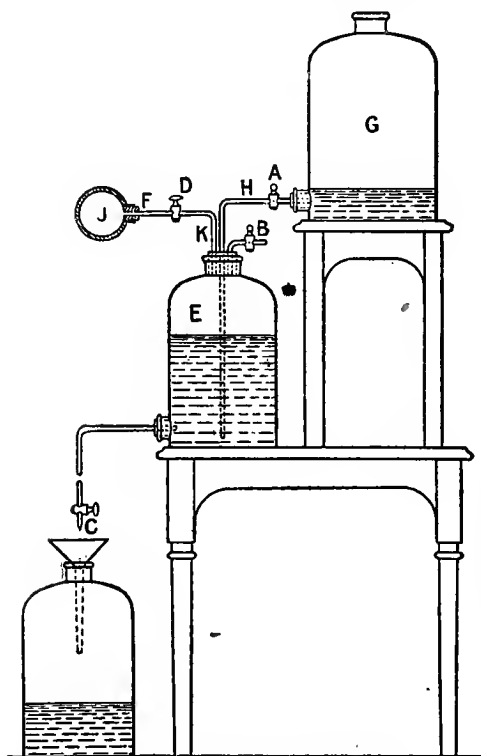


FIG. 80.—Gas-sampling apparatus.

In regular sampling from the same installation the same saturated water is continually in use in the aspirator, and as the gas will not vary much in composition its exposure over a large water surface in the aspirator will not cause any alteration in composition. In other cases, where the water cannot be regarded as saturated with the gas or where the composition of the gas to be tested differs much at different

times, the water in the aspirator may be covered with a layer of petroleum (boiling point 195° – 200° C., 383° – 392° F.), which does not absorb any of the constituents of the gas, or a solution of brine may be used instead of water.

In order to transfer the sample to the laboratory for analysis, the water which has run out at **C** is poured into the bottle **G**, and the gas-sampling tube (Fig. 79) filled with saturated water, is connected at its capillary end to the capillary tube **B**. The cocks **A** and **B** are opened (**C** and **D** being now closed), and on releasing the pinch-cocks on the sampling tube the water in **G** passes into the aspirator, forcing the gas through **B** into the sampling tube. Several sampling tubes may be filled in this way, the remainder of the gas in the aspirator being allowed to escape at **B**.

The apparatus used for the analysis of the gas is that devised by Macfarlane and Caldwell,¹ with some slight modifications. The apparatus is shown in Fig. 81. The measuring tube **A** is graduated up to 50 c.c. and forms one limb of a **U** tube which is connected by rubber tubing to the mercury reservoir **B**. The latter is raised or lowered as required by shifting the balance weight **C**. The cock between the **U** tube and the mercury reservoir is closed while the latter is moved; and by opening this cock the mercury can be allowed to flow to or from the **U** tube as required. The **U** tube is surrounded by water in a cylindrical jacket, so that the gas is always brought to the temperature of the water in the jacket before it is measured.

The upper end of the graduated tube **A** terminates in a capillary tube and a special cock **D**. The gas pipette **E** slides in a groove on the stand **F**, and is connected by rubber tubing to the cock **D**; it can be firmly clamped in its place by means of the screw **G**. The cock can be turned so as to bring the pipette into communication either with the measuring tube or the flask **H**. The stand **F** which carries both the **U** tube and the gas pipette is pivoted at **K** and can be rocked to and fro, or it can be clamped tightly in position by the screw **L**. A cock **M** is provided for drawing off the mercury when required.

The analysis of the gas consists of the following operations:—

1. Absorption of carbon dioxide by caustic potash.
2. Absorption of oxygen by alkaline pyrogallol.

¹ *Journal of the West of Scotland Iron and Steel Institute*, 1892, No. 2, vol. i.

3. Absorption of carbon monoxide by an acid solution of cuprous chloride.

4. Explosion of a portion of the residue mixed with hydrogen and air.

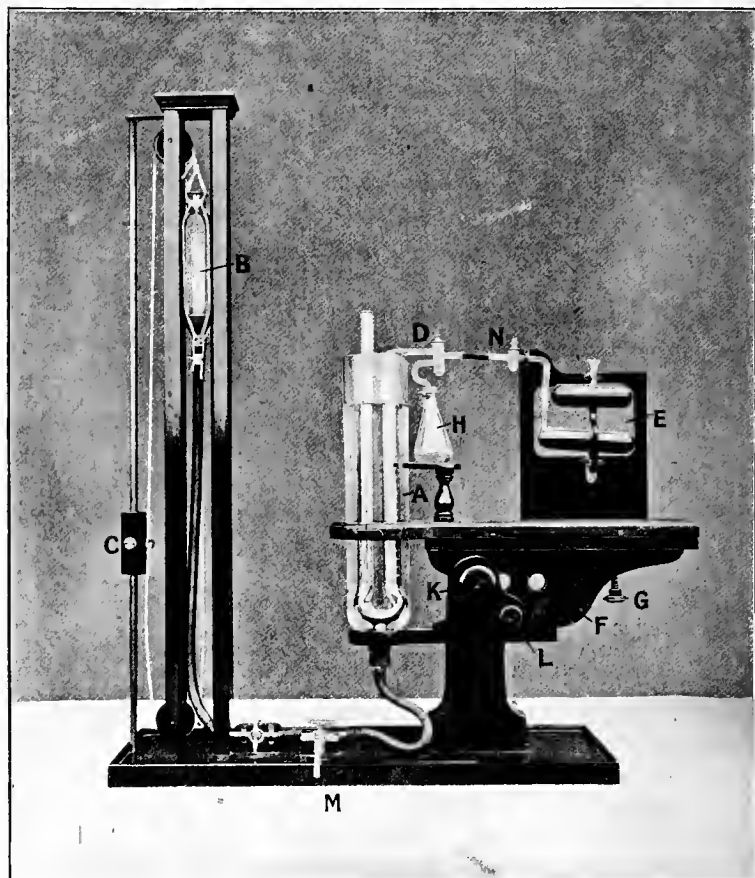


FIG. 81.—Apparatus for gas analysis.

5. Absorption of carbon dioxide formed from the methane in the gas during the explosion.

The reagents used are :—

1. A solution of caustic potash made by dissolving one part of caustic potash in two parts of water.

2. Alkaline pyrogallol solution made by dissolving 120 grams of caustic potash (not purified by alcohol) in 80 c.c. of water and adding 5 grams of pyrogallol dissolved in 15 c.c. of water.

3. Acid cuprous chloride. This solution may be prepared by gradually adding a mixture of 86 grams of copper oxide and 17 grams of copper powder (obtained by reduction) to 1086 grams of hydrochloric acid (sp. gr. = 1.124) the acid being frequently stirred. The solution is then stored in a closed flask containing a spiral of copper wire until it becomes colourless.

The analysis requires the use of four gas pipettes similar to the one shown in the figure, viz. one each for caustic potash and alkaline pyrogallol, and two for cuprous chloride; also a pipette for supplying hydrogen, and an explosion pipette. The two pipettes last mentioned are of the ordinary Hempel form, but with the capillary tube bent horizontally to suit the cock **D**; each pipette has a cock at **N** and is mounted on a suitable stand. The explosion can be made in the measuring tube itself, but it is better to use a separate explosion pipette, as a larger volume of gas can then be taken.

The measuring tube **A** contains about 1 c.c. of saturated water, acidified with sulphuric acid, above the mercury. This can be changed after each analysis, and in this way the mercury is not soiled by contact with the various reagents, and there is always a good meniscus at the upper surface of the water.

In making an analysis the mercury is first of all allowed to rise in the **U** tube until the capillary tube and cock are filled with water. The capillary end of the gas-sampling tube is connected to the cock, and its lower end opened under saturated water in a basin. The mercury reservoir is lowered and the stop-cocks are turned so that mercury runs from the **U** tube into the reservoir, and the gas is thus drawn from the sampling tube into the measuring tube **A**. Nearly 50 c.c. should be taken for the analysis. Before the volume of gas taken is measured, the pressure should be adjusted to atmospheric by raising the mercury reservoir and allowing mercury to flow into the **U** tube until it stands slightly higher in the open limb than in the measuring tube. The stop-cock **D** is slightly opened and the motion of the thread of water in it indicates whether the pressure of the gas is above or below that of the atmosphere. With a little practice

the adjustment of the pressure is generally exact at the first trial. Three minutes should elapse between the filling of the measuring tube and the measurement of the volume, in order that the water in the measuring tube may drain down the sides.

The next operation is the determination of the carbon dioxide. The pipette containing caustic potash is placed on the stand and connected to the stop-cock **D**, which is turned so as to connect the pipette with the flask **H**. By gently blowing with the mouth through a rubber tube held in the neck of the pipette a few drops of the liquid are forced out into the flask so that the capillary tube connecting the pipette with the measuring tube is completely filled with the reagent. The mercury reservoir is now raised and the stop-cocks are turned so that the gas is forced out of the measuring tube into the pipette. The water in the measuring tube should be allowed to fill the whole length of the capillary as far as the bulb of the pipette. The stand **F** is now rocked to and fro so that the gas is brought thoroughly into contact with the reagent, and absorption is complete in a few seconds. Before transferring the gas back to the measuring tube a little of the water is allowed to run into the pipette from the measuring tube. This washes the capillary tube and prevents the passing of drops of the reagent into the measuring tube. The gas is transferred to the measuring tube, the pressure adjusted, and the volume measured with the precautions described above. The decrease in volume is the number of cubic centimeters of carbon dioxide absorbed. The stop-cock is then cleared by blowing water through it into the flask by means of the wash-bottle.

The manipulation is the same with the other pipettes, and it is only necessary to refer to the special points in each case.

Absorption of Oxygen.—The gas should be in contact with the reagent for three minutes and the stand should be rocked during the whole of this time. The temperature should not be much below 15°C ., or a longer time will be required for complete absorption.

Absorption of Carbon Monoxide.—The gas is agitated with the acid solution of cuprous chloride for three minutes in the pipette. It is then brought back into the measuring tube, a

second pipette containing fresh cuprous chloride (which has not been used for the first absorption of carbon monoxide in any analysis) is put on the stand, and the gas is passed into this and shaken for a further period of three minutes. Before its volume is measured the gas is passed into the caustic potash pipette, to absorb the vapours of hydrochloric acid evolved in the cuprous chloride pipettes.

The absorbing power of the acid solution of cuprous chloride is not very high, and if frequent analyses of producer gas are being made the solution in the first pipette will soon lose its efficiency and require renewal. This will be indicated by the larger amount of carbon monoxide left to be absorbed in the second pipette, but it will be found useful to keep a record of the total volume of carbon monoxide absorbed in each pipette. The solution should be changed before the total volume of gas absorbed reaches four times the volume of the liquid.

Determination of Hydrogen and Methane.—With ordinary producer gas there will generally be left about 30 to 35 c.c. of gas after the absorption of carbon dioxide, oxygen, and carbon monoxide. Part of this must be allowed to escape, and only 15 or 16 c.c. should be used for the determination of hydrogen and methane. About 5 or 6 c.c. of hydrogen are added from the hydrogen pipette, and the volume of hydrogen added is measured. Air is then drawn into the measuring tube until the total volume is nearly 50 c.c. After the volume has again been measured the mixture is transferred to the explosion pipette and exploded. It is then measured in the measuring tube and the contraction is noted. The volume of carbon dioxide formed by the explosion is determined by absorption in caustic potash, and is equal to the volume of methane which was present in the gas taken for this determination. The contraction due to the combustion of the methane is twice the volume of methane. The remainder of the contraction is due to the combustion of the hydrogen, and the total volume of hydrogen in the mixture is two-thirds of this contraction. The volume of hydrogen which was added is deducted, and the remainder of the hydrogen is that which was present in the gas used for the test.

The following example will make clear the method of calculation :—

Volume of gas taken for the analysis	49.2	c.c.
Volume after absorption of carbon dioxide	46.55	„
Volume after absorption of oxygen	46.45	„
Volume after absorption of carbon monoxide	34.5	„
Volume of residual gas taken for determination of hydrogen and methane	15.05	„
Volume after adding hydrogen	20.0	„
Volume after adding air	48.55	„
Volume after explosion	35.7	„
Volume after absorption of carbon dioxide	35.5	„

We then have—

$$\text{Carbon dioxide} = \frac{49.2 - 46.55}{49.2} \times 100 = 5.4 \text{ per cent.}$$

$$\text{Oxygen} = \frac{46.55 - 46.45}{49.2} \times 100 = 0.2 \text{ „}$$

$$\text{Carbon monoxide} = \frac{46.45 - 34.5}{49.2} \times 100 = 24.3 \text{ „}$$

Methane.—15.05 c.c. of the residual gas contained 35.7 - 35.5 = 0.2 c.c. of methane. But 15.05 c.c. of the residual gas correspond to $15.05 \times \frac{49.2}{34.5}$ c.c. of the original sample, and the percentage of methane is $\frac{0.2 \times 34.5}{15.05 \times 49.2} \times 100 = 0.9$ per cent.

Hydrogen.—The contraction on explosion was 48.55 - 35.7 = 12.85 c.c.

Contraction due to combustion of methane = $2 \times 0.2 = 0.4$ „

Therefore, contraction due to combustion of hydrogen = 12.45 „

Total volume of hydrogen present = $\frac{2}{3} \times 12.45 = 8.3$ „

Volume of hydrogen added was 20.0 - 15.05 = 4.95 „

Therefore, volume of hydrogen in 15.05 c.c. of residual gas was 8.3 - 4.95 or 3.35 c.c., and percentage of hydrogen in the original sample

$$= 3.35 \times \frac{34.5}{15.05 \times 49.2} \times 100 = 15.6$$

The composition of the gas by volume is therefore :—

Carbon dioxide	5.4	per cent.
Oxygen	0.2	„
Carbon monoxide	24.3	„
Methane	0.9	„
Hydrogen	15.6	„
Nitrogen	53.6	„ (by difference).

No correction for temperature and pressure is needed, because all volumes were measured at the same temperature and pressure, and the proportion of the different constituents is the same at 0° C. and 760 mm. as at any other temperature and pressure.

Nitrogen.—In the above example the amount of nitrogen was taken to be the difference between the total volume of the gases

actually determined by analysis and the total volume of the original gas. A direct determination may however be made, as a check on the accuracy of the analysis. For this purpose a separate sample of the gas is exploded with hydrogen and oxygen in the explosion pipette, the carbon dioxide and the excess of oxygen are then absorbed by passing the gas successively into the pipettes containing caustic potash and alkaline pyrogallol, and the residue which consists of the nitrogen present in the original quantity of producer gas, is measured. Air may be used instead of oxygen in this determination, and the nitrogen thus added to the gas deducted from the measured quantity of nitrogen.

Ethylene.—The percentage of ethylene is sometimes determined in the gas made from bituminous coal, but it seldom amounts to more than 0·2 per cent. The ethylene is absorbed either by bromine water or by fuming sulphuric acid in a pipette similar to that used for caustic potash. In either case the gas must be passed into the potash pipette after the ethylene has been absorbed, to free it from the vapours either of bromine or of the fuming acid. The determination of ethylene is made immediately after the determination of carbon dioxide.

Sulphur in Gas.—A considerable volume of the gas (say 50 liters) is burnt, and all the sulphur in the gas is thus converted to sulphurous and sulphuric acids. The products of combustion are passed through some reagent which will oxidise the sulphurous acid to sulphuric acid, and the quantity of sulphuric acid formed is determined by precipitation as barium sulphate in the usual way. There are several well-known forms of apparatus for this determination, suitable for different modifications of the method. In Drehschmidt's method, for example, the products of combustion are passed through a solution of potassium carbonate containing bromine as the oxidising agent. Detailed information is given in standard works on analysis.

CHAPTER XVII

CALORIFIC POWER OF SOLID AND GASEOUS FUELS

IN order to judge of the efficiency of a gas-producer it is necessary to know not only the quantities of fuel used and gas obtained, but also the amounts of heat which can be obtained by the combustion of each, *i.e.* their calorific powers. The most efficient producer is that in which the total heat which can be obtained by the combustion of the gas bears the highest ratio to the total heat that could have been obtained by the complete combustion of the solid fuel.

When gas is used for the production of power the results of tests are frequently stated in terms of the fuel consumption, *e.g.* 450 grams, or 1 lb. per B.H.P.-hour; but as the calorific power of different samples of coal may vary from, say, 7500 to 8500 calories per kilo (13,500 to 15,300 B.Th.U. per pound) it is evident that the calorific power of the fuel should be stated as well as the consumption. For example, a producer-gas installation which would give a fuel consumption of 410 grams (0.90 lb.) per B.H.P.-hour with fuel having a calorific power of 7500 calories per kilo (13,500 B.Th.U. per pound) would show a consumption of only 362 grams (0.80 lb.) per B.H.P.-hour when using a high-grade fuel, the calorific power of which was 8500 calories per kilo (15,300 B.Th.U. per pound). The total amount of heat supplied to the producer by the combustion of the fuel is the same in each case, but the higher fuel consumption is really the better result of the two, as it means that the efficiency of the producer is the same, although the fuel used was of an inferior and cheaper kind. This example is by no means an exaggerated one, and it indicates that a knowledge of the calorific power of the fuel is important from the point of view of the owner of the plant.

If two samples of coal have different calorific powers, but are

otherwise equally well suited for use in the producer, it may sometimes be cheaper to pay a higher price for that coal which has the higher calorific power. In such a case the true basis of comparison is not the price per ton, but the price for equal numbers of heat units.

The value of producer gas, whether used in a gas-engine or for heating or furnace work, depends primarily upon the quantity of heat given out during its combustion, or in other words upon its calorific power.

For engine work it is not essential that the calorific power of the gas should be high. The same quantity of heat can be supplied to the engine by using a larger volume of a weaker gas or a smaller volume of a stronger gas, and gas-engines can be made suitable for using gases differing as widely as ordinary lighting gas and blast-furnace gas, which have calorific powers of about 6000 and 800 calories per cubic meter respectively, or say 650 and 90 B.Th.U. per cubic foot. The power which can be developed per stroke in an engine cylinder of given dimensions depends chiefly upon the quantity of heat in the mixture of gas and air which is supplied to it; and as the richer gases require more air for their combustion than the weaker ones the power obtained in the same engine is not very much greater with a rich gas than with a poor gas. For example, a semi-water-gas as usually made for engine work gives only about 20 per cent. less maximum power than lighting-gas in an engine having the same cylinder dimensions, although the calorific power is only about one-fourth that of the lighting-gas. The relative powers which can be obtained from different kinds of producer gas in the same engine are given in Table XX. on p. 152. For engine work it is more important to ensure that the heat of the gas shall be used to the best advantage, and, as has been shown in Chapter VI., higher compressions can be used with gases of comparatively low calorific power, and a greater proportion of the heat of combustion of the gas can therefore be converted into useful work. The calorific power of the gas supplied to an engine should not vary much from its mean value; excessive variations can be detected if the calorific power is determined from time to time by one of the methods described below.

For the successful application of producer gas to furnace and heating work it is often necessary that the calorific power should

not fall below a certain minimum value, and makers of gas-producer plants are frequently required to give a guarantee of this kind. It is therefore important to have some ready means of determining the calorific power from time to time. We will therefore describe the principal methods which are in use for the experimental determination of the calorific powers of solid fuel and of producer gas.

The determination of calorific power consists in the measurement of the quantity of heat given out during the combustion of a known small quantity of the fuel. This is accomplished by means of an apparatus called a "calorimeter." The heat given out by the combustion of the fuel is used to heat water, and the quantity of heat is known from the weight of water heated and its rise in temperature.

The calorific power of solid fuels is most accurately determined by burning them in compressed oxygen in a bomb calorimeter. In calorimeters of this type a known weight of the fuel to be tested is placed in a capsule or crucible which is supported in the interior of a strong metal vessel. The latter is tightly closed, and oxygen is forced into it until the pressure is about 25 atmospheres. It is then immersed in a known weight of water contained in a suitable vessel; the fuel is ignited electrically, and the rise in temperature of the water is noted. The heat given out by the combustion of the fuel is equal to the heat required to raise the temperature of the water and of the calorimeter itself through the observed range.

The construction of the calorimeter and the details of the method may be illustrated by reference to the Mahler-Donkin bomb calorimeter, which is shown in section in Fig. 82. This is a modified form of the Mahler bomb calorimeter. The bomb itself is capable of withstanding very high pressures; it is constructed of a non-corrosive metal and is gold-plated inside in order to resist the action of the nitric and sulphuric acids formed during the combustion. The cover is held in place by three studs and nuts, the joint being made with a packing of lead wire. This cover carries a valve for the admission of oxygen, also a metal holder which supports the platinum crucible in which the fuel is placed. A metal rod passes through an insulating plug in the cover of the bomb, and a very fine platinum wire

is connected to the lower end of the rod and completes a battery circuit through the coal in the crucible. One terminal of the battery is connected to the insulated rod, and when the second terminal is connected to any point of the cover a current passes through the platinum wire and heats it, igniting the fuel. The bomb is placed within a brass water-vessel

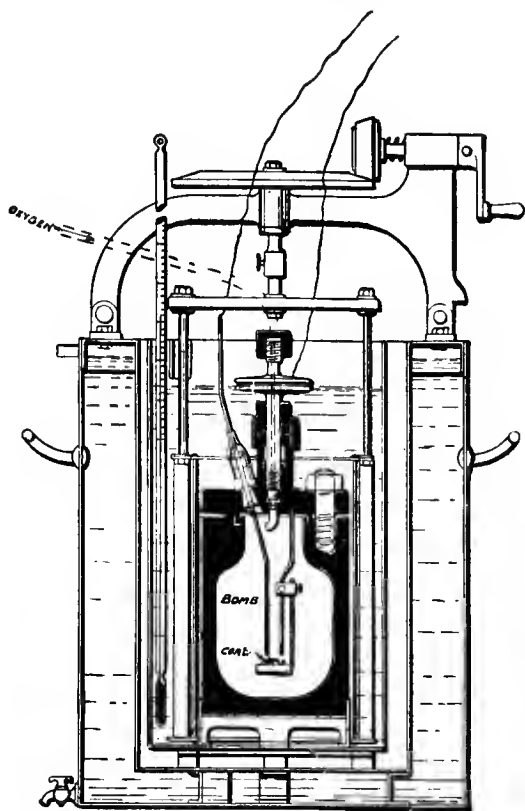


FIG. 82.—Mahler-Donkin bomb calorimeter.

which is provided with an arrangement of paddles rotated by means of a handle. The water-vessel is itself placed on brass supports within an annular water-jacket. The temperature of this water-jacket remains practically constant during an experiment, and the narrow air-space between the two water-vessels ensures that no heat shall pass from one to the other except by

radiation. The water-jacket is provided with an accurate thermometer, so that its temperature can be kept uniform or any variation noted.

In making a determination about one gram of the dry powdered fuel is weighed accurately in the crucible, and the latter is placed in its support with the igniting wire passing through the fuel; the cover is then placed on the bomb and tightly screwed down. The valve is connected to an ordinary cylinder of compressed oxygen, and oxygen is slowly admitted to the bomb until the pressure reaches 25 atmospheres. A special regulating valve and pressure gauge, mounted on a separate stand, are connected between the bomb and the oxygen cylinder, so that the oxygen can be admitted slowly and the pressure in the bomb observed. If the oxygen is admitted too rapidly there is a risk of some coal being blown out of the crucible; apart from this, a rapid increase of pressure in the bomb would cause a rise of temperature. The charged bomb is placed in the water-vessel and a known weight of water, sufficient to cover it completely, is poured in. The water is stirred and its temperature noted. When the temperature is constant and the same as the temperature of the water-jacket the fuel is ignited by completing the battery circuit, and the temperature of the water is observed at short intervals until it has reached a maximum and begun to fall. The maximum temperature attained is carefully noted. The combustion of the fuel is very rapid, but two or three minutes must elapse before the maximum temperature is reached, as the heat must pass from the gaseous products of combustion through the metal walls of the bomb. The stirring must be continued until the maximum temperature has been observed.

Let $t_1^\circ \text{C.}$ be the temperature of the water before ignition of the fuel;

$t_2^\circ \text{C.}$ be the maximum temperature observed;

w grams be the weight of fuel taken;

W_1 grams be the weight of water in the water vessel;

W_2 grams be the water equivalent of the calorimeter (see below);

P be the calorific power of the fuel (in calories per kilogram, or in small calories per gram).

Then the heat given out by the combustion is $P \times w$ small calories, and this quantity of heat has raised the temperature of W_1 grams of water through $t_2 - t_1$ degrees. Certain parts of the apparatus have also been heated, and the quantity of heat required for this is determined once and for all by a separate experiment. It is W_2 small calories for each degree rise of temperature. The heat evolved by the combustion is therefore—

$$W_1(t_2 - t_1) + W_2(t_2 - t_1) \text{ small calories ;}$$

and for the calculation of the calorific power we have—

$$P \times w = (W_1 + W_2) \times (t_2 - t_1)$$

where all the quantities are known except P . Therefore—

$$P = \frac{(W_1 + W_2) \times (t_2 - t_1)}{w}$$

The constant quantity W_2 , called the “water equivalent” of the calorimeter, is determined by making a similar experiment with a fuel of known composition. Fused naphthalene is suitable for this purpose. Using the same letters as before, we again have—

$$P \times w = (W_1 + W_2) \times (t_2 - t_1),$$

but now P is known (9692 calories for naphthalene) and W_2 is the quantity required, so that—

$$W_2 = \frac{P \times w}{t_2 - t_1} - W_1.$$

A determination of the calorific power carried out in this way will give a result correct to within 0.5 per cent. of the true value, and this is sufficiently accurate for most purposes. When greater accuracy is desired corrections must be made for the heat lost by radiation from the water-vessel before the maximum temperature is reached, and for the heat evolved owing to the formation of nitric acid in the bomb during the combustion. The former correction may be dispensed with if the temperature of the water at the beginning of the experiment is adjusted so that the temperature of the water-jacket is midway between t_1 and t_2 . The water in the vessel then receives heat by radiation during the first part of the experiment and loses an equal amount during the latter half.

When coal is burned under ordinary conditions no nitric acid

is formed; the heat due to its formation in the bomb should therefore be deducted from the observed calorific power. In order to make this correction it is necessary to wash out the bomb after the experiment, and to determine by titration the quantity of nitric acid which has been formed. This correction is in the opposite sense to the correction for heat lost by radiation; and the two errors nearly balance one another, so that if both are neglected the result obtained is within 0.5 per cent. of the true value. For detailed information as to the method of making these corrections when necessary the reader is referred to Mahler's "*Etudes sur les Combustibles*."

For less accurate determinations of the calorific power of solid fuels, many calorimeters have been devised in which the combustion takes place in oxygen at atmospheric pressure. These differ in the details of their construction, but the principle may be described without reference to any particular form of calorimeter. The fuel is contained in a crucible which is supported inside a metal or glass enclosure forming the combustion chamber, and this is immersed in water in the calorimeter. The fuel is ignited either electrically or by some other suitable means, and oxygen at atmospheric pressure is passed into the enclosure to maintain the combustion. The oxygen is delivered from a tube just above the open mouth of the crucible; the progress of the combustion is watched (by an arrangement of mirrors if the enclosure is an opaque metal vessel), and the supply of oxygen is regulated accordingly. Before escaping into the air the products of combustion are made to give up their heat to the water in the calorimeter either by passing through a coil of metal pipe immersed in the water or by bubbling through the water.

The disadvantage of calorimeters of this type is that it is difficult to ensure complete combustion and complete cooling of the products. The success of their working depends largely upon the care exercised in regulating the supply of oxygen during combustion: if the oxygen is admitted too rapidly the products may not give up all their heat to the water before they escape from the calorimeter, but if the current of oxygen is too slow there will be smoke, and part of the volatile matter of the fuel will escape combustion. Often too a small amount of carbon is left unburnt in the crucible.

Of the many calorimeters based upon this principle two of the best known are the W. Thomson and the Fischer calorimeters.

Another modification is that of Rosenhain, for which it is claimed that results can be obtained which are quite accurate enough for industrial purposes.¹ Apart from details of construction the essential modification in this calorimeter is that instead of burning the powdered fuel in a crucible it is compressed into a small briquette, which stands upon a flat porcelain plate; in this way the oxygen has readier access to the burning fuel, and experiments show that the amount of unburnt carbon is only 0.3 per cent. Water is admitted to the combustion chamber after the fuel has been burnt and before the final temperature is read, so that all parts of the calorimeter are quickly brought to the same temperature.

A third type of calorimeter for solid fuel is that in which the powdered coal is mixed with substances rich in oxygen, so that when ignited the mixture burns without any supply of gaseous oxygen being required. The Lewis Thompson calorimeter which is based upon this principle has been largely used in this country on account of its simplicity. The results obtained with it are, however, unreliable, and it should be used only where a rough approximation is sufficient. In this calorimeter the coal is mixed with suitable quantities of powdered potassium chlorate and nitrate, and the mixture is put into a small copper cylinder. This is supported inside a copper vessel which forms the combustion chamber, and the latter is immersed in water. The combustion is started by means of a fuse; the products of combustion leave the combustion chamber through a number of small holes near the bottom and bubble through the water in the calorimeter. Water is admitted to the combustion chamber before the final temperature is observed. With this calorimeter a considerable proportion of the coal is always left unburnt, and to get any approach to accuracy it is necessary to recover the unburnt coal from the water after the experiment and to determine its amount. Practically this makes the determination very troublesome, and it is usual to neglect this correction. The results obtained may then be considered as comparative if the fuels

¹ *Philosophical Magazine*, 1902, vol. iv. p. 457.

tested are similar. The amount of unburnt carbon is, however, much greater with anthracite and coke than with coals rich in volatile matter, so that the results cannot be compared with one another when different kinds of fuel are tested.

The results obtained with calorimeters of these three types have been carefully compared by Messrs. Brame and Cowan,¹ and also quite independently by Drs. Gray and Robertson.² These authors are agreed that to obtain accurate results a bomb calorimeter should always be employed. The Lewis Thompson calorimeter and the calorimeters using oxygen at atmospheric pressure always give low results. The results obtained may be summarised as follows:—

DIFFERENCES FROM BOMB RESULTS (PER CENT.).

	Brame and Cowan.	Gray and Robertson.
Lewis Thompson calorimeter .	—6·2 to —1·8 ³	—13·0 to —0·9
Fischer calorimeter . . .	—5·7 to —2·6	not tested
W. Thomson calorimeter . .	—6·9 to —1·8	—2·9 to —0·7

Gray and Robertson, however, conclude that the W. Thomson calorimeter will give results sufficiently accurate for industrial purposes if the supply of oxygen is carefully regulated and the water equivalent of the calorimeter determined by an experiment with a coal of known calorific power. The same sources of error are present in the determination of the water equivalent as in subsequent determinations of calorific power. The number thus obtained for the water equivalent is in excess of the truth, and this approximately balances the various losses which occur in an actual determination. Working in this way, the values obtained with different coals differed from the bomb results by —1·8 to +0·5 per cent. only.

It should be noted that in all determinations of the calorific power either the sample tested should be dried or the percentage of moisture in it should be determined at the time when the test

¹ *Journal of the Society of Chemical Industry*, 1903, vol. xxii. p. 1230.

² *Ibid.*, 1904, vol. xxiii. p. 704.

³ In these experiments allowance was made for the carbon which escaped combustion.

is made. The percentage of moisture in coal varies with the humidity of the air; the calorific power should therefore refer to the *dry* fuel, and if the amount of moisture in the fuel at any time is known the value of the calorific power can be calculated accordingly. Thus if the calorific power of the dried fuel is 8000 calories per kilo, and if the sample contains 3 per cent. of moisture, the calorific power of the sample is $8000 \times 0.97 = 7760$ calories per kilo.

The calorific power of solid fuels can also be calculated approximately from the results of a chemical analysis. Various formulæ have been put forward for this purpose, but as the direct determination by the bomb calorimeter is a much simpler operation than the ultimate chemical analysis, and gives a more reliable value for the calorific power, it will be unnecessary to discuss these and we give only one of them. According to Mahler,¹ the calorific power is equal to $81.4 \times C + 34.5 \times H - 30(O + N)$ calories per kilo, where C, H, O, and N are the percentages of carbon, hydrogen, oxygen, and nitrogen respectively in the dry fuel.

Mahler's experiments show that this formula may be used for any fuel of vegetable origin (peat, lignite, coal, etc.), and that the result obtained for the calorific power is within 3 per cent. of the true value. For ordinary coal the error is much less than this.

As the "proximate analysis" of fuel is simple and is often carried out in order to ascertain whether a fuel is suitable for a given purpose, it will be useful to describe a method by which the results so obtained can be used for a fairly accurate calculation of the calorific power. The formula given by Goutal² is—

$$\text{Calorific power} = 82 \times C + A \times V \text{ calories per kilo,}$$

where C is the percentage of fixed carbon in the fuel,

V is the percentage of volatile matter (exclusive of moisture),
and A is a coefficient depending upon the percentage of volatile matter in the fuel.

The values of the coefficient A are given in Table XL.

¹ "Etudes sur les Combustibles," p. 63.

² *Comptes Rendus*, 1902, vol. 135, p. 477.

TABLE XL.—VALUE OF COEFFICIENT A IN GOUTAL'S FORMULA.

V'.	A.	V'.	A.
Per cent.	Calories.	Per cent.	Calories.
1 to 5	100	23	105
5	145	24	104
6	142	25	103
7	139	26	102
8	136	27	101
9	133	28	100
10	130	29	99
11	127	30	98
12	124	31	97
13	122	32	97
14	120	33	96
15	117	34	95
16	115	35	94
17	113	36	91
18	112	37	88
19	110	38	85
20	109	39	82
21	108	40	80
22	107		

In this table V' is the percentage of volatile matter in the combustible portion of the fuel, *i.e.* supposing the moisture and ash to have been removed. The value of V' is therefore—

$$\frac{100 \times V}{C + V}.$$

The following example is given to illustrate the use of the formula:—

The analysis of a sample of coal gave the following results:—

Fixed carbon	76.4 per cent.
Ash	11.0 „
Moisture	1.1 „
Volatile matter, other than moisture	11.5 „
Total	100.0 „

The value of V' is $\frac{11.5 \times 100}{76.4 + 11.5} = 13.1$.

Referring to Table XL., we see that the corresponding value of A is 122. The calorific power is therefore—

$$82 \times 76.4 + 11.5 \times 122 = 7668 \text{ calories per kilo,}$$

or in round numbers 7670 calories per kilo (13,800 B.Th.U. per pound).

According to Mahler this formula gives results for bituminous

and semi-bituminous coals which are usually within 1 per cent. of the results obtained with the bomb calorimeter. With anthracite coals, which contain very little volatile matter, and with fuels rich in oxygen and containing a high percentage of volatile matter, *e.g.* lignite, the error is greater and the formula should only be regarded as approximate.

Since the percentage of volatile matter in the coal is not a very definite quantity, the value obtained depending to some extent upon the exact method used in the determination (see p. 268), it is necessary in using Goutal's formula to follow a specified procedure. According to Mahler the following method should be used:—

Five grams of the coal are placed in a covered crucible of about 30 c.c. capacity and heated sharply over a Berzelius' rose burner. The flame should completely surround the crucible, and after the volatile matter has ceased to burn at the top of the crucible the heating should be continued for about three minutes. The loss of weight is due to the loss of volatile matter and moisture, and the quantity of the latter must be deducted.

The calorific power of coke may be calculated approximately if the percentages of ash and moisture are determined. According to Butterfield,¹ the calorific power is—

$$80.8 \times (98 - \text{percentage of ash and moisture}).$$

This is equivalent to the assumption that the coke is made up of carbon, ash, and moisture, together with 2 per cent. of oxygen and nitrogen. The small amount of hydrogen in the coke is not taken into account.

The apparatus generally used for determining the calorific power of gas is Junkers' calorimeter, which is shown in Figs, 83, 84, and 85. Gas is burned at a constant rate at the burner, and the heat given out is taken up by a constant stream of water flowing through the calorimeter. The measurements required are the volume, V , of gas consumed while a weight, W , of water passes through the calorimeter, and the temperatures t_1 and t_2 of the water as it enters and leaves the calorimeter. The measurements are not taken until the gas has been burning and the water running for some time, so that the temperature t_2 of the water leaving the calorimeter has reached a steady value. There is, therefore, no alteration in the temperature of the calorimeter

¹ "Chemistry of Gas Manufacture," p. 316.

section and the sectional plan respectively. The cylindrical combustion chamber **28** is surrounded by an annular copper water-jacket **15**. The burner **27** is placed in the combustion chamber, and the products of combustion pass through a number of tubes **30** extending from the top to the bottom of the water-jacket, and escape from the products outlet **32**. Cold water from the supply funnel **3** enters the water-jacket near its base and passes up outside the tubes, taking up the heat from the products. It is well mixed by the discs **17** in the neck of the calorimeter, and after passing the bulb of the thermometer **43** it escapes from the overflow funnel **20**. The water supply funnel **3** is provided with a strainer **2**, and is so constructed as to maintain a constant head of water. The amount of water passing through the calorimeter is regulated by the cock **9** and remains constant during an experiment. The temperature of the cold water as it enters the jacket is measured by the thermometer **12**. An air-jacket **36**, surrounding the water-jacket, prevents loss of heat by radiation. A valve **33** in the products outlet is used to regulate the draught through the calorimeter, and a thermometer can be inserted in the products outlet so that the temperature of the products may be observed.

Fig. 85 shows the complete apparatus set up for making a determination of the calorific power. The gas to be tested is measured by a small wet meter provided with a thermometer. It is also best to pass the gas through a governor to ensure a steady pressure at the burner; and a water column pressure gauge indicates the pressure above atmospheric at which the gas is measured. In making an experiment the water is set flowing through the calorimeter and allowed to run to waste; the gas is then lighted at the burner and the supply adjusted to about 700 liters (25 cub. ft.) per hour. The water supply is then adjusted by means of the cock **9**, so that the rise in temperature of the water in flowing through the calorimeter is from 10° to 20° C. There should always be some water running to waste from the overflow tube **5**. When the thermometers are steady the determination is made by observing the quantity of gas burnt, as shown by the meter, while two liters of water pass through the calorimeter. To do this the hot water from the overflow funnel **C** is collected in a glass vessel of 2 liters

capacity, beginning when the pointer of the gas-meter passes the zero on the dial; when the water reaches the 2-liter mark the gas is turned off and the meter read again. While the water is being collected five or six readings of the thermometer 43 are

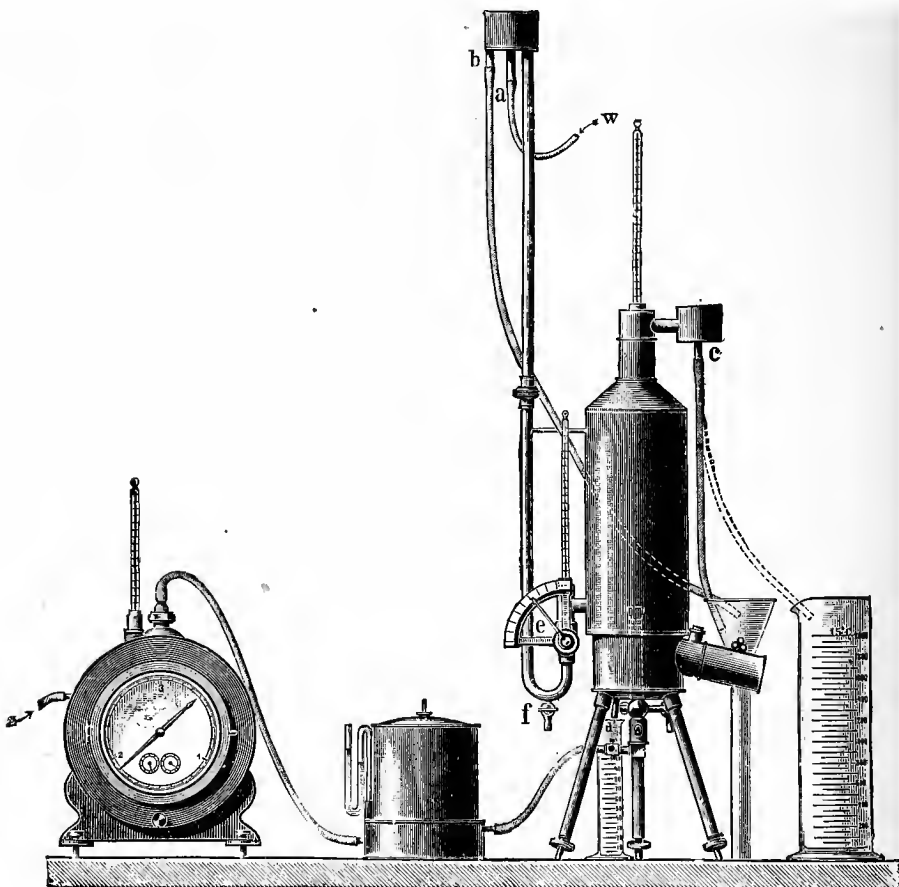


FIG. 85.—Gas calorimeter with meter, governor, etc.

taken at regular intervals. The average of these is the temperature t_2 of the hot water. The temperature of the cold water is read by the thermometer 12 at the beginning and end of the experiment, and the mean of these two readings is the temperature t_1 of the cold water. The temperature and pressure of the

gas and the height of the barometer are also observed. From these data the calorific power of the gas can be calculated. Thus the results of a test of producer gas were as follows:—

Volume of gas recorded by meter 21.72 liters (0.767 cub. ft.) while 2 liters of water passed through the calorimeter.

Temperature of gas at meter 17°C .

Height of barometer, 752 mm.

Pressure of gas above atmospheric, 40 mm. water column.

Temperatures of cold-water supply, 9.20 and 9.20 ; mean $t_1 = 9.20^{\circ}\text{C}$.

Temperatures of hot-water overflow, 21.78, 21.74, 21.70, 21.60, and 21.73; mean $t_2 = 21.71^{\circ}\text{C}$.

The rise in temperature $t_2 - t_1$ is 12.51°C .

The quantity of heat given out during the combustion of 21.72 liters (0.767 cub. ft.) of gas is therefore $2 \times 12.51 = 25.02$ calories (99.28 B.Th.U.),

and the calorific power of the gas is $\frac{25.02}{0.02172} = 1152$ calories per cubic meter, or $\frac{99.28}{0.767} = 129.4$ B.Th.U. per cubic foot.

The result so obtained is the calorific value of the gas supplied to the meter; the volume of gas was measured at a temperature $t^{\circ}\text{C}$., and at a pressure equal to the barometric height h_1 , plus the pressure due to a water column of height h_2 as measured by the pressure gauge on the meter, and minus the pressure of aqueous vapour in the gas. These pressures and temperatures vary in different tests; it is therefore always necessary to calculate from the above data the calorific power of unit volume of the gas when the gas is measured at the standard temperature and pressure (0°C . and 760 mm. of mercury), the gas being *dry*, i.e. free from water vapour. The method of making this correction is as follows:—

Let V_1 be the volume of gas registered by the meter;

V_0 , the volume of gas at standard temperature and pressure;

$t^{\circ}\text{C}$., the temperature of the gas passing through the meter;

h_1 , the height of the barometer;

h_2 , the reading of the gas pressure gauge on the gas-meter;

h_3 , the pressure of saturated water-vapour at the temperature t , expressed in the same units as h_1 , viz. millimeters or inches of mercury.

The pressure due to a water column of height h_2 is the same as that due to a column of mercury of height $h_2 \times 0.0736$.

The actual pressure of the gas when measured by the meter was therefore $(h_1 + 0.0736 \times h_2 - h_3)$ millimeters or inches of mercury. Then—

$$V_0 = V_1 \times \frac{(h_1 + 0.0736 \times h_2 - h_3) \times 273}{760 \times (273 + t)}$$

if the temperature is measured on the Centigrade scale and the pressures in millimeters of mercury;¹ or—

$$V_0 = V_1 \times \frac{(h_1 + 0.0736 \times h_2 - h_3) \times 491.4}{29.92 \times (459.4 + t)}$$

if the temperature is measured on the Fahrenheit scale, and the pressures in inches of mercury.¹

The volume V_0 must then be used instead of V_1 in calculating the calorific power from the figures obtained in the test.

The calorific power of the gas at standard temperature and pressure is clearly $\frac{V_1}{V_0} \times$ the observed calorific power P_1 , so that the correction may equally well be made by multiplying the observed calorific power by either—

$$\frac{760 \times (273 + t)}{(h_1 + 0.0736 \times h_2 - h_3) \times 273}$$

or

$$\frac{29.92 \times (459.4 + t)}{(h_1 + 0.0736 \times h_2 - h_3) \times 491.4}$$

according to the system of measurements employed.

In the example given above the barometric height was 752 millimeters, the gas pressure gauge gave a reading of 40 millimeters above atmospheric pressure, and the temperature of the gas was 17° C. The gas passing through the wet meter is saturated with water-vapour, and the maximum pressure of water-vapour at 17° C. is 14.4 millimeters (see Table XLIV., Appendix B).

The corrected volume of the gas is therefore—

$$21.72 \times \frac{752 + 40 \times 0.0736 - 14.4}{760} \times \frac{273}{273 + 17} = 19.92 \text{ liters}$$

and the calorific power is—

$$1152 \times \frac{21.72}{19.92} = 1256 \text{ calories per cubic meter,}$$

the gas being measured when dry and at standard temperature and pressure.

¹ See Appendix B, p. 324.

In stating the calorific power of gas a distinction is often made between the "higher" and "lower" values, or "gross" and "nett" calorific powers. The gross calorific power is the result determined as described above, and represents the heat obtained by burning unit volume of the gas and cooling the products to the same temperature as that of the gas before combustion, *i.e.* usually to atmospheric temperature. The products of combustion are carbon dioxide and steam in varying proportions, which are mixed with the nitrogen originally present in the gas and that present in the air used for combustion. In cooling the mixture of gases to atmospheric temperature the steam is practically all condensed and its latent heat is given up. It is sometimes considered that for practical purposes this amount of heat is not available for useful heating, since it is only evolved when the products are cooled below 100° C., while in practice the products of combustion are always led away from the furnace or other heating apparatus at a temperature much higher than this. The latent heat of the steam in the products of combustion is therefore deducted from the gross calorific power, and the value thus obtained is called the "lower value" or the "nett calorific power" of the gas. No general statement can be made as to which value of the calorific power should be given, because this depends upon the purpose for which the figure is to be used. In making a general statement of the properties of the gas both values should therefore be given, and each will be useful for certain purposes. For example, in stating a heat balance-sheet for a gas-producer or in calculating its efficiency, the gross calorific power should be taken; for in these cases the manner in which the heat of combustion of the gas is utilised has not to be considered. The fact that the gas-engine or furnace rejects the products of combustion at a high temperature, so that the steam is not condensed, must not be counted against the producer. On the other hand, if it is desired to consider the efficiency of a complete gas installation, either for power or heating, *i.e.* to compare the heat of combustion of the solid fuel with the useful effect obtained in an engine or gas-fired heating apparatus, then, in consequence of the fact that the products of combustion are not completely cooled, the producer gas which yields least steam in its products of combustion will (if the

products are rejected at the same temperature) give the best result.

As regards furnace work, it should be remembered that a considerable proportion of the hydrogen in the gas is derived from the volatile constituents of the fuel and not from the decomposition of steam supplied to the producer, so that even when the fuel is burnt direct in a furnace there is steam in the products and its latent heat is lost. The apparent disadvantage of gas-firing from this point of view is therefore not so great as the difference between the gross and nett calorific powers would seem at first sight to indicate.

In the Junkers' calorimeter the steam in the products condenses and the water formed runs out from the overflow 35 (Fig. 83) at the base of the instrument. In making a test with the calorimeter the water which drips from 35 (Fig. 83) is collected in a graduated glass vessel *d* (Fig. 85), while a convenient volume of gas is burnt.

The amount of heat liberated when one kilo of steam at $t^{\circ}\text{C}$. is condensed to water is $(606.5 - 0.695 \times t)$ calories, and for the ordinary atmospheric temperature it is sufficiently accurate to take this as 600 calories. Hence if unit volume of the gas (liters or cubic feet) yields x c.c. of water at the overflow, the quantity of heat to be deducted from the gross calorific power is $x \times 0.600$ calories, or $x \times 2.38$ B.Th.U.

In the experiment described above, 50 liters of the gas yielded 5.5 c.c. of condensed water. 1 c.m. of gas would therefore yield $20 \times 5.5 = 110$ c.c., and the correction to be applied is $110 \times 0.600 = 66$ calories.

The nett calorific power of the gas is therefore $1152 - 66$, or 1086 calories per c.m. at the observed temperature and pressure, or $1086 \times \frac{21.72}{19.92} = 1184$ calories per c.m. at standard temperature and pressure.

In British units, if 2 cub. ft. of the gas yield 6.2 c.c. of condensed water, the amount to be deducted from the calorific power of the gas at the observed pressure and temperature is 3.1×2.38 , or 7.4 B.Th.U.

For very accurate work the temperature of the products should be observed at the outlet 32, and the water and gas supplies to the calorimeter should be adjusted so that the temperature of the products is the same as that of the atmosphere. When this is not done the products are usually cooled below the

temperature of the atmosphere (since the water supply is generally below atmospheric temperature), and heat is therefore taken up by the calorimeter, not only from the products after they have been cooled to atmospheric temperature, but also from an unknown quantity of air which passes through the calorimeter in consequence of the draught induced by the flame. The result obtained for the calorific power is therefore slightly in excess of the true value, but in ordinary working this difference may be neglected.

The principle used in this calorimeter is very different from that of the various calorimeters used for solid fuel. In the latter a definite limited quantity of the fuel is burnt in all cases, and a definite limited quantity of water is heated; while in the former, the combustion is continuous and there is a constant stream of water through the calorimeter. This principle, which is very convenient for gaseous fuels, was introduced by Hartley in his gas calorimeter. There are several other calorimeters based on the same principle besides that of Junkers. In the modification designed by Mr. Dowson there are two concentric annular water-jackets, the inner forming the walls of the combustion chamber. The products leave the top of the combustion chamber and pass down the annular space between the two water-jackets, while the water passes upwards through each jacket, the two streams of water mixing at the top of the calorimeter. In this way the products are efficiently cooled, and the construction is much simplified by avoiding the use of numerous tubes, the joints of which often give trouble.

The gas calorimeter of Professor C. V. Boys works upon the same principle of continuous combustion and continuous flow; it was specially designed for testing the calorific power of lighting gas, and has been adopted by the Metropolitan Gas Referees for that purpose. With a suitable burner it is, however, capable of giving accurate results with producer gas. In this calorimeter, shown in section in Fig. 86, the water flows through a double coil **M N** formed of copper pipe surrounded by coils of copper wire, as in a motor-car radiator, so as to increase the heat-collecting surface. In this way the water content of the apparatus is reduced to a minimum, so that simultaneous readings of the inlet and outlet thermometers give the true rise of temperature. The hot water from the coil **M** passes through

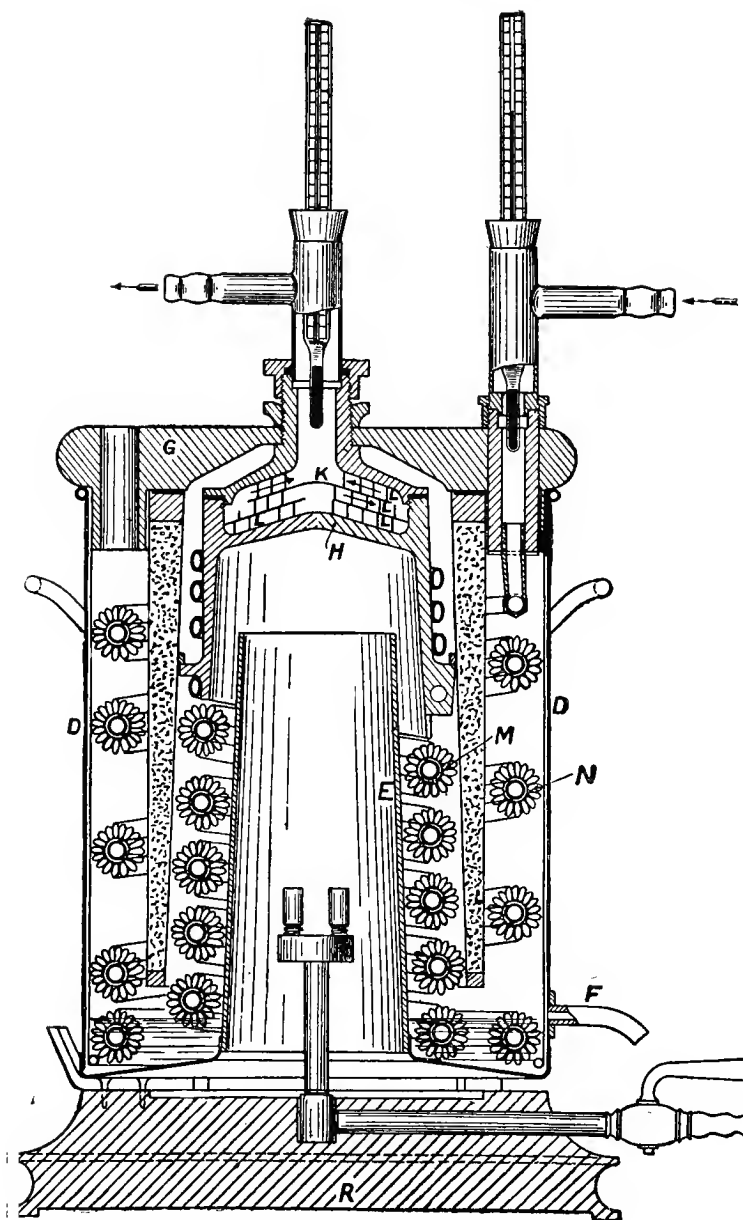


FIG. 86.—Boys' gas calorimeter—vertical section.

a coil of pipe around the hood **H** and thence through spiral passages in the temperature equalising chamber **K** to the outlet thermometer, which is situated at the same level as the inlet thermometer. The chimney **E** surrounding the flame is not directly cooled, except at the lower end, and there is no condensation upon it. The outlet for the water condensed from the products of combustion is at **F**; the instrument is filled with water up to this level before use, and this water is kept cool by the two lowest turns of the cooling coil. When out of use the body of the calorimeter is lifted by the lid **G** out of the casing **D**, and is placed in a similar vessel containing a very dilute solution of sodium carbonate; in this way the coils are preserved from corrosion by the acids in the combustion products.

The "Sarco" gas calorimeter works upon a different principle, and records automatically and continuously the lower calorific value of the gas. In this calorimeter the gas is burned at a constant rate within a well-radiated chimney, which is thus maintained at a temperature which depends on the lower calorific value of the gas. The chimney contains one limb of a **U** tube filled with oil. The other limb of the **U** tube is kept at atmospheric temperature, so that the level of oil in the hot limb will rise above the level in the cold limb to a height depending on the temperature of the chimney, and therefore upon the calorific value of the gas. By means of floats and levers this difference in level causes a pen to move over a paper scale on a drum rotated continuously by clockwork. A special regulating test-meter is provided, having a gas measuring-drum with pendulum escapement, so that there is constant flow of gas to the burner.

The calorific power of gases can also be determined in the bomb calorimeter. For this purpose the crucible is dispensed with, and it is necessary to know the exact capacity of the bomb. This is easily found from the weight of water required to completely fill the bomb with the cover fastened on. To determine the calorific power of a gas the cover is bolted down and the air is exhausted from the bomb by a small air-pump. Gas is then admitted and the bomb is again exhausted by the pump; this double exhaustion ensures all air being removed. The bomb is then filled with the gas to be tested, the height of the barometer

and the temperature of the gas being noted. The gas should be saturated with water vapour; the bomb then contains a known volume of the gas at a known temperature and pressure. Oxygen is then slowly admitted till the quantity is sufficient for complete combustion of the gas. It is necessary to avoid too large an excess of oxygen or the mixture will not explode; it is found that for producer gas the pressure in the bomb should be raised to half an atmosphere, but for ordinary lighting gas 5 atmospheres is a suitable pressure. Pressures as low as half an atmosphere are most suitably measured by means of a mercury pressure gauge. After the bomb has been charged in this manner it is placed in water in the calorimeter, and the determination is carried out in the same manner as with solid fuel. The volume of gas taken is equal to the known capacity of the bomb, and must be reduced to standard temperature and pressure.

The bomb of Professor A. Witz differs considerably from the type of bomb calorimeter described above, and is suitable only for testing gases. This bomb is shown in section in Fig. 87. It consists of a steel cylinder, **A**, of about 250 c.c. capacity, with screwed end covers, **BB**, the joints being packed with oiled paper. The upper cover carries the igniter **C**, and the lower cover slopes downwards to the centre and is provided with a valve, **D**, at the lowest point. All the surfaces are nickel-plated to lessen the corrosive action of the gas. An explosive mixture of gas and air or oxygen is prepared by means of the glass bulb shown in Fig. 88. This may have a capacity of 250 to 500 c.c. It is filled with water, and the cock **A** is connected to the gas supply. The water is then allowed to run out at **B**, so that the bulb is completely filled with gas. This gas is passed into a bell jar which is inverted over water, and displaces some of the water with which the jar was filled. For producer gas an equal volume of air is added in the same way; for lighting-gas seven volumes of air are added. To charge the bomb it is filled with mercury and placed in a mercury trough. The mixture from the bell jar is forced through a rubber tube, and fills the bomb by displacement of the mercury. The valve **D** is closed, and the bomb, which is now filled with the gaseous mixture at a pressure slightly above atmospheric, is removed from the mercury trough. On slightly opening the valve for an instant a little of the

mixture escapes and the pressure falls to atmospheric. The capacity of the bomb and the proportion of gas in the mixture being known, the volume of gas in the bomb is known; the temperature and barometric height are observed when the bomb is charged. The bomb is immersed in a known weight of water in a suitable vessel, and the temperatures before and after explosion are observed, as in the case of the bomb calorimeter described for use with solid fuel. The essential difference between

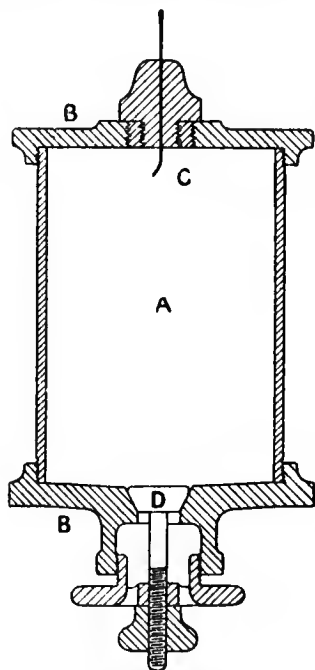


FIG. 87.—Witz bomb calorimeter.

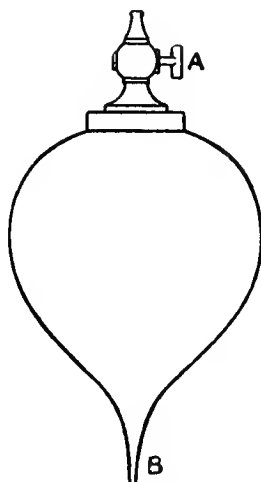


FIG. 88.—Glass bulb for explosive mixture.

the Witz bomb and the type used for solid fuels is that the former is charged only at atmospheric pressure. The quantity of gas used in each test is therefore very small, and the thermometer used to observe the rise in temperature must have a very open scale. The observed rise is only one or two tenths of a degree Centigrade.

When the calorific value of gas is determined in either type of bomb calorimeter the charge in the bomb before explosion is

saturated with water vapour. The steam formed by the explosion will therefore be all condensed, and the result obtained is the gross calorific power of the gas when burnt at constant volume.

In a gas-engine the combustion takes place at constant volume, but when gas is burnt in the usual way the products of combustion are at atmospheric pressure. If the products of combustion occupy a smaller volume than that of the gas and air from which they are formed (the volumes being compared at the same temperature and pressure) work has been done by the pressure of the atmosphere, and the calorific power at constant pressure will be greater than the calorific power at constant volume by an amount of heat equivalent to the work done on account of the change of volume. The change in volume can be calculated from the chemical composition of the gas; the difference between the two values of the calorific power can then be calculated; and the calorific power at constant pressure (the value which is usually referred to simply as the calorific power) can be got from the bomb result. For producer gas the change in volume is not great, and the difference in calorific power due to this is less than 0.5 per cent. For ordinary purposes, therefore, it may be neglected.

In order to ascertain the nett calorific power from the result obtained in the bomb it is necessary to know the quantity of water formed during the combustion. This may be determined by a special experiment in which the carefully dried gas is passed through a tube containing copper oxide at red heat and the water formed is absorbed in weighed tubes containing calcium chloride. If the chemical composition of the gas is known the quantity of steam produced by the combustion of the gas can be calculated (see p. 306). When this quantity has been ascertained by one or other of these methods the nett calorific power can be calculated in the manner already explained (p. 298).

The trouble involved in getting the calorific power at constant pressure and the nett calorific power from the result actually obtained in the bomb is a serious drawback to its use for gases, and it is generally more convenient to use a Junkers' calorimeter or some other of the same type. The quantity of gas used in a test is much greater, and the determination is far more easily and rapidly made. The gas can be kept burning under

the calorimeter, and when once the adjustments have been made and the temperature has become steady, tests can be made as often as desired, each determination occupying no more than about five minutes.

If the composition of producer gas is ascertained by analysis the calorific power can be calculated by means of the known values of the calorific powers of the combustible gases contained in it. This method is adopted when for any reason it is inconvenient or impracticable to obtain a supply of gas for use with the calorimeter. It is also the most suitable method when it is desired to obtain the average calorific power of the gas during a period of time. A sample of gas for analysis can be drawn off at a constant rate during any period, and subsequently analysed; but the determination of the calorific power by means of a calorimeter only gives the value for the gas actually burned during the test. When the producer gas made in a suction plant is to be tested there is no supply available for use with a calorimeter unless a suction pump or fan and a pressure regulator are specially installed; this is necessary in order to draw off gas from the main, where it is at reduced pressure, and deliver it at a constant pressure of 25 to 50 mm. of water at the testing meter. Where this cannot be done there is no special difficulty in taking a sample of the gas for analysis, and this method is generally adopted. The apparatus described in Chapter XVI. for collecting a sample of the gas can be used for a suction plant as well as for those cases in which the pressure of the gas is slightly above that of the atmosphere.

The values for the calorific powers of hydrogen, carbon monoxide, and methane are given in Table XLVIII., Appendix B.

The calculation of the calorific power from the analysis of the gas may be illustrated by means of an example—

<i>Composition of Gas (Per Cent. by Volume).</i>	
Hydrogen	16·2
Carbon monoxide	21·0
Methane	1·3
Carbon dioxide	8·5
Oxygen	0·2
Nitrogen	52·8
Total	<u>100·0</u>

The gross calorific power per cubic meter will be the sum of the quantities of heat given out by the combustion of the first three constituents—

Due to the hydrogen . . .	$0\cdot162 \times 3088 = 500$	calories
Due to the carbon monoxide . .	$0\cdot210 \times 3046 = 640$	„
Due to the methane . . .	$0\cdot013 \times 9545 = 124$	„
Total . .	<u>1264</u>	calories per c.m.

The value in B.Th.U. per cubic foot can be calculated in a similar way.

The calorific power can also be obtained from the analysis by means of Table L. in Appendix B.

The nett calorific power is calculated as follows :—

The volume of steam formed by the combustion of 1 c.m. of gas is—

$$\begin{array}{r}
 0\cdot162 \text{ c.m. due to the hydrogen.} \\
 \text{and } 2 \times 0\cdot013 = 0\cdot026 \text{ c.m. due to the methane.} \\
 \hline
 \text{Total } 0\cdot188 \text{ c.m.} \\
 \hline
 \end{array}$$

The latent heat of the steam formed by the combustion of 1 c.m. of hydrogen is 486·7 calories, and the number which must be deducted from the gross calorific power is $486\cdot7 \times 0\cdot188 = 91\cdot5$ calories.

The nett calorific power of the gas is therefore $1264 - 91\cdot5 = 1172\cdot5$ calories per cubic meter.

If the calorific power is expressed in B.Th.U. per cubic foot, the calculation is as follows :—

The quantity of steam formed by the combustion of 1 cub. ft. of the gas is 0·188 cub. ft. (see above).

The latent heat of the steam formed is—

$$0\cdot188 \times 54\cdot7 \text{ B.Th.U.} = 10\cdot3 \text{ B.Th.U.,}$$

and this quantity must be deducted from the gross calorific power in B.Th.U. per cubic foot.

CHAPTER XVIII

PRACTICAL NOTES

1. *Carbon Monoxide Poisoning.*—Although there are thousands of gas-plants in use, there have been few cases of poisoning or asphyxiation. It is, however, important that certain risks attending the use of producer gas should be fully recognised and provided against. We all know that precautions have to be taken when gunpowder, dynamite, high-tension electric currents, etc., are used ; and in the same way those who use producer gas should know that certain precautions are necessary.

The only poisonous constituent of producer gas is carbon monoxide before it is burnt to carbon dioxide, and care must be taken that the unburnt gas is not inhaled. When the gas is taken direct from a producer to a furnace there is no risk of this occurrence unless there is a leak in the gas-main or flue which conveys the gas ; the same may be said when a gas-engine is driven with producer gas. This is especially the case when a suction plant is used (provided that certain precautions are taken when starting the engine), because the gas in the main is below the atmospheric pressure when the engine is running. If the gas is used for heating purposes, with open burners, it is possible for unburnt gas to escape in the workroom if the attendant is ignorant or careless ; the gas should be lighted as soon as it is turned on, and care should be taken to ensure complete combustion. For such work it is essential that the room in which the gas is used should be well ventilated. The risk of leaks from mains is increased when the gas is forced through at a high pressure ; but the ordinary pressure in the distributing pipes of a factory does not exceed that of a column of water 40 to 50 mm. ($1\frac{1}{2}$ to 2 ins.) high.

Special care should also be taken not to enter any part of a plant before the gas has been completely expelled. In par. 10

we have described in detail the precautions which should be taken in connection with gasholders.

Carbon monoxide has the peculiar property of combining with the hæmoglobin of the blood, and when this occurs the blood corpuscles will not take up oxygen from the air and convey it to the tissues. According to Dr. Haldane,¹ air containing so small a percentage as 0·2 per cent. of carbon monoxide should be regarded as entailing risk to life. The danger in using this gas is increased because it is inodorous, and unless it is associated with some other gas or vapour which has a characteristic odour its presence cannot be detected by the nose.

“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, when affected by the gas, is to 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.”²

The first-aid measures to be adopted in cases of carbon monoxide poisoning are fresh air, artificial respiration, administration of oxygen, and the application of warmth; but medical aid should be summoned immediately. It is recommended that a cylinder of compressed oxygen, fitted with rubber tubing and a mouthpiece, should be kept in readiness in factories where this danger is likely to arise.

We think it well to add a special word of caution with regard to suction plants. It is true that gas cannot escape from the main while the engine is running, but when the engine is about to be started the producer is worked with a blower which sends gas at pressure to the engine. If through ignorance or carelessness the attendant attempts to start the engine with the crank a

¹ Report of Departmental Committee on Water-gas [C. 9164], 1899; Appendix A.

² Memorandum as to the Use of Water-gas in Factories, issued by the Home Office, September, 1904.

complete revolution ahead of the correct position for starting, both the gas and air valves will be open; and if the blower is in operation, and gas is being blown through to the engine, it will pass through the gas-valve, the air-valve, and air-box into the engine-room. When starting an engine the attendant should, therefore, look to the lay shaft to see that the cams are not holding open the gas and air-valves.

It is also obvious that in testing the gas near the engine it should not be allowed to escape unburnt into the engine-room, even when it may not be strong enough to burn.

2. *Working Two or More Producers together.*—If suitable arrangements are made, there is no limit to the number of producers which can be worked together satisfactorily; but it is important that each one should be provided with a shut-off valve, or that the gas outlet pipe of each producer should be sealed in water. Apart from any question of convenience in working, each producer should be isolated in order that when one is not in use gas from the others cannot pass through it and escape.

3. *Depth of Fire.*—Not infrequently workmen have the mistaken idea that a gas-producer needs a comparatively shallow fire for a reduced output of gas; they think that if there is the same depth of fuel as for the maximum output there will be a greater consumption for a given volume of gas. The depth of fire should never be less than the minimum required to produce the necessary reactions, but within certain limits it is possible to make a reduced quantity of good gas with a less depth of fire than is required for the maximum output. It is, however, a mistaken idea to suppose that the consumption of fuel per unit volume will at any time be more or less than that required for the maximum rate of production, provided gas of the same composition is made; but if at any time the fire is less than the correct minimum depth an excess of carbon dioxide will be produced, and the consumption of fuel will be wasteful. In practice it is simplest and best to maintain the depth of fire required for the maximum rate of production, as it ensures the making of good gas without increasing the fuel consumption per unit volume.

In suction plants and in some pressure plants it is usual at starting to fill up the producer to the level of the feeding hopper, and never to let the top of the fire fall below the level at which

the gas leaves the fuel. There is then always a store of fresh fuel in the container, which gradually descends as the fuel below burns away, and the depth of the fire is thus automatically kept constant whether the engine be working under a full or reduced load. This helps to secure uniformity in the quality of the gas, and it does not add to the fuel consumption. The top of the fire is at the level at which the gas leaves the column of fuel (*e.g.* see Figs. 45 and 46), and can only alter if the attendant allows the container to become empty and the fuel to burn away below this level.

In a pressure plant, if no fuel container is provided below the feeding hopper, the top of the fire should not be above the level of the gas outlet, nor should it be lower than is required for making good gas. It is a common practice to allow the depth of fire to decrease at the end of the day's run in order to facilitate the operation of clinkering on the following morning, and there is no objection to this if the depth is not reduced too far.

The actual depth of fire to be used in a given case depends upon the nature and size of the fuel, and upon the velocity of the current of gases passing through the fire. With these two factors remaining unaltered, any desired output of gas can be obtained by increasing the sectional area of the producer. In practice, however, it is often convenient to vary the velocity of the gases with the size of the producer, and to use a greater depth of fire for the same kind of fuel in the larger producers. With anthracite in pieces $\frac{3}{8}$ in. to $\frac{3}{4}$ in. cube, the depth of incandescent fuel should be about 24 in. up to 50 B.H.P.; about 30 in. up to 100 B.H.P.; and about 36 in. for any power above this. With larger anthracite the fire should be deeper. With bituminous coal, and with coke or charcoal, a greater depth is required than with anthracite.

Experience has shown that with anthracite it is best to allow the following sectional areas:—

B.H.P.	Area of grate per B.H.P.	Area within brick lining per B.H.P.
10 to 100	3 to 4 square inches.	8 square inches.
150 to 300	” ”	7 ” ”

4. *Stirring the Fire.*—When anthracite is used the fire should

not be poked or stirred while the plant is working. When anthracite is subjected to heat it decrepitates and breaks up into small pieces which are slippery, so that automatically the lower part of the fire is as close and compact as it should be; if it is stirred this part of the fire will be too dense, and will offer too great a resistance to the passage of air. When the producer is not working the fire can be poked from the top to remove any clinker which adheres to the brick lining.

Coke does not behave as anthracite does. Its shape and structure do not alter with heat, as the coke has already been subjected to a high temperature in the retort at the Gas Works, and it is merely consumed gradually in the producer as the chemical reactions occur. For this reason, and because it has rough irregular surfaces, it holds itself up in the producer, and should be poked from the top, at intervals, to keep the pieces close enough for making good gas.

Bituminous coal requires poking or stirring, chiefly because it fuses when subjected to heat, and has a tendency to cake; in this way hollows or channels are formed which should be closed by stirring or poking.

5. *Removal of Condensed Moisture.*—Provision should always be made for removing condensed moisture from the pipes which convey producer gas, except in cases where hot gas is taken direct from a producer to a furnace. When a gasholder is used it is very important to keep the inlet and outlet pipes free from water, also the distributing mains and the branches or connections to the burners or gas-engines for which the gas is to be used. As far as is possible the gas-mains should drain towards one common point, and the moisture which collects there can be allowed to flow away through an overflow pipe sealed in water; or if the level is too low for the water to flow away by gravity provision should be made for removing it occasionally by a small pump. Neglect of these simple precautions often leads to a stoppage of the gas supply, with its attendant troubles.

6. *Testing the Pressure of the Gas.*—When gas will not pass freely through the gas-plant and piping, the gas pressure should be taken at various points to locate the obstruction. An ordinary water-column U gas-pressure gauge is generally used for this purpose, and in most cases it need not be more than about 300 mm.

(say 12 ins.) long. In large installations it is convenient to lead small pipes from various points of the plant to gauges fixed in some convenient spot, preferably in the gas-house. Means should be provided for testing the pressure of the gas at or near the outlet of the producer, at the inlet and outlet of each separate scrubber or other part of the plant, and at any points in the gas-main where water may collect. When such permanent arrangements are made for testing it is simple to arrange the gauges and pipes so that the pressure of the gas above that of the atmosphere at any point of the plant can be observed, and also the difference between the pressures of the gas at any two points. To avoid risk of stoppage it is advisable (especially with large plants) to observe the pressures regularly, and any tendency for the pressure to increase beyond the normal amount should be at once investigated.

7. *Lining of Gas-producers.*—It is usual to line the inside of a gas-producer with firebricks, and it is most important that these bricks should be well set with thin joints of fireclay; it is also desirable that there should be a backing of sand or small pieces of broken brick mixed with fireclay between the firebrick lining and the steel casing. When the lining has been finished a small fire should be lighted in the producer to dry the brickwork gradually before it is subjected to the great heat which is developed when the producer is used for making gas. These precautions are necessary to prevent cracks in the brickwork through which air can pass; for if air mixes with the gas in the producer some of the gas is burnt, and this is not only wasteful but it dilutes the gas by increasing the proportion of nitrogen and carbon dioxide. When this occurs to any considerable extent blue flames may be seen inside the producer; they could not occur if there were no air to burn with the gas. When the gas is analysed a small quantity of free oxygen is sometimes detected, which is a sure sign that air has mixed with the gas; this more often occurs with suction plants, as there is naturally a tendency for air to be drawn in. For this reason all the joints in the ironwork, hopper valves, etc., should be attended to carefully.

8. *Test-flames.*—When a pressure plant is used for engine or heating work requiring uniformity in the quality of the gas it is often convenient to have a small test-flame burning continuously.

The flame should be enclosed in a lantern, as it will then be steadier, and there can be a vertical scale behind it to denote more exactly the variations in height. If the gas is at a constant pressure, as it would be from a gasholder, the attendant soon gets to know the height and appearance of the flame when the gas is good; he should also notice the colour and character of the flame, which are useful guides.

With a suction plant it is not possible to keep a flame burning while the engine is working, as the pressure is reduced below atmospheric; but when the plant is started with a blower the gas is at a pressure above that of the atmosphere, and during the period of blowing it is useful to have a test-cock on the outlet of the producer. As soon as gas will burn properly at this point the cock on the waste pipe should be closed, so that the gas may flow to the engine; and near the latter there should be a blow-off pipe and another test-cock. When the gas will burn properly at this cock the engine should be started, and immediately afterwards the blow-off pipe should be closed to prevent air being sucked in.

9. *Starting a Gas-fired Oven or Furnace.*—It seems obvious that when an oven or furnace is to be heated by gas the latter should not be turned on before a light is introduced; but this simple precaution is sometimes neglected, and the inevitable explosion occurs. In a large furnace it is usual to light some cotton waste soaked in petroleum, and to place it on the floor of the furnace near the gas inlet; or sometimes a shovelful of burning coal or coke is used instead. The gas should then be turned on gradually until there is a certainty that all gas admitted will be ignited.

In small ovens or other apparatus it is sufficient to use a taper, or some cotton waste soaked in petroleum fixed to the end of a rod.

Sometimes it is convenient to have a pilot light always burning in the oven (to ensure that the gas used for heating is always ignited) if there is any risk of the supply being interrupted, or of there being great fluctuations in the pressure.

10. *Gasholders.*—When gas is to be used for the first time after the erection or cleaning of the plant it is best to fill the gasholder with gas and then blow off the contents into the air without

igniting the gas. Without this precaution there would be a mixture of gas and air in the various parts of the plant, and there would be serious risk of explosion if the mixture were ignited.

When it is necessary to enter a gasholder after it has been used the procedure should be as follows:—

(a) Let the tank be full of water.

(b) Blow off all gas in the gasholder until the latter rests on the bottom of the tank.

(c) Draw the fire out of the producer and put on the doors; close the valve nearest the holder on the outlet main.

(d) Fill the gasholder with steam and air if the producer is of the steam-jet type. If there is no steam at pressure to act as an injector, fill the gasholder with air from a blower, and blow off the contents of the holder. Again fill and blow off, and repeat this operation a third time.

(e) After filling the gasholder with steam and air, or air only, and after blowing off the contents three times, take off the cover of the manhole on the top of the gasholder.

(f) If the tank is above the ground level, empty the water out of the tank. If the tank is sunk in the ground it need not be emptied.

(g) The gasholder and tank may now be entered.

It is important that the inlet and outlet pipes of the gasholder should be drained, and when syphon boxes are used they should be pumped clear of condensed moisture as often as is necessary.

11. *Steam Supply*.—When a producer is worked with a steam-jet air injector the pressure of the steam must be high enough to overcome the resistances opposed to the passage of gas through the various parts of the plant, and to raise the gasholder. The steam pressure necessary depends also on the size of the producer and the volume of gas required; it usually varies from 2 to 4 atmospheres (30 to 60 lbs. per square inch).

In practice, when pressure gas is used for driving engines or for heating work of various kinds, it seldom happens that the consumption is at a constant rate; it is therefore desirable to approximate the rate of production to a varying rate of consumption. To effect this in a simple way Mr. Dowson introduced a method of governing the production by the rise and fall of the gasholder. His first arrangement was to blow off some steam and air from the lower part of the producer, as shown in Fig. 34, and as described on page 103. Later he adopted the method of regulating the admission of steam to the producer without blowing off steam or air. For this purpose the steam admission valve

has a weighted lever which is attached to a wire cord running on pulleys; at the other end of the cord there is a weight suspended over the crown of the gasholder, and the length of the cord is adjusted so that when the gasholder is nearly full the weight rests on it and the weighted lever on the steam valve falls and closes, or partly closes, the valve. When the gasholder falls the weight suspended over it raises the weighted lever on the steam valve, and the full supply of steam enters the producer. In this way (within certain limits) the rate of production is governed automatically to suit a varying rate of consumption. This arrangement has the further advantage that it reduces the size of the gasholder required as less storage capacity is necessary.

12. *Overflow Water*.—When a gas-plant is near a drain it is easy to carry the overflow water to it; but the water should not be too hot, or vapours may rise from it which would pass the gratings or ventilators in the public roads or streets. In some cases there is no drain, and it also happens sometimes that there is a stream near the gas-plant which must not be polluted; the disposal of the overflow water is then a matter of some difficulty, and it will be well to consider the nature of the water which has to be disposed of.

When the fuel in the producer is burnt part of the sulphur remains in the ash as sulphate and the remainder is present in the gas chiefly as sulphuretted hydrogen. This gas is soluble in water and is partially absorbed by the scrubbing water; the remainder goes with the gas. We cannot estimate, even approximately, the proportion of the sulphur in the coal which is taken up by the scrubbing water, as it depends on so many factors—*e.g.* the manner in which the sulphur in the coal is combined (whether as pyrites or in organic combination), the efficiency of the scrubbing, the temperature of the scrubbing water, etc. However, for the purpose of an example we will assume that the fuel contains 1 per cent. of sulphur, and that half of it is ultimately found in the overflow water from the scrubber, chiefly as sulphuretted hydrogen.

With these assumptions, which are probably in excess of the truth, a 100 B.H.P. gas-plant working at full load, and using, say, 400 grams or 0.9 lb. of coal per B.H.P.-hour, would give about 200 grams (0.45 lb.) of sulphur in the overflow water each

hour. If this cannot be allowed, care should be taken to use fuel which does not contain more than 0.5 per cent. of sulphur. The quantity of the overflow water can also be reduced considerably if the gas from the producer is sufficiently cooled by passing through a series of pipes before it enters the scrubber.

In suction plants there is always a small quantity of air drawn in above the fire through the hopper, and as it mixes with the hot gas it oxidises part of the sulphuretted hydrogen to sulphur dioxide. The latter is also soluble in water, so that the overflow water from the scrubber of a suction plant usually contains both sulphur dioxide and sulphuretted hydrogen dissolved in it.

When necessary special methods can be adopted for getting rid of the sulphur compounds before discharging the overflow water. One method is to provide cooling tanks for the water, and to use the same water repeatedly in the scrubbers, circulating it by means of a pump. The impure water is treated from time to time with lime, which throws down the sulphur compounds in the form of mud, and small quantities of the water which has been treated are discharged at intervals, fresh water being added in the cooling tanks.

When the amount of the effluent is small it can be rendered harmless by treatment in a settling tank with permanganate of potash. This method has been adopted in some cases where objection has been raised by Sanitary Authorities.

13. *Gas-plants at High Altitudes.*—Producer gas-plants and gas-engines can be used in places situated far above sea-level if proper attention is paid to the effect of the lower atmospheric pressure which exists in these conditions, and a Dowson plant supplying gas to Westinghouse engines has been installed with satisfactory results at a works situated 7000 feet above sea-level. In such cases, the density of the gas and the actual calorific power per unit volume are less than they would be for a gas of the same composition at sea-level, and a greater volume of gas is required to produce the same heating effect or to give the same power in an engine. The weight of fuel consumed is, however, the same as at sea-level, a larger volume of gas at the lower pressure being obtained from the same weight of fuel. The practical difference in working at high altitudes is that a larger

plant must be used in order to prevent excessive velocities of the gaseous currents through the producer, scrubbers, and connecting pipes. If the gas-plant is used with an engine, the engine also will be of larger cylinder dimensions than are required to give the same power at sea-level, as a larger volume of gas must be drawn in at each suction stroke, and the size of the producer for a given engine should be the same whether the engine is used to give, say, 200 B.H.P. at sea-level or 150 B.H.P. at some much higher level. If the gas-plant is required for heating, the size should be suitable for the actual volume of gas required, and should not be determined by reference to the weight of solid fuel to be consumed, as the fuel consumption for a given volume of gas is less at high altitudes than at sea-level. In Appendix B, Table LIII., are given the necessary data for dealing with any practical case that may arise.

APPENDIX A

(See Chap. VII. p. 133.)

TABLE XLI.—TRIAL OF 30 B.H.P. SUCTION PLANT WITH ANTHRACITE.

	FUEL.					GAS.				Heat efficiency.	
	Calorific value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.	Calorific value.	Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Lower value.	Higher value.
	B.Th.U. per lb.	Per cent.	Per cent.	Lbs.	B.Th.U.	Per cent. by volume.	By calculation.	By Jankens' rimeter.	B.Th.U.	Per cent.	Per cent.
Whole run—cold start.	14,819	3.37	3.975	241.37	3,456,000	H 15.2 CH ₄ 1.2 CO 21.0 CO ₂ 8.2 O 0.2 N 54.2	(Higher), 137.7 (Lower), 128.0	139.7	18,785	70	75
								—			
Last six hours—hot start.	14,919	3.37	3.975	158.60	2,271,000	H 15.60 CH ₄ 1.21 CO 21.05 CO ₂ 8.41 O 0.20 N 53.53	(Higher), 139.2 (Lower), 129.4	139.7	13,522	77	83
								—			

APPENDIX A

TABLE XLII.—TRIAL OF 40 B.H.P. SECTION PLANT WITH ANTHRACITE.

	FUEL.					GAS.					Heat efficiency.	
	Calorific value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.	Calorific value.		Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Lower value.	Higher value.
							By calculation.	By Junkers' calorimeter.				
Whole run—cold start.	B.Th.U. per lb.	Per cent.	Per cent.	Lbs.	B.Th.U.	Per cent. by volume.	B.Th.U. per cubic foot.	Cubic feet.	B.Th.U.	Per cent.	Per cent.	
	13,887	3.60	8.76	245.25	3,406,000	H 15.59 CH ₄ 1.31 CO 19.05 CO ₂ 5.98 O 0.79 N 57.33	(Higher). 132.6 (Lower). 122.6	21,890	2,903,000	79	85	
Last six hours—hot start.	13,887	3.60	8.76	180.00	2,500,000	H 15.64 CH ₄ 1.16 CO 20.13 CO ₂ 6.09 O 0.74 N 56.24	(Higher). 135.3 (Lower). 125.5	16,715	2,261,000	84	90	

APPENDIX A

TABLE XLIII.—TRIAL OF 40 B.H.P. SUCTION PLANT WORKING WITH COKE.

FUEL.					GAS.					Heat efficiency.			
	Caloric value by bomb calorimeter.	Moisture.	Ash and clinker.	Quantity of fuel burnt.	Total heat in fuel burnt.	Analysis—mean composition.		Caloric value.		Total gas generated, dry, at 0° C. and 760 mm.	Total heat in gas generated.	Lower value.	Higher value.
						Per cent.	Lbs.	By calculation.	By Junkers' calorimeter.				
Whole run—cold start.	12,477	—	11.37	276.2	3,446,000	H 12.0 CH ₄ 0.4 CO 25.5 CO ₂ 5.3 O 0.65 N 56.15		(Higher). 133.3 (Lower). 122.4		21,786	2,903,700	80	84
						Per cent. by volume.		B.Th.U. per cubic foot.					
Last six hours—hot start.	12,477	—	11.37	209.1	2,609,000	H 13.2 CH ₄ 0.85 CO 25.3 CO ₂ 5.4 O 0.6 N 55.15		(Higher). 136.2 (Lower). 128.6		17,053	2,322,500	84	89
						Per cent. by volume.		B.Th.U. per cubic foot.					

APPENDIX B

1. Temperature.

Temperature is measured either on the Centigrade or on the Fahrenheit scale.

On the Centigrade scale, ice melts at 0° and water boils (under a pressure of 760 mm. of mercury) at 100° .

On the Fahrenheit scale, ice melts at 32° and water boils (under a pressure of 760 mm. of mercury) at 212° .

To convert degrees Centigrade to Fahrenheit, multiply by 9, divide by 5, then add 32.

To convert degrees Fahrenheit to Centigrade, subtract 32, then multiply by 5 and divide by 9.

The absolute temperature of a body is its temperature measured from the absolute zero (-273° C. or -459.4° F.).

If the temperature of a body is t° C., its absolute temperature is $t + 273$ Centigrade degrees.

If the temperature of a body is t° F., its absolute temperature is $t + 459.4$ Fahrenheit degrees.

The absolute temperature of melting ice is 273 Centigrade degrees, or 491.4 Fahrenheit degrees.

2. Heat Units.

The "calorie" is the quantity of heat required to raise the temperature of 1 kilo of water through 1° C.

The "small calorie" is the quantity of heat required to raise the temperature of 1 gram of water through 1° C.

The "British thermal unit" (B.Th.U.) is the quantity of heat required to raise the temperature of 1 lb. of water through 1° F.

$$1 \text{ calorie} = 1000 \text{ small calories.}$$

$$= 3.968 \text{ B.Th.U.}$$

$$1 \text{ B.Th.U.} = 0.252 \text{ calorie.}$$

3. Latent Heat of Steam.

The latent heat of steam at any temperature is the quantity of heat required to convert unit mass of water at that temperature into steam.

The latent heat of 1 kilo of steam at t° C. is $(606.5 - 0.695 \times t)$ calories.

The latent heat of 1 lb. of steam at t° F. is $(1114 - 0.695 \times t)$ B.Th.U.

4. Specific Heat.

The specific heat of a substance is the quantity of heat required to raise the temperature of unit mass of it through 1 degree.

The specific heat of many substances is greater at high than at low temperatures.

The mean specific heat of a substance between any two temperatures t_1 and t_2 is the quantity of heat required to raise the temperature of unit mass of it from t_1 to t_2 , divided by the range of temperature $(t_2 - t_1)$.

5. Maximum Pressure of Aqueous Vapour.

At a given temperature, water will evaporate until the pressure of its vapour above the surface of the liquid increases to a definite limit. Evaporation then ceases, and the space above the liquid water is said to be saturated with aqueous vapour. The maximum pressure of aqueous vapour depends solely on the temperature, and is not affected by the presence of gases or of other vapours in the same space.

TABLE XLIV.—PRESSURE AND MASS OF SATURATED AQUEOUS VAPOUR.

Temperature $^{\circ}$ C.	Pressure.		Mass.		Temperature $^{\circ}$ C.	Pressure.		Mass.	
	Milli- meters of mercury.	Inches of mer- cury.	Grams per cubic meter.	Pounds per cubic foot.		Milli- meters of mercury.	Inches of mer- cury.	Grams per cubic meter.	Pounds per cubic foot.
0	4.57	0.18	4.75	0.000297	10	9.14	0.36	9.22	0.000576
1	4.91	0.19	5.09	0.000317	11	9.77	0.38	9.83	0.000613
2	5.27	0.21	5.44	0.000340	12	10.43	0.41	10.47	0.000653
3	5.66	0.22	5.82	0.000364	13	11.14	0.44	11.14	0.000695
4	6.07	0.24	6.23	0.000389	14	11.88	0.47	11.85	0.000740
5	6.51	0.26	6.66	0.000416	15	12.67	0.50	12.61	0.000787
6	6.97	0.27	7.11	0.000444	16	13.51	0.53	13.40	0.000837
7	7.47	0.29	7.60	0.000474	17	14.39	0.57	14.24	0.000889
8	7.99	0.31	8.11	0.000506	18	15.33	0.60	15.12	0.000944
9	8.55	0.34	8.65	0.000540	19	16.32	0.64	16.05	0.001002

TABLE XLIV.—*continued.*

Temperature °C.	Pressure.		Mass.		Temperature °C.	Pressure.		Mass.	
	Milli- meters of mercury.	Inches of mer- cury.	Grams per cubic meter.	Pounds per cubic foot.		Milli- meters of mercury.	Inches of mer- cury.	Grams per cubic meter.	Pounds per cubic foot.
20	17·36	0·68	17·03	0·001058	60	148·88	5·86	130·67	0·008139
21	18·47	0·73	18·06	0·001127	61	155·95	6·14	136·50	0·008521
22	19·63	0·77	19·14	0·001195	62	163·29	6·43	142·54	0·008896
23	20·86	0·82	20·29	0·001266	63	170·92	6·73	148·81	0·009313
24	22·15	0·87	21·49	0·001341	64	178·86	7·04	155·30	0·009695
25	23·52	0·93	22·75	0·001420	65	187·10	7·37	162·04	0·010115
26	24·96	0·98	24·07	0·001503	66	195·66	7·70	169·01	0·010550
27	26·47	1·04	25·46	0·001590	67	204·56	8·05	176·23	0·011001
28	28·06	1·10	26·92	0·001666	68	213·79	8·42	183·70	0·011467
29	29·74	1·17	28·45	0·001777	69	223·37	8·79	191·44	0·011951
30	31·51	1·24	30·06	0·001877	70	233·31	9·18	199·45	0·012737
31	33·37	1·31	31·74	0·001977	71	243·62	9·59	207·73	0·012967
32	35·32	1·39	33·51	0·002092	72	254·30	10·01	216·30	0·013503
33	37·37	1·47	35·36	0·002207	73	265·38	10·45	225·16	0·014056
34	39·52	1·56	37·29	0·002328	74	276·87	10·90	234·32	0·014627
35	41·78	1·65	39·32	0·002740	75	288·76	11·37	243·78	0·015218
36	44·16	1·74	41·44	0·002587	76	301·09	11·85	253·55	0·015828
37	46·65	1·84	43·65	0·002725	77	313·85	12·36	263·65	0·016459
38	49·26	1·94	45·97	0·002869	78	327·05	12·88	274·08	0·017110
39	52·00	2·05	48·38	0·003020	79	340·73	13·41	284·84	0·017782
40	54·86	2·16	50·91	0·003178	80	354·87	13·97	295·95	0·018475
41	57·87	2·28	53·55	0·003343	81	369·51	14·55	307·43	0·019192
42	61·02	2·40	56·30	0·003515	82	384·64	15·14	319·27	0·019930
43	64·31	2·53	59·18	0·003694	83	400·29	15·76	331·49	0·020694
44	67·76	2·66	62·18	0·003881	84	416·47	16·40	344·10	0·021481
45	71·36	2·81	65·30	0·004076	85	433·19	17·05	357·11	0·022293
46	75·13	2·96	68·56	0·004280	86	450·47	17·74	370·51	0·023130
47	79·07	3·11	71·95	0·004481	87	468·32	18·44	384·34	0·023993
48	83·19	3·28	75·48	0·004712	88	486·76	19·16	398·58	0·024882
49	87·49	3·44	79·16	0·004942	89	505·81	19·91	413·26	0·025799
50	91·98	3·62	82·99	0·005181	90	525·47	20·69	428·38	0·026742
51	96·66	3·81	86·97	0·005429	91	545·76	21·49	443·95	0·027714
52	101·55	4·00	91·12	0·005688	92	566·71	22·31	459·99	0·028715
53	106·65	4·19	95·43	0·005957	93	588·33	23·16	476·50	0·029746
54	111·97	4·40	99·91	0·006237	94	610·64	24·04	493·49	0·030807
55	117·52	4·63	104·56	0·006527	95	633·66	24·95	510·98	0·031899
56	123·29	4·85	109·40	0·006829	96	657·40	25·88	528·97	0·033045
57	129·31	5·09	114·42	0·007143	97	681·88	26·84	547·48	0·034177
58	135·57	5·34	119·64	0·007469	98	707·13	27·84	566·52	0·035365
59	142·10	5·59	125·05	0·007789	99	733·16	28·86	586·09	0·036587
					100	760·00	29·92	606·21	0·037843

6. The Laws of Gases.

(a) At a given temperature, the volume of a given mass of gas is inversely proportional to its pressure. (Boyle's Law.)

(b) At a given pressure, the volume of a given mass of gas is directly proportional to its absolute temperature. (Charles's Law.)

Hence if V_1 be the volume of a given mass of gas at pressure P_1 and absolute temperature T_1 , and if V_0 be the volume which the gas would occupy at some other pressure P_0 and absolute temperature T_0 , then—

$$\frac{P_1 V_1}{T_1} = \frac{P_0 V_0}{T_0}$$

and therefore—
$$V_0 = V_1 \times \frac{P_1}{P_0} \times \frac{T_0}{T_1}.$$

7. Reduction of the Volume of a Gas to the Standard Temperature and Pressure.

Unless otherwise stated, the volume of a gas means the volume it would occupy under the standard conditions of temperature and pressure, viz. 0°C . (32°F .) and 760 mm. (29.92 inches) of mercury.

If V_1 be the observed volume of the gas, measured at a temperature $t_1^\circ \text{C}$. and under a pressure P_1 mm. of mercury, the reduced volume (*i.e.* the volume which the gas would occupy at the standard temperature and pressure) is—

$$V_0 = V_1 \times \frac{P_1}{760} \times \frac{273}{t_1 + 273}.$$

If V_1 be the observed volume of the gas, measured at a temperature of $t_1^\circ \text{F}$. and under a pressure P_1 inches of mercury, the reduced volume is—

$$V_0 = V_1 \times \frac{P_1}{29.92} \times \frac{491.4}{t_1 + 459.4}.$$

When a gas is measured over water (*e.g.* in a gasholder or by a wet meter) it is saturated with aqueous vapour. The actual pressure P_1 of the gas is the observed pressure minus the maximum pressure of aqueous vapour at the temperature of the gas.

8. Chemical Equations. Molecular Weights and Densities of Gases.

In a chemical equation the formulæ representing the different substances always refer to a quantity of the substance equal to its molecular weight in grams, kilos, or pounds.

The molecular weight in grams of any gas occupies 22.32 liters, or the molecular weight in kilos occupies 22.32 cubic meters, or the molecular weight in pounds occupies 357.5 cubic feet, if measured at the standard temperature and pressure. This volume is called the "molecular volume" of a gas.

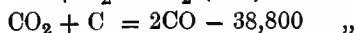
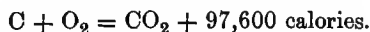
The chemical formula of a gas therefore always refers to the quantity of the gas which occupies 1 molecular volume at the standard temperature and pressure.

TABLE XLV.—MOLECULAR WEIGHTS AND DENSITIES OF GASES.

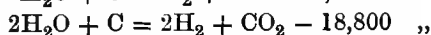
Gas.	Formula.	Molecular weight.	Density.	
			Air = 1.	Weight of 1 liter in grams, or of 1 cubic meter in kilos.
Air	—	—	1.0000	1.2930
Carbon dioxide . . .	CO ₂	48.90	1.5197	1.9650
Carbon monoxide . . .	CO	27.94	0.9671	1.2505
Ethylene	C ₂ H ₄	27.95	0.9674	1.2509
Hydrogen	H ₂	2.00	0.0692	0.0895
Methane	CH ₄	15.97	0.5530	0.7150
Nitrogen	N ₂	28.02	0.9701	1.2544
Oxygen	O ₂	31.93	1.1052	1.4291
Water vapour	H ₂ O	17.96	0.6218	0.8040

The following are the chemical equations representing the principal changes which occur in the formation and combustion of producer gas.

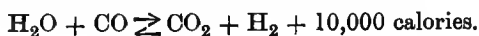
Formation of producer gas from air and carbon :—



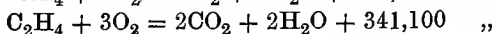
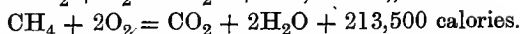
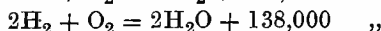
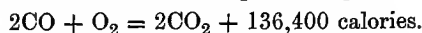
Reactions between steam and carbon :—



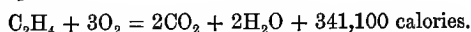
Reaction between steam and carbon monoxide :—



Combustion of the constituents of producer gas:—



Example—



This equation tells us that 27.95 kilos of ethylene (see Table of Molecular Weights) combine with 3×31.93 or 95.79 kilos of oxygen to form 2×43.90 or 87.80 kilos of carbon dioxide and 2×17.96 or 35.92 kilos of water, and that 341,100 calories are evolved. The equation also tells us that 1 volume of ethylene requires for its combustion 3 volumes of oxygen, and that the products consist of 2 volumes of carbon dioxide and 2 volumes of steam (if the latter is not condensed).

9. Specific Heats of Gases.

The specific heat of a gas is greater when the gas is heated under a constant pressure (and therefore allowed to expand) than when it is heated at constant volume.

The difference between the specific heats of a gas at constant pressure and at constant volume is—

$$\frac{1.98}{\text{molecular weight of the gas}} \quad \text{Centigrade units,}$$

or—
$$\frac{3.564}{\text{molecular weight of the gas}} \quad \text{Fahrenheit units.}$$

TABLE XLVI.—MEAN SPECIFIC HEATS OF GASES AT CONSTANT PRESSURE BETWEEN THE ABSOLUTE ZERO AND THE TEMPERATURE $t^\circ \text{C.}^1$

Gas.	Mean specific heat (Centigrade units).
Carbon monoxide	$0.2326 + 0.0000214 \times (t + 273)$
Hydrogen	$3.2500 + 0.0003000 \times (t + 273)$
Methane	$0.4070 + 0.0000376 \times (t + 273)$
Nitrogen	$0.2320 + 0.0000214 \times (t + 273)$
Oxygen	$0.2036 + 0.0000188 \times (t + 273)$
Carbon dioxide	$0.1481 + 0.0000843 \times (t + 273)$
Water vapour	$0.3619 + 0.0001615 \times (t + 273)$

The mean specific heat of a gas between any two temperatures t_1° and $t_2^\circ \text{C.}$ is found as follows:—

¹ Based on Chatelier's values, "Cours de Chimie Industrielle."

The mean specific heat between absolute zero and t° C. is—

$$a + b(t + 273)$$

where the values of a and b are taken from Table XLVI.

The heat required to raise the temperature of 1 kilo of the gas from the absolute zero to t_1° C. is—

$$a(t_1 + 273) + b(t_1 + 273)^2 \text{ calories.}$$

The heat required to raise the temperature of 1 kilo of the gas from the absolute zero to t_2° C. is—

$$a(t_2 + 273) + b(t_2 + 273)^2 \text{ calories.}$$

The heat required to raise the temperature of 1 kilo of the gas from t_1° to t_2° C. is the difference between these two quantities, or—

$$a(t_2 - t_1) + b(t_2 - t_1)(t_2 + t_1 + 546) \text{ calories.}$$

The mean specific heat between t_1 and t_2 is therefore—

$$a + b(t_2 + t_1 + 546).$$

Example.—The mean specific heat of carbon dioxide, at constant pressure, between 0° C. and 1000° C. is—

$$0.1481 + 0.0000843 \times 1546 = 0.2784.$$

10. Molecular Heat of Gases.

The molecular heat of a gas is the quantity of heat required to raise the temperature of 22.32 cubic meters of the gas (or of its molecular weight in kilos) through 1° C.

TABLE XLVII.—MEAN MOLECULAR HEATS OF GASES AT CONSTANT PRESSURE BETWEEN THE ABSOLUTE ZERO AND THE TEMPERATURE t° C.

Gas.	Mean molecular heat ¹ (Centigrade units).
Carbon monoxide	$6.5 + 0.0006 \times (t + 273)$
Hydrogen	
Methane	
Nitrogen	
Oxygen	
Carbon dioxide	$6.5 + 0.0037 \times (t + 273)$
Water vapour	$6.5 + 0.0029 \times (t + 273)$

The mean molecular heat of a gas between any two temperatures

¹ Le Chatelier, "Cours de Chimie Industrielle."

t_1 and t_2 can be found from this table in the same way that the mean specific heat is found from Table XLVI.

Example.—The mean molecular heat of carbon dioxide between 0°C . and 1000°C . is—

$$6.5 + 0.0037 \times 1546 = 12.22.$$

11. Calorific Power.

The calorific power of a substance is the quantity of heat given out by the combustion of unit mass (or of unit volume if the substance be a gas), the products of combustion being cooled to the temperature of the air.

1 calorie per kilo = 1.8 B.Th.U. per pound.

1 B.Th.U. per pound = 0.555 calorie per kilo.

1 calorie per cubic meter = 0.1124 B.Th.U. per cubic foot.

1 B.Th.U. per cubic foot = 8.900 calories per cubic meter.

TABLE XLVIII.—CALORIFIC POWER OF GASES (BURNT AT CONSTANT PRESSURE).

Gas.	Calorific power.							
	Calories per kilo.		B.Th.U. per pound.		Calories per cubic meter.		B.Th.U. per cubic foot.	
	Higher value.	Lower value. ¹	Higher value.	Lower value. ¹	Higher value.	Lower value. ¹	Higher value.	Lower value. ¹
Carbon monoxide	2,436 ²	—	4,385	—	3,046	—	342.4	—
Ethylene . . .	12,182 ²	11,404	21,928	20,527	15,239	14,266	1713.0	1603.0
Hydrogen . . .	34,500 ²	29,050	62,100	52,290	3,088	2,601	347.1	292.3
Methane . . .	13,344 ²	11,981	24,019	21,566	9,541	8,567	1072.0	963.0
Carbon . . .	8,137.5 ²	—	14,647.5	—	—	—	—	—

If the combustion is accompanied by a change in volume, the calorific powers, at constant pressure and at constant volume will be different.

Let n_1 be the number of molecular volumes (22.32 c.m.) of the gas together with the oxygen required for its combustion, and let n_2 be the number of molecular volumes of the products of combustion.

Then $n_1 - n_2$ is the change in volume, and the work done by or

¹ See p. 297.

² Berthelot, *Annales de Chimie et de Physique*, Series 5, Vol. XXIII., 1881; Series 6, Vol. XVIII., 1889; and Series 6, Vol. XXX., 1893.

against the pressure of the atmosphere is equivalent to $541 \times (n_1 - n_2)$ calories.

The nitrogen in the air used for combustion is also present in the products, and is therefore not taken into account.

If the volume of the products (at 0°C.) is less than the volume of the mixture of gas and oxygen, work is done by the pressure of the atmosphere when the gas is burnt at constant pressure, and the heat of combustion at constant pressure is greater than the heat of combustion at constant volume by $541 \times (n_1 - n_2)$ calories.

Example.—The combustion of 2 kilos (1 molecular volume) of hydrogen at constant pressure (760 mm. of mercury) gives 69,000 calories, the steam being condensed.

The oxygen required for the combustion is 0.5 molecular volume, and the volume of the products is zero. (The volume of the condensed water is negligible.)

Hence $n_1 = 1.5$, $n_2 = 0$, and $(n_1 - n_2) = 1.5$. The difference between the heats of combustion is therefore—

$$541 \times 1.5 = 811 \text{ calories,}$$

and the "heat of combustion at constant volume" (steam condensed) is $69,000 - 811 = 68,189$ calories, for 2 kilos of hydrogen.

The gross calorific power of hydrogen at constant volume is therefore—

$$34,095 \text{ calories per kilo.}$$

TABLE XLIX.—CALORIFIC POWER OF GASES (BURNT AT CONSTANT VOLUME).

Gas.	Calorific power.							
	Calories per kilo.		B.Th.U. per pound.		Calories per cubic meter.		B.Th.U. per cubic foot.	
	Higher value.	Lower value.	Higher value.	Lower value.	Higher value.	Lower value.	Higher value.	Lower value.
Carbon monoxide	2,426	—	4,867	—	3,033	—	340.9	—
Ethylene . . .	12,143	11,365	21,858	20,457	15,191	14,218	1707.0	1597.0
Hydrogen . . .	34,095	28,645	61,371	51,561	3,052	2,565	343.0	288.2
Methane . . .	13,276	11,913	23,897	21,444	9,492	8,518	1067.0	958.0
Carbon . . .	8,137.5	—	14,647.5	—	—	—	—	—

In calculating the lower value of the calorific power, the change of volume during combustion is the same as for the higher value; the products of combustion are cooled to 0°C. , so that the steam is actually condensed, but the

lower value of the calorific power is found by deducting the latent heat of the steam from the higher value, whether the gas is burnt at constant volume or at constant pressure.

The calorific power of a sample of producer gas may be readily found from its analysis by the aid of Table L.

TABLE L.—GROSS CALORIFIC POWER OF GAS AT CONSTANT PRESSURE, THE GAS BEING MEASURED DRY, AT 0° C. AND 760 MM. PRESSURE.

Calories per Cubic Meter.

		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Carbon monoxide (CO), per cent. by volume.	5	152	155	158	161	165	168	171	174	177	180
	6	183	186	189	192	195	198	201	204	207	210
	7	213	216	219	222	225	228	232	235	238	241
	8	244	247	250	253	256	259	262	265	268	271
	9	274	277	280	283	286	289	292	295	299	302
	10	305	308	311	314	317	320	323	326	329	332
	11	335	338	341	344	347	350	353	356	359	362
	12	366	369	372	375	378	381	384	387	390	393
	13	396	399	402	405	408	411	414	417	420	423
	14	426	430	433	436	439	442	445	448	451	454
	15	457	460	463	466	469	472	475	478	481	484
	16	487	490	493	497	500	503	506	509	512	515
	17	518	521	524	527	530	533	536	539	542	545
	18	548	551	554	557	560	564	567	570	573	576
	19	579	582	585	588	591	594	597	600	603	606
	20	609	612	615	618	621	624	628	631	634	637
	21	640	643	646	649	652	655	658	661	664	667
	22	670	673	676	679	682	685	688	691	695	698
	23	701	704	707	710	713	716	719	722	725	728
	24	731	734	737	740	743	746	749	752	755	758
	25	762	765	768	771	774	777	780	783	786	789
	26	792	795	798	801	804	807	810	813	816	819
	27	822	826	829	832	835	838	841	844	847	850
	28	853	856	859	862	865	868	871	874	877	880
	29	883	886	889	893	896	899	902	905	908	911

TABLE L.—(Calories per Cubic Meter)—continued.

		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Hydrogen (H ₂), per cent. by volume.	0	—	3	6	9	12	15	19	22	25	28
	1	31	34	37	40	43	46	49	53	56	59
	2	62	65	68	71	74	77	80	83	86	90
	3	93	96	99	102	105	108	111	114	117	120
	4	124	127	130	133	136	139	142	145	148	151
	5	154	158	161	164	167	170	173	176	179	182
	6	185	188	191	195	198	201	204	207	210	213
	7	216	219	222	225	229	232	235	238	241	244
	8	247	250	253	256	259	263	266	269	272	275
	9	278	281	284	287	290	293	296	300	303	306
	10	309	312	315	318	321	324	327	330	334	337
	11	340	343	346	349	352	355	358	361	364	368
	12	371	374	377	380	383	386	389	392	395	398
	13	402	405	408	411	414	417	420	423	426	429
	14	432	435	439	442	445	448	451	454	457	460
	15	463	466	469	473	476	479	482	485	488	491
	16	494	497	500	503	507	510	513	516	519	522
	17	525	528	531	534	537	540	544	547	550	553
	18	556	559	562	565	568	571	574	578	581	584
	19	587	590	593	596	599	602	605	608	612	615
	20	618	621	624	627	630	633	636	639	642	645
	21	649	652	655	658	661	664	667	670	673	676
	22	679	683	686	689	692	695	698	701	704	707
	23	710	713	717	720	723	726	729	732	735	738
	24	741	744	747	751	754	757	760	763	766	769
	25	772	775	778	781	784	788	791	794	797	800
	26	803	806	809	812	815	818	822	825	828	831
	27	834	837	840	843	846	849	852	856	859	862
	28	865	868	871	874	877	880	883	886	889	893
	29	896	899	902	905	908	911	914	917	920	923
Methane (CH ₄), per cent. by volume.		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	0	—	10	19	29	38	48	57	67	76	86
	1	95	105	114	124	133	143	152	162	172	181
	2	191	200	210	219	229	238	248	257	267	277
	3	286	296	305	315	325	334	344	353	363	372
	4	382	391	401	410	420	429	439	448	458	468
Ethylene (C ₂ H ₄), per cent. by volume.		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	0	—	15	30	46	61	76	92	107	122	137
	1	152	168	183	198	213	229	244	259	274	290
	2	305	320	335	351	366	381	396	412	427	442
	3	457	472	487	502	517	533	548	563	578	594
	4	609	624	639	655	670	685	700	716	732	747

Example—

	Composition of gas.	Calorific Power (from
	Per cent. by volume.	Table L.).
		Calories per c.m.
Hydrogen	16.2	500
Carbon monoxide	21.0	640
Methane	1.3	124
Carbon dioxide	8.5	—
Oxygen	0.2	—
Nitrogen	52.8	—
Total	100.0	1264

The gross calorific power of the gas burnt at constant pressure is 1264 calories per cubic meter, or 142.0 B.Th.U. per cubic foot.

The gross calorific power of the gas burnt at constant volume may be found from Table LXIX. :—

	Calorific Power.
Due to the hydrogen . . .	$0.162 \times 3052 = 494.4$ calories.
Due to the carbon monoxide	$0.210 \times 3033 = 636.9$ „
Due to the methane . . .	$0.013 \times 9492 = 123.4$ „
Total	1254.7 calories per cubic meter.

or 141.0 B.Th.U. per cubic foot.

Or it may be calculated from the gross calorific power at constant pressure, found as above, and the change in volume during combustion, as follows :—

Constituent.	Molecular volumes in 22.32 c.m. of the gas.	Molecular volumes of oxygen required for combustion.	Volume after com- bustion (molecular volumes).
Hydrogen	0.162	0.081	—
Carbon monoxide	0.210	0.105	0.210
Methane	0.013	0.026	0.013
Carbon dioxide	0.085	—	0.085
Oxygen	0.002	—	0.002
Nitrogen	0.528	—	0.528
Total	1.000	0.212	0.838

The contraction on combustion of 22.32 c.m. of the gas is therefore—

$$1.212 - 0.838 = 0.374 \text{ molecular volumes.}$$

The difference between the calorific powers at constant pressure and constant volume is therefore—

$$\frac{0.374}{22.32} \times 541 = 9 \text{ calories per cubic meter,}$$

and the gross calorific power at constant volume is—

$$1264 - 9 = 1255 \text{ calories per cubic meter.}$$

The nett calorific powers may be found from Tables XLVIII. and XLIX. :—

	Nett Calorific Power (constant pressure).
Due to the hydrogen . . .	$0.162 \times 2601 = 421.4$ calories.
Due to the carbon monoxide	$0.210 \times 3046 = 639.7$ „
Due to the methane . . .	$0.013 \times 8567 = 111.4$ „
Total . . .	<u>1172.5</u> calories per cubic meter.

or 131.7 B.Th.U. per cubic foot.

	Nett Calorific Power (constant volume).
Due to the hydrogen . . .	$0.162 \times 2565 = 415.5$ calories.
Due to the carbon monoxide	$0.210 \times 3033 = 636.9$ „
Due to the methane . . .	$0.013 \times 8518 = 110.8$ „
Total . . .	<u>1163.2</u> calories per cubic meter.

or 130.7 B.Th.U. per cubic foot.

The nett calorific powers may also be calculated by deducting the latent heat of the steam in the products from the corresponding gross calorific powers, as explained on p. 306.

12. Calorific Intensity.

The calorific intensity or theoretical flame temperature of a substance is the temperature to which the products of combustion would be raised if the initial temperature were 0°C . or 32°F ., assuming that the combustion is complete, that no excess of air or oxygen is used, and that all the heat evolved during the combustion of the substance is taken up by the products.

The actual flame temperature is always lower than the calculated value because none of these conditions are realised in practice.

In calculating the calorific intensity it is usually assumed that the specific heat of the products of combustion is the same at high as at low temperatures. The calorific intensity is then equal to—

Calorific power

Specific heat of products \times Mass of products from the combustion of unit mass

The values obtained in this way are much higher than the observed flame temperatures, and it is better to take into account the increase of specific heat with temperature. This may be done with the help of Tables LI. and LII., which show the number of calories required to raise the temperature of 22.32 liters of various gases from 0°C . to

various temperatures, under constant pressure and under constant volume respectively.

TABLE LI.—CALORIES REQUIRED TO HEAT 22.32 LITERS OF VARIOUS GASES FROM 0° C. TO VARIOUS TEMPERATURES, UNDER CONSTANT PRESSURE.¹

Temperature.	Oxygen, nitrogen, carbon monoxide, or hydrogen.	Steam.	Carbon dioxide.
100° C.	0.68	0.83	0.87
200	1.39	1.73	1.85
300	2.10	2.67	2.87
400	2.82	3.69	3.99
500	3.56	4.76	5.17
600	4.31	5.89	6.44
700	5.07	7.07	7.77
800	5.85	8.30	9.16
900	6.63	9.62	10.66
1000	7.43	10.98	12.22
1100	8.24	12.40	13.85
1200	9.05	13.87	15.55
1300	9.89	15.41	17.33
1400	10.73	17.00	19.18
1500	11.59	18.65	21.11
1600	12.46	20.35	23.09
1700	13.34	22.13	25.18
1800	14.23	23.93	27.31
1900	15.14	25.83	29.55
2000	16.05	27.76	31.83
2100	16.98	29.74	34.18
2200	17.92	31.81	36.64
2300	18.87	33.91	39.14
2400	19.84	36.10	41.75
2500	20.81	38.32	44.40
2600	21.80	40.62	47.16
2700	22.80	42.95	49.96
2800	23.82	45.37	52.87
2900	24.84	47.82	55.81
3000	25.88	50.35	58.86

¹ Based on the values given in Table XLVII. Mahler, *Revue Universelle des Mines*, 1904, vol. v. p. 8.

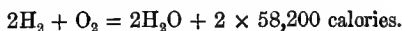
TABLE LII.—CALORIES REQUIRED TO HEAT 22·32 LITRES OF VARIOUS GASES FROM 0° C. TO VARIOUS TEMPERATURES, UNDER CONSTANT VOLUME.¹

Temperature.	Oxygen, nitrogen, carbon monoxide, or hydrogen. °	Water-vapour.	Carbon dioxide.
100° C.	0·48	0·63	0·67
200	0·99	1·33	1·45
300	1·51	2·08	2·28
400	2·03	2·90	3·20
500	2·57	3·77	4·18
600	3·12	4·70	5·25
700	3·68	5·68	6·38
800	4·27	6·72	7·58
900	4·85	7·84	8·88
1000	5·45	9·00	10·24
1100	6·06	10·22	11·67
1200	6·67	11·49	13·17
1300	7·32	12·84	14·76
1400	7·96	14·23	16·41
1500	8·62	15·68	18·14
1600	9·29	17·18	19·92
1700	9·97	18·76	21·81
1800	10·67	20·37	23·75
1900	11·38	22·07	25·79
2000	12·09	23·80	27·87
2100	12·82	25·58	30·02
2200	13·56	27·45	32·28
2300	14·32	29·36	34·59
2400	15·09	31·35	37·00
2500	15·86	33·37	39·45
2600	16·65	35·47	42·01
2700	17·45	37·60	44·61
2800	18·28	39·83	47·33
2900	19·10	42·08	50·07
3000	19·94	54·41	52·92

Examples—

(a) Calorific intensity of hydrogen, when burnt in air, at constant pressure.

The combustion takes place according to the equation—



The combustion of 2 grams of hydrogen therefore requires $\frac{1}{2} \times 22\cdot32$ liters of oxygen, and 58·2 calories are evolved.

The products of combustion consist of 22·32 liters of water-vapour, mixed with $\frac{1}{2} \times 3\cdot76 \times 22\cdot32$ or $1\cdot88 \times 22\cdot32$ liters of nitrogen (see p. 6).

To raise the temperature of the products from 0° C. to 2000° C. at constant pressure requires, according to Table LI. :—

¹ Based on the values given in Table LI.

For the water-vapour . . .	$1 \times 27.76 = 27.76$	calories.
For the nitrogen	$1.88 \times 16.05 = 30.17$	„
Total	<u>57.93</u>	„

To raise the temperature of the products from 0°C. to 2100°C. at constant pressure requires—

For the water-vapour . . .	$1 \times 29.74 = 29.74$	calories.
For the nitrogen	$1.88 \times 16.98 = 31.92$	„
Total	<u>61.66</u>	„

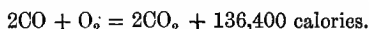
The quantity of heat available for heating the products is 58.2 calories, and the calorific intensity is therefore between 2000°C. and 2100°C. The excess above 2000°C. is approximately—

$$100 \times \frac{58.20 - 57.93}{61.66 - 57.93} = 7^\circ \text{C.}$$

The calorific intensity of hydrogen in air at constant pressure is therefore 2007°C. or 3645°F.

(b) Calorific intensity of carbon monoxide, when burnt in air, at constant pressure.

The combustion takes place according to the equation—



The combustion of 28 grams of carbon monoxide therefore requires $\frac{1}{2} \times 22.32$ liters of oxygen, and 68.2 calories are evolved.

The products of combustion consist of 22.32 liters of carbon dioxide and 1.88×22.32 liters of nitrogen.

To raise the temperature of the products from 0°C. to 2100°C. at constant pressure requires—

For the carbon dioxide . . .	$1 \times 34.18 = 34.18$	calories.
For the nitrogen	$1.88 \times 16.98 = 31.92$	„
Total	<u>66.10</u>	„

To raise the temperature of the products from 0°C. to 2200°C. at constant pressure requires—

For the carbon dioxide . . .	$1 \times 36.64 = 36.64$	calories.
For the nitrogen	$1.88 \times 17.92 = 33.69$	„
Total	<u>70.33</u>	„

The calorific intensity exceeds 2100°C. by—

$$100 \times \frac{68.20 - 66.10}{70.33 - 66.10} = 50^\circ \text{C.}$$

The calorific intensity of carbon monoxide in air at constant pressure is therefore 2150°C. or 3900°F.

(c) Calorific intensity of a sample of producer gas when burnt in air at constant pressure.

	Composition of gas. Per cent. by volume.
Hydrogen	16.2
Carbon monoxide	21.0
Methane	1.3
Carbon dioxide	8.5
Oxygen	0.2
Nitrogen	52.8
	<hr/>
	100.0
	<hr/>

The nett calorific power of the gas at constant pressure is 1172.5 calories per c.m. (see p. 333), and the heat of combustion of 22.32 liters is $1172.5 \times 0.02232 = 26.17$ calories.

(The nett calorific power is taken because the steam in the products of combustion is not condensed.)

The products of combustion of 22.32 liters of the gas consist of:—

Water vapour—

0.162×22.32 liters due to the hydrogen.

0.026×22.32 liters due to the methane.

Total . 0.188×22.32 liters.

Carbon Dioxide—

0.210×22.32 liters due to the carbon monoxide.

0.013×22.32 liters due to the methane.

0.085×22.32 liters present in the producer gas.

Total . 0.308×22.32 liters.

Nitrogen—

The oxygen required for combustion is:—

0.081×22.32 liters for the hydrogen.

0.105×22.32 liters for the carbon monoxide.

0.026×22.32 liters for the methane.

0.212×22.32 liters.

Less . 0.002×22.32 liters present in the producer gas.

Total . 0.210×22.32 liters.

The nitrogen in the air used for combustion is therefore—

$0.210 \times 22.32 \times 3.76 = 0.790 \times 22.32$ liters.

and the nitrogen present in the gas is 0.528×22.32 „

Total . . . 1.318×22.32 „

To raise the temperature of the products from 0° C. to 1500° C. at constant pressure requires—

For the water vapour	$0.188 \times 18.65 =$	3.51 calories.
For the carbon dioxide	$0.308 \times 21.11 =$	6.50 „
For the nitrogen	$1.318 \times 11.59 =$	15.28 „
Total	<u>25.29</u>	„

To raise the temperature of the products from 0° C. to 1600° C. at constant pressure requires—

For the water vapour	$0.188 \times 20.35 =$	3.83 calories.
For the carbon dioxide	$0.308 \times 23.09 =$	7.11 „
For the nitrogen	$1.318 \times 12.46 =$	16.42 „
Total	<u>27.36</u>	„

The calorific intensity exceeds 1500° C. by—

$$100 \times \frac{26.17 - 25.29}{27.36 - 25.29} = 42^\circ \text{C.}$$

and the calorific intensity of the gas when burnt in air at constant pressure is 1542° C. or 2808° F.

(d) Calorific intensity of a sample of producer gas when burnt in air at constant volume.

For the same sample of gas the nett calorific power at constant volume is 1163.2 calories per cubic meter (see p. 333), and the heat of combustion of 22.32 liters is $1163.2 \times 0.02232 = 25.96$ calories.

To raise the temperature of the products from 0° C. to 1800° C. at constant volume requires—

For the steam	$0.188 \times 20.37 =$	3.83 calories.
For the carbon dioxide	$0.308 \times 23.75 =$	7.32 „
For the nitrogen	$1.318 \times 10.67 =$	14.06 „
Total	<u>25.21</u>	„

To raise the temperature of the products from 0° C. to 1900° C. at constant volume requires—

For the steam	$0.188 \times 22.07 =$	4.15 calories.
For the carbon dioxide	$0.308 \times 25.79 =$	7.94 „
For the nitrogen	$1.318 \times 11.38 =$	15.00 „
Total	<u>27.09</u>	„

The calorific intensity exceeds 1800° C. by—

$$100 \times \frac{25.96 - 25.21}{27.09 - 25.21} = 40^\circ \text{C.}$$

and the calorific intensity of the gas when burnt in air at constant volume is 1840° C. or 3344° F.

It is interesting to note that the theoretical flame temperature is considerably higher (nearly 300° C. or 540° F.) when the combustion takes place at constant volume than when the gas is burnt at constant pressure.

13. Corrections for Altitude.

The data required for calculations in connection with producers operating above sea-level are given in the following table (see Chapter XVIII., p. 316).

TABLE LIII.—BAROMETRIC PRESSURE, VOLUME OF GAS AND CALORIFIC POWER AT DIFFERENT ALTITUDES.

Altitude above sea-level.		Height of barometer corresponding to 36 in. (76 cms.) at sea-level		1000 cub. ft. (or c.m.) of gas measured at sea-level become :—	Actual calorific power of gas per unit volume.
Feet.	Meters.	In.	Cms.	Cub. ft. (or c.m.).	
500	152	29·4	74·5	1020	0·98
1000	305	28·9	73·1	1040	0·962
1500	457	28·3	71·7	1060	0·944
2000	610	27·8	70·4	1080	0·926
2500	762	27·25	69·2	1100	0·909
3000	915	26·75	67·9	1122	0·892
3500	1067	26·25	66·7	1143	0·875
4000	1219	25·75	65·4	1165	0·859
4500	1371	25·25	64·2	1188	0·842
5000	1524	24·8	63·0	1210	0·827
5500	1676	24·3	61·8	1234	0·811
6000	1829	23·85	60·6	1257	0·796
6500	1981	23·4	59·4	1282	0·780
7000	2134	22·95	58·3	1307	0·765
7500	2286	22·5	57·2	1333	0·750
8000	2438	22·1	56·1	1358	0·736
8500	2590	21·65	55·0	1384	0·722
9000	2743	21·25	54·0	1411	0·709
9500	2895	20·85	53·0	1438	0·695
10,000	3048	20·45	51·9	1466	0·682

multiplied by calorific power per unit volume measured at sea-level.

14. Metric Equivalents.

Length.

1 meter = 39·37 inches.

1 inch = 25·4 millimeters.

1 meter = 3·281 feet.

1 foot = 304·8 „

Surface.

1 sq. meter = 1550·06 sq. ins.

1 square inch = 6·45 sq. cms.

1 sq. meter = 10·7643 sq. feet.

1 square foot = 929·0 „

Volume.

1 cub. cm.	= 0.061 cubic in.	1 cubic inch	= 16.4 cub. cms.
1 cub. meter	= 35.317 cubic ft.	1 cubic foot	= 0.028315 c. meter.
1 liter	= 0.2201 gallon.	1 gallon	= 4.543 liters.

Weight.

1 kilo	= 2.2046 lbs.	1 lb.	= 453.59 grams.
1000 kilos (1 } metric ton)	= 2204.6 lbs.	1 ton (British)	= 1016.05 kilos.

Pressure.

1 kilo per sq. cm.	= 14.22 lbs. per sq. in.	1 lb. per sq. in.	= 0.07032 kilo per sq. cm.
--------------------	--------------------------	-------------------	----------------------------

15. General Data.

One liter of water (at its greatest density) weighs 1 kilo.

One cubic meter or 1000 liters of water (at its greatest density) weighs 1000 kilos or 1 metric ton.

1 lb. per sq. in.	= 27.65 inches water column.
	= 2.035 inches mercury column.
1 in. water column	= 0.0736 inch mercury column.
1 B.Th.U.	= 778 foot pounds.
1 Calorie	= 42.7 kilogram-meters.
1 B.H.P.-hour	= 641.4 calories.
	= 2545 B.Th.U.
1 Electrical H.P.-hour (Board of Trade Unit—B.T.U.)	} = 1 kilowatt-hour.
	= 1.34 B.H.P.-hours.

INDEX

A.

Aarts. *See* Kramers.

Adam's tests of Dowson suction plant, 139-145, 151, (App. A) 318, 319.

Air—

Combustion of coal, air required, 65.

Combustion of gas, air required, 21, 66, 147, 152, 281.

Composition of, 6.

Density, (App. B) 325.

Production of gas, air used, 21.

Air, action on carbon—

Carbon dioxide, effect of shallow fire, 2, 39.

Carbon monoxide—

Direct combination of carbon with oxygen, 3.

Complete combustion of carbon the same in one stage or in successive stages, 5.

Heat liberated, 5.

Rhead and Wheeler on, 3.

Temperature—

Reaction between air and carbon at various temperatures and at atmospheric pressure, 3, 55.

Temperature attained in producer, 6, 7.

Velocity of reaction, effect on, 44.

Refer also to Air-gas.

Air-blast—

Injection by steam, 73.

Saturation temperature of, 38, 77, 99, 184-186.

Effect of varying, Bone and Wheeler's tests, 185, 186.

Velocity, effect of, 43

Boudouard's experiments, 40, 43.

Air and steam, action on carbon—Semi-water-gas—

Calorific power of gas—

Examples of ideal gases, 12, 14.

Greater than with air alone, 10, 14.

Composition of gas—

Standard of comparison for gas made at high temperature, 36.

Theoretical composition, assuming no heat losses—

Carbon dioxide alone formed by action of air on carbon, 32.

Carbon dioxide and carbon monoxide formed by action of air on carbon, 33-36.

Carbon monoxide alone formed by action of air on carbon, 12, 14.

Comparison with practical results, 21, 27, 28.

Richest gas theoretically obtainable, 11, 12, 15.

Decomposition of steam—

Maximum quantity, conditions regulating, 11.

Quantity decomposed in accordance with—

(a) Equation (4), 12.

(b) Equation (5), 13.

Definition of semi-water-gas, 19.

Depth of fire, effect on proportions of CO and CO₂, 39.

Temperature, effect of—

Advantages of low temperature in certain cases, 13.

Equilibrium between carbon dioxide, carbon monoxide, hydrogen, and steam, 59.

Reduction of working temperature by use of steam, 9.

Air and steam—*continued*.

Theoretical and practical results—

Differences, discussion of, 26-37.

Table summarising, 21.

Explanatory comments, 20-26.

Yield of gas, steam decomposed in accordance with—

(a) Equation (4), 12.

(b) Equation (5), 14.

Comparison with air-gas, 12, 14.

Air at pressure, use of, in burners, 102, 103.

Air-gas—

Burners, air-gas unsuitable for small burners, 104.

Composition of best gas theoretically obtainable, calorific power, etc., 6.

Definition, 19.

Table summarising theoretical and practical results, 21.

Explanatory comments, 20, 22, 23.

Yield per kilo of carbon, 6.

Altitude—

Effect on working of producer, 316.

Corrections for, 339.

Ammoniacal liquor obtained from brown coal, 255.

Ammonium sulphate—

Recovery of, from bituminous coal—

Description of Mond plant, 176.

Fuel used must contain high percentage of nitrogen, 247.

Recovery of, from peat, 200, 201, 207.

Analysis of fuels—

Preparation of sample for analysis, 267.

Proximate analysis, methods of—

Ash, determination of, 269.

Fixed carbon, calculation of, 269.

Moisture, determination of, 267.

Sulphur, determination of, by Eschka's method, 269.

Volatile matter, determination of, 268.

Sampling, method recommended, 266.

Analysis of producer gas, 270, etc.

Absorption of carbon dioxide, 276.

Absorption of carbon monoxide, 276.

Absorption of oxygen, 276.

Analysis of producer gas—*continued*.

Apparatus used, 273.

Determination of hydrogen and methane, 277.

Example illustrating method of calculation, 278.

Operations of which analysis consists, 273.

Sample, collection of, 270-273.

Annealing in gas-fired furnace, 96.

Anthracite—

Action of heat on. *See* Volatile constituents.

Advantages compared with—

Bituminous coal, 175, 196, 247.

Coke, 24, 25, 127.

Ash—

Formation of clinker, 261-263.

Fusibility of, 261.

Increased proportion in small sizes, table of composition of large anthracite and peas, 262.

Percentage and nature of ash in, 248, 261, 263.

Belgian anthracite, 264.

Calorific power, 265.

Clinker. *See* that title.

Composition—

Approximating to pure carbon, 249.

Average composition, table, 248.

Comparison of "large" and "peas," 263.

Hydrogen in, 25, 248.

Definition, 255, 259.

Distribution of, 258, 259, 264.

Dust—

Loss from dust on "peas" when shipped, 263

Removal by washing, 262.

French anthracite, 264, 265.

Lower grades, 263.

Moisture, loss of heat due to, 29.

Output, 259.

Scotch anthracite, 264.

Sizing, 259.

Composition of anthracite, "large" and "peas," 262.

List of sizes produced, 260, 265.

Percentage of waste, 261.

Uses of, 259.

Anthracite—continued.**Volatile constituents—**

Gas evolved on heating anthracite without air, 24.

Percentage of, 256.

Tarry matter, yield of 263, 264.

Washing of, 262.

Aqueous vapour. *See* Water vapour.

Arbos gas plant and engine, 133.

Area (sectional) of producer fire. *See*

Air-blast, velocity of.

Ash, 248.

See also names of fuels.

Atkinson's scavenging engines, 120.

Ayrton and Perry on scavenging, 120.

B

Bamber on gas traction, 212.

Beardmore on gas propulsion of vessels, 219.

Bénier suction plant and engine, 134, 135.

Birmingham Small Arms Factory, gas plant at—

Stand-by losses, 231.

Bischof gas-producer, first internally fired gas-producer, 68, 69.

Bishop on stand-by losses of steam boilers, 230, 232.

Bituminous coal—

Action of heat on. *See* Volatile constituents.

Ash, proportion of, 257.

Caking and non-caking varieties, 256.

Caking coals not suitable for gas-producers, 196, 257.

Composition and specific gravity—
Table, 256.

Non-caking coals suitable for gas-producers, 256.

Calorific power, 257.

Engine-work, production of gas from bituminous coal—

Bone and Wheeler's tests with Mond producers, 183-186.

Competition of gas power with steam power, bearing on, 175.

Bituminous coal—continued.**Engine-work—continued.**

Producers for. *See* Boutillier, Crossley, Deschamps, Dowson, Farnham, Fichet and Heurtey, Loomis-Pettibone, Mond, Whitfield, Wilson.

Tar in producer gas—

Conversion of tarry vapours into fixed gases, 23, 187-189.

Down-draught producers, 187.

Plant with two producers, 195.

Producers with fuel-feed at bottom, 191-195.

Producers with up- and down-draughts, 188-191.

Removal of—

Centrifugal tar extractor, 191.

Cooling gas, 186.

U. S. Geological Survey tests on, 241-244.

Furnaces work, suitability of gas for, 176.

Volatile constituents—

Effect of, on composition of semi-water-gas, 25.

Gas evolved on heating bituminous coal without air, 24.

Percentage of, 256.

Tar, destruction of. *Refer to sub-heading* Engine-work.

Tarry matter given off on distillation, 23.

Blowpipes, best air-pressure for producer gas, 102.

Boilers. *See* Steam-boilers.

Bollinckx suction plant, 156-158.

Bone and Jerdan on direct union of carbon and hydrogen, 26, 27.

Bone and Wheeler's tests with Mond producers at Warrington, 183-186.

Bonecourt gas-fired boiler, 100, 101.

Bone on—

Dellwik-Fleischer water-gas plant, 21, 22.

Gas-fired boiler, 100.

Kramers and Aarts' water-gas plant, 88.

Boudouard's experiments, etc., 40-42, 45-49, 52, 55, 56.

Boutillier et Cie.'s gas-producer, 191.

- Boyle's law, (App. B) 323.
 Boys' gas calorimeter, 299-301.
 Brame and Cowan on fuel calorimeters, 288.
 "British Thermal Unit," definition, (App. B) 321.
 Brook and Wilson gas-producer, 73, 74.
 Brown coals—
 Ash, amount of, 248, 255.
 Average composition—Tables, 248, 254.
 Calorific power, 255.
 Distribution of, 254.
 Lignite, use of, for producer gas, 247, 255.
 Moisture, percentage of, 248, 255.
 Process of formation, 248.
 Uses of, by-products, etc., 255.
 Bunte and Harris on decomposition of steam by carbon, 59.
 Burham, Dowson suction plant at, 190.
 Burners and small gas-jets—
 Air supply, important not to use excess, 102.
 Use of "atmospheric" burners or air at pressure, 102, 103.
 Cleaning of gas essential, 63, 102.
 Chemical purification sometimes necessary, 112.
 Pressure at burners should be constant, 64, 102.
 Suitable and unsuitable kinds of producer gas, 104.
 Burstall on fuel consumption, 121.
 Butterfield on—
 Calorific power of coke, 291.
 Composition of coal, 256.

C

- Caking and non-caking coals. *See* Bituminous coal.
 Calorie, definition, 2 *note*, (App. B) 279.
 Calorific intensity—
 Carbon monoxide, (App. B) 336.
 Constant volume and constant pressure, (App. B) 339.
 Definition, (App. B) 333.
 Hydrogen, (App. B) 335.
 Methods of calculating, (App. B) 333-339.

Calorific intensity—*continued*.

 Producer gas, 21, (App. B) 337, 338.

Calorific power, definition, (App. B) 328.

Calorific power of gas—

Calculation from analysis—

 Advantages of method, 305.

 Example, 305-306, (App. B) 332.

 Nett calorific power, 306, (App. B) 333.

 Suction plants, gas made in, convenience of method for, 305.

 Tables, (App. B) 330, 331.

 Constant pressure, gases burnt at,

 Table XLVIII., (App. B) 328;

 Table L., (App. B.) 330, 331.

 Constant volume, gases burnt at—

 Table XLIX., (App. B) 329.

 Example, (App. B.) 332.

 Conversion values, (App. B) 328.

 Determination, method of, 291, etc., 299, 301. *See also* Calorimeters.

 Difference between calorific powers at constant pressure and constant volume, 304, (App. B) 328, 329.

 Examples, (App. B) 329, 332.

 Dowson's early gas plant, 105.

 Engine work, 281.

 Fuel consumption, bearing on, 280, 281.

Gross and nett (higher and lower)—

 Calculation of nett calorific power, 306, (App. B) 333.

 Distinction between gross and nett values, 297.

 Higher and lower. *See* Gross and nett.

 Importance of knowing, 280, 281.

 Increased by use of steam, 10, 62, 107, 105.

Producer gas—

 Practical results, 21, 24, 115, 131, 144, 146, 147, 152, 167, 172, 173, 178, 186, 189, 190, 194.

See also under Peat.

 Theoretical results, 6, 12, 14, 17, 19, 21.

Suction plants—

 Diagrams showing variations in calorific power, 148-150.

 Effect of rate of production, 167, 173.

Calorific power of gas—*continued.*

Water-gas—

Practical results, 21, 88, 90.

Theoretical results, 17, 21.

See also under Peat.

Calorific power of solid fuel—

Calculation from analysis—

Coke, Butterfield's formula, 291.

Proximate analysis, Goutal's formula, 289.

Accuracy of results, 291.

Example, 290.

Table, 290.

Volatile matter, determination of, 291.

Ultimate analysis, Mahler's formula, 289.

Determination by calorimeters, 282, etc. *See* Calorimeters.

Importance of knowing, 280.

Moisture, effect of, 289.

See also names of fuels.

Calorimeters—

Bomb calorimeters—

Calorific power at constant pressure, 304.

Description, 282, 283.

Gases, determination of calorific power of, 301.

Disadvantages of bomb calorimeters, 304.

Nett calorific power, method of ascertaining, 304.

Witz bomb calorimeter, 302, 303.

Mahler-Donkin calorimeter, construction and use of, 282-286, 301.

Accuracy of results, 285, 286.

Calorimeters for solid fuel, comparison of different types—Table, 288.

Calorimeters using oxygen at atmospheric pressure, 286.

Disadvantages, 286.

Fischer's calorimeter, 287.

Rosenhain's calorimeter, 287.

W. Thomson's calorimeter, 287.

Gas calorimeters with continuous combustion and continuous flow, 291.

Calorimeters—*continued.*Gas calorimeters with continuous combustion and continuous flow—*continued.*

Boys' calorimeter, 299-301.

Correction of results for temperature and pressure, 295, 296.

Dowson's calorimeter, 299.

Hartley's calorimeter, 299.

Junkers' calorimeter, 291-299.

Accuracy of results, 298.

Advantage as compared with bomb calorimeters, 304.

Nett calorific power. method of determining, 298.

Lewis Thompson's calorimeter, 287, 288.

Moisture in solid fuel, sample should be dried or moisture determined, 288.

"Saroo" recording gas calorimeter, 301.

Water equivalent, 285.

Cannel coal, 256.

Capitaine on gas propulsion of vessels, 219.

Carbon—

Air and steam, action upon carbon.

See that title.

Calorific power, (App. B) 328, 329.

Fixed carbon, determination of, 269.

Chief constituent of fuels used for producer gas, 2.

Carbon and carbon dioxide, reaction between—

Depth of fuel, effect of, 2, 3, 38.

Wendt's experiments, 38, 39.

Equilibrium between carbon, carbon dioxide, and carbon monoxide, 49-56.

Physical condition of fuel, Boudouard's experiments, etc., 40.

Pressure, effect of increasing, 51.

Size of fuel, Boudouard's experiments, etc., 41, 42.

Temperature, effect of, 44-48, 51-57.

Boudouard's experiments, 45, 46.

Point beyond which no further gain from increased temperature, 54, 56.

- Carbon and carbon dioxide, reaction between—*continued*.
 Temperature—*continued*.
 Proportions of carbon dioxide and carbon monoxide at different temperatures, 45–49, 52–54.
 Reversible reaction, 49–51.
 Conversion of carbon monoxide to carbon dioxide and carbon after gases leave producer, 56, 57.
 Rhead and Wheeler's experiments, 45–47.
 Velocity with which change occurs, effect of temperature, 44–47.
Refer also to Carbon monoxide.
 Carbon and air, reaction between. *See* Air, action on carbon.
 Carbon and hydrogen, direct combination of, 26, 27.
 Carbon and steam, reaction between. *See* Steam, action on carbon.
 Carbon dioxide—
 Air-gas, carbon dioxide in, 57.
 Calories required to heat, to various temperatures—
 (a) Constant pressure, (App. B) 334.
 (b) Constant volume, (App. B) 335.
 Carbon and carbon dioxide, reaction between. *See* that title.
 Density, 325.
 Determination of, 276.
 Dissociation of, 60.
 Formation of, 2, 3.
 Hydrogen and carbon dioxide, reaction between, 14, 15, 58.
 Reduction to methane, 26.
 Reversible reaction, 57–58.
 Molecular heat, (App. B) 327.
 Molecular weight, (App. B) 325.
 Specific heat, (App. B) 326.
 Water-gas, carbon dioxide in, 59.
 Carbon monoxide—
 Calorific intensity, (App. B) 336.
 Calorific power, (App. B) 328, 329, 330.
 Density, 325.
 Determination of, 276.
 Hydrogen and carbon monoxide, reaction between, 26.
 Molecular heat, (App. B) 327.
 Carbon monoxide—*continued*.
 Molecular weight, (App. B) 325.
 Poisoning by, precautions against, etc., 307.
 Producer gas, carbon monoxide in—
 Depth of fuel, effect of, 38, 39.
 Direct combination of carbon with oxygen, 3.
 Same result by two methods of production, 4.
 Refer also to title Carbon and carbon dioxide, reaction between.
 Specific heat, 7, (App. B) 326.
 Steam and carbon monoxide, reaction between, 14.
 Reversible reaction, 57, 58.
 Carbonic acid. *See* Carbon dioxide.
 Carbonic oxide. *See* Carbon monoxide.
 Carburetted hydrogen. *See* Methane.
 Case on composition of Mond gas, 178.
 Cellulose, 248.
 Change of volume during combustion, (App. B) 328, 332.
 Charcoal—
 Peat charcoal, formation of, 249.
 Wood charcoal—
 Calorific power, 251.
 Composition, 251.
 Formation of, 249, 250.
 Volatile matter expelled, 251.
 Specific gravity, 251.
 Suitability for use in gas-producers—cost, etc., 41, 251, 252.
 Charles' law, (App. B) 324.
 Chemical equations, (App. B) 324.
 Chingford, Humphrey pump at, 128–132.
 Clark's tests of Dowson gas plant, 105, 114.
 Cleaning and cooling of gas—
 Chemical purification, 112.
 For burners or small jets, 63, 102.
 For furnace work, 63.
 Hydraulic seal and coke scrubber, 124.
 Loss of sensible heat, etc., 102.
 Siemen's regenerative furnace, 91.
 Method of cleaning, 102.
 Method of cooling, 29, 124.
 Water, quantity required, 124.
 Clerk gas-engine, 119.

Clerk, Sir D., on—

Farnham gas-producer, 194.

Fuel consumption, 121.

Gas-engines, 116, 161, 164.

Heat efficiency, 121, 139.

Pre-ignition, 126.

Scavenging, 119.

Suction plants, heat efficiency, 139.

Olinker—

Formation of, 44, 73.

Composition of ash, influence of, 261, 263.

Down-draught producer, 187.

Suction plant, 261.

Preventing adherence to lining of producer, 75.

Prevention of, 138, 261.

Removal of, 75, 82, 176, 310.

Coal—

Air required for combustion, 65.

Caking and non-caking, 256.

Cannel coal, 256.

Common coal—

Calorific power, 257.

Classification according to behaviour on heating, 256.

Composition, 248.

Formation, 248.

Volatile matter, 255.

Moisture in coal, 248, 289.

Volatile matter, determination of, 248.

See also Anthracite; Bituminous coal; Brown coal, etc.

Cocoa beans, roasting by gas, 108-110.

Codigoro, plant using peat at, 203.

Coffee, roasting by gas, 110.

Coke—

Anthracite, comparison with, 24, 25, 127, 147, 153.

Bituminous coal, comparison with, 175, 247.

Brown coal, coke from, 255.

Caking coals, nature of coke from, 256.

Calorific power, calculation from analysis, 291.

Definition, 257.

Formation of, 249.

Fuel for gas-producers, 247, 249, 257, 258.

Coke—*continued.*

Gas coke, 257, 258.

Oven coke, 258.

Coke-scrubber, 124.

Combustion of producer gas—

Air required, 21, 66, 147, 152.

Common coal. *See* Coal.

Composition of producer gas, 1.

Average composition about the same as in 1882.. 114.

Brook and Wilson producer, composition of gas, 74.

Dowson's early plant—composition of gas, 105.

Dowson pressure plant at Chingford, 131.

Dowson suction plant for bituminous coal, 189, 190.

Farnham gas-producer, 194.

Fuel, nature and depth of fuel, effect on composition of gas. *Refer to* Fuel.

Hydrogen in producer gas, 24, 25, 26, 115, 125.

Mond producer, composition of gas, 178, 186.

Nitrogen in producer gas, 16, 27, 82.

Oxygen in producer gas, 312.

Siemens' producer, composition of gas, 71.

Size of producer, effect of, 115.

Suction and pressure plants, comparison, 151, 152.

Suction plants—

Comparison of gas made from anthracite and from coke, 147-150.

Composition of gas, 144, 146.

Full load and half load, 173.

Full load, no load, and varying load, 166-174.

Theoretical and practical results—

Table summarising, 21.

Explanatory comments, 20-26.

Theoretical composition of gas, 6, 12, 14, 21, 32, 33.

Volatile matter in fuel, effect of, 22, 23, 24.

Water-gas, 21, 84, 86, 88, 90. .

See also under Peat.

Compression. *See* Engine work.

Consumption of fuel. *See* Fuel.

- Continuous furnace, 96, 97.
 Convection currents, loss of heat due to, 65.
 Conversion values—
 British and metric weights and measures, (App. B) 339, 340.
 Calorific power, (App. B) 328.
 Heat units, (App. B) 321.
 Miscellaneous, (App. B) 340.
 Temperature, (App. B) 321.
 Conveyance of producer gas. *See* Distribution.
 Cooking by producer gas, 106–108, 111.
 Cooling of gas. *See* Cleaning and cooling.
 Cost of producer gas, 110.
 Cost of repairs of gas-producers, 246.
 Crompton on stand-by losses in steam boilers, 229, 232.
 Crossley Bros., Ltd.—
 Bituminous plant, 191.
 Centrifugal tar extractor, 191, 205.
 Stand-by losses in gas-producers, 227.
 Suction plant, 157, 158.
 Results of tests, 199, 200.
 Using peat, 199, 200, 203, 205.
 Use of waste fuels, 196.

D

- Deeley on stand-by losses in steam-boilers, 229, 232.
 Definition of "producer gas," and of "gas-producer," 1.
 Delassue suction plant, 153, 154.
 Dellwik and Fleischer water-gas apparatus, 85.
 Water-gas made in, 21, 22.
 Densities of gases, (App. B) 324, 325.
 Depth of fuel. *See* Fuel.
 Derby, Royal Agricultural Society's trials of suction plants at, 153, 167, 173, 174.
 Deschamps on gas-producers, 69, 187.
 Deville on dissociation, 60.
 Dissociation—
 Carbon dioxide, 60.
 Steam, 60.

- Distribution of producer gas, 244.
 Comparison with steam power, 245.
 Distribution over large areas—South Staffordshire Mond Gas Co.'s undertaking, 179–183.
 Donkin, Mr. Bryan, on—
 Heat efficiency of steam-boilers, 235.
 Stand-by losses of steam-boilers, 228.
 Down-draught gas-producer, 187.
 Dowson's gas calorimeter, 299.
 Dowson gas-producer—
 Air-gas made in, 21.
 Bituminous coal, producer for, 188–190.
 Early gas plant, 103–106.
 Engine-work, first trial with producer gas, 114.
 Installations—
 Chingford pumping station, 130.
 Gloucester County Asylum, 106–108.
 Van Houten's Cocoa Factory at Weesp, Holland, 108–110.
 Walthamstow Isolation Hospital, 108.
 West Bromwich, Kenrick and Sons, 189.
 Semi-water-gas made in, 21.
 Size of fuel used, 259, 260.
 Stand-by losses, 227, 228.
 Suction plant for 100 B.H.P., 158, 159.
 Suction plant for bituminous coal, 188–190.
 Suction plants—Trials—
 Anthracite, 140–145, 148, 149, (App. A) 318, 319.
 Coke, 146, 150, (App. A) 320.
 Comparison of full load and half load, 173.
 Comparison of gas from anthracite and from coke, 147.
 Heat efficiency—
 Comparison of tests with anthracite and coke, 147.
 Lower efficiency of smaller apparatus, 145.
 With cold start and hot start, 143, 144, 146, 147.
 Varying loads, 167.

Dowson, Mr. J. E., on—

Furnace designs—

Continuous furnace for carbonising, 96, 97.

Furnace for heating armour plates, 94-96.

Rate of producing gas, method of regulation, 314.

Suction plant, methods of regulating quantity of steam, 139.

Drehschmidt's method for determination of sulphur in gas, 279.

Drying producer gas, 123.

Dust in fuel, 42, 262.

Duisberg on plant using peat in Hanover, 203.

E

Economic advantages of producer gas—
Heat losses—saving effected in furnace work, 65-68.

Repairs and maintenance, cost of, 246.

Refer also to titles Heat efficiency, and Stand-by losses.

Efficiency. *See* Heat efficiency.

Ehrhardt and Sehmer's gas-producer, 75, 76.

Ekenberg's process of treating peat, 199.
Engine work—

Bituminous coal, production of gas for engine work. *See* Bituminous coal.

Bituminous fuel, producers using, 176, 177, 187-195.

Cleaning and cooling gas, 177, 178, 189, 191.

Composition of gas—

Comparison of hydrogen and carbon monoxide, 126.

Percentage of hydrogen desirable, 125.

Pre-ignition, effect of hydrogen on, 125, 126.

Table of analyses, 115.

Compression in cylinder—

Higher pressure, effect of, 120.

Otto engine of 1881, compression in, 116.

Typical indicator diagram with producer gas (1881), 117.

Engine work—*continued.*

Compression in cylinder—*continued.*

Pre-ignition, effect of high compression, 126.

Consumption of gas, 115, 116, 120.

First trial of a gas-engine with producer gas, 114.

Fuel—

Bituminous coal. *See* that title—*sub-heading* Engine-work.

Coke and anthracite, comparison of, 127.

Consumption of fuel per H.P., 121, 135, 153, 175, 190, 240, 264.

Heat losses—

Conduction through walls of cylinder, 121, 238.

Exhaust, 121, 238.

Ignition, means of, 126, 127.

Improvements in gas-engines, 116-121.

Marine work. *See* Gas propulsion of vessels.

Moisture in pipes, cause, prevention, and removal of, 122, 123.

Motor vehicles. *See* Gas traction on roads.

Otto engine working with Dowson gas plant, 1881, results of trials, 114.

Peat, use of. *See* heading Peat.

Present position of gas-engines, 121.

Scavenging, advantages and disadvantages, 118-120.

Size of engines, effect on fuel question, 175.

Speed of engines, 121.

Temperature of gas supplied to engine, 122.

Enright, Mr. J., on—

Stand-by losses in gas-producers, 231, 232.

Equilibrium in reversible reactions, 50.
See also particular reactions.

Eschka's method for determination of sulphur in fuel, 269.

Ethylene—

Calorific power, (App. B) 328, 329.

Density, (App. B) 325.

Determination of, 279.

Molecular weight, (App. B) 325.

F

- Farnham's gas-producer, 192.
 Feeding producer automatically, 75, 80.
 Fétu-Defize suction plant, 155.
 Fichet and Heurtey's gas-producer, 191.
 Fischer's calorimeter, 287, 288.
 Flame temperature. *See* Calorific intensity.
 Fluid friction in gas-engines, 161, 164, 165.
 Food products, cooking or roasting with producer gas, 106-111.
 Foster on composition of producer gas, 105, 115.
 Föttinger, hydraulic transformer, 220.
 Fuel, 202, etc.
 Action of heat on, 22, 249.
 Analysis. *See title* Analysis of fuel.
 Calorific power. *See title* Calorific power of solid fuels.
 Composition, 248.
 Consumption of—
 Humphrey pump, 131, 132.
 Pressure plants—
 Comparison of gas and steam power, 239.
 Dowson plant in 1879. . 175.
 Farnham's gas-producer, 194.
 General result of tests, 121.
 Stand-by losses, 227, 229, 231.
 Table, 232.
 U.S. Geological Survey tests of, 241-244.
 Usual guarantee, 136.
 Steam power, 239, 243.
 Stand-by losses, 227, 230, 231.
 Table, 232.
 Suction plant—
 Bénier's suction plant, 1895. . 133-136.
 Charcoal, consumption of, 252.
 Comparison at half and full load, 153.
 Royal Agricultural Society's trials, 153.
 Scotch anthracite, Highland Society's trials, 264.
See also Peat; Gas propulsion of vessels; Gas traction on roads.

Fuel—*continued.*

- Depth of fuel—
 Composition of gas, effect of depth of fuel, 2, 3, 38, 39, 43, 44, 186.
 Gas-producer for road vehicles, 211, 216.
 General considerations, 43, 44.
 Level of fire in suction and pressure plants, 309, 310.
 Reduction of, at end of day's run to facilitate clinkering, 310.
 Dust in, 42, 262.
 Feeding device, 75, 80, 212, 216.
 Formation of, 248, 249.
 Kinds suitable for making producer gas, 1, 23, 127, 175, 196, 247.
 Comparison of anthracite and coke, 24, 25, 127.
 Engine-work, 127, 175, 196, 247.
 Furnace-work, 247.
 Moisture—
 Heat loss due to, 29, 30.
 Percentage of, 248.
 Nature of fuel, 1, 23, 247.
 Composition of gas, largely influenced by, 1, 22, 36.
 See also sub-heading Volatile constituents.
 Physical condition, effect of, 40.
 Sampling of. *See* Analysis of fuel.
 Size, effect of, 41, 43.
 Limit of size in practice, 42.
 Stirring, 81, 82, 310, 311.
 Volatile constituents, 22, 23, 24.
See also names of fuels.
 Function of gas-producer, 64.
 Furnaces and furnace-work—
 Air supply for producer—
 Blast of air, 73.
 Chimney draught method, 68, 71.
 Injection by steam jet, 73, 77.
 Saturation temperature of, 77, 99.
 Two independent supplies, 77.
 Cleaning and cooling of gas a disadvantage, 63.
 Comparison of direct-fired and gas-fired furnace, 64-68, 93.
 Fuel used for production of gas, 247, 254.

Furnaces and furnace-work—continued.**Gas-fired furnaces—**

Advantages of, 66, 67.

Air required in, 65.

Annealing in, 93, 96.

Continuous furnace, 96–98.

Control of temperature in, 68, 92, 96.

Developments in, 91.

Enamelling in, 96.

Heating armour plates in, 94–96.

Heating billets of steel in, 93.

Heat losses in, 66.

Moisture in gas, 98.

Oxidation and reduction in, 68, 93.

Regenerative furnaces—

Continuous current of flame in one direction, 91, 92.

Gaillard and Haillot system, 91, 92.

Heating air only, by products of combustion, 91, 92.

Siemens' system, 70, 72, 91.

Weardale furnace, 93–96.

Reverberatory furnace, 93, 94.

Starting, 313.

Water-gas, use of, 85, 86.

Heat losses, saving by use of gas, 65–67.

Latent heat of steam in products of combustion, 298.

Producers for. *See* Gas-producer (*various types*).

Steam supply for producer, 77, 99,

G

Gaillard and Haillot, system of heating air, 91, 92.

Galusha producer for marine work, 233, etc.

Gas-engines. *See* Engine-work, various sub-headings.**Gases—**

Calorific power of, (App. B) 328–330.

Densities of, (App. B) 325.

Laws of, (App. B) 323, 324.

Molecular heats of, (App. B) 327.

Molecular volume of, (App. B) 325.

Molecular weights of, (App. B) 325.

Gases—continued.

Specific heats of, (App. B) 326.

Volume of, correction for temperature and pressure, (App. B) 324.

Gasholders—

Entering, precautions to be observed, 314.

First time of using, precautions to be observed, 313.

Use of, for regulating pressure, 102.

Gas-producer—

Bamber and Parker's, for road vehicles, 212.

Bischof's, 68, 69.

Boutillier et Cie.'s, 191.

Brook and Wilson's, 73, 74.

Crossley's, 157, 158, 191.

Definition, 1.

Deschamps', 187.

Down-draught, 187, 188.

Downson's, 103, 104, 130, 140, 142, 159, 188.

Early history of, 69.

Ehrhardt and Sehmer, 75, 76.

Farnham's, 192.

Fichet and Heurtey's, 191.

Galusha, for marine work, 223, etc.

Howson's, 187.

Loomis-Pettibone, 195.

Mond's, 13, 25, 61, 176, 177, 183–186.

Morgan Construction Co.'s, 74.

Siemens', 70.

Smith, D. J., for road vehicles, 216.

Tessié du Motay's, 73.

using bituminous fuel for engine-work, 176–195.

using peat. *See* under Peat.

Whitfield's, 187.

Wilson's, 73, 186.

with automatic feeding device, 75, 80, 216.

with automatic removal of ash and clinker, 82, 216.

with automatic stirring device, 77–82.

with fuel feed at bottom, 191, 192.

with rotating body, 77–82.

with rotating grate, 75.

with steam-jet, 73, 77, 104.

with two independent supplies of steam and air, 77.

with up- and down-draught, 188–190.

Gas-producer—*continued*.
 with water bottom, 75, 77-82, 177.
 with water jacket, 75.
 Wood & Co.'s, 77-82.
 working two or more together, 309.
Refer also to Suction plant; Water gas.

Gas propulsion of vessels, 218, etc.
 Beardmore's experiments, 219.
 Capitaine's experiments, 219.
 Föttinger's hydraulic transformer, 220.
 Fuel consumption, 221, 222.
 Galusha producer, 223, etc.
 H.M.S. *Rattler*, 219.
 Holzapfel's trials, 220.
 Machinefabriek Drakenburgh's vessels, 221.
 Ocean-going schooner with gas-power as auxiliary, 225.

Gas traction on roads, 209, etc.
 Automatic fuel feed, 212, 216.
 Bamber's experiments, 212.
 Cost, fuel-consumption, etc., 212, 213, 214.
 Depth of fuel bed in producer, 211, 216.
 Inter-Departmental Committee's report, 214, 215.
 Parker's experiments, 212.
 Smith, D. J., producer for, 216.
 Working conditions, comparison with stationary plant, 210-212.

General data, (App. B) 340.

Giles and Gough on use of producer gas for cooking and heating, 107.

Glazing, advantages of producer gas, 96, 98.

Gloucester County Asylum, gas installation, 106-108.
 Comparison of gas-fired and coal-fired copper, 107.

Goutal's formula for calorific power of fuel, 289-291.

Graphite, 249.

Gray and Robertson on fuel calorimeters, 288.

Greenwood on effect of temperature on velocity of chemical change, 44.

H

Haldane on poisoning by carbon monoxide, 308.

Harris. *See* Bunte.

Hartley's calorimeter, 299.

Heat efficiency—
 Air-gas, production of, 5.
 Engine-work—
 Comparison of gas-engine and steam-engine, 240, 241.
 Comparison of gas-power and steam-power plants—
 Working at full-load, 235-240.
 Working at reduced loads, 241.

Furnace-work—
 Comparison between gas firing and direct firing, 65-67.
 Heat efficiency of furnaces, 66.

Gas-engines—
 Heat efficiency of, 237.
 Possibilities of improvement, 121, 240.
 Working at reduced loads, 241.

Gas-producers—
 Actual heat efficiency of—
 Working at full load, 21, 132, 237.
 Working at reduced loads, 241.
 Effect of temperature, 61, 62.
 Furnace-work, 65.
 Theoretical heat efficiency, 5.

Humphrey pump, heat efficiency of, 132.

Steam-boilers, heat efficiency of, 66, 236.
 Table, 235.
 Working at reduced output, 241.

Steam-engines, heat efficiency of, 237.
 Working at reduced output, 241.

Suction plants, heat efficiency of, 237.
 Adam's tests using anthracite, 140-145, (App. A) 318, 319.
 Larter's test, using coke, 146, (App. A) 320.

Heat losses, recovery and utilisation of waste heat—
 Engine-work. *See* that title.

Heat losses, recovery and utilisation of waste heat—*continued*.

Furnace-work—

Sources of loss, 65, 66.

Recovery of heat in gas-fired furnaces, 67.

Gaillard and Haillet's system, 91, 92.

Siemens' system, 70–72.

Gas-power installations, heat losses in, 239, 240.

Gas-producers—

Effect of heat losses, 30, 36.

Recovery of heat—

Decomposition of steam, effect of, 8, 9.

Temperature required, 59, 60.

Hot gas, use of, 63.

Mond plant, 177.

Raising steam by sensible heat of gas, 29.

Suction plants, 37, 122, 136.

Sources of loss, 5, 28, 29.

Steam, effect of, 8, 9.

Steam power installations, heat losses in, 239.

Heat units—

Definitions, (App. B) 321.

Equivalents, (App. B) 321.

Heating work—

Applications of producer gas, 110, 111.

Producer gas for, 63, 104.

Producers for. *See* Gas-producer (*various types*).

Products of combustion, 111.

See also titles Furnace-work and Burners and small gas-jets.

H.M.S. *Rattler*, 219.

Holzappel on gas propulsion of vessels, 220.

Horsehay Co., 186.

Howson's down-draught gas-producer, 187.

Humphrey on the Mond gas-producer, 22, 179.

Humphrey pump, 128–132.

Hydraulic box, 104.

Hydrogen—

Calorific intensity, (App. B) 335.

Calorific power, (App. B) 328, 329, 331.

Hydrogen—*continued*.

Carbon and hydrogen, direct union of, 26.

Carbon dioxide and hydrogen, reactions between, 14, 15, 26, 57, 58.

Carbon monoxide and hydrogen, reaction between, 26.

Density, (App. B) 325.

Determination of, 277.

Molecular heat, (App. B) 327.

Molecular weight, (App. B) 325.

Pre-ignition, bearing of hydrogen on, 125, 126.

Producer gas, hydrogen in, 26, 115, 125, 126, 298.

Comparison of anthracite and coke, 24, 25, 147.

Specific heat, (App. B) 326.

I

Ignition in gas-engines, 126, 127.

Illuminating gas. *See* Lighting gas.

Indicator diagrams—

Engine using producer gas in 1881.. 117.

Scavenging, effect of, 118.

Suction plant—

Suction diagram, light spring, 163.

Variable load, effect of, 170, 171.

Injection of air-blast by steam, 73.

Installations—

Crossley suction plants using peat—

Portadown, Ireland, 205.

Veenhuizen, Holland, 203.

Dowson gas plant—

Burham, Associated Portland Cement Manufacturers, Ltd., 190.

Chingford pumping station, 130.

Gloucester County Asylum, 106–108.

Van Houten's Cocoa Factory, Weesp, Holland, 108–110.

Walthamstow Isolation Hospital, 108.

West Bromwich, Kenrick & Sons, 189.

Humphrey pump at Chingford, 130–132.

Installations—*continued*.

- Körting Bros., suction plants using peat. Skabersjö, Sweden, 201.
 Kramers and Aarts' water-gas plant at Leeds, 88.
 Mond producers at Warrington, 184.
 Power Gas Corporation, Ltd., recovery plants using peat—
 Codigoro, Italy, 203.
 Norfolk, 201.
 Orentano, Italy, 202.
 Osnabrück, Hanover, 203.
 South Staffordshire Mond Gas Co.'s installation, 179-183.

J

- Japanning and enamelling, 110, 112.
 Jones on composition of producer gas, 115.
 Junkers' calorimeter, 291-299.
 Accuracy of results, 299.
 Advantages compared with bomb calorimeters, 304.
 Nett calorific power, method of determining, 298.

K

- Kennedy, Sir A., on—
 Heat efficiency of steam-boilers, 236.
 Stand-by losses in steam-boilers, 230.
 Körting Bros. gas plant using peat, 201.
 Kramers and Aarts' water-gas plant, 87, 89.

L

- Lancashire boilers, stand-by losses, 228, 229, 231.
 Langer on composition of producer gas, 115.
 Larter's test of Dowson suction plant, 146, (App. A) 320.
 Latent heat of steam, 11.
 Definition, (App. B) 322.
 Latta on Loomis-Pettibone gas plant, 195.
 Laws of gases, (App. B) 323, 324.

Le Chatelier on—

- Dissociation, 60.
 Equilibrium in reversible reactions 51.
 Lea, Mr. H., on—
 Stand-by losses in gas-producers, 231, 232.
 Stand-by losses in steam-boilers, 229, 232.
 Leeds, water-gas plant at, 88.
 Lewes on the Dellwik-Fleischer water-gas process, 86.
 Lewis Thompson's calorimeter, 287, 288.
 Lignine, 249.
 Lignite. *See* Brown coal.
 Lining of gas-producers, 312.
 Loomis-Pettibone gas-producer, 195.
 Lowe water-gas-producer, 82-84.

M

- Macfarlane and Caldwell's gas analysis apparatus, 273-276.
 Machinefabriek Drakenburgh's vessels using gas-power, 221.
 Mahler on calorific power of fuel, 289, 291.
 Mahler-Donkin bomb calorimeter—
 Accuracy of results, 285, 286.
 Construction and use of, 282-286, 301.
 Mallard on dissociation, 60.
 Marsh-gas. *See* Methane.
 Mathot on fuel consumption, 121.
 McCourt and Bone's gas-fired boiler, 100, 101.
 Metallic paints, affected by sulphur compounds in products of combustion of producer gas, 112.
 Methane—
 Calorific power, (App. B) 328, 329, 331.
 Density, (App. B) 325.
 Determination of, 277.
 Formation of, 26.
 In producer gas, 24, 27, 147.
 Molecular heat, (App. B) 327.
 Molecular weight, (App. B) 325.
 Proportion of, greater in gas from anthracite than from coke, 24, 25.
 Specific heat, (App. B) 326.

Metric equivalents, (App. B) 339, 340.
 Meyer on fuel consumption, 121.
 Mixed gas, 19.
 Moisture—
 Producer gas, moisture in, 98, 122, 123.
 Removal of condensed moisture, 311.
 See also Fuel, and Names of fuels.
 Molecular heats of gases, (App. B) 327.
 Molecular volume of gases, (App. B) 325.
 Molecular weights of gases, (App. B) 325.
 Monaco on composition of producer gas, 115.
 Mond, Dr. Ludwig, 176.
 Mond gas-producer, 21, 22, 61, 176, 177, 183–186.
 Ammonium sulphate, recovery of, 13, 178.
 Composition of gas made, 178.
 Distribution of gas over a large district—South Staffordshire Mond Gas Co.'s plant, 179–183.
 Smaller powers, plant constructed for, without ammonia recovery, 183.
 Tarry vapours partially destroyed in producer, 25.
 Morgan on utilisation of peat, 207, 208.
 Morgan Construction Co.'s gas-producer, 74, 75.
 Motor vehicles, producer gas for. *See* Gas traction on roads.

N

Nicolaussé boiler, stand-by losses, 231.
 Nitric acid, formation of, in bomb calorimeter, 286.

Nitrogen—

Calories required to heat to various temperatures under—
 (a) Constant pressure, (App. B) 334.
 (b) Constant volume, (App. B) 335.
 Density, (App. B) 325.
 Determination of, 278.
 Molecular heat, (App. B) 327.
 Molecular weight, (App. B) 325.

Nitrogen—*continued.*

Producer gas, nitrogen in, 16, 27, 82, 104.
 Specific heat, 6, (App. B) 326.
 Water-gas, nitrogen in, 84.
 Number of producers which can be worked together, 309.

O

Ocean-going schooner with gas-power as auxiliary, 225.
 Olefiant gas. *See* Ethylene.
 Orentano, plant using peat at, 202.
 Osnabrück, plant using peat at, 203.
 Otto gas-engine, 113.
 Compression used in 1881.. 116.
 Trial with producer gas in 1881.. 114.
 Typical indicator diagram, 117.
 Ovens—starting a gas-fired oven, 313.
 Overflow water—
 Disposal of, 315.
 Using again, 124.
 Oxidation and reduction in furnaces, 68, 93.
 Oxygen—
 Calories required to heat to various temperatures under—
 (a) Constant pressure, (App. B) 334.
 (b) Constant volume, (App. B) 335.
 Density, (App. B) 325.
 Determination of, 276.
 Molecular heat, (App. B) 327.
 Molecular weight, (App. B) 325.
 Producer gas, oxygen in, 312.
 Reactions between oxygen and carbon. *See titles* Air, action on carbon, and Air and steam.
 Specific heat, (App. B) 326.

P

Parker on gas traction, 212.
 Pattinson and Stead on composition of producer gas, 74.
 Peat—
 Ash in, 248, 253.
 By products from, 200, 206, 207, 253.

Peat—*continued.*

- Calorific power, 253.
- Carbonisation of, 253.
- Composition, 248, 253.
- Distribution of, 252.
- Drying of, 198, 199.
- European countries, peat industry in, 201.
- Formation, 248.
- Gas-producers, use of peat in, 198, etc., 247.
 - Ammonium sulphate, recovery of, 200, 201, 202, 203, 206, 207.
 - Calorific power of gas, 200, 202, 203.
 - Composition of gas, 200, 202.
 - Consumption of fuel, 202, 203, 205.
 - Crossley Bros., 199, 200, 203, 205.
 - Körting Bros., 201.
 - Power Gas Corporation, 201, 202, 203.
 - Suction-plants, 199, 201, 203, 205.
 - Yield of gas, 202, 203.
- Refer also to headings,* Installations; Tests of gas-producer installations.
- Methods of using peat as a source of power, 206.
- Moisture in 30, 198, 201, 202, 203, 205, 248, 254.
- Morgan on utilisation of peat, 207, 208.
- Occurrence of, 252.
- Specific gravity, 253.
- Tar from peat, uses of, 200, 208.
- Variation in physical characteristics, 252.
- Peat charcoal, 249, 254.
- Perry & Co., water-gas plant, 88.
- Poisoning by carbon monoxide, 307.
- Portadown, plant using peat at, 205.
- Pottery, use of producer gas for glazing, 98.
- Pousard on recovery of heat in gas-fired furnaces, 91.
- Power Gas Corporation, Ltd., plants using peat, 201-203.
- Pre-ignition, 125, 126.
- Pressure—
 - Pressure during suction stroke of gas-engine, 161, 162, 164, 165.

Pressure—*continued.*

- Producer gas—
 - Constant pressure required, 64, 102, 103.
 - Distribution, pressure required for, 245.
 - Testing pressure of, 311.
- Reversible reactions, effect of pressure on equilibrium in, 51.
- Pressure plants, comparison with suction plants. *See* Suction plants.
- Products of combustion—
 - Foodstuffs, effect on, 111.
 - Heat carried away by, 67.
 - Nature of, 111.
 - Recovery of waste heat from, 67, 71, 91.
 - Sulphur in, 111, 112.
- Pumping plant at Chingford, 130-132.
- Purification of producer gas—
 - Chemical purification, method of, 111, 112.
- Cleaning and cooling of gas. *See* that title.

R

- Rate of production of gas—
 - Automatic control of production to suit a varying rate of consumption, 104, 135, 166, 169, 174, 314.
 - Effect on calorific power of gas made in suction plant, 166, 167, 173, 200.
- Recovery of sensible heat. *See* titles Heat losses, and Furnace-work.
- Recovery plants, 13, 176, 179.
 - using peat, 200-203.
- Reduction in gas-fired furnaces, 68, 93.
- Regenerative furnaces. *See* Furnace-work.
- Repairs and maintenance of gas plants, 246.
- Reverberatory furnace, 93, 94.
- Reversible reactions, 14, 49, 57.
 - Effect of temperature and pressure, 51.
 - Equilibrium in, 50.
 - See also* particular reactions.
- Rhead and Wheeler on—
 - Equilibrium between carbon, carbon dioxide, and carbon monoxide, 53.

Rhead on—

Action of air on carbon, 3.

Rate of conversion of CO_2 to CO , 45.

Roasting coffee by producer gas, 110.

Rosenhain's calorimeter, 287.

Rowan on gas-producers, 69.

Royal Agricultural Society's trials of suction plants, 153, 167, 173, 174.

S

Sampling of fuel, 266.

Sampling of producer gas, 270-273.

Sankey, Captain H. R., on suction plants, 153, 174.

"Sarco" recording gas calorimeter, 301.

Scavenging. *See* Engine-work.

Scharff on peat-tar, 207.

Schottler on fuel consumption, 121.

Scotch anthracite, 264.

Sehmer. *See* Ehrhardt.

Semi-bituminous coal as fuel for gas-producers, 191, 192, 247.

Volatile matter, percentage of, 256.

Semi-water-gas, 19.

Composition, 21, 24, 27, 71, 74, 105, 115, 131, 144, 146, 147, 152, 167, 172, 173, 178.

Theoretical composition of, 12, 13, 21, 32, 33.

Refer also to title Air and steam, action on carbon.

Ships and boats, gas-producers for.

See Gas propulsion of vessels.

Siemens, F., 69.

Siemens, W., 70, 106.

Siemens' gas-producer and regenerative furnaces, 70, 72

Composition of gas, 71.

Method of obtaining draught, 71.

Regenerative furnace, 71, 72, 91.

Size of fuel. *See* Fuel.

Skabersjö, plant using peat at, 201.

Slaby on fuel consumption, 121.

Smith, D. J., on gas traction, 216.

Smith, H. E., water gas plant, 89.

Smoke, loss of heat due to, 65.

Smoke Abatement Committee's award.

105.

Smoke nuisance, advantages of draught working, 187.

Solid hearth without grate, producers with, 73.

Soot in pipes and coolers of gas-producer plant, 57.

South Staffordshire Mond Gas Co.'s installation, 179-183.

Specific gravity of producer gas, 179.

Specific heat, definition, (App. B) 322.

Specific heats of gases, (App. B) 326.

Speed of gas-engines, 121.

Stand-by losses—

Gas-producers, 227, etc.

Steam-boilers, 228, etc.

Tables of results, 232.

Starting a gas-engine and suction plant, 141, 142, 174, 308.

Starting a gas-fired oven or furnace, 313.

Steam—

Carbon monoxide and steam, reaction between, 14, 15.

Reversible reaction, 57, 58.

Condensation in pipes, 245.

Dissociation, 60.

Latent heat of steam, 11.

Definition, (App. B) 322.

Suction plants, production of steam, 136-140, 153, 157, 158, 261.

Quantity used, 138.

Regulation of supply, 139, 140, 153, 158, 159.

Use of steam in gas-producers—

Advantage of using steam, 7, 8, 9, 57.

Bone and Wheeler's tests on effect of varying quantity of steam, 183-186.

Preventing condensation, 137.

Quantity decomposed, 61, 99, 124, 176, 184-186.

Quantity used, 21, 77, 99, 138, 145, 146, 184-186, 194.

Effect of excess, 139, 169, 176, 185.

Regulation of supply, 105, 139, 140, 153, 158, 159, 314.

Steam-jet air injector, 73.

Pressure required, 77, 314.

Superheated steam, use of, 105, 137.

Steam, action on carbon, 8, 57.

Carbon dioxide, percentage formed at different temperatures, 59.

Composition of gas formed at different temperatures—Bunte and Harris' results, 59.

Ideal water-gas, composition, calorific power, yield, etc., 17-19.

Quantity of steam decomposed at different temperatures, 59.

Temperature, effect on reactions, 12, 57-61.

Theoretical and practical results—

Differences, discussion of, 26-37.

Table summarising, 21.

Explanatory comments, 20, 22.

Refer also to Water-gas.

Steam and air, action on carbon. *See* Air and steam.

Steam-jet, gas-producer with, 73, 104.

Steam-boilers—

Bonecourt boiler, 100, 101.

Gas-fired boilers, 99-101.

Heat efficiency, 66.

Refer also to title Heat efficiency.

Heating with producer gas, 22, 99-101.

Stand-by losses, 228, etc.

Steam-power and gas-power, comparison of—

Bituminous coal, use of, 175, 241, 244.

Convenience of gas-engine using lighting gas, 113.

Distribution of power, 244, 245.

Heat efficiency. *See* that title.

U.S. Geological Survey tests, 241-244.

Stirring fuel in producer, 80, 81, 310, 311.

Suction fan, use of, with suction plants, 164.

Suction plants—

Advantages of, 152.

Air in gas, 312.

Air supply, advantages of heating, 137.

Arbos gas-plant and engine, 133.

Bénier suction plant and gas-engine, 134-136.

Bituminous coal, for, 187-191.

Suction plants—*continued.*

Bollinckx suction plant, 156-158.

Calorific power of gas—

Determination of, 305.

Diagrams showing variations, 148-150.

Carbon monoxide poisoning, 308, 309.

Charcoal, use of, 251, 252.

Clinker due to absence of sufficient steam, 138, 261.

Composition of gas, 144, 146, 147, 152, 167, 172, 173, 189, 190.

Diagrams showing variations, 148-150.

Crossley suction plant, 157, 158.

Bituminous coal, for, 191.

Peat, using, 199, 203, 205.

Delassue suction plant, 153, 154.

Depth of fire, 309.

Deschamps', for bituminous coal, 187.

Distance of producer from engine, 162.

Dowson suction plant, 158, 159.

Bituminous coal, for, 188-190.

Results of tests, 144, 145, 167, 173, 189, 190.

Early apparatus, drawbacks of, 133, 136.

Exhauster, use of, 164.

Expansion box, 163.

Fétu-Defize suction plant, 155.

Fuel, comparison of results obtained with anthracite and with coke, 147.

Fuel, consumption of. *See title* Fuel.

Half-load, 173.

Heat efficiency. *See* that title.

Labour required, 152, 174.

Light or variable loads, working with, 166-174.

Steam supply, effect of excess, and methods of regulating, 139.

Tables showing composition of gas with different loads on engine, 167, 173.

Loss of power—

Fluid friction, losses due to, 161, 164, 165.

Importance of reducing resistances, 163.

Suction plants—*continued.*Loss of power—*continued.*

Quantity of charge drawn into cylinder, 161, 162.

Overflow water, impurities in, 315.

Peat, use of, 199, 201, 203, 205.

Pressure and suction plants, comparison of—

Composition of gas, etc., 151, 152.

Power obtained, 162.

Pressure in gas-main, 163.

Pump on engine with early suction plant, 134, 136.

Rate of production—

Automatically governed in proportion to consumption of gas, 135, 166, 169, 174.

Calorific power of gas, effect on, 166, 167, 173.

Repairs and maintenance, cost of, 246.

Starting, method of, 141, 309.

Time required, 174.

Steam supply—

Effect of excess, 139, 169.

Preventing condensation, 137.

Production of steam, 136–140, 157, 158.

Regulation, 139, 140, 153, 158, 159.

Superheating, 137.

Test flames, use of, 313.

Tests, 139–153.

Crossley suction plant, 109, 203.

Dowson suction plant. *See* that title.

Royal Agricultural Society's trials, 153, 167, 173, 174.

Vaporisers, 136, 137, 153, 155, 157, 158.

Wages, cost of, 246.

Water, quantity used, 145, 146, 153.

with down-draught, 187.

with open hearth, 158.

advantages of, 159.

with rotating grate, 158.

with up- and down-draught, 188.

with water bottom, 158, 189.

advantages of, 159.

Working with more than one engine, 164, 189.

Refer also to Gas traction on roads.

Sulphur—

Brown coal, sulphur in, 255.

Determination of—

In fuel, 269.

In producer gas, 279.

Overflow water, sulphur in, 315, 316.

Peat, sulphur in, 254.

Products of combustion, sulphur in, 111, 112.

Sulphuretted hydrogen in producer gas, 112.

T

Tar. *See* Bituminous coal—*sub-heading* Engine-work; *see also under* Peat.

Temperature, (App. B) 321.

Absolute temperature, definition, (App. B) 321.

Conversion values, (App. B) 321.

Effect on chemical reactions, 44.

Equilibrium in reversible reactions, 51.

Refer also to particular reactions.

Explosion in gas-engine cylinder, temperature of, 60.

Gas-producers—

Temperature attained, 6.

Temperature necessary, 45, 47, 56, 59, 60, 84.

Temperature reduced by use of steam, 8.

Tessié du Motay gas-producer, 73.

Test flames, 312, 313.

Tests of gas-producers installations, fuel consumption, cost of working, etc.—

Comparison of theoretical and practical results—Table, 21.

Crossley's suction plants, using peat, 199, 203.

Dowson gas plant in 1881.. 105, 106.

Dowson gas plant at—

Burham, Associated Portland Cement Manufacturers, Ltd., 190.

Gloucester County Asylum, 106–108.

Van Houten and Sons' Cocoa Factory, Weesp, Holland, 108–110.

Tests of 'gas-producer installations,
fuel consumption, cost of working,
etc.—*continued*.

Dowson gas plant at—*continued*.

West Bromwich, Kenrick and
Sons, 189.

Dowson suction plant—

Adam's tests with anthracite, 139–
145, 151, (App. A) 318, 319.

Larter's test with coke, 146,
(App. A) 320.

Farnham gas producer, 194.

Körting Bros. suction plant using
peat, 202.

Kramers and Aarts' water-gas plant,
at Leeds, 88.

Mond gas-producer at Warrington—
Bone and Wheeler's tests, 183–
186

Power Gas Corporation, Ltd., plants
using peat, 201, 202, 203.

Royal Agricultural Society's trials
of suction plants, 153, 167, 173,
174.

U.S. Geological Survey tests, 241–
244.

Refer also to Gas traction on roads.

Theoretical and practical results in
manufacture of producer gas—

Causes of difference, 22, 36.

Discussion of differences, 26–37.

Table summarising, 21.

Explanatory comments, 20–26.

Thompson's calorimeter, 287, 288.

Thomson's calorimeter, 287, 288.

Town gas. *See* Lighting gas.

U

Unwin on the Humphrey pump, 130.

Up- and down-draught, producers with,
188–191.

Uppenhorn on composition of producer
gas, 115.

Uses of producer gas, 110, 111.

U.S. Geological Survey tests with
bituminous coals and lignites, 241–
244.

V

Valve-setting of gas-engines for working
with suction plants, 163.

Vapourisers in suction plants, 136, 137,
153, 155, 157, 158.

Van Houten's Factory—Dowson gas
plant at, 108–110.

Velocity of chemical changes, effect of
temperature on, 44.

Veenhuizen, plant using peat at, 203.

Volatile matter in fuel. *See* Fuel.

Volume of gases, correction for tem-
perature and pressure, (App. B) 324.

W.

Wages, cost of—Comparison between
gas and steam power, 246.

Walthamstow—

Electric light and power station—
Dowson gas plant at, 231.

Isolation Hospital—Dowson gas plant
at, 108.

Waste water from gas-producers, 315,
316.

Sulphur in, 315, 316.

Water—

Quantity required for cooling gas,
124.

Quantity used in producers with
water-jackets, 75.

Quantity used in suction plant, 145,
146, 153.

Refer also to Overflow water.

Water bottom, producers with, 75, 77–
82, 177.

"Water equivalent" of calorimeter,
285.

Water-gas—

Blue water-gas, 85.

Carbon dioxide in, 59.

Carhuretted water-gas, 85.

Composition, etc., 21, 59, 84, 86,
88, 90.

Theoretical, 17, 21.

Dellwik-Fleischer process, 85, 86.

Furnace-work, disadvantages of
water-gas, 85.

Water gas—continued.

- Intermittent production, 17.
- Kramer and Aarts' producer, 87, 89.
 - Bone's tests at Clayton and Sons, Leeds, 88.
 - Smith's modified plant, 89.
- Lowc's producer, 82, 83.
- Methane in, 90.
- Method of production and object of process, 16, 17-19.
- Nitrogen in, 84, 90.
- Peat, water-gas from, 90.
- Temperature required for production, 59, 84.
- Uses of, 85, 88.
- Yield of, 18, 21, 88.
- Water-jacket, producers with, 75.
- Water seal, 124.
- Water vapour—
 - Calories required to heat to various temperatures under—
 - (a) Constant pressure, (App. B) 324.
 - (b) Constant volume, (App. B) 325.
 - Density, (App. B) 325.
 - Molecular heat, (App. B) 327.
 - Molecular weight, (App. B) 325.
 - Pressure and mass, (App. B) 322.
 - Table, (App. B) 322, 323.
 - Producer gas, water vapour in, 98, 122, 123.
 - Specific heat, (App. B) 326.
 - Weight in 1 kilo of saturated air at different temperatures, 138.
- Weardale furnace, 93-96.
- Weights and measures, conversion values, (App. B) 339.
- Wendt on effect of depth of fuel on formation of carbon monoxide, 38, 39.
- West Bromwich, Dowson gas plant at, 189.

- Wheeler. *See* Bone; Rhead.
- Whitfield gas-producer, 187.
- Wilkinson on stand-by losses—
 - Gas-producers, 232.
 - Steam-boilers, 231, 232.
- Willans and Robinson on stand-by losses in steam-boilers, 231, 232.
- Wilson gas-producer, 73, 186.
- Witz bomb calorimeter, 302, 303.
- Witz on—
 - Composition of producer gas, 115.
 - Fuel consumption, 121.
 - Tests of Bénier suction plant, 135.
- Wood—
 - Ash in, 248, 250.
 - Calorific power, 250.
 - Composition, 248, 250.
 - Destructive distillation, 250, 251.
 - Fuel for gas-producers, wood as, 247, 250.
 - Moisture, 248, 250.
- Wood & Co.'s, automatic producer, 77-82.
- Wood-charcoal. *See* Charcoal.
- Wood-gas, 251.
- Working two or more producers together, 309.

Y

- Yield of producer gas, 21, 131, 147, 152, 186.
 - See also under* Peat.
- Yield of water-gas, 18, 21, 88.

Z

- Zeemeeuw* and other vessels of the Machinefabriek Drakenburgh fitted with gas power, 221.

PRINTED IN GREAT BRITAIN BY
WILLIAM CLOWES AND SONS, LIMITED,
BECCLES.

