UC-NRLF
$B 31 990

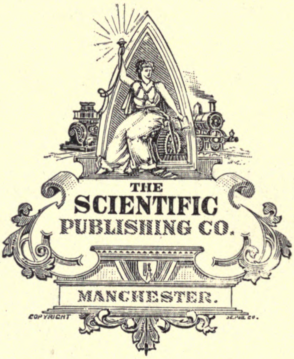
LIBRARY
OF THE
UNIVERSITY OF CALIFORNIA.

Class

Kt|m

PRODUCER GAS.

Lm


THE
SCIENTIFIC
PUBLISHING CO.
MANCHESTER.
COPYRIGHT
SC. PUB. CO.

PRODUCER GAS.

A SKETCH OF

THE PROPERTIES, MANUFACTURE,
EOUS FUEL.

Net Book.

¶ This book is supplied to the trade on terms which do not allow them to give a discount to the public.

F.I.C., F.C.S.,
land Technical College;
Past-President West of Scotland Iron and Steel Institute;
Author of "Fuel," "The Metallurgy of Iron and Steel," &c., &c.

PRICE, 10s. NET.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

MANCHESTER:
THE SCIENTIFIC PUBLISHING COMPANY.

[*ALL RIGHTS RESERVED.*]

c1905.

THE
SCIENTIFIC
PUBLISHING CO.
MANCHESTER.
COPYRIGHT SC. PUB. CO.

PRODUCER GAS.

A SKETCH OF

THE PROPERTIES, MANUFACTURE,
AND USES OF GASEOUS FUEL.

BY

A. HUMBOLDT SEXTON, F.I.C., F.C.S.,
Professor of Metallurgy in the Glasgow and West of Scotland Technical College;
Past-President West of Scotland Iron and Steel Institute;
Author of "Fuel," "The Metallurgy of Iron and Steel," &c., &c.

PRICE, 10S. NET.

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

MANCHESTER:
THE SCIENTIFIC PUBLISHING COMPANY.

[*ALL RIGHTS RESERVED.*]

c1905.

TP761
P95

GENERAL

BOOKS BY THE SAME AUTHOR.

ELEMENTARY INORGANIC CHEMISTRY. 4th Edition. **2/6.**

A MANUAL OF QUALITATIVE CHEMICAL ANALYSIS. 3rd Edition. **3/6.**

A MANUAL OF QUANTITATIVE CHEMICAL ANALYSIS. 4th Edition. **3/-**

HOME-WORK IN CHEMISTRY. 1/-

AN ELEMENTARY TEXT BOOK OF METALLURGY. 3rd Edition. **6/-**

FUEL AND REFRACTORY MATERIALS. 6/-

THE CHEMISTRY OF MATERIALS OF ENGINEERING. 5/-

THE METALLURGY OF IRON AND STEEL. 16/-

METALLURGICAL ANALYSIS AND ASSAYING (in conjunction with Mr. E. L. RHEAD, Manchester). **10/6.**

THE FIRST TECHNICAL COLLEGE. "A sketch of the history of the Andersonian." **3/6.**

PREFACE.

In 1902 the Author gave a course of lectures on Producer Gas at the Technical College, Glasgow. These attracted considerable attention, and it was requested that they should be published. As there was no convenient book dealing with the subject, the Author thought such a one might be useful; so he has prepared this little book, which is based on the notes of the lectures. Owing to unavoidable circumstances, the publication has been somewhat delayed, but this has perhaps not been altogether a disadvantage.

The subject of gaseous fuel has been attracting a great amount of attention during the last few years, and very important advances have been made. The use of fuel gas is becoming every year more general, though the Author feels that at present it is only in its infancy, and that in the near future it will be used on a much larger scale, and for many purposes.

Special attention has been given to the principles on which the production of gaseous fuel depends, as once these are mastered the practical questions as to the best form and design of producer are quite simple. Typical producers have been described, and in an appendix some of the latest forms. The patented gas producers are extremely numerous, and it is certain that many of them involve no new principle or even important improvement in detail, but it is advantageous to the student and the practical man to know what has been done.

Many important branches of the subject are not touched—as, for instance, domestic heating—as to have dealt with them satisfactorily would have increased the

141384

size of the book far beyond what is desirable. For the same reason other topics are dealt with very briefly.

As changes are constantly taking place, the Author will be much obliged to inventors or makers of gas plant if they will inform him of any new design of plant they may bring out, and he will also welcome details of the results obtained, since increased information may lead to the formation of sounder judgments on many points. He will also welcome additional information on any of the subjects dealt with, with a view of making a second edition—should such be called for—a great improvement on the first.

The best thanks of the Author are due to his colleague, Dr. Gray, for looking through the proofs; to his assistant, Mr. Claude A. Meiklejohn, for reading the proofs and checking the calculations; and to the many friends who have assisted the work by the gift or loan of drawings, by giving information as to work done, by permission to reproduce published illustrations, and in many other ways.

CONTENTS.

PRODUCER GAS.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

CHAPTER I.

CONSTITUENTS OF FUEL GAS. THE AIR. VARIATION OF THE VOLUMES OF GASES WITH CHANGES OF PRESSURE AND TEMPERATURE. CALCULATION OF THE PERCENTAGE COMPOSITION OF GASES BY WEIGHT FROM THE COMPOSITION BY VOLUME.

GASES used as fuel are always prepared by the gasification of solid fuel, usually coal or coke, either by destructive distillation as in the manufacture of coal gas, by incomplete combustion as in the production of coke producer gas and water gas, or by a combination of the two methods, as in coal producer gas. In the first method a gas rich in illuminating constituents is obtained consisting almost entirely of combustible constituents, and a large proportion of the fuel is left in the form of a solid residue or coke; in the two last, a gas of a different character is obtained, and the whole of the fuel except the ash is gasified.

Gas made by any of the methods is not a definite compound, but a mixture of several gases in very varying proportions.

As the same gases are present in all forms of fuel gas, the character of the gas will depend on the proportions in which these constituents are mixed; and as the properties of a mixture are always the mean of those of its constituents, it is essential that the properties of the individual constituent gases should be known in order that those of the mixture may be understood and that the influence of the separate constituents may be judged, and also in order that an idea of the value and properties of a gas may be formed from an analysis which gives the proportions of its constituents.

The constituents of all fuel gases may be classified into two groups: (1) Those which are combustible and which, therefore, have a greater or less value in the gas; and (2) those which are not combustible, and which, therefore, have no heating value, but only act as diluents.

The following are the most important gases, but higher members of the hydrocarbon series, to which marsh gas, ethylene, and acetylene belong, may also be present:—

(1) **Combustible gases.**
    Hydrogen, H.
    Carbon-monoxide, CO.
    Marsh gas, methane, CH_4.
    Ethylene, C_2H_4.
    Acetylene, C_2H_2.

(2) **Diluents.**
    Nitrogen, N.
    Carbon-dioxide CO_2.
    Oxygen, O.

In addition, there may be present combustible and non-combustible vapours, such as tarry matters and some other substances which may have considerable influence on the quality of the gas, but which are not given in the ordinary analysis of the gas, because they are condensed, and thus removed in the preparation of the sample for analysis.

COMBUSTIBLE GASES.

Hydrogen (H). Atomic weight, 1; mol. weight, 2.—This gas is always present in larger or smaller quantity. It is found in considerable quantity in the products of the destructive distillation of coal, and is therefore present in coal gas. It is also liberated whenever steam comes in contact with very hot carbon, carbon-monoxide or carbon-dioxide being formed at the same time, according to the temperature and the quantity of carbon present, thus

$$(1)\ C + H_2O = CO + 2H.$$
$$(2)\ C + 2H_2O = CO_2 + 4H.$$

It is colourless and odourless and very light; indeed, it is the lightest known substance. It is less than $\frac{1}{14}$ as heavy as air; its specific gravity (air = 1) being ·06926 and 1 cub. ft. weighs at 0°C. and 760 mm. bar, ·0056lbs., or 1lb. occupies 178·57 cub. ft. Its specific heat is 2·414.

It is very readily combustible, and burns with a pale blue almost non-luminous, flame. One pound evolves on combustion 34,180 Centigrade units or 61,524 B.Th.U. of heat. It is therefore one of the most valuable constituents of fuel gas, but owing to its extreme lightness, if present in large proportion, it makes the gas light and bulky. One cubic foot only evolves 191·4 C.U. or 344·5 B.Th.U. of heat on combustion. When it burns water is formed—

(3) $2H + O = H_2O$.

It requires eight times its own weight or half its own volume of oxygen for combustion, and yields nine times its own weight of water, which, if the temperature be above 100° C., will occupy the same volume as the hydrogen would do under the same conditions of temperature and pressure. It requires about 2·4 times its own volume or 34·78 times its own weight of air for complete combustion. The influence of hydrogen in a gas is to make it light and bulky, to add largely to its heating power, and, at the same time, to increase very much the amount of air required for combustion, and, since the specific heat of steam is very high, also to increase the amount of heat carried away in the products of combustion.

Carbon-monoxide (CO). Mol. weight, 27·93 (28).—This is one of the most important constituents of fuel gas. It is colourless and odourless, and burns with a characteristic pale blue, feebly luminous flame, forming carbon-dioxide thus—

(4) $CO + O = CO_2$

One pound evolves on combustion 2,430 C.U. or 4,374 B Th.U. of heat. It requires for complete combustion ·57 times its own weight and half its own volume of oxygen, and yields 1·57 times its own weight of carbon-dioxide. The amount of air required is about 2·4 times its own volume, or 2·48 times its own weight.

It is among the products of the destructive distillation of coal, and is produced by the action of hot carbon on carbon-dioxide, thus—

(5) $CO_2 + C = 2CO$

and of steam on hot carbon (equation 1).

As the specific heat of carbon-dioxide is only ·2479, the amount of heat carried away by the products of combustion is not large. Its specific gravity $(H = 1)$ is

14 and (air=1) is ·9671 (·968), and one cubic foot weighs ·0781lb

Marsh Gas (Methane CH_4). Mol. weight, 15·97 (16).—This is a colourless and odourless gas which occurs in large quantity in natural gas. It is produced by the decompositions by which vegetable matter passes into coal, and is therefore often present in coal mines, where it is known as fire-damp. It is among the products of the destructive distillation of coal, and is therefore always present in coal gas, though rarely in large quantity. Its specific gravity (air = 1) is ·5530, whence it is often called light carburetted hydrogen. One cubic foot weighs ·0447lb. It burns readily with a slightly luminous flame, forming carbon dioxide and water, thus—

$$(6)\quad CH_4 + 4\,O = CO_2 + 2\,H_2O.$$

If the quantity of oxygen be insufficient for complete combustion it yields carbon monoxide, hydrogen, and lower hydrocarbons with but little free carbon, so that little or no smoke is produced. It requires for complete combustion four times its own weight and twice its own volume of oxygen, or 17·3 times its weight and 9·52 times its own volume of air. It yields 2·25 times its own weight of water and 2·75 times its own weight of carbon dioxide. Its calorific power is 13,062 C.U., or 23,512 B.Th.U.

Ethylene (C_2H_4). Mol. weight, 27·94 (28).—This gas is present in considerable quantity in gases such as coal gas produced by destructive distillation. It is colourless and odourless, burns very easily, with a very luminous flame, which becomes readily smoky. It is the chief illuminating constituent of coal, and similar, gases. On complete combustion it yields water and carbon dioxide.

$$(7)\quad C_2H_4 + 6\,O = 2\,CO_2 + 2\,H_2O$$

It requires for complete combustion 3·42 times its own weight and three times its own volume of oxygen, or 14·87 its own weight, and 14·28 times its own volume of air. It yields twice its own volume of carbon dioxide and twice its own volume of steam. With an insufficient supply of air it burns with a very smoky flame. Its specific gravity (air=1) is ·9784, and a cubic foot weighs ·0784lbs. Its specific heat is ·4040. It yields on complete combustion 11,143 C.U. or 20,057 B.Th.U. of heat.

Acetylene ($C_2 H_2$).—This is a colourless gas, having a most unpleasant odour. It burns readily with a very brilliant flame, and shows a great tendency to produce smoke by the separation of carbon.

(8) $C_2H_2 + 5\,O = 2\,CO_2 + H_2O$

It requires three times its own weight and 2·5 times its own volume of oxygen for complete combustion. Its specific gravity (air=1) is ·9100, and a cubic foot weighs ·0734lbs. It is an unstable body, decomposing very readily with evolution of heat, and is of little importance as a fuel gas.

DILUENTS.

Nitrogen (N). Atomic weight 14; mol. weight 28.—This is a colourless and odourless gas, always present in fuel and lighting gases. It is produced in small quantity by the destructive distillation of nitrogenous organic matter, and is therefore present in small quantities in coal, and similar, gases. It forms a large percentage of the air, is therefore always present in large quantity in gases produced by incomplete combustion. Its specific gravity (air=1) is ·9701, and one cubic foot weighs ·0784lbs. It is not combustible, and has no influence on fuel gas, except to act as a diluent. Its specific heat is ·2438.

Carbon Dioxide (CO_2). Mol. weight 43·89 (44).—This is a colourless, odourless, non-combustible gas. It is produced in small quantity by destructive distillation, and is therefore present in small quantity in coal gas. It is often present in producer gas in considerable quantity, being produced by the combustion of carbon. Its specific gravity (air=1) is 1·5196; one cubic foot weighs ·1227lbs., and its specific heat is ·2163. In presence of excess of carbon at high temperatures it is reduced to carbon monoxide, thus—

(9) $CO_2 + C = 2\,CO$.

Oxygen (O).—This gas is never present in fuel gas except by leakage after the gas has cooled, since at high temperatures it would at once combine with the combustible constituents of the gas.

Steam (H_2O). Mol. weight, 17·97 (18).—Water vapour is always present in fuel gas, being produced by the vaporisation of the moisture in the fuel, and it is always among the products of destructive distillation, and it may be produced by the combustion of hydrogen or hydrocarbons owing to the leakage of air into the gas. At temperatures above 100° C. the whole of the water will be in the condition of vapour, and will behave exactly like any other gas. At temperatures below 100° C. part of the steam will condense, but a certain amount of water vapour will always remain in the gas, the amount depending on the temperature, as at every temperature water can exist in the condition of gas or vapour till it exerts a definite pressure.

Table I.* gives the proportions of steam and water vapour that will be present in a given space at each degree from 0° C. to 100° C.

The specific gravity of steam or water vapour at 0° and 760mm. is ·622(air=1), and one cubic foot weighs ·0502lbs.

As its specific heat is ·4805, the presence of water vapour causes a large amount of heat to be carried away in the products of combustion.

There may also be present a considerable amount of condensed water in the form of fine globules or mist.

Tarry Matters.—These are mostly dense hydrocarbons of very uncertain composition, which condense at moderate temperatures to tarry and oily liquids. They burn with a luminous, often smoky, flame. On being passed over red hot coke or red hot brickwork they are broken up into carbon, which is deposited, and permanent gases, largely marsh gas and hydrogen. The influence of tarry matters on the quality of gas will be discussed later.

THE AIR.

In practice, fuels are always burnt in air. The air consists of a mixture of oxygen and nitrogen with small quantities of other substances, some inert gases resembling nitrogen, which have been recently discovered, but which, since they have no influence on combustion, can be neglected, carbon dioxide, very minute quantities of ammonia, acid gases, &c., and a considerable quantity of water vapour. For all practical purposes dry air may be taken as containing—

	By weight.	By volume.
Oxygen	23	... 21
Nitrogen	77	... 79
	100	100

---

* For Table I see Appendix.

These proportions are very nearly constant, and the other constituents are present in such small quantities as to be of no importance when the air is considered merely as a supporter of combustion. Carbon dioxide, the impurity present in largest proportion, rarely exceeds ·04 per cent.

The amount of moisture present is very variable. The amount of water vapour which the air is capable of holding at different temperatures is given in Table I, but the air is rarely saturated, so that the amount of water present at any time can only be guessed unless it be determined by analysis, or unless the dew point, *i.e.*, the temperature at which the air would be saturated with the moisture present, be determined by a hygrometer.

The presence of water does not alter the proportions in which the constituents of the air are present, but simply displaces some of the air, the relative volumes of air and water being proportional to the pressure they exert.

Thus for instance air at 15°C. saturated with moisture would contain in 100 volumes—

Water vapour ...	1·67	
Air	98·33	Oxygen, 20·65 Nitrogen, 77·68

Variation in the Volumes of Gases.—It must be borne in mind that the volume of a gas changes very considerably with changes of temperature and pressure, and therefore that when weights of gases are compared it must always be under the same conditions of temperature and pressure. As, however, all gases are affected in the same proportion, the percentage composition by weight or volume is not altered, however much the actual weight of a given volume may vary.

When weights of gases are given it is always the weight of a standard volume under normal temperature and pressure, *i.e.*, 0° C. (32° F.), and 760 mm. of mercury (30″) barometric pressure. Volumes of gases at any other temperature or pressure must always be reduced by calculation to these conditions.

The pressure to which a gas is subjected is measured either by the height of a column of mercury which it will support, measured in inches or millimetres, or, what is the same thing, if it be at the atmospheric pressure, the height at which the barometer stands, or by the pressure in pounds or other units per square inch to which it is subjected above the atmospheric pressure*.

Boyle's Law.—The law according to which the volume of a gas varies with the pressure to which it is subjected is called Boyle's law, and may be simply stated—

"The volume occupied by a given mass of any gas is inversely proportional to the pressure to which it is subjected." Or if it is put into the form of an equation: If V be the volume of gas at pressure P, and V' be the volume at pressure P'.

Then $V : V' : : P' : P$.
Whence $V = V'P'/P$ and $V' = VP/P'$.

From these equations the required volumes are easily calculated.

Example 1.—A mass of gas occupies a volume of 10 cub. ft. when the barometer stands at 30in., what volume will it occupy if the pressure falls to 29in.? Obviously with decreased pressure the volume will be larger.

$$V^1 = 10 \times \frac{30}{29} = 10{\cdot}34 \text{ cub. ft.}$$

Example 2.—A mass of gas occupies a volume of 10 cub. ft. when the pressure is 29in., what volume will it occupy at 30in.? Obviously the volume will be less.

$$V = 10 \times \frac{29}{30} = 9{\cdot}67 \text{ cub. ft.}$$

Example 3.—A volume of gas occupies 100 cub. ft. at atmospheric pressure, what volume will it occupy at a

---

*Atmospheric pressure is always measured by the height of the column of mercury which it will sustain, this being called the barometric pressure. It may be measured either in inches or millimetres, and the one is very easily converted into the other.

(1) To convert inches into millimetres, multiply by 25·4.

(2) To convert millimetres into inches, multiply by 0·03937 = about $\frac{1}{25}$.

The barometric pressure measured in inches, multiplied by 0·4908, will give the pressure in pounds per square inch.

The barometric pressure in millimetres, multiplied by 0·01932, will give the pressure in pounds per square inch.

In some cases the pressure is measured in inches of water.

The specific gravity of mercury (water = 1) is 13·58, so that
To convert pressure measured in inches of mercury into pressure measured in inches of water, multiply by 13·58.

To convert pressure in inches of water into pressure in inches of mercury, multiply by 0·07364.

pressure of 5lbs. per square inch above atmospheric pressure? Here again the volume will obviously be less.

$$V' = \frac{100 \times 15}{15 + 5} = \frac{1500}{20} = 75 \text{ cub. ft.}$$

As the volume varies inversely as the pressure it is quite evident that the density, that is, the weight of a given volume, must vary directly as the pressure, so that if

D be the density at a pressure P
and D' " " " " P'

$$D : D' :: P : P'$$

$$\text{and } D = D' \times P/P' \text{ and } D' = D \times P'/P$$

Example 4.—A cubic foot of air weighs ·0807lb. when the pressure is 760mm., what will be the weight of a cubic foot under a pressure of 900mm. Obviously the weight will be greater.

$$D' - \frac{\cdot 0807 \times 900}{760} = \cdot 0955$$

Charles' Law.—The law which connects the change of volume of a gas with change of temperature is known as Charles' law. It may be stated in several ways, the simplest probably being as follows:—

Gases expand $\frac{1}{273}$ of their volume at 0° C. for each 1° C. rise of temperature, and $\frac{1}{491}$ of their volume at 32° Fah. for each 1° Fah. rise of temperature, so that

273 volumes at 0° C.	491 volumes at 32° Fah.
$273 + 1$ at 1° C.	$491 + 1$ at 33° Fah.
$273 + 2$ at 2° C.	$491 + 2$ at 34° Fah.
$273 - 2$ at $-$ 2° C.	$491 - 2$ at 30° Fah.
and in general $273 \pm t$ at $\pm t°$ C.	$491 \pm t$ at $\pm t°$ Fah.

A proportion, therefore, will give the volumes at any temperature. If V be the volume at 0° C., and V' be the volume at $t°$ C.,

$$\text{then } V : V' :: 273 : 273 + t$$

$$V' = V \times \frac{(273 + t)}{273}$$

$$V = \frac{V' \times 273}{273 + t}$$

Example 5.—A mass of gas occupies a volume of 100 cub. ft. at 20° C., what volume will it occupy at 0° C.?

$$V = \frac{100 \times 273}{273 + 20} = \frac{27300}{293} = 93{\cdot}17 \text{ cub. ft.}$$

A temperature 273 below 0° C. or 491−32=459° below 0° Fah. is called the absolute zero, and temperatures measured from this point are called absolute temperatures. So that the absolute temperature in C. degrees will be the temperature measured on the ordinary scale + 273, and similarly the absolute temperature in Fah. degrees will be the ordinary temperature + 459. From the equations given above it follows that the volume of gas is proportional to its absolute temperature.

As the volume is directly, the density or weight of a given volume will obviously be inversely as the absolute temperature.

When corrections have to be made for both temperature and pressure, one correction may be made first, and then the other, using the corrected volumes as the starting point, or both corrections may be made together.

Example 6.—A mass of gas occupies 100 cub. ft. at 10° C. and 750mm. bar., what will its volume be at 0° C. and 760 mm. bar.?

(1) Taking the pressure first. As the pressure is greater the volume will be less.

$$760 : 750 :: 100 : x$$

$$x = \frac{750 \times 100}{760} = 98{\cdot}68$$

(2) As the temperature is less the volume will also be less.

$$273 + 10 : 273 :: 98{\cdot}68 : x$$

$$x = \frac{273 \times 98{\cdot}68}{273 + 10} = 95{\cdot}19$$

or the two equations may be combined and worked as a compound proportion.

$$\left.\begin{matrix} 760 : 750 \\ 283 : 273 \end{matrix}\right\} :: 100 : x$$

$$x = \frac{750 \times 273 \times 100}{760 \times 283} = 95{\cdot}19$$

The student should make himself quite familiar with these methods of calculation.*

---

* See the author's "Home Work on Chemistry." Hall, 1s.

Calculation of the Composition of Gases by Weight.—Analyses of gases are almost invariably stated in percentage by volume, since gases are usually measured and not weighed. For many purposes this is quite convenient, but it is often necessary to calculate the percentage composition by weight, and this can be readily done from an analysis by volume using the data already given.

An example will make the method quite clear. The following figures represent the composition of a sample of producer gas by volume:—

Hydrogen	9·60	Combustible, 34·90.
Marsh gas	3·60	
Ethylene	·10	
Carbon monoxide. ...	21·60	
Oxygen	1·50	Diluent 65·10
Carbon dioxide	5·00	
Nitrogen	58·60	
	100·00	

If we assume the total 100 to stand for 100 cub. ft. then the percentage of each constituent will stand for cubic feet in the hundred, and by multiplying these figures by the weight of 1 cub. ft. (see above) the weight of each constituent in 100 cub. ft. will be obtained.

Hydrogen	9·60	×	·0056	=	·0537lb.
Marsh gas	3·60	×	·0447	=	·1609lb.
Ethylene	·10	×	·0784	=	·0078lb.
Carbon monoxide ...	21·60	×	·0781	=	1·6869lbs.
Oxygen	1·50	×	·0893	=	·1339lb.
Carbon dioxide ...	5·00	×	·1227	=	·6135lb.
Nitrogen	58·60	×	·0784	=	4·5942lbs.
	100 cub. ft.			=	7·2509lbs.

One cubic foot therefore weighs ·072509lb.

From these figures the percentage composition by weight can be easily calculated.

Thus: Of hydrogen 7·2509lbs. of the gas contains ·0537lb., so that the amount in 100lbs. will be—

$$\frac{\cdot 0537 \times 100}{7 \cdot 2509} = \cdot 74 \text{ per cent.}$$

Working out the other items in the same way—

	Per cent. by weight.
Hydrogen	·74
Marsh gas	2·22
Ethylene	·11
Carbon monoxide	23·27
Oxygen	1·85
Carbon dioxide	8·47
Nitrogen	63·34
	100·00

If it be not desired to obtain the weight of 100 cub. ft., but only the percentage composition by weight, the result can be obtained more simply by multiplying the percentage, of each gas, by volume by its specific gravity, and then working out the percentage as before. As the specific gravity of a gas is always half its molecular weight, these numbers—using the approximate molecular weights, which are always round numbers—can be used. It must be noted that for various reasons the densities of gases, as deduced from their chemical composition, do not always agree exactly with the figures determined by direct experiment. The former are taken in most of the calculations given here.

							Per cent.
Hydrogen ...	9·60	×	1	=	9·60	=	·74
Marsh gas ...	3·60	×	8	=	28·80	=	2·22
Ethylene	·10	×	14	=	1·40	=	·11
Carbon monoxide ...	21·60	×	14	=	302·40	=	23·32
Oxygen	1·50	×	16	=	24·00	=	1·85
Carbon dioxide ...	5·00	×	22	=	110·00	=	8·48
Nitrogen	58·60	×	14	=	820·40	=	63·27
					1,296·60		99·99

The small percentage of hydrogen by weight compared with its large percentage by volume is noteworthy.

Amount of Air required for Combustion.—Since the air is usually measured, not weighed, this can be obtained from the volume composition of the gases.

The volume of oxygen required for the combustion of each of the constituent gases has already been given, and by multiplying the percentage of each gas by the volume of oxygen required for the complete combustion of one volume, taking the gas, the analysis of which has already been given, and adding the results, the amount of oxygen required for 100 cub. ft. will be obtained.

	Gas by vol.		Cubic feet.
Hydrogen	9·60	× ·5 =	4·80
Marsh gas	3·60	× 2 =	7·20
Ethylene	·10	× 3 =	·30
Carbon monoxide	21·60	× ·5 =	10·80
Carbon dioxide	5·00	—	—
Nitrogen	58·60	—	—
Oxygen	1·50	—	—
	100·00		23·10

Amount of oxygen required for combustion of 100 cub. ft.	23·10
Less oxygen in gas	1·50
	21·60

As air contains 21 per cent. by volume of oxygen, the volume of air which will contain 21·60 parts of oxygen will be 21·60/21 × 100 = 102·85 cub. ft. at 0° C. and 760mm. bar., and this amount will therefore be required for each 100 cub. ft. of gas at the same temperature and pressure. In practice, an excess of 5 to 50 per cent. over this amount must be allowed.

The same results could have been obtained from the percentage by weight, but in that case the weight of air would have been obtained.

The Volume and Weight of Products of Combustion.—The volume of the products of combustion can be easily obtained, it being of course assumed that they leave the furnace at a temperature above 100° C., so that the water is in the form of steam.

		Vol. of water for one part by vol. of gas.	Vol. of CO_2 for one part by vol. of gas.	Vol. H_2O.	Vol. CO_2.
Hydrogen	9·60	× 1	—	9·60	—
Marsh gas	3·60	× 2	—	7·20	—
	3·60	—	× 1	—	3·60
Ethylene	·10	× 2	—	·20	—
	·10	—	× 2	—	·20
Carbon monoxide ...	21·60	—	× 1	—	21·60
Carbon dioxide ...	5·00	—	—	—	5·00
Nitrogen	58·60	—	—	—	—
Oxygen	1·50	—	—	—	—
				17·00	30·40

So that 100 cub. ft. of the gas will yield—

Water (steam)	17·00 cub. ft.
Carbon dioxide	30·4 ,,
Nitrogen (from gas)	58·6 ,,
,, (from air)	81·25 ,,
Excess of air, say, 25% N. ...	20·31 ,,
,, ,, O. ...	5·40 ,,
Total products of combustion for 100 cub. ft. of gas at the same temperature and pressure ...	212·96

The weight of the products of combustion can be calculated from the volume thus obtained, or from the percentage composition of the gas by weight, the latter being in general the most convenient.

If the weight of the oxygen used be known, the weight of the products of combustion can be easily calculated. It will be the sum of the weights of the gas consumed, the oxygen required for combustion, the nitrogen mixed with this oxygen in the air, and the excess of air mixed with the actual products of combustion.

In the case of the gas already considered the oxygen required by weight for each 100lbs. of gas will be 28·45lbs. − 1·85lbs. present in the gas = 26·60lbs., and the products of combustion for each 100lbs. will be—

Water		11·77
Carbon dioxide		51·46
Nitrogen from gas		63·34
Nitrogen from air		89·04
Excess of air 25%	N ...	22·26
	O ...	6·65

CHAPTER II.

THERMAL UNITS. HEAT OF COMBUSTION. CALORIFIC POWER. CALCULATION OF THE CALORIFIC POWER OF FUELS. CALORIFIC INTENSITY. TEMPERATURE OF COMBUSTION. HEAT CARRIED AWAY BY PRODUCTS OF COMBUSTION. HEATING BY CONTACT AND BY RADIATION.

EVERY chemical change is attended with either the evolution or the absorption of heat, and when in any chemical change the amount of heat evolved is sufficient to cause the production of light, combustion is said to take place. In some cases, however, the action is complex, and whilst the ultimate result is heat evolution, there may be intermediate changes in which heat is absorbed, and the final result will be the algebraic sum of all the thermal changes that have taken place. The heat is always measured in units, the unit being the amount of heat required to produce some definite change, usually to heat a given mass of material through a definite range of temperature. There are thus three things to be selected in order to determine the unit, viz., the substance to be heated, the weight to be taken, and the temperature through which it is to be raised.

The material used is always water; the weight is 1lb., 1 gramme, or 1 kilogramme, according to the system of weights being used, and the temperature is one degree on either the Centigrade or the Fahrenheit scale. As it does not follow that the amount of heat required to raise 1lb. of water 1° will be the same at all parts of the scale, it is necessary to define at what temperature the experiment is to be made. The difference in the amount of heat required for any ordinary range of temperature, say between 0° to 20° C., is so small that for all practical purposes the temperature may be disregarded.

Three units are in use:

(1) The amount of heat required to raise 1lb. of water 1°C. This is called the centigrade unit (C.U.), and will usually be used in this book.

(2) The amount of heat required to raise 1lb. of water 1°F. This is called the British thermal unit (B.Th.U.), and is commonly used by engineers and other practical men in this country.

It will be seen that in these two systems the weight of water is the same, the degree being the only variable, and therefore the value of the units must be directly proportional to the degree used. As the centigrade degree is larger than the Fahrenheit degree in the proportion of 9 : 5, the centigrade unit will bear the same ratio to the Fahrenheit unit.

As an amount of heat expressed in any given set of units will vary inversely as the size of the units, an amount of heat expressed by x C.U. units will be $9/5\ x$ B.Th.U., and any amount of heat expressed by y B.Th.U. will be expressed by $5/9\ y$ C.U.

(3) The amount of heat required to raise one kilogramme of water 1°C. is called a calorie, and that required to raise one gramme of water 1°C. is called a gramme-calorie.

As in most cases the fuel used will be weighed in the same units as the water, the same number will express either the C. U. or the calories.

Evaporative Power.—Engineers very frequently express amounts of heat by the quantity of water at 100°C. (212°F.) which would be evaporated into steam at the same temperature, thus eliminating the difference due to the use of different thermometric scales. This is called the **evaporative power.** In general an evaporative power of 1lb. = 537 C.U. or 966 B.Th.U., but, as will be seen below, the relationship is not always quite so simple.

Heat of Combustion.—The amount of heat evolved by any chemical change, and therefore by the complete combustion of a given weight of a combustible, is fixed and definite, and is quite independent of the rate of combustion, or any other circumstance, so that it is possible to assign fixed heat values to the combustion of any fuel of definite composition. The amount of heat evolved by the combustion of one unit weight (pound, kilogramme, or gramme) of any fuel is called its absolute heating power, or **calorific power,** and is indicated by the letters C.P.

Carbon.—When carbon is burnt with a sufficient excess of oxygen for the combustion to be complete, carbon dioxide is formed, and each 1lb. of carbon in burning will form $3\frac{2}{3}$lbs. of carbon dioxide, and will evolve 8,080 units of heat or the C.P. of C (to CO_2) = 8,080 C.U. 14,544 B.Th.U. Carbon, however, can be burnt in two stages. When the temperature is very high and the oxygen is limited in quantity, or, what comes to the same thing, when the carbon is in large excess, carbon monoxide is formed $C + O = CO$. The combustion of carbon to carbon monoxide only yields about one-third the heat which would be evolved if it were burnt to carbon dioxide. C.P. of C (to CO) = 2,416—say, for all practical purposes 2,400 C.U. = 4,320 B.Th.U.

The difference between the two amounts, *i.e.*, the 8,080 and the 2,400 units, is evolved when the carbon monoxide is burnt to carbon dioxide. Thus 1lb. of carbon forms $2\frac{1}{3}$lbs. of carbon monoxide, and evolves 2,400 C.U.; $2\frac{1}{3}$lbs. of carbon monoxide forms $3\frac{2}{3}$lbs. of carbon dioxide, and evolves 5,680 C.U.; 1lb. of carbon burning to carbon dioxide yields $3\frac{2}{3}$lbs. of the gas, and evolves 8,080 C.U.

As $2\frac{1}{3}$lbs. of carbon monoxide burning to carbon dioxide gives 5,680 units of heat, 1lb. will give $5{,}680 \div 2\frac{1}{3} = 2{,}434$ = say, 2,400 C.U.; so C.P. of carbon monoxide (CO) burning to carbon dioxide CO_2 = 2,400 C.U. = 4,320 B.Th.U.

Carbon can be made to combine with many other elements, and although the union cannot be brought about directly it is possible to determine indirectly the amount of heat evolved. For instance, 1lb. of carbon combining with $\frac{1}{3}$lb. of hydrogen to form $1\frac{1}{3}$lbs. of Marsh gas (CH_4) evolves 1,543 C.U., 1lb. of carbon combining with $\frac{1}{6}$lb. of hydrogen to form $1\frac{1}{6}$lbs. of ethylene (C_2H_4) evolves 664 units, whilst 1lb. of carbon combining with $\frac{1}{12}$th its weight of hydrogen to form $1\frac{1}{12}$lbs. of acetylene not only evolves no heat but absorbs 1,852 units. These figures may be expressed.

Heating power of 1lb. C (to CH_4) = 1543 + C.U.*
,, ,, (to C_2H_4) = 664 + ,,
,, ,, (to C_2H_2) = 1852 − ,,

The importance of these facts will be seen later

---

* The sign + in this connection indicates evolution of heat, and the sign − absorption of heat. The sign is placed after the figures

Hydrogen.—One pound of hydrogen burning evolves 34,180 C.U., so that C.P. of H = 34,180 C.U. = 61,524 B.Th.U.

This is on the assumption that the water formed is condensed, the temperature of the gases produced being reduced below 100°C., which is the condition under which all thermo-chemical experiments are made. If the products of combustion be kept above 100°C., the steam will be kept in the gaseous condition, and the heat evolved will therefore be less by the amount of heat which the steam would give up on condensation, *i.e.*, the latent heat of the steam. The latent heat of steam is 537 C.U., or 966 B.Th.U., and, as each pound of hydrogen forms 9lbs. of water, the heat thus not given out will be 537 × 9 = 4,833 C.U., or 8694 B.Th.U., so that C.P. of H (above 100°C.) = 34,180 − 4,833 = 29,347 C.U., or 61,524 − 8,694 = 52,830 B.Th.U., or, in round numbers, near enough for all practical purposes, 29,300 C.U. = 53,000 B.Th.U.

Calorific Power of Solid Fuels.—The calorific power of a solid fuel can be calculated from these data if it be assumed that the elements in the fuel evolve the same amount of heat which they would do if they were in the free condition. This assumption is certainly not correct, but is near enough to allow of comparative results being obtained for ordinary fuels, as these are made up of more or less unstable compounds which have been formed without a very large absorption or evolution of heat. Such fuels consist mainly of carbon and hydrogen, with sometimes other combustible elements, such as sulphur, &c.

(1) The fuel contains carbon and hydrogen only.

Let C = the percentage of carbon and H the percentage of hydrogen in the fuel, then if the products of combustion be above 100°C.

$$\text{C.P.} = \frac{8080\ C + 29300\ H}{100},$$ or if the steam be condensed

$$\text{C.P.} = \frac{8080\ C + 34180\ H}{100}.$$

(2) If the fuel contains oxygen the case is a little more complex. The oxygen is not present as free gas, but is already in combination, so that it is evident that the elements with which it is combined will be able to

take up so much less oxygen, and therefore evolve so much less heat. The oxygen is assumed to be combined with hydrogen in the proportions required to form water, so that the oxygen, being combined with one-eighth its own weight of hydrogen, that amount will be unavailable for combustion. If C H and O be the percentage of these elements, then

$$\text{C.P.} = \frac{8080\,C + 29300\,(H - \frac{1}{8}\,O)}{100} \text{ in C.U.,}$$

$$\text{C.P.} = \frac{14544\,C + 53000\,(H - \frac{1}{8}\,O)}{100} \text{ in B.Th.U.}$$

assuming the products of combustion not to be condensed. If they are, the higher values for H must be used.

The term $(H - \frac{1}{8}\,O)$ is called the available hydrogen, as it expresses the amount of hydrogen in the fuel which is available for combustion.

Calorific Power of Gaseous Fuel.—The calorific power of a compound gas cannot be calculated from that of the elements, because the formation of a compound is always attended with the evolution of absorption of heat, and the heat of combustion of the compound will be less or greater than that of the elements just by this amount.

For example, Marsh gas CH_4 contains 75 per cent. C and 25 per cent. H. Its heat of combustion calculated from the elements and the water being condensed would be

$$\begin{aligned} C &= \cdot 75 \times 8080 = 6060 \\ H &= \cdot 25 \times 34180 = \underline{8545} \\ &\qquad\qquad\qquad 14605 \end{aligned}$$

The calorific power of Marsh gas as determined by experiment is 13,062, so that the difference is 14,605 − 13,062 = 1,543. In this case the heat evolved by the combustion of the gas is less than that which would be evolved by the combustion of the elements by 1,543 units, which is the amount of heat which would be evolved by 1lb. of C combining with hydrogen to form Marsh gas.

In the case of acetylene, which contains 92·3 per cent. of C and 7·7 per cent. H, the figures would be

$$\begin{aligned} C\ 8080 \times \cdot 923 &= 7457{\cdot}8 \\ H\ 34180 \times \cdot 077 &= \underline{2631{\cdot}8} \\ &\quad 10089{\cdot}6 \text{ C.U.} \end{aligned}$$

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

The heat evolved by the combustion of 1lb. of the gas is 11,941 C.U., so that the gas in this case evolves more heat on combustion than the free elements would do, and the difference, 10,089 − 11,941 = − 1,852, is the heat absorbed by the union of 1lb. of carbon with hydrogen to form acetylene.

It is obvious, therefore, that the calorific power of a mixed gas must be calculated from the compound or elementary gases of which it is a mixture, and not from the elements which they contain considered as being free. As the products of combustion will in practice be always at temperatures above 100°C., the amount of latent heat held by the steam must be deducted from the experimental figures in all cases where the gases contain hydrogen.

The following calorific powers will be needed :—

Marsh gas, methane CH_4.

C.P. = 13062 C.U. = 23512 B.Th.U.

Here for each pound of the gas burnt 2·25lbs. of water will be formed, so that the effective calorific power

C.P. = 13062 − (537 × 2·25) = 11854 C.U.
= 23512 − (966 × 2·25) = 21339 B.Th.U. ;

or, in round numbers for practical purposes, we may say 12,000 C.U. or 21,000 B.Th.U.

Ethylene (C_2H_4).

C.P. = 11143 C.U. or 20057 B.Th.U.

As each pound of the gas produces 1·28lbs. of water, the effective calorific power will be

C.P. = 11143 − (537 × 1·28) = 10456 C.U.

C.P. = 20057 − (966 × 1·28) = 18821 B.Th.U.; say, in round numbers, 10400 C.U. or 18800 B.Th.U.

Acetylene.

C.P. = 11941 C.U. = 21493 B.Th.U.

As each pound of gas produces ·69lb. of water, the effective C.P. will be

C.P = 11941 − (537 × ·69) = 11571 C.U.
= 21493 − (966 × ·69) = 20827 B.Th.U. ; say, in round numbers, 11500 C.U. and 20800 B.Th.U.

From these figures it is easy to calculate the calorific power of any gas. Take, for example, the gas already considered :—

Hydrogen	·74	× 29,300	= 21,682	C.U.
Marsh gas	2·22	× 12,000	= 26,640	,,
Ethylene	·11	× 10,400	= 1,144	,,
Carbon monoxide ...	23·27	× 2,400	= 55,848	,,
Nitrogen	63·34			
Carbon dioxide & oxygen	10·32			
For 100lbs.			105,314	

C.P., *i.e.*, heating power for 1lb. = 1,053·1 C.U.

As 100 cub. ft. of the gas weighs 7·2482lbs., 1,000 cub. ft. will weigh 72·482lbs., and the calorific power per 1,000 cub. ft. will be

76,333 C.U.
= 137,399 B.Th.U.

The calorific power of any other gas known composition can, of course, be calculated in the same way.

Calorific Intensity.—The actual amount of heat evolved by the combustion of any fuel is, as already explained, fixed and definite, but the temperature that can be obtained varies very much with varying conditions, such, for instance, as rate of combustion.

The calorific intensity or pyrometric heating power is the increment temperature that would be produced by the combustion of 1lb. of the fuel. The temperature that can be attained in practice can never be calculated, as the conditions vary so much, but it is possible to calculate what it would be under certain well-defined conditions, and though the results obtained are not attainable in practice, they are very valuable for comparison. The assumption which lies at the base of all such calculations is that all the heat is transferred to the products of combustion, and that therefore there is no loss of heat.

In order to show how the calorific intensity of fuels may vary, and that the calorific intensity is not by any means proportional to the calorific power, the cases of carbon, hydrogen, and Marsh gas will be considered.

Carbon.—One pound of carbon on burning forms 3$\frac{2}{3}$lbs. of carbon dioxide and evolves 8,080 units of heat, so that if there were no loss of heat, and if the heat were all imparted to the products of combustion, the resulting temperature would be

$$\frac{8080}{3{\cdot}67 \times {\cdot}2163} = 10178^\circ \text{ C.}$$

$$\text{or} \qquad \frac{14544}{3{\cdot}67 \times {\cdot}2163} = 18321^\circ\text{F}.$$

·2163 being the specific heat of carbon dioxide.

If, instead of being burnt in oxygen, the carbon were burnt in air, the amount of heat would be the same, but the oxygen used would be mixed with nitrogen, which would remain with the carbon dioxide, and would have to be heated to the same temperature. The $2\frac{2}{3}$lbs. of oxygen required for the combustion of 1lb. carbon would be mixed with $2{\cdot}67 \times \frac{77}{23} = 8{\cdot}9$ parts of nitrogen in the air. So that the C.I. would be

$$\text{C.I.} = \frac{8080}{(3{\cdot}67 \times {\cdot}2163) + (8{\cdot}9 \times {\cdot}2438)} = 2733,$$

and if there be an excess of air, then the excess of air × its specific heat must also be added to the denominator, and would thus further reduce the temperature.

Hydrogen.—In the case of hydrogen the heat evolution is, assuming the temperature of the gases to be above 100°C. 29,300 units, and it yields nine parts of water which as steam has a specific heat of ·4805 ; so that

$$\text{C.I.} = \frac{29300}{9 \times {\cdot}4805} = 6775;$$

and if the combustion be in air, as eight parts of oxygen will be mixed with $8 \times \frac{77}{23} = 26{\cdot}8$ parts of nitrogen,

$$\text{C.I.} = \frac{29300}{(9 \times {\cdot}4805) + (26{\cdot}8 \times {\cdot}2438)} = 269.$$

Therefore, whilst the actual amount of heat evolved by the combustion of carbon and hydrogen is in the ratio of 1 : 3·62, the temperature attainable by the combustion of hydrogen and carbon in oxygen is in the ratio of 1 : ·68.

The calculation of the calorific intensity of some other gases, though not of much practical importance, is instructive.

Carbon Monoxide.

$$\text{C.I.} = \frac{2400}{1{\cdot}57 \times {\cdot}2163} = 7067,$$

or if burnt in air

$$\frac{2400}{(1{\cdot}57 \times {\cdot}2163) + (1{\cdot}91 \times {\cdot}2438)} = 2980$$

Marsh Gas.—The calorific power is 12,000. In oxygen

$$\text{C.I.} = \frac{12000}{(2{\cdot}75 \times {\cdot}2163) + (2{\cdot}25 \times {\cdot}4805)} = 7160.$$

And in air

$$\text{C.I.} = \frac{12000}{(2{\cdot}75 \times {\cdot}2163) + (2{\cdot}25 \times {\cdot}4805) + (13{\cdot}4 \times {\cdot}2438)}$$
$$= 2427.$$

In order to calculate the calorific power of any mixed gas it is necessary to know the nature and weight of the products of combustion, the specific heat, and the amount of oxygen consumed.

To take again the gas dealt with in the previous examples, which contained

Hydrogen	·74
Marsh gas	2·22
Ethylene	·11
Carbon monoxide	23·27
Oxygen	1·85
Carbon dioxide	8·47
Nitrogen	63·34

The calorific intensity in oxygen will be

$$\text{C.I.} = \frac{({\cdot}0074 \times 29300) + ({\cdot}0222 \times 12000) + ({\cdot}001 \times 10400) + ({\cdot}2327 \times 2400)}{({\cdot}5146 \times {\cdot}2163) + ({\cdot}1177 \times {\cdot}4805) + ({\cdot}6334 \times {\cdot}2438)}$$
$$= 3264$$

Or in air

$$\text{C.I.} = \frac{({\cdot}0074 \times 29300) + ({\cdot}0222 \times 12000) + ({\cdot}001 \times 10400) + ({\cdot}2327 \times 2400)}{({\cdot}5146 \times {\cdot}2163) + ({\cdot}1177 \times {\cdot}4805) + (1{\cdot}5238 \times {\cdot}2438)}$$
$$= 1950.$$

Temperature of Combustion.—In order that combustion may take place a certain temperature is necessary, and if the gas be very much diluted, or if a very large excess of air be used, it may happen that the temperature produced by combustion is insufficient to keep the gas alight. This is not uncommon with poor gas, such as blast-furnace gas, and in such cases it is necessary to keep a fire of solid fuel burning on the grate, or to keep up the temperature in some other way.

Heat Carried Away by the Products of Combustion.—It is always essential, except in certain cases where a forced draught is used, to allow the products of combustion to leave the furnace at a high temperature, in order that a good draught may be produced, and thus a large amount of heat may be carried away. If the temperature of the gas be known, it is easy to calculate the amount of heat carried. Thus in the gas which has already been considered, for each pound of gas the products of combustion are :—

Carbon dioxide...	·5146lbs.	× ·2163 =	·1113 C.U.
Water	·1177lbs.	× ·4805 =	·0565 ,,
Nitrogen	·6334lbs.	× ·2438 =	·3715 ,,
,, ...	·8904lbs.		
			·5393 ,,

If the weight of each gas be multiplied by its specific heat, the sum will be the amount of heat carried away by each pound of fuel consumed—in this case ·5393 units of heat for each 1°C. of temperature of the gas above the temperature of the air; or if the gases were at 200°C. (the air being at 0°), a very moderate temperature, the loss would be 107·8 units, or 10·8 per cent. of the heating power of the fuel. In practice the amount of heat carried away will be much larger, as there will always be considerable excess of air

Heating by Contact and by Radiation.—The way in which the heat is to be applied to a certain extent modifies the value of the gas. A non-luminous flame, such as that of hydrogen or carbon monoxide, may have a very high temperature and be very efficient for heating where the flame can come in contact with the surface being heated, but it radiates heat very feebly, and therefore is not efficient where heating by radiation is required. On the other hand, a luminous flame loaded with hot carbon is not very efficient where contact heating is required, and deposits soot very readily, but it is excellent for heating by radiation. As heating by radiation is far more extensively used than heating by contact, a gas which burns with a luminous flame is in general better than one the flame of which is non-luminous.

CHAPTER III.

NATURAL GAS. COAL GAS. OIL GAS. ACETYLENE.

Natural Gas.—This gas is of little importance in this country. A brief mention of it may, however, be of interest, in order that it may be compared with other gases used for fuel. The following may be taken as an average analysis by volume :—

Carbon dioxide	·6
Carbon monoxide	·6
Oxygen	·8
Ethylene..................	1·0
Ethane ($C_2 H_6$)	5·0
Methane ($C H_4$).........	67·0
Hydrogen	22·0
Nitrogen..................	3·0
	100·0

Percentage of combustible gas, 95·6

It will be seen, therefore, that the gas is composed almost entirely of combustible gases, there being only 4·4 per cent. of diluents, and its calorific power will therefore be very high. Owing to the large quantity of ethylene, it burns with a very luminous flame. The percentage composition by weight will be :—

Carbon dioxide...	·6	×	·1227	=	·0736 ...	1·82
Carbon monoxide	·6	×	·0781	=	·0469 ...	1·16
Oxygen	·8	×	·0893	=	·0714 ...	1·77
Ethylene	1·0	×	·0784	=	·0784 ...	1·94
Ethane	5·0	×	·0837	=	·4185 ...	10·35
Methane	67·0	×	·0447	=	2·9949 ...	74·09
Hydrogen	22·0	×	·0056	=	·1232 ...	3·05
Nitrogen	3·0	×	·0784	=	·2352 ...	5·82
					4·0421	100·00

Coal Gas.—Coal gas, as is well known, is prepared by the destructive distillation of coal. The gases are not present in the coal, but are produced by destructive action of the heat, whence the name destructive distillation.

The gas consists almost entirely of combustible gases, and burns with a highly luminous, often smoky, flame. The composition of the gas varies considerably according to the coal used and conditions of distillation, but the lighting power varies much more than the heating power, probably because the dense hydrocarbons, which are the principal illuminating constituents, are somewhat unstable, and tend to break up at high temperatures. The principal illuminating constituent is ethylene, but this is always associated with larger or smaller quantities of its higher homologues of the olefine, or $C_n H_{2n}$ series, and hydrocarbons of lower series, such as the acetylene $C_n H_{2n-2}$ series. The distillation also produces large quantities of liquid hydrocarbons which are removed by condensation and washing, and which are known collectively as coal tar, and also gaseous and liquid compounds containing sulphur, viz., hydrogen sulphide $H_2 S$ and carbon disulphide CS_2, which are removed when the gas is to be used for illuminating purposes. Some of the nitrogen present in the coal is given off as ammonia which is dissolved in the water used for washing the gas, and is afterwards recovered and converted into ammonium sulphate. There are two varieties of coal gas, that made from ordinary bituminous gas coal and that made from cannel coal, the latter containing a much larger percentage of the olefines, and therefore having much greater illuminating power.

The following analyses may be taken as illustrating the composition of coal gas by volume.

	(1)	(2)	(3)
Hydrogen	51·80	48·32	36·10
Carbon monoxide	9·10	4·63	6·80
Marsh gas	31·80	39·55	37·80
Olefines	5·20	5·18	16·40
Nitrogen	2·10	2·32	2·90
	100·00	100·00	100·00

(1) and (2) London gas, (3) cannel gas.

It will be seen that the gas consists almost entirely of combustibles, there being only about 2 or 3 per cent. of diluents, and that the great bulk of it is gases that burn with a non-luminous flame, though by the high temperature they produce they assist in making luminous the carbon separated from the ethylene.

Taking an average analysis as : *

							By Weight.
Hydrogen ...	48	×	·0056	=	·2688	=	8·59 %
Carbon monoxide	8	×	·0781	=	·6248	=	19·96 ,,
Methane ...	36	×	·0447	=	1·6092	=	51·41 ,,
Ethylene ...	3·8	×	·0784	=	·2979	=	9·52 ,,
Nitrogen ...	4·2	×	·0784	=	·3293	=	10·52 ,,
					3·1300		100·00

1,000 cub. ft. of the gas would weigh 31·31lbs.

The calorific power can be easily calculated :—

Hydrogen	·0859	×	29300	=	2516·9
Carbon monoxide	·1996	×	2400	=	479·0
Methane	·5141	×	12000	=	6169·2
Ethylene	·0952	×	10400	=	990·1
Nitrogen	·1052		—		—
					10155·2

and as 1,000 cub. ft. weigh 31·3lbs., the heat evolved by the combustion of 1,000 cub. ft. will be 317858 C.U., 572144 B.Th.U. Such a gas will require a very large amount of oxygen for its combustion.

Hydrogen	48	×	·5	=	24
Carbon monoxide	8	×	·5	=	4
Methane	36	×	2	=	72
Ethylene	3·8	×	3	=	11·4
Nitrogen	4·2		—		—
					111·4

100 volumes of the gas will thus require 111·4 volumes of oxygen or 530·5 volumes of air. The weight of the products of combustion will also be very large.

The advantages of coal gas as a fuel are :—

(1) Owing to its high calorific power, a large amount of heat can be obtained from a small quantity of gas, and therefore for many small operations where cost of the fuel is of small importance it is of great value, and is very largely used.

---

* J. S. C. I., 1888, p. 20.

(2) It burns with a very luminous flame, and thus is well suited for heating by radiation where the flame is not brought in contact with any cold surface.

Against these advantages are to be set two disadvantages:—

(1) The cost is very great. Assuming gas to be supplied at 2s. 6d. per 1,000 cub. ft., the cost per 1,000 units of heat will be in pence $\frac{30000}{317858} = \cdot094$.

Supposing a coal with a heating power of 8,000 to be obtainable at 15s. a ton, the cost per 1,000 units of heat obtained from it would be

$$\frac{15 \times 12}{2240 \times 8000} = \frac{180 \times 1000}{17920000} = \cdot01\text{d.}$$

In some cases the convenience of the gas is so great that even with this great difference in cost its use is advantageous, but it is quite obvious that such cases will not be very numerous.

(2) The gas has a great tendency to smoke and to deposit soot, a defect common to all highly luminous gases, hence burners must be so arranged that there is a large surface exposed to the air. This prevents the use of large flames, and therefore renders the gas unsuitable for use on a large scale. When the burning gas comes in contact with a cold surface, combustion is always incomplete, soot is deposited, and thus the efficient heating power is very much reduced. The soot is a very bad conductor, and is extremely troublesome.

In order to avoid the difficulty, when coal gas is used as a fuel it is usually diluted with air, as in the Bunsen burner, till its richness is reduced and the flame becomes non-luminous. It will be seen, however, that this is to sacrifice the chief advantages of coal gas and to reduce it to the rank of the cheaper non-luminous producer gas. Coal gas is largely used for domestic heating in this way, not because it is the cheapest or best gas for the purpose, but because it is the only one which is available.

The high cost of coal gas is due to several reasons:—

(1) When the coal is distilled only a small proportion of the fuel, rarely 30 per cent., is converted into gas, the greater part being left as a residue or coke. The coke is

of course a by-product, and has a relatively small value because the coals which are best for gas making usually yield an inferior coke, which is often very high in ash.

(2) The coals are selected because of the high illuminating power of the gas they yield, and are therefore relatively costly.

(3) A considerable quantity of fuel is used in the distillation.

(4) As the gas is to be used mainly for illuminating purposes, and therefore will be burnt in rooms often with little ventilation, and often containing articles that might be damaged by sulphur oxides, the gas must be thoroughly freed from sulphur, which is a somewhat costly process.

Oil Gas.—This gas is made by the destructive distillation of mineral oils by very rapid heating to a high temperature. The composition of the gas varies considerably. the following analysis will serve as an illustration of its composition :—

	By Volume.	By Weight.
Hydrogen	31·61	4·43
Carbon monoxide	·14	·27
Luminous hydrocarbons‡	16·29	31·96
Marsh gas	46·17	51·77
Nitrogen	5·06	9·93
Oxygen	·73	1·64

It will be seen that the gas resembles coal gas in some respects. Owing to the high percentage of ethylene, it burns with a very luminous flame, and shows a very great tendency to produce smoke and deposit soot. It requires a very large quantity of air for its combustion, and is quite unsuited for use as a fuel gas under ordinary conditions, even if its cost were not prohibitive.

Assuming the luminous hydrocarbons to be ethylene, the calorific power of the gas and the amount of oxygen required for combustion would be :—

---

‡ Chiefly Ethylene.

		C P	O per 100 cub. ft.
Hydrogen..........	·0443	1298·	15·80
Carbon monoxide ..	·0027	6·5	·07
Ethylene	·3196	3323·8	48·87
Marsh gas	·5177	6212·4	92·34
Nitrogen	·0993	—	—
Oxygen............	·0164	—	—
		10840·7	157·08
Less oxygen present..	—	—	73
	1·0000		156·35 cf or air 744·5 cf.

According to Mills & Rowan, the amount of gas produced by the process in which the oil is broken up by being allowed to fall into retorts filled with red-hot bricks or similar processes is about 150 cub. ft. per gallon of oil. Assuming the oil to have a specific gravity of ·9200, one gallon of the oil would weigh about 9·2lbs. and the yield would be 36,522 cub. ft. per ton.

Acetylene.—Closely allied to these highly luminous gases, though made by quite a different process, is acetylene. When a mixture of lime and carbon is heated to a very high temperature by the electric arc, decomposition takes place, carbon monoxide is evolved, and a carbide of calcium is left.

$$CaO + 3C = CaC_2 + CO.$$

When this carbide is treated with water acetylene is evolved,

$$CaC_2 + 2H_2O = CaO, H_2O + C_2H_2$$

Acetylene burns with a more luminous flame than any other hydrocarbon. The gas is, however, quite unsuited for use as fuel. It is very unstable, its decomposition evolving a considerable amount of heat, and at high temperatures it may even decompose with explosion. There is a great tendency to the separation of carbon during combustion, and consequent production of smoke, and when used for lighting it requires the use of very small burners and a copious supply of air.

The following series of analyses of acetylene made from calcium carbide are given by Prof. Lewes in his Cantor lectures on acetylene § :—

---

§ Journal of the Society of Arts, vol. 47 (1899), p. 137.

	American Carbide.	German Carbide.	Swiss Carbide.
Phosphoretted hydrogen ...	0·05	0·03	0·03
Sulphuretted hydrogen......	0·08	0·07	0·10
Ammonia	0·08	0·07	0·11
Hydrogen	0·09	0·07	0·16
Nitrogen	0·42	0·20	0·34
Oxygen	0·87	0·55	0·63
Acetylene	98·41	99·01	98·63
	100·00	100·00	100·00

CHAPTER IV.

SIMPLE PRODUCER GAS. STEAM ENRICHED PRODUCER GAS. COAL ENRICHED PRODUCER GAS. CARBON DIOXIDE IN PRODUCER GAS. EFFICIENCY OF A GAS PRODUCER. LOSS OF HEAT IN GAS PRODUCER.

IN all gases produced by destructive distillation a considerable portion of the fuel used is left as a solid non-volatile residue, and unless this can be economically used the gas must be very costly. In order to prepare a gas for use as fuel at cheap rate the whole of the fuel must be gasified, and this is done in the manufacture of producer gas. When carbon in any form, for example, coke or charcoal, is burnt in a limited supply of air at a high temperature the product of combustion is carbon monoxide, and this is combustible. If, therefore, the fuel be thus burnt all the carbon is converted into combustible carbon monoxide, and no residue is left except the non-combustible ash.

In order that theory of the manufacture of producer gas may be clearly understood it will be best to describe some simple form of gas producer, and consider what changes take place in it, and then to consider the commercial forms of producer in use to-day. For this purpose the producer designed by Bischof and once used in the Hartz may be taken. It is shown in section in Fig. 1.

It will be seen from the sketch that it is little more than a deep fireplace—indeed, this is the character of all simple producers. The fuel is supplied at the top, the ashes are poked out through the bars at the bottom, and the gases are drawn off near the top.

Simple Producer Gas.—In a gas producer almost any fuel may be used, but at the outset it will be best to consider the case of a more or less pure carbon such as coke or charcoal, as the reactions which take place are simpler in this case than in any other Coke is now rarely used in practice except when the gas is to be used for gas

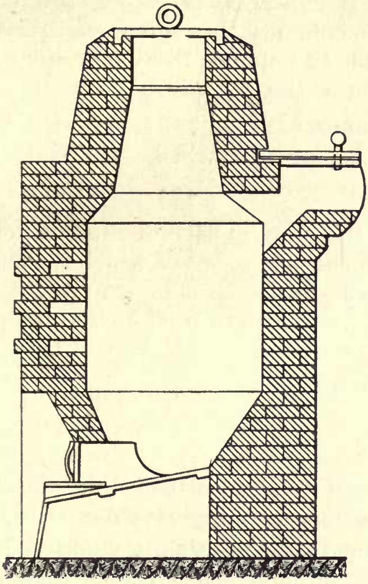


FIG. 1.—BISCHOF PRODUCER.

engines, and therefore the absence of tarry matter is essential. Suppose the producer figured above to be full of coke or charcoal which is burning. As the air passes in between the bars combustion will take place and carbon dioxide will be formed, which will, however, if the temperature be high enough and the quantity of coke large enough, be at once reduced to carbon monoxide, so that the net result will be the combustion of the carbon to carbon monoxide ($C + O = CO$), in which form it leaves the producer. Such a gas may be called simple producer gas, to distinguish it from the steam and hydrocarbon enriched gases which are usually used.

The air consists of oxygen and nitrogen mixed in approximately the following proportions :—

	By Volume.	By Weight.
Oxygen	21 ...	23
Nitrogen	79 ...	77

When carbon burns to form carbon monoxide, the carbon monoxide produced occupies twice the volume of the oxygen which it contains, therefore 100 volumes of air will yield 79 volumes of nitrogen, passing through unchanged, and 42 volumes of carbon monoxide, so that the composition of the gas will be—

Carbon monoxide ...	42	=	34·7 per cent.
Nitrogen	79	=	65·3 ,,
	121		100·0

provided that there be no carbon dioxide left unreduced. As in this case the two gases of which the gas is composed have almost the same specific gravity, the percentage composition by weight will be the same as that by volume, so that the composition by weight will be—

Carbon monoxide...	34·7
Nitrogen	65·3
	100·0

1,000 cub. ft. of the gas will weigh about 78lbs., and one ton of carbon would give about 190,000 cub. ft. of gas. Assuming the coke used to contain 90 per cent. of carbon, one ton of coke would yield about 171,000 cub. ft. of gas.

The heating power of the gas will necessarily be small, as 65·3 per cent. of it is not combustible, and the remaining portion, which is combustible, has a low calorific power.

The calorific power of the gas will be ·347 × 2,400 = 832·8 CU = 1,499 B.Th.U., and 1,000 cub. ft. of the gas weighing about 78lbs., evolve 64,958 C.U., or 116,925 B.Th.U.

One pound of carbon will have combined with 1·33lbs. of oxygen and produced 2·33lbs. of carbon monoxide, which, mixed with the nitrogen, will give 6·71lbs. of simple producer gas.

	C.U.	B.Th.U.
1lb. of carbon burning to carbon dioxide would give	8,080	14,500
6·71lbs. of simple producer gas burning to carbon dioxide will give	5,588	10,058
Difference	2,492	4,442

This difference is just about 31 per cent. of the total heat which the solid fuel could evolve on combustion, and therefore the conversion of the fuel into gas has been attended with a loss of 31 per cent. of the heating power of the fuel.

This loss of heat is not, however, an absorption. It is not of the character of latent heat, or heat absorbed in doing work, as when water is boiled into steam, which heat can be recovered by reversing the change by condensing the steam back into water, but it is heat evolved, but evolved in the producer, where it is only to a small extent useful, instead of in the furnace, where it is wanted. What becomes of this heat will be fully considered later.

Simple producer gas can be used in a few cases, but its low heating power and the large loss of heat in its production are great disadvantages.

The gas can, however, be enriched by the use of coal instead of coke in cases where the products of distillation of the coal are not objectionable, and it can also be enriched and at the same time the expenditure of heat in its production can be reduced by using steam in conjunction with the air.

Steam Enriched Gas.—When steam is blown over red-hot coke it is decomposed thus: $C + H_2O = CO + 2H$, so that the steam yields its own volume of carbon monoxide and its own volume of hydrogen.

Each pound of carbon burnt by steam yields the same volume of carbon monoxide which it would do if burnt in air, but this, instead of being mixed with about twice its own volume of nitrogen, which is useless, is mixed with its own volume of hydrogen, which is combustible, and has a high calorific power. Thus the gas is enriched by the addition of hydrogen and at the same time by a reduction in the percentage of nitrogen.

The decomposition of steam by carbon is made up of two parts, each of which will have its own thermal value; first, the formation of a molecule of carbon monoxide, and second, the decomposition of a molecule of water. The first of these will evolve and the second will absorb heat.

It will be seen that for each pound of hydrogen liberated 6lbs. of carbon will be consumed, and will produce 14lbs. of carbon monoxide. The thermal changes can be thus expressed, taking the figures in round numbers :—

	C.U.	B.Th.U.
Heat absorbed in separating 1lb. of hydrogen from the oxygen with which it was combined in the water	29,000−	52,200−
Heat evolved in the combustion of 6lbs. of carbon to carbon monoxide	14,400+	25,920+
Heat absorbed by the reaction for each 6lbs. of carbon oxidised...	14,600−	26,280
Heat absorbed for each pound of carbon oxidised	2,433−	4,380−

It is obvious that the amount of steam which can be used is limited, for if steam alone were used, unless heat were supplied from some external source, the fuel would soon be cooled below the temperature at which the decomposition could take place, and the reaction would cease.

If air and steam be blown in together the combustion of the carbon by the air will supply the necessary heat to keep up the combustion, and as the combustion of carbon by air takes place at a much lower temperature than the decomposition of steam, if excess of steam be used it will not stop the combustion altogether, but by lowering the temperature will cause the production of a large quantity of carbon dioxide, and at the same time the excess of steam will pass through undecomposed, and thus will remain mixed with the gas.

It is obvious that if air and steam be supplied together and the steam is to be decomposed the quantity of air must be sufficient to keep up the temperature of the fuel to the point at which decomposition of the steam can take place. Since each pound of carbon burnt by steam absorbs 2,433 C.U., and each pound burnt by air evolves 2,400 C.U., it is clear that if there were absolutely no loss of heat the quantity of carbon burnt by air must be about the same as that burnt by steam. In practice loss of heat cannot be avoided, and to compensate for this a much larger quantity of carbon must be burnt by air.

In order to see the effect of the use of steam a case may be assumed in which for every 5lbs. of carbon consumed 4lbs. is burnt by air and 1lb. by steam, proportions not very far removed from those in actual practice.

For simplicity in expressing the results 12 grammes will be taken as the unit. Twelve grammes of carbon burnt by air gives 22·4 litres of carbon monoxide, whch will be mixed with 42·1 litres of nitrogen, and 12 grammes of carbon burnt by steam will give 22·4 litres of carbon monoxide and 22·4 litres of hydrogen, so that

48 grammes of carbon burnt by air will give—

Nitrogen = 42·1 × 4 = 168·4
Carbon monoxide = 22·4 × 4 = 89·6

12 grammes of carbon burnt by steam will give—

Carbon monoxide ... ... 22·4
Hydrogen ... ... 22·4

And the composition of the resulting gas will be (by volume)—

Carbon monoxide... 37·0 per cent. 44·4 per cent.
Hydrogen... ... 7·4 ,, combustible.
Nitrogen ... ... 55·6 ,,

The gas is therefore much richer in combustibles than simple producer gas.

The composition of the gas by weight will be—

Carbon monoxide	39·73
Hydrogen	·57
Nitrogen	59·70
	100·00

Owing to its extreme lightness the percentage of hydrogen by weight is very small.

The calorific power of the gas will be—

·3973 × 2400 ... ... = 953·5 C.U.
·0057 × 29300 ... ... = 167·0 C.U.
1120·5 C.U.

as against 832, an increase of 287 C.U., or about 35 per cent.

In B.Th.U the figures will be

·3973 × 4320 = 1716·3
·0057 × 53000 = 302·1
2018·4 B.Th.U.

One ton of carbon thus burnt will yield about 181,000 cub. ft. of gas, or, assuming the coke to contain as before 90 per cent. of carbon, one ton will yield about 163,000 cub. ft.

One thousand cubic feet of the gas will weigh about 72·9lbs., and will evolve on combustion about 81,684 C.U., or 147,141 B.Th.U.

One pound of the gas will contain ·1705lb. of carbon. This if completely burnt to carbon dioxide would give—

·17 × 8080 = 1374 C.U. = 2473 B.Th.U.

One pound of the gas gives—

1120·5 C.U. = 2018·4 B.Th.U.

Loss... ... 253·5 454·6

Or only about 20 per cent. of that which the solid fuel would give.

Thus by the use of steam in the proportion assumed the gas has been enriched by about 35 per cent., and the loss of heat in its production has been reduced from 31 to 20 per cent., a saving of about 11 per cent.

The action of the steam can be easily explained. Owing to the absorption of heat by the decomposition of the steam less heat is evolved in the producer, and an additional amount equal to that thus saved can be evolved in the furnace. The steam thus acts as a carrier of heat, and, whilst it cannot increase the total amount of heat evolved, it alters its distribution. The larger the proportion of steam that can be used the better, but for the reasons explained above excess must be carefully guarded against.

Coal Enriched Gas.—The gas may be further enriched by the use of coal instead of coke. The coal is then distilled at the top of the producer by the heat of the ascending gas, the otherwise waste heat being thus utilised, and the producer gas is enriched by the addition of the coal gas produced by the distillation.

Assume the producer to be charged with a coal yielding, say, 65 per cent. of fixed carbon and 5 per cent. of ash, and giving, say, 10,000 cub. ft. of gas per ton, the gas containing by volume, say, 50 per cent. of hydrogen, 40 per cent of hydrocarbons, and 10 per cent. of carbon monoxide. It will not be difficult to see the nature of the gas which will be produced. It may be assumed that steam is used as before. As there is only 65 per cent. of fixed carbon in the fuel, it will yield 181,000 × ·65 = 117,650 cub. ft. of producer gas per ton of coal, which will have the same composition as that already given, and, in addition, there will be 10,000 cub. ft. of coal gas having the composition given above, so that the 128,000ft. of gas will contain—

From the coal gas ...	Hydrogen ...	5,000
	Hydrocarbons ...	4,000
	Carbon monoxide...	1,000
From the producer gas	Hydrogen	8,706
	Carbon monoxide...	43,530
	Nitrogen	65,414

This will give the composition by volume—

Hydrogen	10·8
Hydrocarbons	3·1
Carbon monoxide	34·9
Nitrogen	51·2
	100·0

Assuming the hydrocarbons to be all Marsh gas the percentage composition by weight will be—

Hydrogen	·87
Hydrocarbons (Marsh gas)	1·98
Carbon monoxide	39·38
Nitrogen...	57·76

The calorific power will be, in Centigrade units—

Hydrogen	·0087 × 29300 =	254·9
Marsh gas	·0199 × 12000 =	238·9
Carbon monoxide ...	·3938 × 2400 =	945·1
		1438·8

In British thermal units—

Hydrogen... ...	·0087 × 53000 =	461·1
Marsh gas... ...	·0199 × 21000 =	417·9
Carbon monoxide...	·3938 × 4320 =	1701·2
		2580·2

1,000 cub. ft. of the gas will weigh about 69·5lbs. and will evolve on combustion 99,996 C.U., or 179,323 B.Th.U.

The following analyses of producer gas will serve to show how the composition of gas, in practice, agrees with the examples worked above. When coal is used, calculations as to the composition of the gas can only be rough approximations owing to variations in the quantity and composition of the coal gas, with the quality of the coal used.

EXAMPLES OF PRODUCER GAS.

	(1)	(2)	(3)	(4)	(5)
Hydrogen	8·60	12·13	10·90	19·43	12·60
Hydrocarbons	2·40	2·00	1·28	2·66	3·50
Carbon monoxide ...	24·40	26·40	27·00	16·15	20·40
Carbon dioxide ...	5·20	9·16	4·50	11·53	5·50
Nitrogen	59·40	50·31	56 32	50·23	58·00
Per cent. combustibles ..	35·40	40·53	39·18	38·24	36·50

Carbon Dioxide in Producer Gas.—It will be noticed that all the above analyses show in addition to the constituents already considered the presence of carbon dioxide. This gas is very objectionable, and if present in larger quantities than 4 or 5 per cent. shows either badly designed producers or careless working, very frequently by use of excess of steam, and therefore undue cooling. The effect of the carbon dioxide is threefold.

(1) It represents its own volume of carbon monoxide burnt in the producer, and therefore so much the less combustibles and the more non-combustibles present in the gas.

(2) Since it contains twice as much oxygen as carbon monoxide it adds an additional amount of nitrogen, which is useless, to the gas.

(3) It causes the useless evolution of a large additional amount of heat in the producer.

The extent to which carbon dioxide deteriorates the value of the gas can be seen by considering the case of simple producer gas. Suppose that in such a gas instead of all the carbon being burnt to carbon monoxide one-fifth of it leaves the producer as carbon dioxide. Since carbon dioxide occupies the same volume as carbon monoxide containing the same amount of carbon, 60 grammes of carbon would give—

4 × 12 grammes of C. burnt to carbon-monoxide 4 × 22·4 = ...	89·6 litres
1 × 12 grammes of C. burnt to carbon dioxide 1 × 22·4 = ...	22·4 ,,
Nitrogen from air yielding 67·2 litres of oxygen required for the combustion ...	252·8 ,,
	364·8 ,,

The percentage composition by volume will be :—

Carbon monoxide	24·6
Carbon dioxide	6·1
Nitrogen	69·3

By weight the composition would be :—

Carbon monoxide ...	23·7
Carbon dioxide	9·3
Nitrogen	67·0
	100·0

The calorific power would be :—

In C. units ... ... ·237 × 2400 = 568·8
In B.Th. units ... ... ·237 × 4320 = 1024

The gas contains 12·69 per cent. of carbon, or in 1lb. ·1269lb., and this burnt completely would yield—

·1269 × 8080 = 1025·3 C.U.
·1269 × 14500 = 1840·0 B.Th.U.

The loss of heat in the producer, therefore,

1025 — 568 = 457 C.U.
1840 — 1024 = 816 B.Th.U.

The presence of 6·1 per cent. of carbon dioxide by volume—an amount well within that often found in practice in the gas—represents a loss of one-fifth of the carbon consumed, a reduction of the calorific power of the gas by about 264 C.U., or about 32 per cent., and an increase of loss of heat in the producer from 31 to 46 per cent. This obviously means a very large waste of fuel.

The presence of carbon dioxide in the gas is always due to one of three causes :—

(1) Too low a temperature in the producer, generally produced by the use of too large a quantity of steam.

(2) The layer of hot fuel not being sufficiently thick to allow of the complete decomposition of the carbon dioxide produced.

(3) The leakage of air into the producer above the zone of combustion. This is, however, of rare occurrence.

Efficiency of Gas Producers.

The object of the gas producer is to convert the solid fuel into gas, and this (as already described) always involves the expenditure of some heat, so that the heating power of the gas will always be less than that of the solid fuel from which it is derived. The smaller the difference—that is, the nearer the heat obtained by the combustion of the gas approaches that which could be obtained by the direct combustion of the solid fuel from which the gas is made—the greater will be the efficiency of the producer.

If H be taken as the heating power of 1lb. of coal or other fuel from which gas is being made, H' the heating power of the gas derived from 1lb. of the fuel, and H'' the heat evolved in the producer, then obviously, if all the fuel be consumed, $H = H' + H''$.

The efficiency of the producer will be the ratio of $H' : H$ or $\frac{H'}{H}$, so that it may be written $E = \frac{H'}{H}$.

If there were no heat evolved in the producer, then obviously H' would be equal to H, and the ratio would be 1. This can never be attained, but the nearer it is approached the more efficient is the producer.

To take as an example the simple producer gas made from charcoal without steam, $H = 8080$ and $H' = 5588$, so that $E = \frac{5588}{8080} = \cdot691$, or 69·1 per cent.; whilst in the case of the example of steam-enriched gas considered above $H = 8080$ H' 6591, so that $E = \frac{6591}{8080} = \cdot 81$, or 81 per cent.; and in the case of a coal-fed producer, it may be higher still. In practice the efficiency will rarely be above 80 per cent., but with well-constructed producers and careful working it should reach that, or even 85 per cent.

The efficiency will obviously be reduced by any action which tends to cause the evolution of heat in the producer, and therefore it is very much reduced by the presence of carbon dioxide in the gas.

It is assumed in the above statement that the gas is burnt cold. If it is used hot in such a way that the sensible heat of the gas can be utilised the efficiency will be higher, as all the heat evolved in the producer will not be lost.

It is quite obvious that the minimum amount of heat that must be evolved in the producer to keep the production of gas going on will be that required to balance the sources of loss of heat and keep the producer at the required temperature.

Losses of Heat in Producer.—There are several sources of loss of heat in the producer, none of which can be completely prevented, but all of which should be reduced to a minimum.

(1) Heat carried off by the escaping gas. The gas always leaves the producer at a high temperature, sometimes as high as 600° C. (1,000° F.), and thus a large amount of heat may be carried away. One pound of carbon will give about 6·7lbs. of producer gas with a specific heat of about ·245, so that the heat carried away will be 6·7 × ·245 = 1·64 units for each degree of temperature of the escaping gases per pound of fuel, or at 600° C. 985 units. As each pound of carbon can only evolve 8,080 units, this will be about 12 per cent. of the total available heat. Ten per cent. is a very usual amount to be thus carried away, but it may be much higher, especially if undecomposed steam be passing through the producer or if the gas contain a large quantity of hydrogen, as both of these have a very high specific heat. For economical working, therefore, unless the gas is to be used hot and the sensible heat thus utilised, the temperature of the escaping gases must be kept as low as possible. With most forms of producer in use it is, however, impossible to keep the escaping gas at a low temperature without unduly cooling the mass of fuel, which is likely to produce greater evils.

(2) Loss of heat by radiation. The mass of hot fuel is surrounded by walls which are exposed to the air, and from which radiation must be taking place. The

thicker the walls the less heat will be lost through them. It is therefore not advisable that the producer should be a mere shell of iron lined with a thin layer of brickwork. Radiation may be much reduced by building the producers in banks of from six to twelve, instead of singly.

(3) Heat carried out in the ashes. This is never large in amount, and in modern producers is so much reduced as to be of no importance. Assuming the fuel to contain 10 per cent. of ash having a specific heat of ·2, and that it be drawn at a temperature of 600° C., the loss will only be $600 \times {\cdot}02 = 12$ units for each pound of fuel consumed.

(4) In some types of producer fuel may escape combustion and pass away in the ashes. The amount thus lost should not be large even with bar-bottom producers, but it will necessarily vary with the quality of the fuel and the care with which the producer is attended. Five per cent. is a common loss, but it may reach 10 per cent., or even more, and cases have been quoted in which it has reached 30 per cent. The proportion of fuel actually gasified to that supplied is called the grate efficiency of the producer. Assuming the loss of fuel in the ashes to be 10 per cent., the grate efficiency will be ·9, or 90 per cent.

The true efficiency of a producer will, of course, be the efficiency, as before defined, multiplied by the grate efficiency.

Thus in the case of simple producer gas made in a producer having a grate efficiency of ·9 the real efficiency would be $\cdot691 \times \cdot9 = \cdot621 = 62{\cdot}1$ per cent.

Use of Hot Gas.—In describing the efficiency of a gas it has been assumed that the gas is burnt cold. If it be burnt hot so that the sensible heat of the gas can be utilised in furnace heating the efficiency will, of course, be somewhat higher, and the loss of heat in the producer will be less. The heat obtained by the combustion of 1lb. of the hot gas (E'), *i.e.*, the effectual calorific power of the hot gas, will be the heat evolved by the combustion of the cold gas added to heat carried over by the hot gas—that is, it will be $CP + (W \times S \times T)$ where W is the weight of the gas per lb. of fuel consumed, S its specific heat, and T its temperature above that of the air, the last term giving the sensible heat of the gas in thermal units. The efficiency of the gas will, of course, be increased, and the hot gas efficiency will equal the cold gas efficiency

$$+\frac{\text{Sensible heat of gas from 1lb. of fuel}}{\text{Calorific power of fuel}}\quad E'=\frac{H'+W\,S\,T}{H}.$$

There is another point which has to be taken into account in considering the efficiency of a gas producer which is usually neglected. If the gas is made from coal it will be laden with tarry matter, and if the gas mains be short this will be carried forward and will be burnt, whilst if the mains be long it will be wholly or partially condensed in the mains. In any case the tarry matter is condensed in taking the sample for analysis, and thus is not taken into account in the analysis. The amount of tar is considerable, and may sensibly increase the calorific power of the gas as burnt, and therefore the efficiency of the producer. The question of tar in producer gas will be considered more fully later.

In a paper read before the Institute of Civil Engineers in 1896, Mr. C. T. Jenkins describes a method of calculating the efficiency of gaseous fuels, and gives a considerable number of examples.

The formula he uses for the gas used cold is

$$\text{Efficiency} = \frac{M \times K \times G}{H}$$

Where M is the heat of combustion of the gas for each kilogramme of carbon contained in it, which he calls the "figure of merit" of the gas, K is the proportion of carbon in the coal, G is the proportion of carbon which is gasified, and H is the heat of combustion of one kilogramme of the coal used for making the gas. If the whole of the carbon is gasified, G becomes 1, and the efficiency is $\frac{M\,K}{H}$, and $M\,K$ is the calorific power of the gas per kilogramme of the coal. Pounds could, of course, be substituted for kilogrammes without altering the proportion, and "figure of merit" M could then be taken as the heat of combustion of the gas for each pound of carbon it contains. The hot gas efficiency he gives as "the cold gas efficiency ×

$$\left\{1+\frac{\text{sensible heat per cubic metre of the gas}}{\text{calorific power of the gas}}\right\}"$$

CHAPTER V.

CHIMNEY DRAUGHT PRODUCERS. THE OVERHEAD COOLING TUBE. FORCED DRAUGHT PRODUCERS. BLOWERS. AMOUNT OF STEAM REQUIRED.

The proper supply of air and steam to the producer is a matter of the utmost importance for successful working.

CHIMNEY DRAUGHT PRODUCERS.

In the early types of producer the ashpit was open and the draught was of the character of a chimney draught, no steam being used, or only so much as could be drawn in with the air, this being supplied either by blowing a steam jet or a water jet under the bars, or by keeping the ashpit full of water, which was evaporated by the heat radiated from the fire bars or by the hot ashes falling into it. In such a producer the amount of steam used was very small.

It appears at first sight as if the only conditions under which a chimney draught could be used would be when the producer was at a much lower level than the furnace, so that the gas had to pass upwards—a condition that could very rarely be arranged. Sir W. Siemens overcame this difficulty by the introduction of the overhead cooling tube connecting the gas producer with the furnaces.

The gas from the producer passed into a vertical brick stack 8ft. to 12ft. high, thence by a horizontal tube to near to the furnaces, which were intentionally placed at some distance from the producers, and then down by another vertical tube to the ports, or to an underground flue. The set of tubes thus arranged acted as a syphon to draw the gas over. The gas in the up-comer tube being hotter was much lighter than the cooler gas in the down-comer tube, and thus a syphon was produced, the legs of which were of equal length, but the gas in the one was much heavier than the gas in the other, thus producing a draught, and at the same time cooling the gas, so that a large proportion of the tar was condensed in the cooling tube. Siemens says that the cooling tube should have a surface of not less than 60 sq. ft. per producer.

Siemens thus explains the action of the tube. "The gas rising from the producer at a temperature of 1,100° Fah. is cooled as it passes along the overhead tube, and the descending column is consequently denser and heavier than the ascending column of the same length, and continually overbalances it. The system forms, in fact, a syphon in which the two limbs are of equal length, but one is filled with a heavier liquid than the other. The height of cooling tube required to produce as great a pressure as would be obtained by placing the gas producer, say, ten feet deeper in the ground may be readily calculated. The temperature of the gas as it rises from the producer has been taken as 1,100° Fah., and we may assume that it is cooled in the overhead tube to 100° Fah. an extent of cooling easily attained. The calculated specific gravity, referred to hydrogen, of the gas of which I have quoted the analysis, being 13·4. We obtain the following data :—

Weight of gas per cubic foot at 1,100° Fah. = ·022lb.
100° Fah. = ·061lb.
Weight of atmosphere per cubic foot at .... 60° Fah. = ·076lb.

and from these we have on the one hand the increase of pressure per foot of height in the flue rising directly from the gas producer = ·076 — ·022 — ·054lb. per square foot, and on the other hand the excess of pressure at the foot of the down-take from the cooling tube over that at the same level in the flue leading up from the gas producer (per each foot of height of the cooling tube) = ·061 — ·022 = ·039lb. per square foot. The height of the cooling tube above the level of the flue which will be sufficient to produce the required pressure equal to 10ft. of heated gas column is therefore $\frac{\cdot 054}{\cdot 039} \times 10\text{ft.} =$ 13ft. 10in., or say 14ft." * The cooling tube cools the gas and condenses a large amount of the tar and water, and this Siemens contended was an advantage.

It will be seen that with the cooling tube, the air current must be very sluggish, and therefore the combustion must be slow, for the pressure will be very small. The layer of fuel will be much thicker in a producer than in an ordinary fireplace, though in a "chimney draught" producer it can never be very thick, and this

---

* Siemens' Collected Works, Vol. I., p. 222.

will retard the passage of the air. Such a producer must also work with an open hearth, so that air can have free access, and therefore very little steam can be used. The open-grate chimney draught producer is now very little used.

When the air is supplied under pressure by a fan, or otherwise, the conditions are considerably changed, a much greater pressure can be used, and therefore combustion can be made much more rapid, the hearth can be closed, and air and steam supplied in any required proportions. The overhead cooling tube becomes unnecessary, the producers can be put as near the furnaces as is convenient, and underground flues can be used. Air and steam can be supplied in any convenient way, the air by means of a fan or blower, and the steam by a jet from a boiler, but as the air and steam are always required together, a steam jet blower is almost always used.

BLOWERS.

Steam Jet Blower.—The principle of this blower is very simple. A jet of steam is blown into a tube leading to the producer, and carries with it, by friction, the air required.

Siemens designed a steam jet blower for the purpose, which he described in a paper read before the Institution of Mechanical Engineers in 1872, and though simpler forms are now generally used for gas producers, this one is of great interest. It is shown in section in Fig 2. Siemens thus describes it:—

" A very thin annular jet of steam is employed in the form of a hollow cylindrical column discharged from the annular orifice between the two conical nozzles, the steam being supplied from the pipe C into the space between the two nozzles. The inner nozzle can be adjusted up or down by the hand screw D so as to diminish or increase the area of the annular orifice between the two nozzles for regulating the quantity of steam issuing. The air to be propelled by the steam jet is admitted from the pipe E through an exterior annular orifice surrounding the steam jet, and also through the centre of the hollow jet. The tube G, into which the steam jet issues, is made of a conical shape at the bottom, so as to form with the outer nozzle a rapidly converging annular passage, regulated by adjusting the outer nozzle by means of the nut H at the bottom. The tube G continues to diverge very gradually for some distance above the jet orifice, the length of the convergent portion increasing with the outer annular air orifice, and also with the steam pressure employed." "A tapering spindle I is sometimes fixed in the centre of the inner nozzle and carried up through the mixing chamber G, for the purpose of preventing reflux through the centre of the combined current.

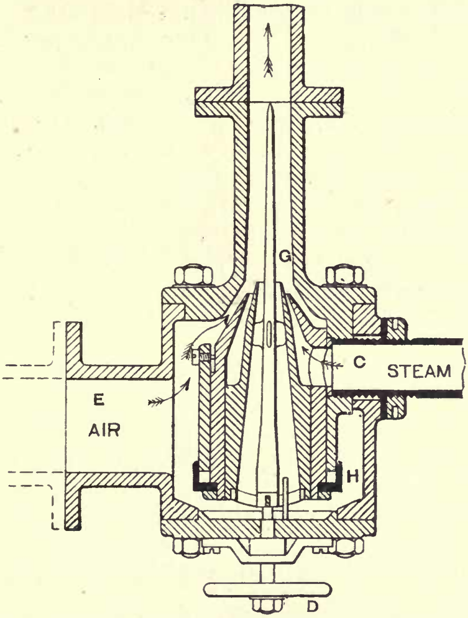


Fig. 2.—Siemens' Steam Jet.

"The rationale of this arrangement is as follows: First, by gradually contracting the area of the air passages on approaching the jet the velocity of motion of the entering air is so much accelerated before it is brought into contact with the steam that the difference in the velocity of the two currents at the point where they come together is much reduced, and in consequence the eddies which previously impaired the efficiency of the steam jet are to a large extent obviated, and a higher useful effect is realised; secondly, by the annular form of the steam jet the extent of surface between the air and the steam is greatly increased, and the quantity of air delivered is very much augmented in proportion to the quantity of steam employed."*

By means of this jet used as an exhauster Siemens obtained a vacuum of 24in. of mercury, and with it he made many experiments to elucidate the laws according to which the jet blower acts.

Principles of the Blower.—As the jet of steam rushes from the orifice into the air it draws a considerable quantity of air with it, and if it be directed into a tube a stream of air and steam will be obtained. Apparatus on exactly the same principle is used for various purposes with fluids other than air and steam. In the trompe used in blowing the primitive Catalan forge for the manufacture of malleable iron, a current of water was the moving power, the air being carried along by it and discharged into the forge, and in the ordinary injectors used for feeding steam boilers a jet of steam is made to carry forward a stream of water.

Sir W. Siemens says: "The result of a long series of experiments with this form of steam jet for exhausting and compressing air have led to the following conclusions:—

"First, that the quantity of air delivered per minute by a steam jet depends on the extent of surface of contact between the air and steam irrespective of the steam pressure up to the limit of exhaustion or compression that the jet is capable of producing.

"Second, that the maximum degree of vaccum or of pressure attainable increases in direct proportion to the steam pressure employed, other circumstances being similar.

"Third, that the quantity of air delivered per minute within the limits of effective action of the apparatus is in inverse relation to the weight of air acted upon, and a better result is therefore obtained in exhausting air than in compressing it.

"Fourth, the limits of air pressure attainable, with a given pressure of steam, are the same in compressing as in exhausting within the limit of a perfect vacuum in the latter case."†

---

* Siemens' Collected Works, Vol. I., p. 142.

† Siemens' Collected Works, Vol. I., p. 143.

There are certainly other conditions besides steam pressure and the area of aperture of the steam jet which modify the action. If a jet of steam be blown from a nozzle so shaped that the jet is a cylinder, it will retain its form for a considerable distance, and therefore can only draw in the air by surface friction. On the other hand, if the jet be of such a form that the issuing jet of steam is conical, the area of section will increase rapidly, the steam will be mixed with the air, and the action will certainly not be merely due to friction of the air at the surface of the steam jet. The molecules of air being mixed with those of steam there will be impact, and the air will be swept forward by the steam, it has been said, "much in the same way as a piston would do, but, of course, with less solidity of action." In this case the propelling force would seem to be the momentum of the steam, which, in its turn, is due to the mass and the velocity. The best results seem, on the whole, to be obtained with solid diverging jets, and some engineers, after experimenting with hollow jets, have given them up, and returned to solid jets.

The whole subject of the propelling force of the steam jet needs careful experimental examination.

A blower therefore consists essentially of two parts, the steam jet and the tube into which it blows.

Blower Tube.—The receiving tube consists usually of two portions, a short upper portion expanding upwards, and a lower portion joining this at its narrowest point and expanding downwards. The best size has been arrived at by experience rather than from theory, and very few experiments have been made on the influence of varying size and form of the receiving tubes. As pointed out by Siemens, the upper part of the tube should be opened out into an inverted cone near the bottom of which the point blower should be put.

The Simple Jet Blower.—In this type of blower the steam jet is a simple tube, as shown in Fig. 3, the dimensions given being those commonly used.

Annular Jets.—A solid steam jet of small diameter, say $\frac{1}{4}$in., offers a very small surface of contact, so that the quantity of air carried forward is small in proportion to the amount of steam used, and as in a gas producer the quantity of steam that can be used with advantage is small, an excess of steam is likely to be supplied.

To overcome this difficulty annular jets have been devised. The jet is made much larger in diameter, but has a central air pipe, so that the steam escapes in the form of a ring, and air is admitted both inside and outside the jet. If the amount of air carried in depended entirely on the area of contact between the steam and air, a much larger quantity of air could thus be carried through by a given quantity of steam.

The annular blowers have, however, not been altogether successful. The layer of steam is excessively thin, say $\frac{1}{32}$in. or less, so that the continuity of the cylinder of steam is easily broken, and thus the efficiency is impaired, and therefore most users still prefer the solid jet.

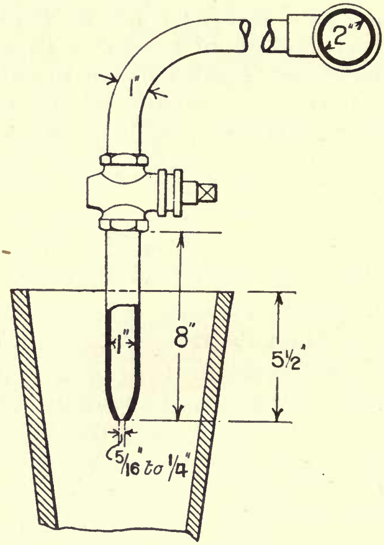


FIG. 3.—STEAM JET.

Adjustable Jets.—It is often necessary, or at any rate advantageous, to be able to adjust the relative quantities of steam and air, and various blowers have been devised for the purpose. In the annular jet blowers adjustment is comparatively simple. The best known of this type is the blower of Mr. Thwaite. (Fig. 4). In this two bronze nozzles are fitted, one inside the other, so as to leave an annular steam space, and they are so shaped that by raising or lowering the inner tube by means of a screw the width of the annular space can be increased or diminished, thus increasing or diminishing the supply of steam, whilst the area of contact with the air remains unchanged.

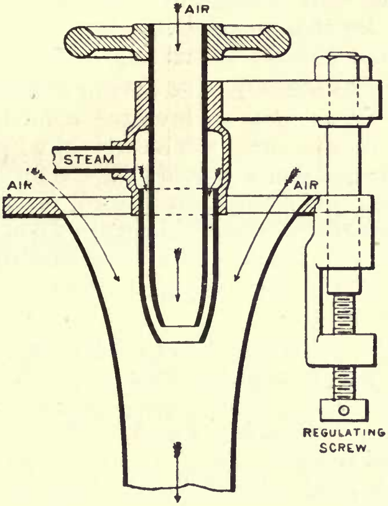


FIG. 4.—THWAITE ADJUSTABLE ANNULAR STEAM JET BLOWER.

The Argand Blower.—This type of blower (Fig. 5) has been used in the United States, and is said to be very efficient, but the author does not know if it has been used in this country. As will be seen from the illustration,

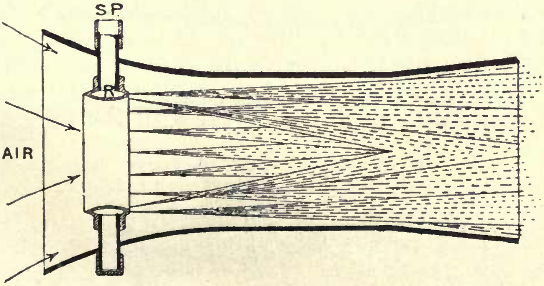


FIG. 5.—ARGAND BLOWER. S.P., STEAM PIPE.

the steam is delivered into a ring of circular or elliptical section, from which it passes by a large number of small holes, thus giving a very large number of small steam jets. By this means a very large surface of contact between the air and the steam is provided.

The Körting Blower.—In this blower a solid steam jet is used, which blows into an inverted cone like the top of the ordinary blower tube, the bottom of which opens into a second inverted cone into which the mixture of steam and air blows, this opens into a third, and, if required, a fourth, so that there are from three to five inverted cones through which the steam and air passes into the air tube, the volume of the gas being increased and its speed diminished in each.

A pressure of from 3in. to 12in. of water can be obtained. The following details are given by Messrs. Körting:—

No. of blower ...	0	1	2	3	4	5	6	7
Air delivered per minute in cubic feet ...	150	400	650	900	1500	2000	3000	4000
Bore of steam pipe in inches	½	¾	1	1¼	1½	1¾	2	2½
Diameter of air conduit in inches ...	4	8	9	10	12	13	16	18

The supply of steam can be regulated by means of a spindle, which can be lowered into the top nozzle.

Granger's Blower.—This is a solid jet adjustable blower. It has three separate nozzles of different sizes, so arranged that by turning a handle any one of them can be brought into use, but never more than one at the same time, each jet as it comes into use coming at the same time into a position so as to be central with the tube.

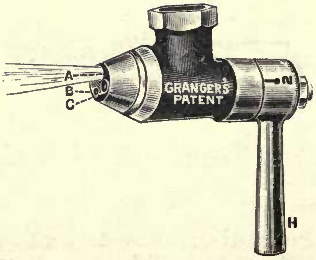


FIG. 6—A B C JETS. H, HANDLE FOR BRINGING ANY PARTICULAR JET INTO ACTION.

This blower seems to be one of the most efficient, and is very satisfactory in action. For ordinary purposes the smallest blower is used, but as any one of the others may be put into action varying proportions of steam and air may be obtained. If the amount of air depends only on the surface of contact, then as the surface of contact, *i.e.*, the circumference of section, varies as the radius, and the area varies as the square of the radius, the changing of the nozzle will increase both air and steam, but will increase the amount of steam in a larger ratio than the amount of air. The writer has no data by which he can determine to what extent this actually is the case.

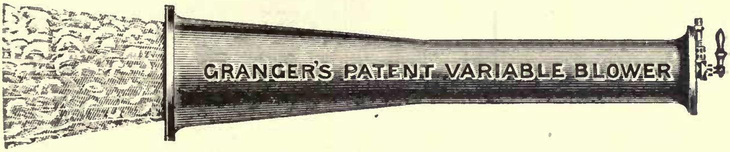


FIG. 7.

Other types of blowers have been suggested, but these are the principal ones in use.

Blower Tube.—The form of the blower tube is of great importance. (See Fig. 8.) The upper part has always the form of the frustum of an inverted cone, and at the bottom of this the current may be considered to be formed. It then widens out, so that, as the current of air and steam flows, its diameter is increased, and therefore its speed is reduced, till at the bottom of the tube it is delivered to the producer.

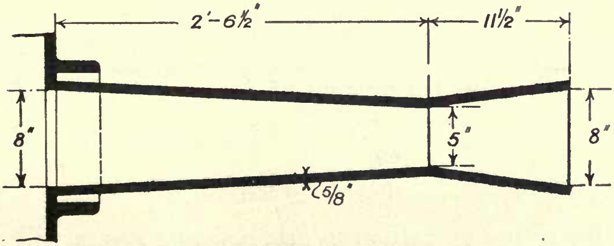


FIG. 8.—TUBE FOR STEAM JET BLOWER.

Power of Blowers.—The air is not required to be sent to the producer at a high pressure, from 5in. to 10in. of water being that usually used, though some blowers will give up to 12in.

Mr. Thwaite gives the following table of the power of his annular blower :—

Diam. of steam jet. Inches.	Cubic feet of air per minute at atmospheric pressure.
$\frac{3}{8}$	60
$\frac{9}{16}$	250
$\frac{3}{4}$	350
1	1,200
$1\frac{1}{8}$	2,000

Steam at 60lbs. pressure.

Amount of Steam Required.—The best proportions of steam and air cannot be rigidly fixed, the more steam that is used the better, until a limit is reached, this limit depending mainly upon the amount of heat that is available for decomposing the steam without unduly cooling the producer, and this will depend on the loss of heat in the producer itself. The average proportions when a producer is working well are about 10 parts steam and 90 parts air by volume, rising sometimes to 12·5 parts of steam to 87·5 parts air, but rarely passing beyond this.

Taking 10 per cent. of steam by volume as being a good working proportion, this will be about 6 per cent. of steam by weight, and about one-fifth of the carbon will be burnt by steam and four-fifths by air.

Assuming 6 per cent. of steam by weight, it is very easy to calculate the amount of fuel that will be consumed.

Since 1lb. of carbon will combine with 1·33lbs. oxygen to form carbon-monoxide, and air contains 23 per cent. by weight of oxygen, the amount of air required to burn 1lb. of carbon will be $\frac{1{\cdot}33 \times 100}{23} = 5{\cdot}8$lbs., therefore 1lb. of air will burn $\frac{1}{5{\cdot}8} = {\cdot}171$ lb. of carbon.

One pound of carbon in decomposing steam will also combine with 1·33lbs. of oxygen, and this will be contained in 1·49lbs. of steam, therefore 1lb. of steam will burn $\frac{1}{1{\cdot}49} = {\cdot}67$lb. of carbon, so that for 100lbs. of the gaseous mixture

94lbs. of air = ·171 × 94 = 16lbs. of carbon burnt by air.
6lbs. of steam = ·67 × 6 = 4· ,, ,, ,, steam.
100 20·

If loss of heat in the producer could be guarded against, a much larger proportion of steam could be used. One engineer of large experience has stated to the author that 7 per cent. by weight is the maximum amount of steam which should be used in an ordinary steam blown producer.

Assuming the proportions above given to be correct, it is easy to ascertain what amount of steam will be required to work a gas producer. In all such calculations only the fixed carbon of the fuel must be taken into account, as all volatile matter will be expelled before the residue comes under the action of the air and steam. The amount of fixed carbon in and the amount of gas given off by the fuel should therefore always be determined.

The amount of steam required will be 6lbs. for each 20lbs. of carbon burnt, or ·3lbs. of steam for each pound of carbon.

Assuming the coal used to yield 60 per cent. of fixed carbon, ·6 × ·3 = ·18lbs. of steam will be required for each pound of coal consumed. To be on the safe side, the boilers should be capable of supplying two or three times this amount.

Each pound of carbon will require 5·8lbs. of air, or 1lb. ofcoal of the composition assumed will require 3·48lbs. of air.

As 1lb. of air under normal conditions of pressure and temperature occupies 12·36 cub. ft., the volume of air required will be 58·1 cub. ft. for each pound of carbon, or 34·9 cub. ft. for each pound of coal consumed.

The steam should be supplied at a high pressure, 60lbs. to 75lbs. being usually used.

CHAPTER VI.

Chimney Draught Producers. Closed-Hearth Producers. Bar-Bottom Producers. Solid Bottom Producers. Water-Bottom Producers. Automatic Producers. Blast-Furnace Producers.

The early forms of producer, such as those of Bischof and Ebelman, were little more than enlarged fireplaces, and for many reasons were not efficient. In 1861 Siemens introduced his gas producer, which did not differ in principle from those which had gone before, but which became a success, not so much on account of any improvement in the producer itself as because it was for the first time associated with the regenerative system of burning the gas, the regenerative gas furnace having just been invented by Siemens.

The Siemens producer (Fig. 9) was a firebrick chamber about 8ft. square and 6ft. or 8ft. deep, narrowed at the bottom, by the front wall being sloped inwards, and provided with a series of firebars. The action of such a producer is very simple. Air enters through the firebars, and combustion takes place just as in an ordinary fireplace, the hot gases passing upwards are largely reduced to carbon monoxide by the action of the hot coke, and the volatile matters are distilled from the coal in the upper regions of the producer, and the gas thus produced mixes with the carbon monoxide, carbon dioxide, and nitrogen from the combustion of the coke.

The draught is produced entirely by the chimney, or rather by the overhead cooling tube, and is therefore a natural as distinguished from a forced draught. If the furnace could be placed at a considerable elevation above the producer the gas would tend to rise and produce sufficient pressure, but this is rarely possible, the furnaces and the producer being in most cases necessarily at about the same level.

The draught obtained is only about ·54lbs. per square foot or ·003lbs. per square inch, or, say, $\frac{1}{10}$in. of water.

Such a producer can never be very efficient. The draught is small, therefore the combustion is slow, rarely reaching 10lbs. of fuel per square foot of grate area per hour or less than that consumed in an ordinary boiler grate. There is always the possibility of the loss of fuel through the bars, so that the grate efficiency is low. The grates cannot be made of large size, as they must be of such form and size as to allow the ready removal of clinkers, 5ft. or 6ft. being the maximum satisfactory width. Assuming the hearth to be 5ft. × 8ft., this gives an area of 40ft., and with a combustion of 10lbs. per hour will give 400lbs. per hour per producer. The hearth

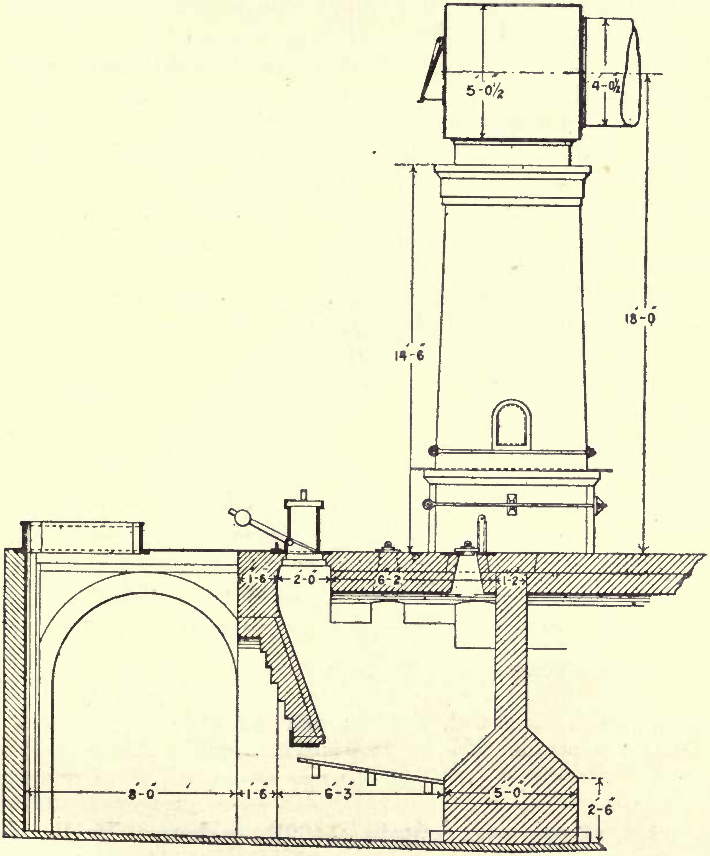


FIG. 9.—SIEMENS GAS PRODUCER (OPEN TYPE).

being open, very little steam can be used; indeed, usually the only water vapour supplied is that evaporated from water in the ashpit or sprinkled on the bars, and therefore the gasification is not likely to be economical. The layer of fuel must also be thin, so that usually a good deal of carbon-dioxide is present in the gas, and in order to produce a draught the gas must leave the producer at a high temperature, the sensible heat being completely lost in the cooling tube.

On the other hand, the producer is cheap and easy to erect and to manage, and requires no steam supply; but the disadvantages so far outweigh the advantages that open producers have almost ceased to be used. There are cases, however, such as when the producer can be practically made a fireplace, and the hot gas passed at once to the furnace, where this type of producer can be satisfactorily applied.

The following is an analysis of gas made in a producer of this type, and will show its general character:—

	By Volume.	By Weight.
Methane, &c....	4·40	2·5
Carbon monoxide	25·60	25·5
Carbon dioxide	4·30	6·8
Nitrogen...	65·70	65·2
	100·00	100·00

Calorific Power.—

	C.U.	B.Th.U.
Methane	·025 × 12000 = 300·0...	·025 × 21000 = 525
Carbon monoxide	·255 × 2400 = 612· ...	·255 × 4320 = 1101·6
	912·0	1626·6

1lb. of gas will contain ·1462lb. carbon. If all the carbon were burnt to carbon dioxide it would evolve 1181·3 C.U., or 2126·3 B.Th.U., and the hydrogen burning to water would give 213·6 C.U., or 379 B.Th.U., so that the heat of combustion of the fuel used would be 1391·8 C.U., or 2495 B.Th.U., and the efficiency of the producer $= \frac{912}{1392} =$ 65·5 per cent.

Closed-hearth Producers.

All modern producers are worked with closed hearths, the steam and air being supplied together. A much larger quantity of steam can thus be used, and it can be supplied much more rapidly and at a higher pressure. As the gas does not need to be hot to produce a draught, it can be cooled to a much greater extent before leaving the producer, if this be deemed desirable. A much richer gas can be obtained with, at the same time, much more rapid gasification, and the process is much more completely under control. The overhead cooling tube, which gives a great deal of trouble from the accumulation of tar, also becomes unnecessary, and is usually replaced by underground conduits. Siemens very early recognised the advantages of steam blowing, and suggested the use of his producer with a closed hearth, air and steam being blown beneath the bars.

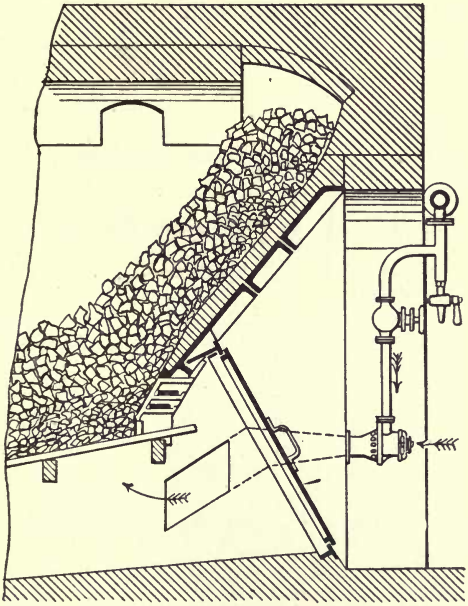


Fig. 10.—Siemens Closed-hearth Producer.

Closed producers may be divided into five groups, though it is impossible to arrange a classification that will be satisfactory from all points of view, and some producers might be put into more than one group :—

1. Bar-bottom producers.
2. Solid-bottom producers.
3. Water-bottom producers.
4. Automatic producers.
5. Blast-furnace producers.

1. Bar-bottom Producers.—In producers of this type the fuel rests on firebars, exactly as in the earlier Siemens producer; but the hearth is closed, the air and steam being supplied beneath the bars. Siemens suggested a producer of this type (Fig. 10) by merely closing the front of the ashpit of his producer and blowing air and steam beneath the bars. Another well-known producer of the type is the Simplex of Mr. Thwaite (Fig. 11), modified also in the Twin and Duplex producers, which will be subsequently described; but the best known is

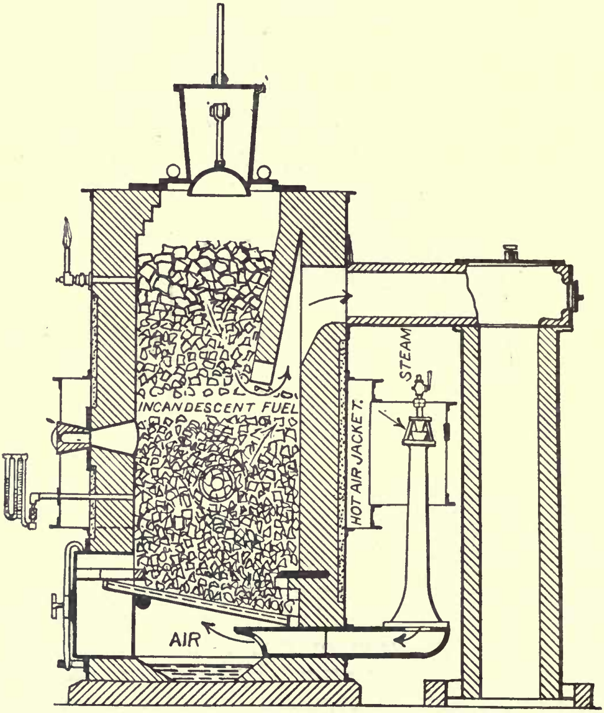


FIG. 11.—THWAITE SIMPLEX GAS PRODUCER.

probably that of Mr. Dowson, largely used in the preparation of gas for small motors and similar purposes.

It is not necessary to discuss these producers in detail, as they are now rarely used except under special circumstances. The disadvantages of this type of producer are easily seen. Clinker accumulates on the bars, and must be removed from time to time by poking. The hearth must therefore be small to allow of easy clinkering, and as unburnt coal may fall through with the ashes the grate efficiency will be low. It is impossible to obtain very rapid gasification, rarely above 20lbs. of fuel per square foot of grate area per hour. The bars can, however, be clinkered without actually stopping gas production, though this must necessarily be checked.

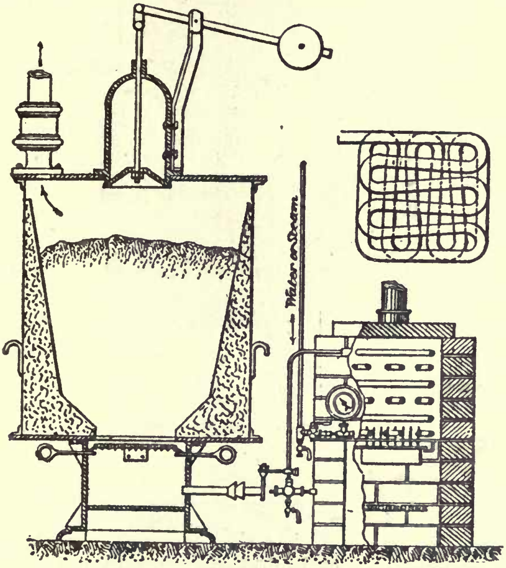


FIG. 12.—THE DOWSON GAS PRODUCER.

For small plants these producers are still used, as they are easy to erect and to manage, but for large installations they have been almost completely abandoned.

The Dowson Producer.—(Patent, 1878, No. 3,997; 1881, No. 2,895.)—This producer, however, calls for remark, owing to its extensive use in the production of gas for small gas engines.

The generator is cylindrical, and consists of an iron casing lined with firebrick, and is provided at the bottom with firebars, on which the fuel is consumed, and beneath which a jet of air and steam is supplied. No special boiler is needed, but the steam is produced and superheated in a coil of pipe contained in a separate superheating furnace, which, when once the producer is started, is heated by part of the gas. Coal, anthracite, or coke may be used; but when the gas is to be used for gas engines, one of the two last named is preferable, or the gas is purified by washing, as described later.

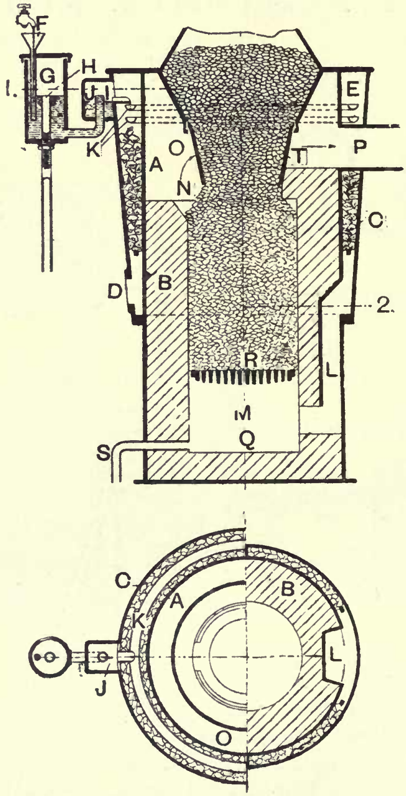


FIG. 12A.—DOWSON'S GAS GENERATOR.

Mr. Dowson has recently patented a new form of producer, which is shown in Fig. 12A. It is a bar-bottom producer, and the chief peculiarity is that it is so arranged that air can be aspirated through or supplied by a blower, as may be required. It comprises a casing A partly lined with firebricks B, an outer casing C with air inlet D and space E containing loose pieces of iron. There is a water supply F to chamber G with overflow H and outlet I. When air is drawn into the generator by the action of the engine connected therewith, the air pressure in the chamber J is reduced, and water is thereby caused to flow through the outlet I from the chamber G where the pressure is momentarily in excess. The water thus admitted into the chamber J flows to one or more channels K K where all or part of it is evaporated, and the steam mixes with the heated air in inclosed space E. If any excess of water falls from the channels K K it will fall on the loose pieces of iron in the inclosed space E, and will then be evaporated by coming in contact with heated surfaces.

When air is forced into the generator by means of a blower or pump, the overflow H is raised so that the head of water in the chamber G is sufficient to overcome the pressure caused by the blower or pump in the chamber J. The heated air and the water vapour formed in the inclosed space E pass downwards through the passage L to the lower part of generator M and thence upwards through the fire. The gas formed leaves the fire at N, and after passing through the passage O round the fuel container T it leaves the generator at P. When the generator is worked by the suction of an engine, the level of the water in G can be regulated by the height of the overflow H, so that none will enter the generator until the engine sucks, and then it will automatically draw in the quantity of water required to be vaporised. In this way the quantity of water admitted and the quantity of steam produced are governed by the engine, and are in proportion to the quantity of gas produced in the generator. In some cases an excess of water is purposely allowed to drain from the space E on to the floor Q of the generator so that some water may be vaporised by the heat of the fire on the grate R. An overflow for any excess of water is provided at S.

Fig. 13 shows a bar bottom producer used in Sweden for gasifying wood.

Solid-bottom Producers.—In these producers the fuel rests on the solid bottom of the combustion chamber, or, rather, when the producer is at work there is a layer of ash or clinker on the bottom, upon which the fuel in process of gasification rests. The air is blown into the mass of ash and fuel either near the bottom or higher up, and the clinker is drawn off from time to time through doors placed near the bottom, so that the charge can descend, a certain thickness of clinker being always left.

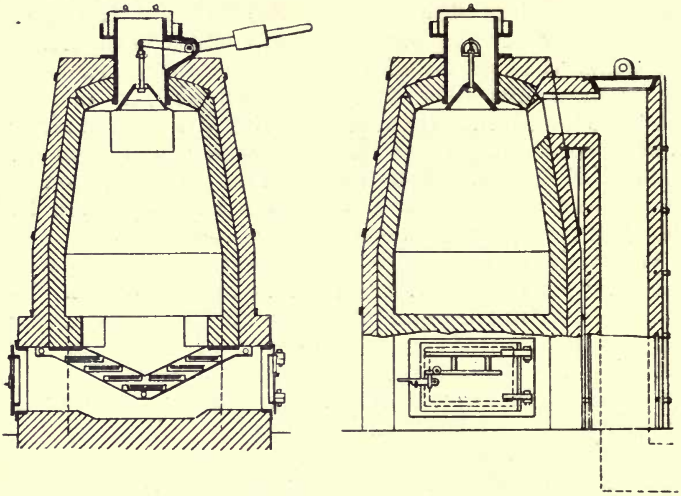


FIG. 13.—SWEDISH GAS PRODUCER FOR USING WOOD.

As there are no firebars, and the fuel is kept high in the producer, the combustion is almost if not quite perfect, and the grate efficiency approaches 1. The air and steam are supplied into the centre of the hot mass of fuel, and the combustion is rapid and complete. The air supply may be either by a central pipe or by a passage passing across the chamber. So there are no bars to be clinkered, and the ash only need be withdrawn periodically. This can be done from both sides or from several points in the circumference if necessary, and the hearth can be made larger than when bars are used.

Essentially, therefore, such a producer consists of a firebrick chamber, round, square, or of any other form, cased with iron, and having a flat or slightly sloping bottom, and an arrangement for blowing in air and steam. The details may be modified to almost any extent, engineers frequently building producers for themselves to suit their own needs. If a producer of this sort is to be a success, great attention must be given to the arrangements for the supply of steam and air, so that it shall be evenly distributed through the mass, and no portion of the fuel shall escape combustion (this being far more important than in the case of bar-bottom producers, where the bars act as distributors), and to arrangements for the withdrawal of ashes. If the producer be too large, or be not properly provided with cleaning doors, it will be impossible to remove the ashes completely. As a rule, a distance of about 2ft. 6in. to 3ft. is as great as it is possible to reach to remove the ashes, unless the charge be held up, when a somewhat greater thickness is

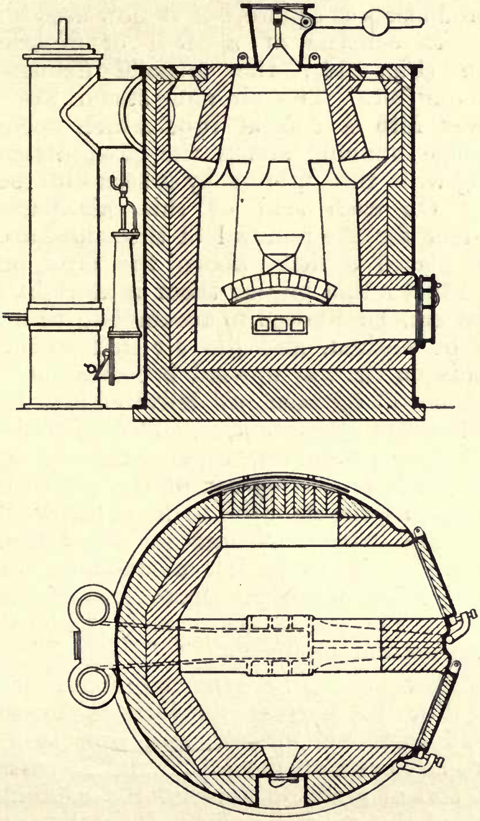


FIG. 14.—WILSON GAS PRODUCER.

allowable. Either, therefore, there must be an efficient means of holding up the charge during cleaning, or the producer must be considerably narrowed at the bottom. Many solid-bottom producers have been designed, but only one or two need be mentioned.

The Wilson Producer.—This is the best known and most widely used of all the solid-bottom producers. It was patented by Messrs. Brook & Wilson in 1876. The original producer was square, but as now used it is always circular. It consists of a shell of firebrick cased with iron (Fig. 14), the internal diameter being usually about 8ft. The air and steam are supplied by a blower into a conical tube which opens into a brick passage running across the producer and communicating with the interior by a series of rectangular openings. On each side of this air passage is a cleaning door for the removal of the ashes, and narrow doors are placed a little above the level of the air passage, so that a line joining them is at right angles to it. Clinker can be allowed to accumulate to any height that may be desired, and the air and steam passing through this on its way upward becomes hot. The air and steam, as will be seen, are delivered into the centre of the contents of the producer, and combustion is very perfect. The maximum size which such a producer can be made depends on the power of the air to reach the circumference, as, should it fail to do so, fuel would escape combustion and would be lost in the ashes. These producers are made up to 12ft. in diameter, and a consumption of 40lbs. of fuel per square foot of bottom can be obtained. The gas is also usually richer than that made in bar-bottom producers.

The clinker has to be removed about once every 24 hours. For this purpose the blast is turned off, the narrow side doors are opened, and iron bars are put through, so as to rest on the top of the air passage, thus forming a sort of grate to support the contents of the upper part of the producer whilst the ashes are drawn out. The cleaning doors are then opened and the ashes raked out, the doors are closed, the bars withdrawn, the side doors closed, and the blast put on, the whole operation of cleaning occupying about half an hour.

Another important part of the Wilson producer is the arrangement for destroying tar. At the top of the producer a cone of brickwork is built, so as to descend about

2ft. 6in. into the producer, and is supported by arches thrown from the lining, so as to form an annular space round the top, communicating with the interior of the producer by the above-mentioned arches, and also with the gas main. As the producer is kept full of coal, distillation can only take place at the top, and the products of distillation must pass downwards through the hot fuel before reaching the gas main. The tarry matters are thus decomposed by the hot coke into carbon, which is afterwards burnt, and permanent gases, which escape.

The apparatus is efficient and compact. The ordinary size will gasify 4 cwt. of coal per hour. The space occupied is only about 9ft. by 14ft., allowing 126 square feet for coal storage.

The table shown is an analysis of Wilson gas published by Mr. Wilson.

	By Volume.	By Weight.
Nitrogen...	55·96	61·66
Carbon monoxide	22·32	24·59
Hydrogen	12·11	·95
Carbon dioxide	6·18	10·65
Marsh gas	3·43	2·15
	100·00	100·00

It will be readily seen that solid-bottom producers may be modified to almost any extent. Fig. 15 shows a form used at one steel works. The brick air passage is replaced by an iron tube opening by a number of openings into the body of the producer, and communicating below with an air chamber into which air and steam are supplied by the blowers. Across the producer is fixed an iron bar to carry the ends of the temporary bars used for holding up the charge during cleaning.

The old type of Siemens open producer can readily be converted into a solid-bottom producer. Fig. 16 illustrates the method of doing this. A ridge or brickwork, carrying an air tube, is built up longitudinally along the bottom of the producer, and cleaning doors are arranged at each side of it.

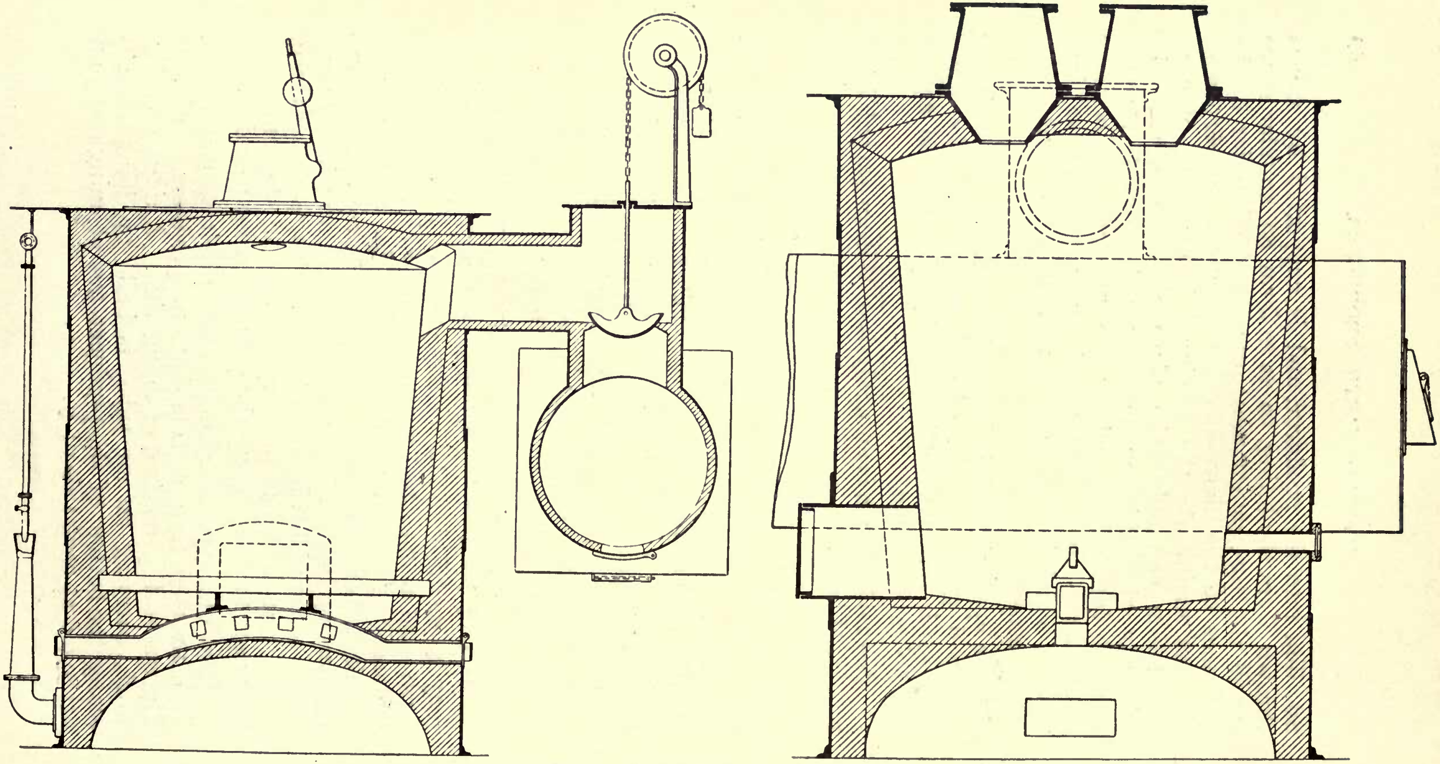


FIG. 15.—MODIFIED WILSON PRODUCER.

Water-Bottom Producers

All solid-bottom producers are intermittent in their action; that is, they must be periodically stopped for cleaning. If, however, the ashes be allowed to fall into a vessel of water, so arranged that there is a water seal to prevent the escape of gas, the ashes can be removed at intervals without stopping the gas production. Such a producer is usually called a water-bottom producer. In addition to allowing the ready removal of ashes, the ash is thoroughly cooled, any heat it may bring down being utilised in vaporising some water.

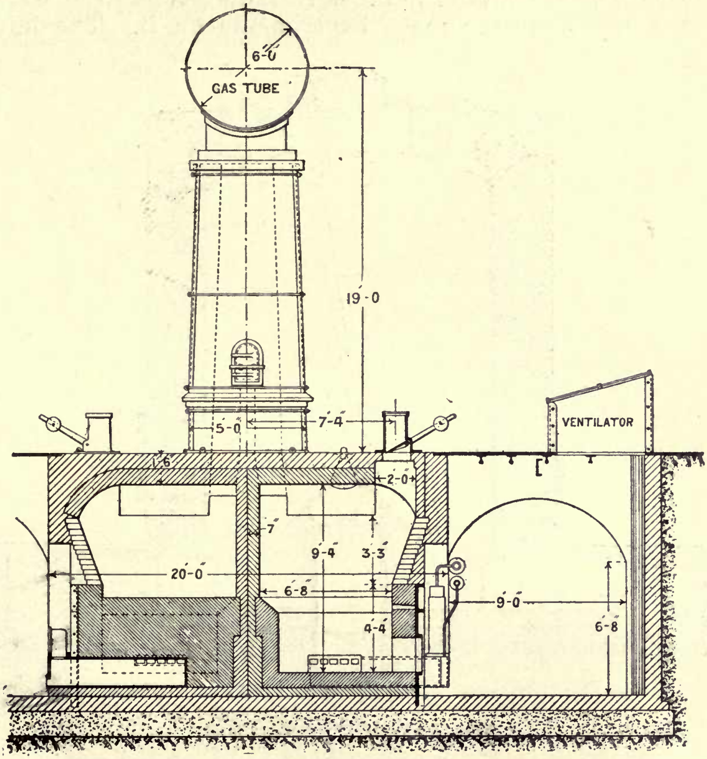


Fig. 16.—Siemens Open Producer Converted into a Solid-bottom Producer.

It has been stated by at least one steel works chemist that, when steel is made in a furnace fired by gas from a water-bottom producer, there is much greater difficulty in keeping down the sulphur in the steel than when dry-bottom producers are used. The author has made extensive inquiries among steel makers, and whilst one or two think this to be the case, the majority have noticed no indication of such an action. Under these circumstances it does not seem that there is any serious danger in this direction, except, perhaps, when an extremely low sulphur content is required, but he mentions the matter in order to induce those who have the opportunity to make experiments on it. The only explanation of such a fact will be that certain sulphides, such as iron sulphide (iron pyrites) or calcium sulphide (from calcium sulphate), which might remain in the ash in the case of the dry-bottom producers, might be decomposed by water, the sulphur passing into the gas as hydrogen sulphide, in the case of the water-bottom producer.

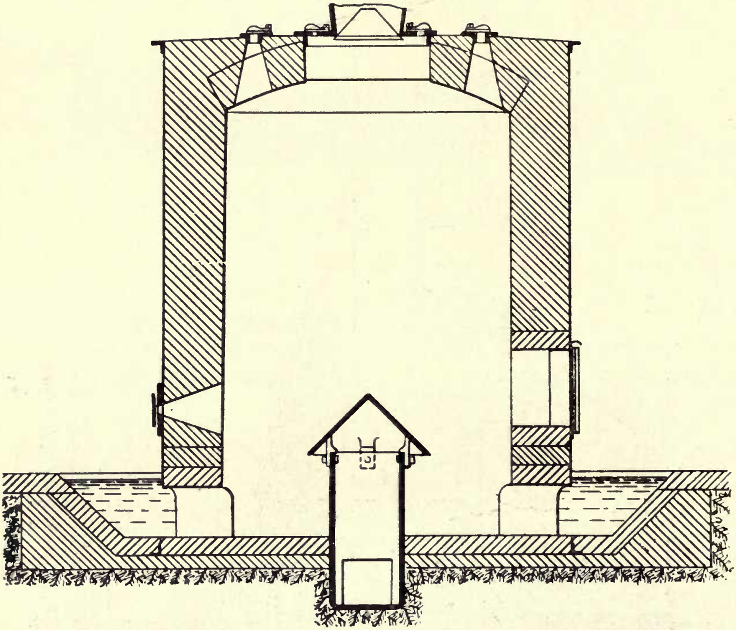


FIG. 17.—THE DAWSON PRODUCER.

The first water-bottom producer was that of Mr. Dawson; but as this type has been modified, it will be sufficient to describe the later type of Dawson producer, patented in 1894, No. 15,150.

The Dawson Producer.—This producer (Fig. 17) consists of a circular shell of masonry cased with iron plates, supported on short columns, the casing plates being continued downwards into a water trough so as to give a water seal all round sufficient to prevent the escape of gas. The air and steam are supplied in the usual way, and are delivered by means of a vertical pipe covered with a hood, which passes well up into the mass of fuel. Poking holes are provided round the circumference and at the top. The ashes can be drawn all round the circumference, and as the blast need not be stopped, the producer can be worked continuously.

The Duff Producer.—Of the modern water-bottom producers the best known and most largely used is that of Mr. Duff (Fig. 18). This may be made circular or square, but is usually made circular externally, the internal brickwork being so arranged as to give a rectangular combustion chamber. It is cased with iron, and the casing dips into a water trough on the two sides so as to form a water seal. Across the body of the producer from back to front, and occupying about half the width of the producer, is a ridge of brickwork. On this are fixed vertical iron plates, and above these two sloping grates. The producer is thus divided into two parts, about half the area being occupied by the grates, the other half by the water trough. The air is blown into the space beneath the grate, and passes between the bars into the fuel. The supernatant mass of fuel is thus partly supported on the grate and partly on the mass of ashes resting on the water trough, and as the charge sinks the ashes slip off the bars into the water trough. The producer is very easily cleaned, as the space from which the ashes have to be raked is comparatively narrow. The essential peculiarity of the producer is the arrangement of its bars, and these, as will be seen, differ in function from the bars of an ordinary bar-bottom producer in so far that the ashes are not removed through them, but slide off. This principle can obviously be applied to other forms ot producer. The old type Siemens producer, for instance, can be comparatively easily converted into a producer of the Duff type.

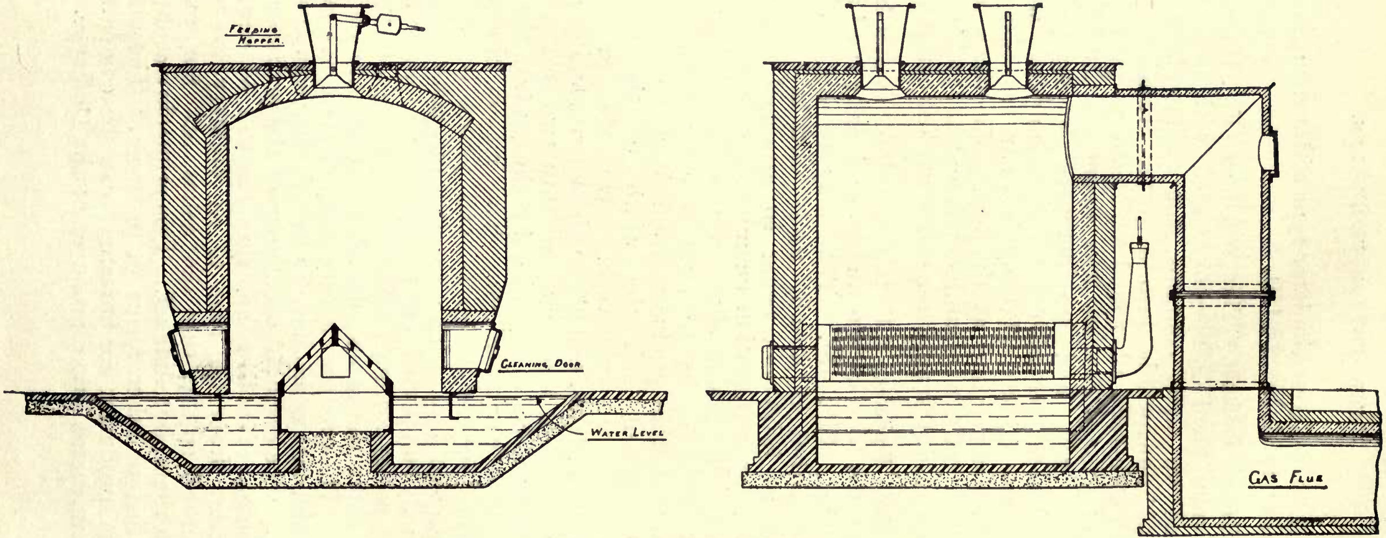


FIG. 18.—DUFF PATENT PRODUCER.

The details of water-bottom producers can, of course, be varied indefinitely. In the Swindell producer inclined grates are used, sloping from the sides downwards, but not meeting, so as to leave a central mass of ash which passes down into the water trough, from which it can be drawn as usual.

In the Thwaite small power producer (Fig. 19) a hanging grate is used, the ashes passing centrally into the water trough, the air being supplied into an annular space round the bars.

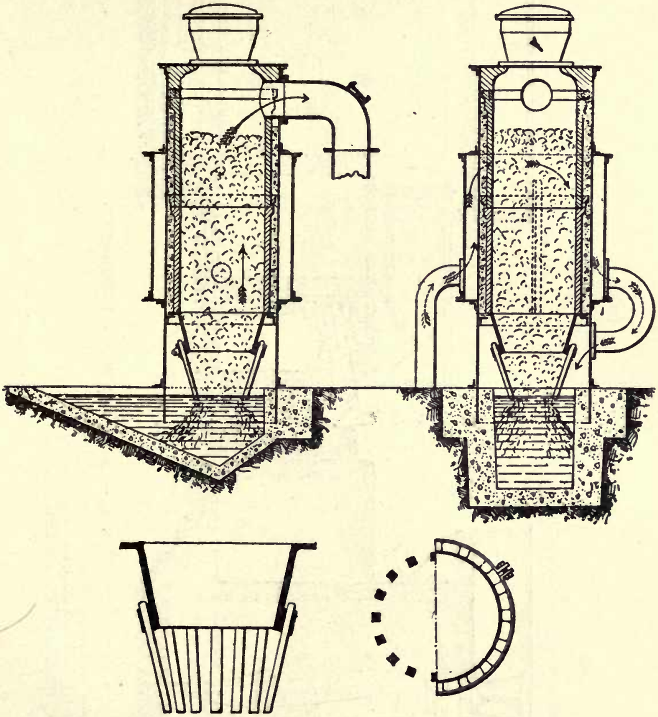


FIG. 19.—THE THWAITE SMALL POWER PRODUCER.

The Wilson Water-bottom Producer.—The Wilson producer may readily be converted into a water-bottom producer. This is done by Mr. Wilson, as shown in Fig. 20.

The Smith and Wincott Producer (Patent 1901, No. 12,895).—This is the most recent and one of the best of the water-bottom producers. It is circular, cased with iron, the casing

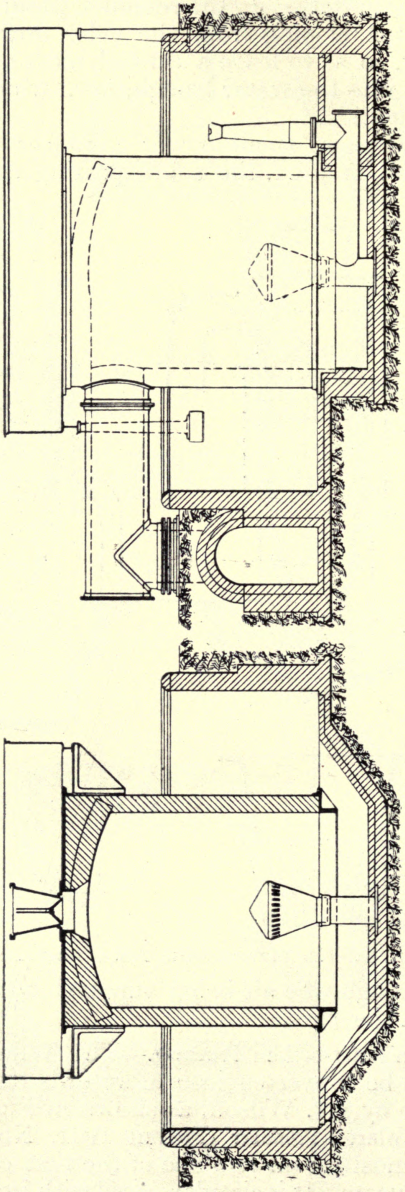


FIG. 21.—SMITH AND WINCOTT PRODUCER.

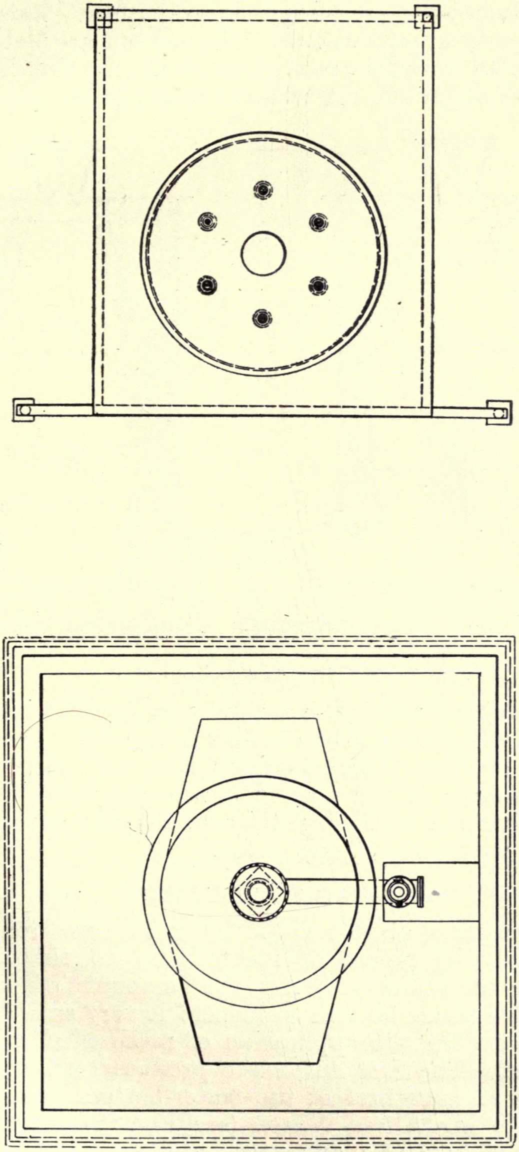


Fig. 21a.—Smith & Wincott Producer.

being carried down so as to form a water seal in the usual manner. The principal peculiarity is in the way in which the air and steam is supplied to the fuel. This is by a vertical central pipe which is widened out at the top so as to form an inverted cone, which at the top may have a diameter of about 3ft. A series of openings are provided all round this by which the air and steam passes into the fuel, and the top is closed by a loosely fitting cap. Owing to the form of these openings there is a very large area for the passage of the air and steam, and these cannot possibly become choked with ash, a great advantage, especially with some classes of fuel.

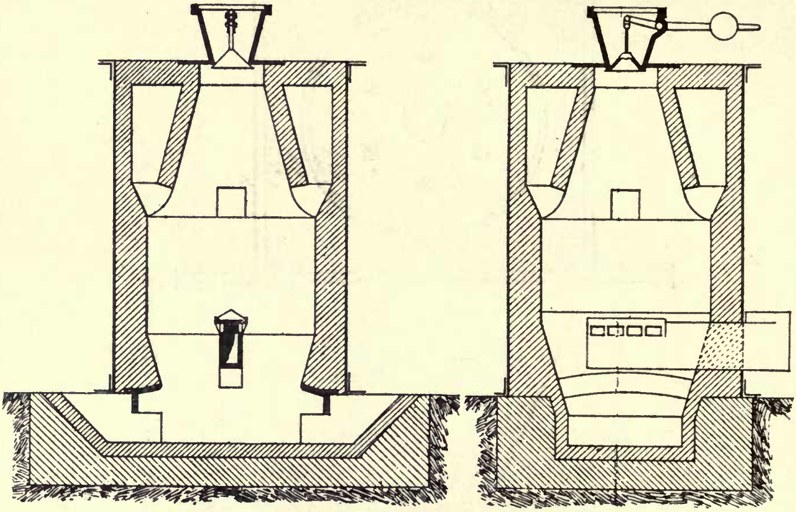


FIG. 20.—WILSON WATER-BOTTOM GAS PRODUCER.

AUTOMATIC PRODUCERS.

In producers of this type the ashes are removed continuously by means of mechanism, so that hand labour is unnecessary. As the amount of labour required for water-bottom producers is very small, it is doubtful how far the application of mechanism will be economical. The first automatic producer, which, in a sense, was also the first of the water-bottom producers, was that of Mr. Alfred Wilson (see Fig. 22), which has now been in use for many years, and has proved itself to be efficient in practice.

The Wilson Automatic Producer.—In some respects this resembles the ordinary Wilson producer, but the air and steam supply is placed at a much higher level, and the spaces each side, instead of being flat-bottomed, are circular in section, and inclined from back to front, so as to make two conical troughs, in each of which works a screw by which the ashes are slowly pushed out. The troughs are kept filled with water, so as to keep the screws cool and protect them from oxidation. The wear and tear is said to be very slight, the screw lasting for years, and the power required to turn it is also small.

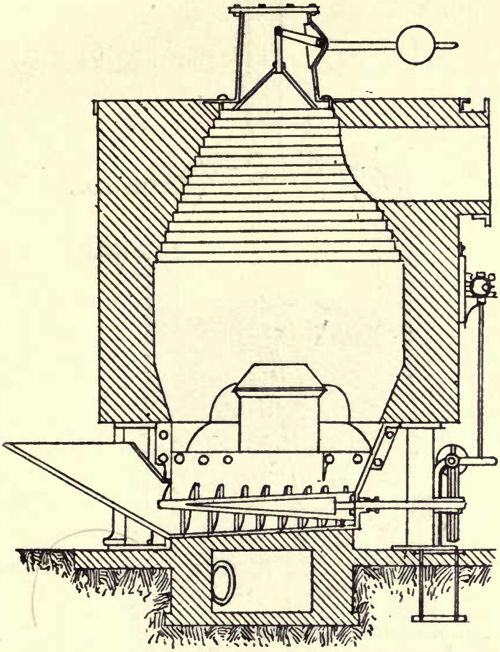


FIG. 22.—WILSON AUTOMATIC GAS PRODUCER.

The Taylor Producer.—This is an American invention, and the author is not aware that it is in use in this country. The bottom of the producer (Fig. 23) is closed by an iron plate, beneath which is the ashpit, and through the centre of which passes the pipe for supplying the air and steam. The iron bottom plate is a little larger than the bottom opening of the producer, and is so placed as to leave an annular space all round. As the ashes accumulate the bottom is rotated, a few turns being given occasionally.

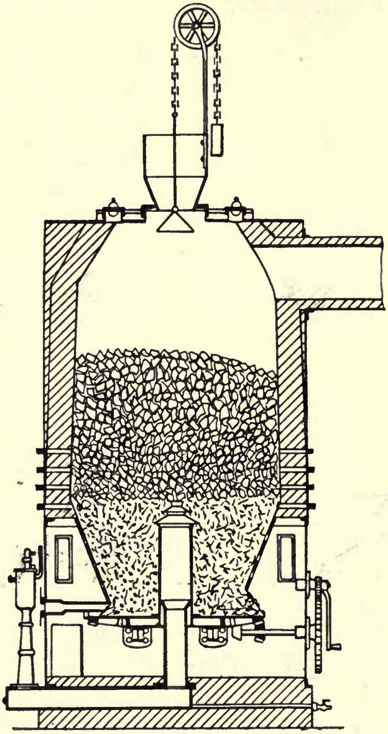


FIG. 23.—TAYLOR PRODUCER.

This breaks up the cinder and forces some of the ashes over the edge of the plate into the ashpit. A few turns of the bottom at frequent intervals will keep the fuel bed always in a solid condition and at the same level.

DOWN-DRAUGHT PRODUCERS.

Several attempts have been made to arrange producers in which the mixture of air and steam is supplied at the top of the gasifying chamber and the gas drawn off from the bottom, the idea apparently being that the tarry matters would be more completely destroyed. (See

Chapter IX.) Such producers have not come largely into use, and are subject to very serious defects, and especially to great difficulty in the removal of the ash.

The first of these, that of Mr. Howson, was simply a solid-bottom producer, with apertures in the floor for the escape of the gas and doors for the withdrawal of the ash, the fuel being charged, as usual, at the top, and the air and steam being supplied from a series of ports near the top.

Körting's Producer.—This producer is a bar-bottom down-draught producer. It is made in several forms to deal with variations in the quality of the fuel available; but that designed for use with bituminous coal, which is shown in Fig. 23A, will illustrate the principle on which it works. The producer is provided with a series of horizontal firebars on which the fuel rests, and with two vertical grates, C and C^1, in this case on opposite sides of the producer, one near the bottom, the other near the top, each provided with its own air main F F^1. The fuel is supplied, as usual, from the hopper B, and the air and steam passing in from the grates causes gasification. A passage N is provided so that the gas produced in the upper part of the producer may find its way to the lower part without passing through the fuel. The gas is drawn off through the grate L to the main M. Ashes can be

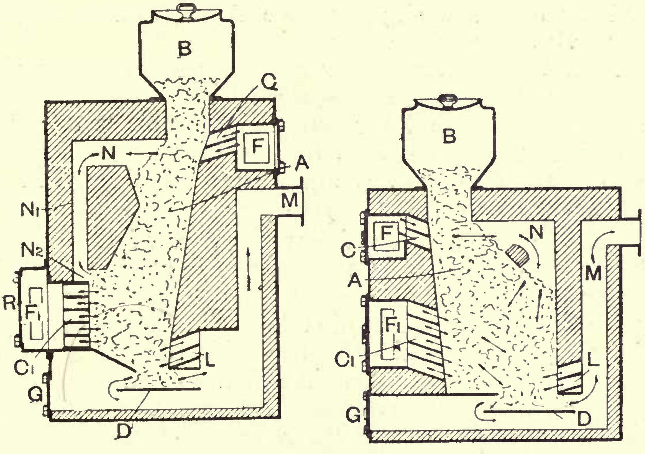


Fig. 23A.—Körting's Gas Producer.

removed through the door G. The vertical grates may be on the same or on opposite side of the producer.

The producers described are, of course, but a few selected from the innumerable forms which have been described and patented. They are, however, typical, and the author does not think he has omitted any distinct types, though, obviously, details may be varied to almost any extent.

THE BLAST FURNACE AS A GAS PRODUCER.

An enormous amount of combustible gas is made in the blast furnaces used for smelting iron. As this gas is a by-product, the blast furnace should hardly be classed as a gas producer in the sense in which gas producers are considered here, but as the gas from it is very largely used for steam raising, furnace firing, and driving gas engines it deserves a brief consideration.

At the tuyeres, in presence of a large excess of carbon and at a very high temperature, which necessarily exists in such a furnace, all the oxygen of the air is combined to carbon monoxide, and, as the only moisture carried in is that of the air, the amount of hydrogen in the gas is very small.

As the gas reaches the upper part of the furnace, carbon monoxide is added to it from the reduction of the carbon dioxide of the limestone by the hot carbon, and at the same time carbon dioxide is formed by the action of the carbon monoxide on the oxide of iron; thus the gas will be somewhat poorer in carbon monoxide and much poorer in hydrogen than producer gas made from coke with the aid of steam. When raw coal is used in the blast furnace the gas distilled from it will of course mix with the carbon monoxide, carbon dioxide, and nitrogen. The following analysis by volume will indicate the nature of the gas from a coke-fed blast furnace.

	(1)	(2)	(3)
Carbon monoxide	28·80	29·50	28·10
Carbon dioxide...........	12·90	9·00	10·00
Nitrogen	57·60	60·00	61·00
Hydrogen	0·70	1·50	0·90

From a coal-fed furnace the amount of hydrocarbons will be much larger. For example:—

	(1)	(2)	(3)	(4)
Carbon dioxide ...	8·57	8·61	5·40	6·79
Carbon monoxide...	27·15	28·06	30·10	26·40
Hydrogen	5·48	5·45	6·26	12·23
Marsh gas	4·27	4·37	3·20	·71
Nitrogen	54·29	53·38	55·10	58·81

It will be seen, therefore, that the gas from a coal-fed furnace is little inferior to ordinary, and better than some varieties of producer gas. The blast furnace, taking into account the other work which it has to do, is probably the most perfect gas producing machine in existence. The column of material is so high that cooling is very perfect, and would be much more so if it were not for the reduction of the oxide of iron which takes place near the top of the furnace, and owing to the depth of the column of material and the high temperature the reduction of carbon dioxide to carbon monoxide is perfect, and as the slag is tapped in a liquid condition there can be no loss of unconsumed carbon.

It has been suggested to model gas producers on the lines of the blast furnaces, adding a little limestone to flux away the ash of the coke, and where a sufficiently large quantity of gas is required such a type of producer would probably be very efficient. Steam could be used as in ordinary producers, but only in limited quantity. The high initial cost would be the chief drawback to a producer of this type.

An ordinary Scotch blast furnace will gasify about 550 tons of coal a week, or something over three tons an hour, the diameter of the hearth being but little larger than an ordinary gas producer, whilst a modern Cleveland furnace will gasify about 1,500 tons of coke per week, or nearly nine tons an hour.

The Thwaite Rapid Cupola Producer.—Mr. B. H. Thwaite has recently designed a producer of the blast-furnace type, which is the first attempt to apply what many have long thought to be the correct principle to practice, and a large installation is at present in course of erection.

The essential differences between this and the ordinary type of producer are (1) that air is supplied at a high pressure, (2) no steam is used, (3) the temperature is sufficiently high to fuse the slag, suitable fluxes being added when necessary.

LIBRARY OF THE UNIVERSI OF

The generator is very like a cupola furnace, about 30ft. high and about 6ft. internal diameter. The air is supplied a little above the bottom by a series of horizontal tuyeres at a pressure of about 2lbs. or 3lbs. on the square inch, though any convenient pressure can be used.

The gas, which leaves the producer at a low temperature, is forced through a "hydraulic head" to separate the tar, then through suitable washers—if necessary—to a gas holder. The bottom of the producer is so shaped that the liquid slag can be tapped off through a tap hole.

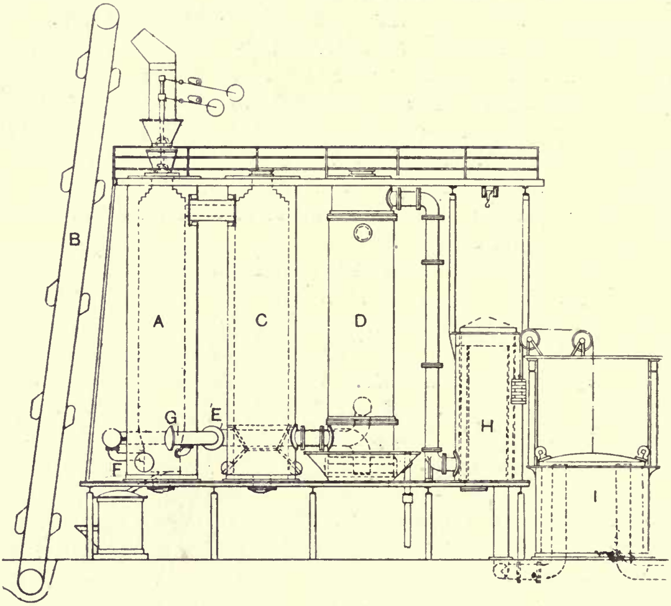


FIG. 23B.—THWAITE'S GAS PRODUCER FOR MOTIVE POWER.

A is the gas producer, which is supplied with fuel by the elevator B. C is a scrubber or rough filter, and D is a tubular recuperator in which the gas is cooled and the air for combustion is warmed. From this the gas passes to the purifier H, and thence to the gas holder I.

The gas is good and of very uniform quality, and owing to the thorough absorption of heat by the mass of fuel in the upper part of the stack the loss of heat is small, and the producer has a very large gasifying capacity. Very little labour is needed, the combustion is complete, and the slag is very easily removed. Automatic charging is easily applied, the fuel being lifted by means of an endless belt lifter and deposited in the charging hopper. The slag is easily converted into a perfectly white slag wool, for which there is a considerable demand.

The following analyses are of gas made in a producer of this type:—

	1.		2.		3.	
Carbon monoxide	29·50		27·0		25·24	
Marsh gas ...	1·56		1·9		1·79	
Hydrogen... ...	3·80		5·5		7·50	
Total combustible		34·86		34·4		34·53
Nitrogen	63·47		61·4		61·55	
Carbon dioxide..	1·67		4·2		3·92	
Non-combustible		65·14		65·6		65·47
	100·00	100·00	100·00	100·00	100·00	100·00

CHAPTER VII.

MOND GAS. THE PRODUCER. THE CONDENSING PLANT. THE PRODUCTS. COST OF WORKING.

As has already been pointed out, if a very large excess of steam be blown into a gas producer, a great deal of it will pass through undecomposed. At the same time this will lead to a considerable modification in the reactions taking place. The amount of steam decomposed will be very large, so that the quantity of hydrogen in the gas will be much larger than in ordinary cases, sometimes rising above 25 per cent. by volume; at the same time the temperature will be much reduced, and from one-half to two-thirds of the carbon will be oxidised to carbon-dioxide. Such a gas will therefore be very different in character from ordinary producer gas, and must be judged by different standards. It is largely a hydrogen and not a carbon monoxide gas. It is not likely such a gas would ever have been made commercially if the process had been considered only from the standpoint of gas production, but the alteration in the method of working brings with it another important change. In an ordinary producer fed with coal comparatively little of the nitrogen escapes in the form of ammonia, especially if the top of the producer be hot, but in presence of a large amount of steam and free hydrogen, and at the necessarily lower temperature of a producer blown with a large excess of steam up to 70 per cent. of the nitrogen in the fuel can be obtained in the form of ammonia, and thus, though the process is more costly, the extra cost may be more than paid for by the large amount of ammonia obtained.

Mr. Beilby some years ago erected a plant at the Oak Bank Oil Works for the preparation of gas and recovery of ammonia, a large excess of steam being used. The method used was based on the principle adopted by Messrs. Young & Beilby in their retorts for the distillation of shale and recovery of the ammonia. The plant is thus described in Mills & Rowans' fuel, p. 276: "A number of vertical retorts are grouped together in a bench or double row, with passages surrounding them for the circulation of the heating gases." These are built of brick, and "have the exit pipe for the gases at about the middle of their height. The coal is fed in from hoppers at the top, and is distilled at a good heat in the upper part of the retorts. The tar vapours, together with the steam, pass down through the hot coke, and are decomposed into permanent gases and ammonia, no tar being found in the pipes when the temperature is properly regulated. The coke passing into the lower half of the retorts is burnt in a mixture of steam and air, with excess of steam in order to secure the ammonia, and the gases from this portion ascend and pass away by the exit pipe. In starting these retorts it is necessary to obtain some gas for combustion in the chambers surrounding them in order to heat them up. This may be made from coke in a subsidiary producer placed alongside. The gases from the retorts are drawn away by the main, and are passed through condensers and scrubbers, when the ammonia is separated and recovered." About 75 per cent. of the nitrogen in the fuel is recovered as ammonia.

Mond's Process.—Dr. Ludwig Mond commenced experimenting with gas plant about 1879, and in his presidential address to the Society of Chemical Industry in 1889 he pointed out what had been done in the direction of recovering ammonia from the products of the gasification of coal, and gave drawings of a gas producer and condensing plant he had devised, and with which he had obtained good results. The plant now used is a modification and improvement of that there described, but the principle is exactly the same. The plant and method of working will be slightly modified according to whether the main object is the production of gas or the recovery of ammonia. It was principally with a view to the ammonia recovery that the process was devised.

The Plant.—The plant consists essentially of two parts, the gas producer and the condensing and recovery plant.

The Producer.—The producer now used is of the water-bottom type, and consists of a double-cylindrical wrought-iron shell, lined with firebrick up to near the top as usual. The bottom of the producer is narrowed, and terminates in an iron ring, on which hang the firebars which form a continuation of the producer, and being attached at the bottom to another iron ring form a hanging grate, through the centre of which the ashes pass out into the water trough. The outer shell of the producer is prolonged downwards into the trough of water so as to form a water seal, and the ashes are drawn from beneath this by means of spades and rakes in the usual way. In the centre of the top of the producer is the charging hopper, to which is attached a bell, which extends some distance into the producer, and which is always surrounded by hot gas when the producer is at work. Steam and air are supplied into the space between the two casings of the producer, and passing downwards are delivered in a ring outside the grate, and thence pass into the mass of fuel, the gas being drawn off near the top of the producer as usual.

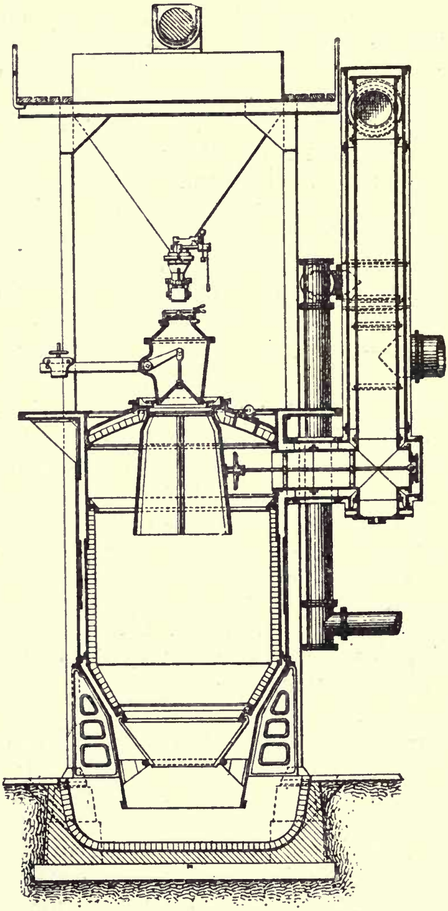


FIG. 24.—MOND PRODUCER.

The Condensing Plant.—One characteristic of the Mond plant is its condensing plant. This is essential even if it be not desired to recover the by-products, on account of the large quantity of steam used, and the necessity for condensing the undecomposed excess.

The ordinary plant consists of three portions, the regenerators, the washer, and the towers.

The regenerators are a series of double wrought-iron tubes united alternately at bottom and top. The hot gas from the producer passes through the inner tubes, up and down, and the mixture of steam and air for supplying the producer passes in the opposite direction through the annular space between the inner and outer tubes, thus surrounding the hot gas, and as the gas is cooled the air and steam mixture is heated.

The washer to which the gas next passes is a large wrought-iron chamber partly filled with water and provided with mechanical dashers fixed along the surface of the water in such a way that as they rotate the blades throw up a large quantity of spray which fills the chamber. The gas is thus cooled to about 90°, and the water vapour formed is swept forward, so that there is no condensation of ammonia liquor.

Three towers are used, called respectively the ammonia recovery or acid tower, the gas-cooling tower, and the air heating and saturating tower.

The gas passes first to the acid tower, entering at the bottom and passing upwards. The tower is filled with a checker-work of firebrick, so as to give a large surface of contact, and a rain of sulphuric acid liquor is allowed to fall down it, which, meeting the free ammonia in the ascending gases, converts it into sulphate. The acid liquor contains only about 4 per cent. of free acid, and is circulated continuously by means of a pump, its strength being maintained uniform by drawing off the sulphate liquor and adding a corresponding amount of fresh acid. The liquor and acid is passed through a settling tank, so as to be thoroughly mixed before it reaches the pump.

The gas from the acid tower, deprived of its ammonia, passes from the top of the tower into a large wrought-iron vessel, 12ft. diam., filled with wood packing so arranged as to give a large surface. The gas containing its burden of steam has here to meet a downward current of cold water, which considerably reduces its temperature.

"When entering the gas-cooling tower it (the gas) is nearly saturated with steam, so that as its temperature begins to fall its capacity for carrying steam rapidly diminishes, and condensation takes place. The table (Appendix 1) shows how considerable the condensation must be, and the result is the utilisation of the latent heat of the steam, as well as the sensible heat of the steam and gas, in raising the temperature of the circulating water, which consequently escapes hot."*

"From the gas-cooling tower the gas is conveyed by the gas mains to the furnaces for combustion for use in gas engines. In the works at Northwich more than 24,000,000 cub. ft. of gas are used daily." The hot water which leaves this tower is pumped to the top of the heating and saturating tower, where its heat is given back to the cold air passing through on its way to feed the producer, and it is at the same time saturated with water vapour. The air is forced through the apparatus and to the producer by suitable blowers.

The Steam.—The amount of steam used is about 2½ tons per ton of fuel consumed. As a ton of carbon could only decompose 1½ tons of water even if it were completely oxidised by steam, and as the fuel will probably not contain more than 60 per cent. of carbon, a considerable quantity of which will be burnt by air, by far the greater portion of the steam will pass through undecomposed; probably, at least, two tons so passing. Hence the necessity for the elaborate condensing plant.

The Products.—Owing to the low temperature of the producer and the large excess of steam, the gas is very unlike ordinary producer gas. The percentage of carbon-dioxide and of hydrogen is high, and that of carbon-monoxide is low.

The following analysis shows the composition of the gas:

	By Volume.	By Weight.
Carbon-monoxide	11·0	13·1
Carbon-dioxide	17·1	32·0
Marsh gas	1·8	1·2
Olefines	·4	·5
Hydrogen	27·2	2·2
Nitrogen...	42·5	51·0
	100·0	100·0

---

* Humphrey's, Proc. Inst. Civ. Eng. cxxix., pt. 3.

The calorific power of such a gas will be—

Carbon monoxide...	·131 × 2400	=314 CU	= 565 B.T.U.
Marsh gas............	·012 × 12000	=144 ,,	= 259 ,,
Olefines (2*e* $C_n H_{2n}$)	·005 × 10000	= 50 ,,	= 90 ,,
Hydrogen	·022 × 29300	=644 ,,	=1159 ,,
		1152	2073

and as 1000 cub. ft. weighs about 65·68 lbs., 1000 cub. ft. will give 75,663 CU of heat=136,193 B.T.U.

The loss of heat in the producer is about 20 per cent., so that the heating power of the gas is about 80 per cent. of that of the fuel consumed.

The gas is free from tar and excess of moisture, burns with a non-luminous flame, and has been successfully used for most purposes for which fuel gas is required, including steel melting.

Ammonia.—The ammonia recovered is equal to about 90 lbs. of sulphate for each ton of coal consumed, or one ton of sulphate for each 23 tons of coal.

As a rule, of course, Mond gas will be made chiefly for the purpose of recovering the by-products, in which case about 2½ tons of steam will be used per ton of fuel, but a similar gas can be made without by-product recovery, in which case only about half this amount of steam need be used.

In a paper read before the Institute of Civil Engineers, Mr. Humphreys gave a detailed account of experiments in connection with the working of a Mond gas plant. Those interested should refer to the paper.

STATEMENT OF COST OF WORKING A MOND PRODUCER AND RECOVERY PLANT.[‡]

(At Winnington, Cheshire.)

Price of coal per ton at works...	£0	6	2
Selling price of sulphate. Price, August, 1896, net naked at works per ton	7	4	6

1 ton of sulphate is obtained from 23 tons of fuel gasified, but adding fuel for steam required the total is 28·56 tons.

Cost per ton of sulphate of ammonia made—

Total cost of all fuel (28·56 tons at 6/2) ...	£8	16	1
Wages at producers (23 tons at 6·4d.)	0	12	3

[‡] Humphreys.

Manufacturing, wages, administration	£0	1	9
Manufacturing, wages, labour	0	19	8
Repair wages and materials, including renewals	0	18	3
Lubricants	0	1	8
Gas for lighting purposes	0	3	11
Sulphuric acid 0·95 tons at 145°Tw	1	4	4
Total for above	12	17	11
Selling price of sulphate naked at works	7	4	6
Final cost of 23 tons of fuel gasified	5	13	5
or final cost of gas from 1 ton fuel gasified	0	4	11
or cost of 1,000 cubic feet of gas (at 15 C) 0·351d.			
or gas for 1 h.p. will cost ·02685d.			
or gas for 1 h.p. for 24 hours a day for a year	£0	19	7·2

The Duff Plant.—It will be evident that gas could be made with other types of producer, but the only one which seems to have been actually used in this way is the "Duff," an installation of which, put up by the United Alkali Company, at Fleetwood, has been running since the spring of 1899, gasifying 500 tons of slack per week without a stop or hitch of any kind, except a slight overhaul after twelve months' working.

The producers used are rectangular, and the slack is distributed mechanically into large hoppers placed directly above the charging hoppers of the gas producers.

The gas, as it leaves the producer, enters the recuperators or superheaters, which are narrow rectangular tanks or chambers with partitions to direct the passage of the air and steam on its way to the producers. These chambers contain zig-zag vertical pipes which convey the hot gases from the producer on their way to the washing plant. The gas then passes to the washing tower, where it meets a stream of descending sulphuric acid; then to a cooling tower, in which the gas is cooled before passing to the engines; and beyond this is a third tower where the incoming air meets the hot water from the cooling tower, and this becomes heated and charged with water vapour."

It will be seen that the condensing plant closely resembles that used in the Mond process.

Quite apart from the recovery of by-products, the gas made with excess of steam, which we may call Mond gas, seems to have advantages over ordinary producer gas for gas engines, and some other purposes. Such a gas may be made in any type of producer by using a large excess of steam, and if the ammonia is not to be recovered the excess of steam need not be so large as that used by Mr. Mond, probably one ton for each ton of coal burnt will be sufficient, and much less elaborate condensing plant will be necessary.

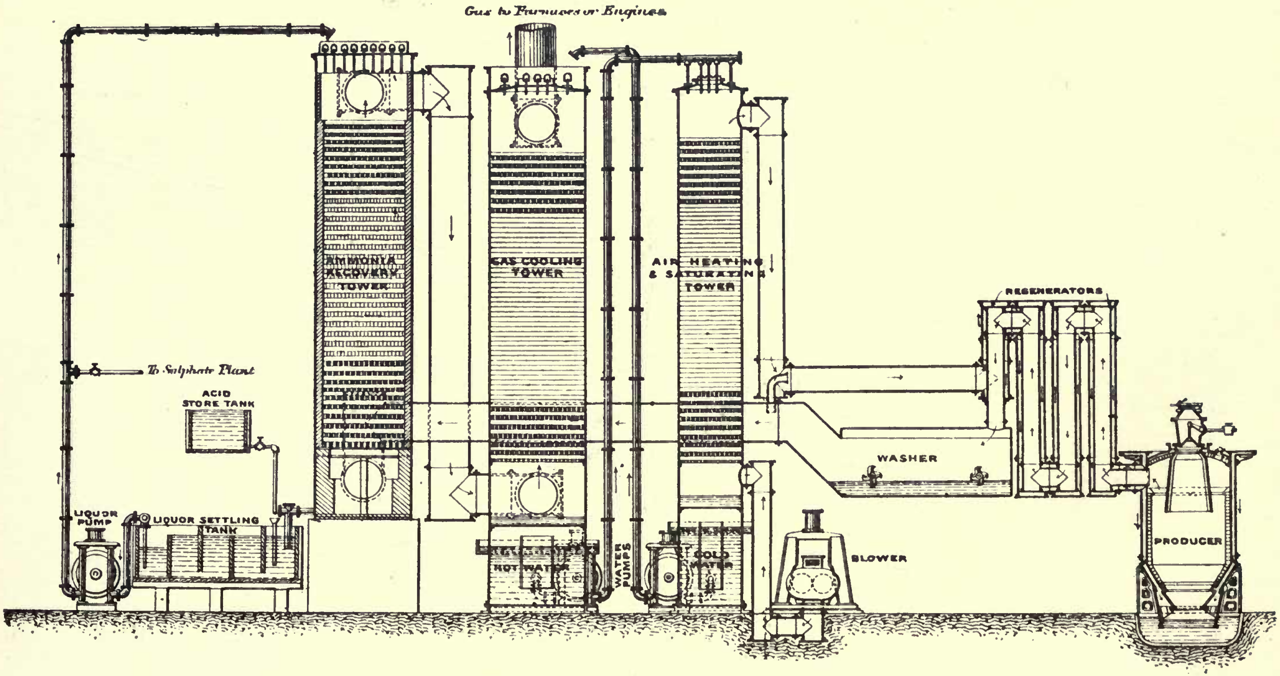


FIG. 25.—DIAGRAM OF MOND GAS PLANT.

CHAPTER VIII.

WATER GAS. THE LEEDS PLANT. THE LOOMIS PLANT. THE DELLWIK-FLEISCHER PROCESS. PROPERTIES OF WATER GAS.

As has been already pointed out, when steam is passed over red hot coke it is decomposed, and a mixture of carbon monoxide and hydrogen is producd thus—

$$C + H_2O = CO + 2H.$$

This reaction, as will be seen, is made up of two parts, the decomposition of a molecule of water which will absorb heat, and the formation of a molecule of carbon monoxide which will evolve heat. The thermal result will be, starting from liquid water—

Heat of formation of one molecule of carbon monoxide	29000 +
Heat of decomposition of one molecule of water	68360 −
Balance	39360 −

If, however, as will actually be the case in practice, steam be used, the latent heat of steam must be deducted from the figure given for the calorific power of hydrogen. The figures will then be—

Heat of decomposition of one molecule of water	68360	
Latent heat of steam, 537 × 18 ...	9666	
Heat of decomposition of steam		58694 −
Heat of formation of one molecule of carbon monoxide		29000 +
		29694

If the reaction is to go on, this 29694 units of heat must be supplied from outside.

It will be seen, therefore, that such a process must either be worked intermittently, or else heat must be supplied by the combustion of fuel in some other way.

The intermittent method of working has been almost universally used. Air is first blown over hot coke till the mass becomes very hot, the reaction being $C + O = CO$, by which 29,000 C units of heat are evolved for each 12 parts of carbon consumed. Steam is then blown over the hot coke, water gas being produced till the mass is so far cooled that the decomposition does not take place readily. The steam is then shut off, and air sent in till the coke is once more hot, and so on.

Theoretically the gas should contain equal volumes of carbon monoxide and hydrogen, so that its composition would be:—

	By Volume.	By Weight.
Carbon monoxide	50	93·33
Hydrogen	50	6·67
	100	100·00

Owing to the conditions of production, however, small quantities of nitrogen and carbon dioxide are always present.

The idea of the manufacture of such gas must have occurred to makers of producer gas, and it is impossible to say by whom it was first put into practice, but a plant for the production of water gas is said to have existed at Phenixville, Pa., in 1874. A patent was granted to J. S. C. Lowe in 1875, and in 1886 the committee of the Franklin Institute awarded a medal of honour to Mr. Lowe for his pioneering work.

Little was heard in this country of water gas as distinguished of course from the gas made in producers into which steam was blown at the same time as air, till the formation of the British Water Gas Syndicate and the erection of the plant of Mr. Samson Fox at the Leeds Forge in 1888.

The Leeds Forge Plant.—As this plant may be regarded as being the pioneer British plant, it will be taken as a type of the class of apparatus to which it belongs. "The generator consists of a cylindrical vessel of boiler-plate lined with firebrick. The bottom of the generator is somewhat narrowed, and the fuel falls on to the bottom in a cone, leaving an annulus round which alternately the air passes to the fuel, and the gas escapes from the fuel. Connected with this annulus through a port or passage formed in the brickwork is the valve chamber, which is kept cool by circulating water, and is provided with three passages,

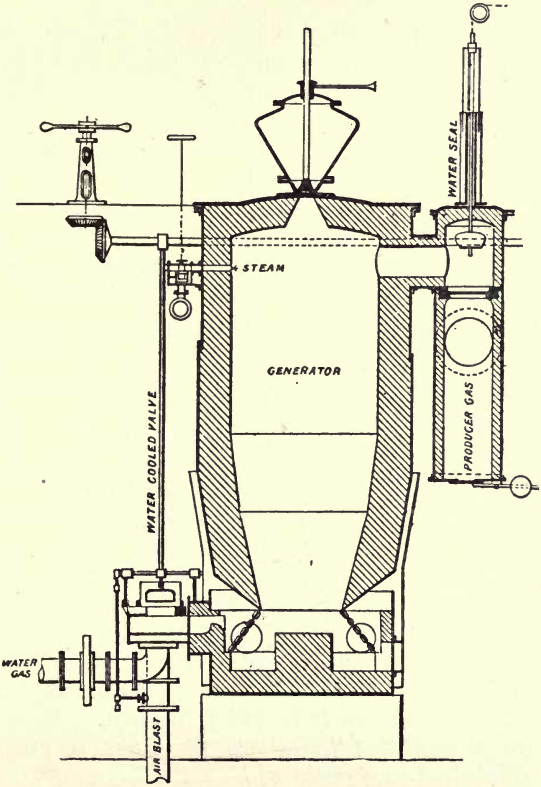


Fig. 26.—Water-gas Plant at the Leeds Forge.

through one of which the air passes, and through another the gas escapes, the centre passage being in connection with the generator. The valve slides on the face of this box, and has a double U-shaped port which may be brought into alternate connection with either the air or gas passage and the centre passage."

The air enters from the main under suitable pressure, being regulated by the valve, and the gas main conducts the water gas through a scrubber to the gas holder.

From the upper part of the producer a producer gas main leads to the furnaces or other appliances where the producer gas is to be burned, and a pipe from a boiler leads a supply of steam to the upper part of the producer above the level of the fuel.

The working is intermittent, coke or anthracite is charged by the hopper, the producer being kept full. Air is blown in from the air main, combustion takes place, and a gas, which is a simple producer gas, consisting almost entirely of carbon monoxide and nitrogen, passes away by the producer gas main. As the combustion of the coke evolves heat, the temperature rapidly rises. As soon as the charge is hot enough the air is shut off, and the producer gas valve is closed and the steam valve and the water gas valves are opened.

The steam passing through tke coke is decomposed, and water gas is formed. This goes on till the coke is sufficiently cooled, when the current is again reversed.

In the plant at the Leeds Forge, gas was made for 4 mins., and the heating up occupied 10 mins. Clinker was cleaned out every six hours through doors at the bottom of the generator, the process occupying about 8 mins.

The average yield of water gas from common gas coke is about **3**4,000 cub. ft. to the ton, and the production of each generator in use at the Leeds Forge was 2,200 cub. ft. per hour, or 52,800 cub. ft. per day, the cost of gas being under 4d. per 1,000 cub. ft., including fuel, water, wages, superintendence, depreciation, and interest. Each cubic foot of water produces 2,250 cub. ft. of gas, or one ton of water (which in Leeds costs 1¼d.) will produce 84,000 cub. ft. of gas.

The amount of producer gas made is very large. Mr. Fox stated that three-quarters of the fuel was used in heating up—*i.e.*, in the production of producer gas—each ton of coke yielding 34,000 cub. ft. of water gas and 140,000 cub. ft. of producer gas, so that unless use can be made of the producer gas the process is not likely to be economical.

If the producer gas formed in the heating-up stage is not to be used for fuel it can be used to heat the steam (so as to lengthen the time occupied in gas production), to raise the necessary steam, or in some other way.

In Germany very similar plant was erected in 1885.

The Lowe Producer.—The producer described above is essentially that of Lowe, but the Lowe process as developed in America has been modified, and has been largely used for producing a lighting gas, for which purpose the water gas must be enriched with petroleum or some similar hydrocarbon, since water gas itself burns with a non-luminous flame.

The apparatus consists of two parts—a producer and a regenerator—the latter being a circular chamber lined with firebrick and filled with a chequer-work of firebrick. The producer gas formed during the heating up is passed into the regenerator and there burnt, thus heating the brickwork to a very high temperature. When the heating up is finished, steam is put on in the usual way. At the top of the regenerator the water gas is made to meet a fine spray of petroleum, which is at once volatilised, and, passing over the hot brick work in the regenerator, is decomposed into permanent gases, which pass through the scrubber to the gasholder. The process is worked intermittently, as in the Leeds plant.

The Loomis Plant.—The producer used in this apparatus consists of a cylindrical casing lined with firebrick, about 12ft. by 9ft. At the top is a charging hopper, as usual, and at the bottom a firebrick grate over an ashpit. As originally described, the ashpit was divided by fireclay slabs. Air was drawn down through a series of ports, and the hot producer gas heated the fireclay slabs under the grate to a very high temperature. When heating up was complete steam was blown into the ashpit, being there intensely heated by passing over the fireclay slabs, and passed up through the hot coke, producing water gas.

Mr. Loomis gave the following estimate of gas production in his producer per 1,000,000 cub. ft., the coal costing about $3 a ton.

	$
Coal—25 tons	75
Coal for steam—3 tons	9
Labour	22
Supplies and repairs	4
Purifying	5
	115
Received for producer gas	44
	75
Interest and depreciation...	25
	$100

Or cost per 1,000 cub. ft., $0·10, or say 5d.; or if the producer gas be lost, $0·14, say 7d.

In the newer plants erected by the Loomis-Pettibone Company the arrangement is a little different. Two producers similar to that described above, except that there are no fireclay slabs in the ashpit, are worked together and are attached to a vertical boiler provided with suitable valves.

"In starting fires, a layer of coal or coke about 5ft in depth is put on and ignited at the top, an exhauster creating a downward draught. When the body of the fuel is ignited coal is frequently charged, raising the fuel bed to about 8ft. above the grates, at which height it is maintained. Bituminous coal is generally used, and is charged at intervals as needed through the feed door at the top of the generator."

Air is also admitted by the same door, and by means of an exhauster is drawn down through the fresh charge of coal and through the hot bed of fuel beneath. The resultant producer or generator gas is drawn through the grates and ashpits of generators Nos. 1 and 2, the valves A and B, up through the vertical boiler to the scrubber and exhauster, through the valve C, and is delivered into a small gasholder for supply to the furnaces. When the exhauster has brought the fuel up to incandescence the charging doors E F are closed, valve B lowered, the valve C closed, and the valve D leading to the water gasholder opened. Steam is then turned on into the ashpit of generator 2, and in passing through the incandescent coal is decomposed, forming water gas. From generator 2 the

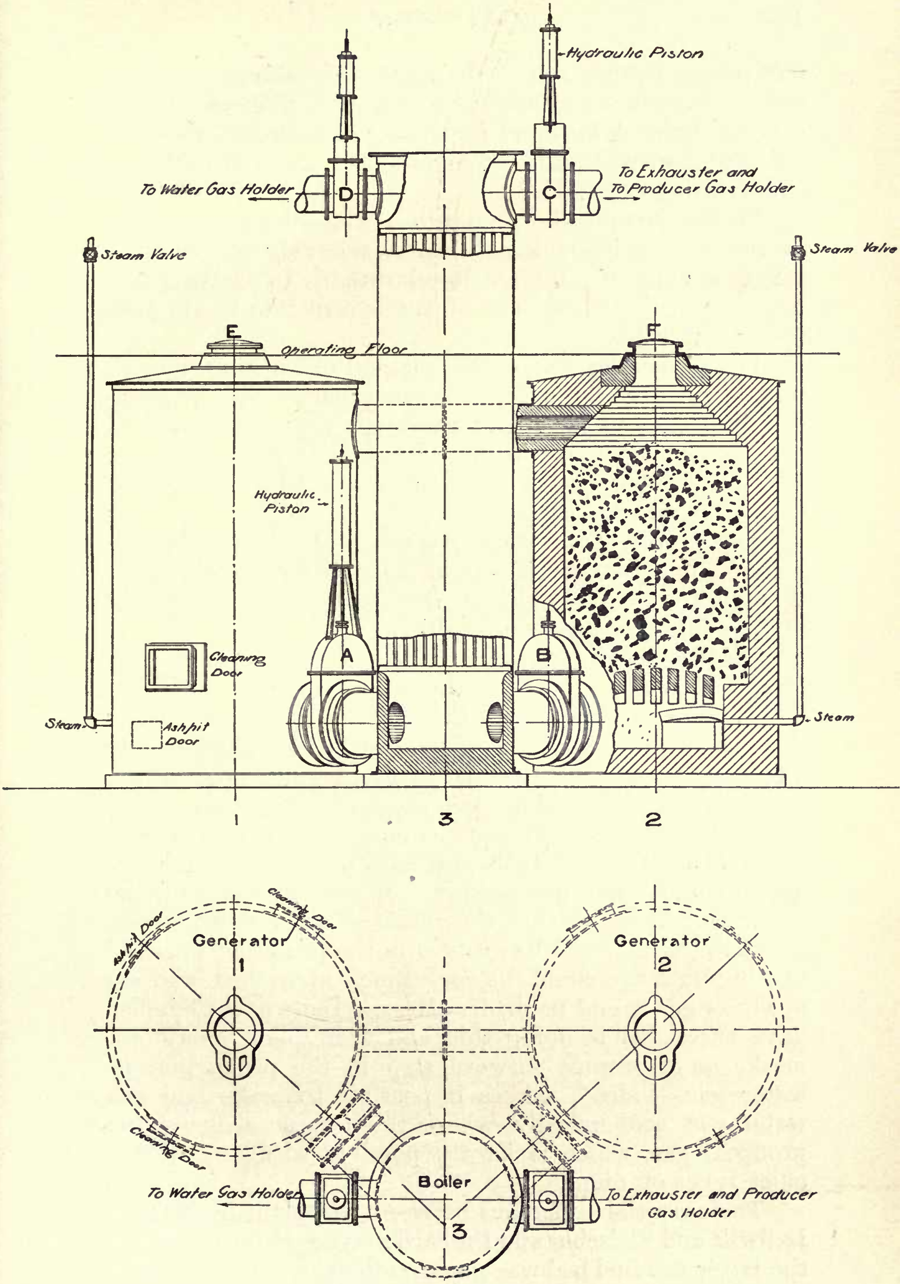


FIG. 27.—LOOMIS-PETTIBONE WATER-GAS PLANT.

gas passes through the connecting pipe shown near the top of the generator and down through producer No. 1, through valve A into and up through the boiler, away by valve D, and then, after being washed in a scrubbler, is conducted into a holder.

Water gas is made for 5 mins., when the temperature of the fuel beds having been considerably reduced the steam is shut off, and air is admitted. In starting the next run of water gas, the steam is sent into the bottom of generator 1.

It will be seen that in this method of working, though coal is or may be used, the tarry matter will be completely broken up by passing through the thick layer of hot fuel, and the steam is very completely decomposed; also the sensible heat of the gases is to a large extent used in raising steam.

The producer and water gas are sent to separate gasholders, but may be mixed in one holder should it be thought to be desirable, or they may be used from the holders in any suitable proportion.

The Dellwik-Fleischer Plant.—It will be seen that all the forms of plant described—indeed all in use until the introduction of the Dellwik-Fleischer plant—labour under the disadvantage that during the heating-up stage a large quantity of producer gas is made, because under the conditions which hold in the producers it is impossible to oxidise the carbon more completely than to carbon monoxide. Thus but little heat is evolved in the producer, and a combustible gas escapes. If the carbon could be burnt to carbon dioxide, the whole of the available heat of combustion would be evolved in the producer, thus the heating-up stage could be very much shortened, and no producer gas would be made. Messrs. Dellwik & Fleischer have succeeded in doing this, and their plant, therefore, marks an enormous forward step in the production of water gas—indeed, makes it possible to make and use water gas economically where there is no demand for producer gas, which is hardly possible with any of the older types of plant.

The essential difference between the plant of Messrs. Dellwik and Fleischer and the earlier types is that while in the latter the fuel bed was made so thick, and the quantity of air supplied was so small that the carbon dioxide formed at first was almost completely decomposed by the hot carbon, as in ordinary gas producers, in the former the bed of fuel is made so thin, and the air is supplied in such quantity that the carbon is completely burnt to carbon dioxide.

The results which are obtained by this change are described in the following extract and accompanying table from Mr. Dellwik's paper, read before the Iron and Steel Institute in 1900.*

The chemistry of the process is, of course, exactly the same as that of the other processes. It is described as follows by Mr. Dellwik:—

"If we look into the chemical reaction in the formation of water gas, we find that 18lbs. of steam, consisting of 2lbs. of hydrogen and 16lbs. of oxygen, require for their decomposition 2 × 28,780 = 57,560 thermal units. The 16lbs. of oxygen combines with 12lbs. of carbon to 28lbs. of carbon monoxide, which in mixture with the 2lbs. of hydrogen form 30lbs. = 753·4 cub. ft. of water gas. The heat developed by the formation of the carbon monoxide is 12 × 2,400 = 28,800 thermal units, thus leaving a balance of 57,560 – 28,800 = 28,760 thermal units, which must be replaced by the combustion of carbon during the blows. Assuming, then, as is approximately the case in practice, that the blow gas leaves the generator at a temperature of 700° C., we find—

	Old Method.	Dellwik Method.
1lb. C requires for combustion	to CO $\frac{16}{12}$ lbs. O	to CO_2 $\frac{32}{12}$ lbs. O
The O is accompanied by	4·32lbs. N	8·64lbs. N
and the products of combustion carry with them at 700° C.	1,136 Th.U.	2,092 Th.U.
The heat of combustion of 1lb. C is	2,400 Th.U.	8,080 Th.U.
Balance available for heating the fuel is	2400 – 1,136 = 1,264 units.	8,080 – 2,092 = 5,988 units.

---

* "Journal Iron and Steel Institute," Vol. i., 1900, p. 123.

	Old Method.	Dellwik Method.
To fill the beforementioned balance of 28,760 Th.U.* the production of 30lbs. of gas, there must be burnt	$\frac{28,760}{1,264}$ = 22·75lbs. C.	$\frac{28,760}{5,988}$ = 4·83lbs. C.
Not counting the heat lost by radiation and other causes, there are required for the production of 30lbs. = 753 cub. ft. of water	12 + 22·75 = 34·75lbs. C.	12 + 4·83 = 16·83lbs. C.
gas or per 1lb. of C are obtained...	21·7 cub. ft. of water gas.	44·7 cub. ft. of gas.
As water gas of theoretical composition contains 167 Th.U. per cubic foot, there are utilised in the water gas from 1lb. of carbon	3,627 Th.U. = 44·8 per cent. of the heating value of the C.	7,465 Th.U. = 92·5 per cent. of the heating value of the C.

The difference between the two processes will be obvious. Indeed, it has long been known what was needed, but it was left for Messrs. Dellwik and Fleischer to devise a practicable method of carrying it out.

In the old water gas process the producer gas formed during the blows is amply sufficient for generating the steam needed for the process. When a combustion to carbon dioxide is effected in the generator this advantage is, of course, lost, the waste heat being only sufficient for preheating the feed water for the boiler. It is, therefore, necessary to add for boiler fuel 12 to 15 per cent. of the fuel used in the generator. This reduces the theoretical quantity of gas obtainable from 12lbs. of carbon to 656 cub. ft., and the possible utilisation of the heating value of the fuel to about 80 per cent.

---

* Mr. Dellwik has taken slightly different values for the calorific power of hydrogen and carbon from those used in this book.

In these figures it will be noted that Mr. Dellwik assumes that in the heating-up all the carbon is burnt to carbon dioxide, and in the gas making to carbon monoxide only. Neither of these conditions are likely to hold good in actual practice.

According to the report of Prof. V. B. Lewes, the blow-up gas contained

	1.	2.
Carbon dioxide	17·9	18·8
Carbon monoxide	1·8	1·0
Nitrogen	78·6	79·5
Oxygen	1·7	0·7

whilst in other blows the carbon dioxide fell to 15·1 per cent., and there is no doubt that in many cases it is much lower.

The gas produced, as will be seen from the analysis on page 109, is not quite free from carbon dioxide, so that the actual efficiency is likely to be less than that here given by an amount which will vary with the care with which the process is conducted.

The Plant.—Externally the producer does not differ much from those of other types. The first form used was circular and cased with iron, and had two projecting channels on each side for the supply of fuel, at the top of each of which was a charging hopper, instead of the usual single hopper in the centre. At the top was a vertical chimney pipe to carry off the products of combustion during the heating-up stage, provided, of course, with a suitable valve.

The newer forms of producer are circular, and have no side chambers, but are fed at the top. They are up to 12ft. diam. The producer is of the bar-bottom type, air being supplied beneath the bars. The ashpit is provided with a door for the removal of ashes, and above the ashpit is another door for the removal of clinker from above the bars. The combustion space is small, and the layer of fuel comparatively thin. There are gas outlet pipes and steam outlets at the bottom and top of the producer, so that it can be worked alternately up and down. The bars are in two sections, resting on a hollow bar which crosses the centre of the producer, and by which air can be blown in in addition to that which passes through the bars. The producer is about 14ft. high outside. The top is narrowed very much, so as to form a circular opening about 2ft. 6in. diam., which is closed during the gas-making stage by a well-fitting lid. Gearing is so arranged that the steam is shut off, and this lid opened by the one motion of lever, and until this is done the air cannot be put on. The air is supplied by Root's blowers.

Method of Working.—The method of working is as follows: A fire having been lighted on the grate, and the generator filled to the proper level with coke, the blast valve is opened, and the fire raised to a high state of incandescence in a few minutes. One of the gas openings—the upper one, for instance—is opened, the blast and stack valves being simultaneously closed by means of the gearing on the working stage. Steam is admitted at the bottom of the generator, and is decomposed on its passage through the bed of incandescent coke, resulting in the formation of water gas.

A set of water gauges and a test flame indicate the condition of the apparatus and the quality of the gas coming off. When the temperature of the fuel has sunk below the point at which carbon dioxide begins to form in large proportion, the steam is shut off and the stack valve opened, the gas valve being simultaneously closed. The blast valve is then opened for another blow. For the next period of gas making the lower gas outlet is opened, and the steam is admitted above the fuel. By thus reversing the direction of the gas making the temperature of the fuel is equalised, and the wear on the brick lining at any one point is diminished. The greater part of the coke being consumed by the action of the steam, the incombustible part is disintegrated to a considerable extent, and falls through the grate as ash, the clinkers that remain on the grate are brittle, and are easily removed.

The layer of fuel on the bars is in the large producers about 4ft. thick.

When the gas-making stage is over, the cover opened, and air put on, a large pale flame escapes from the top of the producer. As soon as the charge is hot enough the air is shut off, the top closed, and steam put on, the opening and closing of the valves only occupying a few seconds. In one plant gas was made for 8mins.,

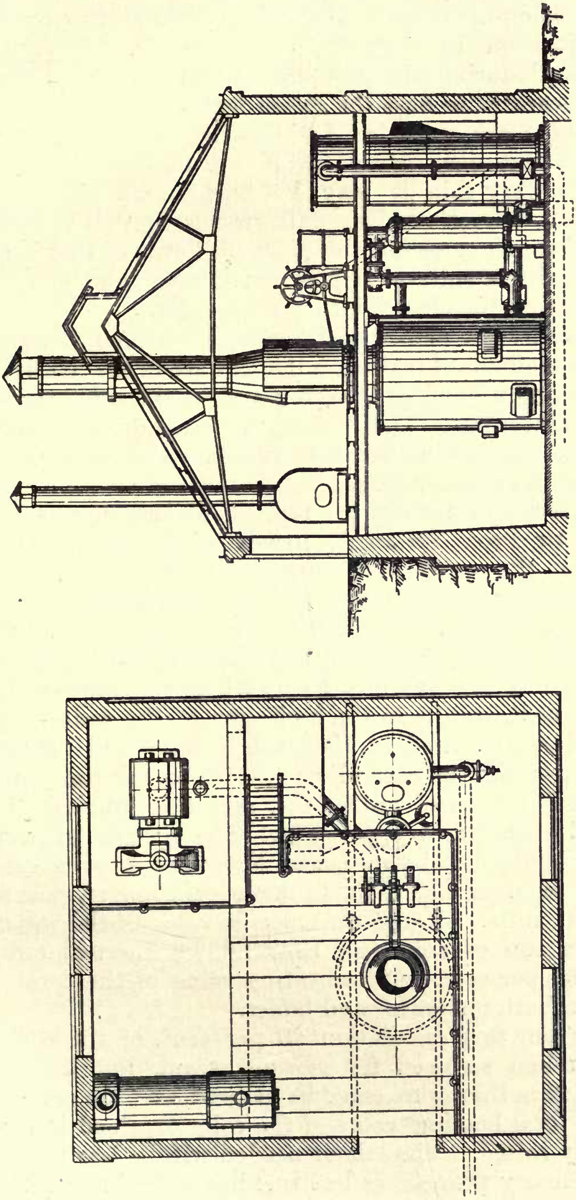


FIG. 28.—GENERAL ARRANGEMENT OF DELLWIK-FLEISCHER WATER-GAS PLANT.

and the heating up occupied 2mins. The flame during the heating-up stage is allowed to burn at the top of the producer on its way to the chimney, but the gas produced during the gas-making stage is passed through a superheater to heat the steam being supplied.

Doors are provided for cleaning the bars. This is done about once every 24 hours, and as the layer of fuel is very thin it may be burnt quite down before cleaning, a fresh fire being afterwards lighted at starting.

After every second blow about 4 cwt. of fuel is added by running a suitable hopper truck over the top opening and letting the charge into the producer.

Results.—The principal differences between this and the earlier methods of making water-gas are in the relative time of heating up and gas making and in the non-production of producer gas. The heating up takes 1·5min. to 2min. and the gas making 8min. to 12min. The amount of gas yielded is therefore large.

A series of tests of the Dellwik-Fleischer process were made by Prof. Vivian B. Lewes, of London, who thus sums up the result of his experiments.†

"One thousand cubic feet of water-gas, containing 15lbs. of carbon, are obtained by a total expenditure of 29lbs. of carbon, so that over 51 per cent. of the carbon is obtained in the gaseous form, while the expenditure of 49 per cent. results in the hydrogen of the water-gas.

"The coke used in the experiments made contained 87·56 per cent. of carbon, or 1,961·3lbs. per ton, equal to 15,876,307 thermal units (°C.), and this amount yielded 77,241 cub. ft. of water gas. The specific gravity, as taken by the Lux balance, was ·5365, and its gross calorific value, as determined in Junker's calorimeter, was 4,089 thermal units. Hence the calorific value of the water gas from a ton of coke was 13,033,059·8 thermal units, or over 82 per cent. of the heating value of the total coke used in both generator and boiler.

"From this calculation 20 per cent. of the coke has been taken as used for raising steam, but in a large installation this figure could be reduced, and the percentage of the total heating value of the coke obtained in the gas slightly raised. The labour needed will be less than with the ordinary process, as less fuel has to be handled."

---

† Dellwik, Journal of the Iron and Steel Institute, 1900, vol. i.

Other tests made by Prof. Bunte of Karlsruhe, Prof. Lunge of Zurich, Dr. Leybold of Hamburg, and others have given similar results. The most trustworthy figures for continued work have been obtained from an installation at the Corporation Gasworks at Königsberg, in Prussia, where an average yield of 38·44 to 39·72 cub. ft of water gas are obtained per pound of carbon contained in the coke which is charged into the generator. This corresponds to a utilisation of 75·2 to 77·7 per cent. of the calorific value of the fuel. At another gas-plant the tests showed a yield of 41·6 cub. ft. per pound of carbon, or an efficiency of 81·3 per cent."

It will be seen that the essential of the process is not so much in the form of plant as in the fact that a very thin layer of fuel is used and a very large excess of air is blown in.

Water Gas.—As already pointed out water gas consists essentially of hydrogen and carbon-monoxide. The following analyses will indicate its usual composition :—

	1	2	3	4	5
Hydrogen	52·43	50·09	52·76	49·17	51·0
Carbon-monoxide ..	38·30	39·95	33·50	43·75	42·0
Carbon-dioxide ...	4·73	5·38	4·08	2·71	4.0
Methane	—	—	—	·31	·5
Oxygen	·74	1·22	·46	—	—
Nitrogen	3·80	3·36	5·20	4·00	2·5

Nos. 1, 2, 3 Dellwik-Fleischer analysis by Prof. Lewes.
No. 5 Dellwik-Fleischer average given by Mr. Dellwik.
As will be seen, the gas is nearly all combustible.
Taking No. 5—

	By Vol.	ByWeight.	C.P.	B.T.U.
Hydrogen	51	6·7	1963 C.U.	= 3533
Carbon-monoxide ..	42	76·7	1841 ,,	3314
Carbon-dioxide ...	4·0	11·5	—	—
Methane	·5	·5	60	108
Nitrogen	2·5	4·6	—	—
			3864 ,,	6955

Volume for volume the heating power is about twice that of the best producer gas. 1,000 cubic feet weigh about 43lbs. and will therefore give about 166,152 C.U. or 299,065 B.T.U.

The gas is of course colourless and odourless, and burns with a pale blue slightly luminous flame, hence it is sometimes called blue producer gas, to distinguish it from the gas enriched with various hydrocarbons which burns with a luminous flame.

Carbon-monoxide is very poisonous, and so therefore is water gas, and as it has no odour by which an escape can be detected, many poisoning accidents have occurred with it. To avoid this danger attempts have been made to give the gas an odour by saturating it with some highly odoriferous body such as carbon-disulphide. Water gas may be used for lighting purposes by making it heat a mantle or comb of some material which becomes highly incandescent, or by charging it with some hydrocarbon which will give the flame luminosity.

CHAPTER IX.

CONDITIONS WHICH MUST BE FULFILLED BY A GOOD GAS PRODUCER. THE AIR SUPPLY. SPEED OF GASIFICATION. SHAPE OF PRODUCERS. SOURCES OF LOSS OF HEAT IN GAS PRODUCERS. QUALITY OF THE GAS. CHARGING PRODUCERS. ASH REMOVAL. TAR REMOVAL. AMMONIA RECOVERY.

WHILST among the producers described there are differences in almost every point of detail, the principles are the same in all cases. In any application of a process or apparatus to a particular purpose real usefulness, and therefore success, depends very largely on the careful adjustment of details, and many processes perfectly correct in principle have failed from lack of this. Hence also very frequently a new idea takes some time to become practically useful because the working out of the details never comes by a flash of inspiration but by steadily testing and correcting defects as they arise.

The conditions which a good producer must fulfil are many.

(1) The gasification of the fuel must be complete. This will depend on the design of the producer and the method of air supply.

(2) It should allow the use of fuel of quality varying within wide limits.

(3) The gasification must be rapid. Obviously the more rapid the gasification the less plant will be required for a given output of gas.

(4) The working must be continuous, or if stoppages are essential they must be at long intervals and of as short duration as possible.

(5) The quality of the gas must be good, that is, it must be as rich as possible in combustible constituents.

(6) The loss of heat in the producer must be as small as possible.

(7) The cost of labour and upkeep must be small.

(8) The first cost should be small. This is, however, of much less importance than the other considerations.

It is impossible to obtain a producer which will be best in every particular, so that in all actual cases the selection is more or less of a compromise.

Several points in connection with producers will be briefly considered that will illustrate the conditions mentioned above.

Air Supply.—The conditions of gasification both as to completeness of combustion and rate and uniformity of gasification will depend largely on the air supply. In general the air may be supplied in three ways—

(1) From below, as in bar-bottom producers.

(2) From the centre, as in ordinary centre-blown producers.

(3) From the circumference.

When the air is supplied from the bottom it is equally distributed over the whole, or at any rate a large portion, of the bottom of the producer. The area of air supply is very large, and the air passes at once into the mass of fuel. However large, therefore, the producer be, the air supply will be fairly uniform. There is, however, an objection to the air being supplied too near the circumference, as it tends to creep up the wall, where resistance is least, and some may even get through unburnt. In the ordinary bar-bottom producers there is the disadvantage of possible loss of fuel through the bars and the trouble of clinkering, which may outweigh the advantage of uniform distribution, though with suitable fuel this may be to a large extent overcome by burning the fuel on a bed of clinker. The necessity for clinkering limits the size of producer which can be advantageously used.

In the Duff producer advantage is taken of the even air distribution of the bar-bottom, whilst the objections are to a large extent overcome. As, however, the bars do not quite reach the outer wall there is a part of the fuel into which the air is not supplied vertically. With the long narrow grate it is found best to make the inside of the producer rectangular in form, by building up inside the circular casing, thus reducing the effective fuel area of the producer. With any bar-bottom producer there is always a danger of the production of clinker, which may be difficult to remove. This is sometimes due to the use of a fuel which cokes, and which, therefore, hinders the uniorm distribution of air, and allows the air only to pass through the narrow cracks or crevices in the "caked" mass, thus producing a very high local temperature and consequent fusion of the ash, or it may be due to the fuel containing a large amount of fusible ash.

With the central air supply the size of the producer is limited by the power of the air to reach the circumference, and this will depend somewhat on the blast pressure. In the centre of the producer, where the steam and air enter, there will be a zone of very vigorous combustion just round the top of the entry pipe, and as the air recedes from this combustion must become much less vigorous, as not only is there the increased resistance, but the stream of air and steam is constantly spreading over a much larger area, and the free oxygen is being rapidly removed. The temperature must, therefore, fall off very rapidly, and there may be a tendency for unburnt fuel to sink down round the circumference. The air and steam are usually delivered horizontally and rise upwards and outwards, and thus, if combustion is complete, at the circumference it will be at a much higher point than the centre.

The larger the diameter of the pipe by which the steam and air enter the better, and in many producers this is made far too small. The stream of air and steam should also be delivered horizontally, so as to give as great an impetus as possible towards the circumference. It is quite easy to arrange the delivery in such a position that the openings cannot be choked, even partially, by the descending ashes. As the air is delivered into the centre of the fuel, equidistant at all points from the wall, there is no possibility of unconsumed air creeping up the walls. The zone of most intense combustion is as far as possible from the walls, so that there is less loss by radiation, and the walls are not likely to be damaged by the intense heat. Provided (1) the diameter of the producer be not too great, say, not more than 8ft. or 10ft.; (2) the air and steam pressure be sufficient to reach the circumference of the producer; and (3) the layer of fuel be sufficiently deep, centre blowing seems to be the most suitable for gas producers, and has been most largely used. Centre-blown producers of very large size, as a rule, do not work very satisfactorily.

The arrangement in the Wilson producer, where the gas is delivered right and left from a central ridge or main, appears to give a uniform combustion.

In producers blown from the circumference the air and steam penetrate inwards, and therefore they have less and less area to cover, but as the area at the outside is very large the rate at which the gas enters is apt to be small, unless tuyeres be used, placed some distance apart, in which case fuel may escape combustion between them, and there is the possibility of a central core of unconsumed matter being left, and there is also the possibility of air creeping up the walls. This method of working gas producers is rarely used, though it is the universal method of air supply in the blast furnace.

The conditions of uniform air supply limit the size of producers of various types. A circular centre-blown producer should not be above 8ft. or 10ft. diam., and circumference-blown producers are usually narrowed to much less than this at the zone where the air enters. The size of bar-bottom producers is generally limited by other conditions.

If the producer can be worked with a layer of clinker above the air supply, so that the air blows into this and not directly into the fuel, the air and steam will become heated and the distribution may also be much more uniform. This is, however, only possible where the fuel leaves a good open clinker.

Speed of Gasification.—The amount of fuel gasified will depend on the amount of air and steam sent in, and this will depend on the pressure and the area of the supply pipes. Some figures have already been given, but the following, which represent a case of actual work, may be useful.

A Wilson or circular producer 8ft. diam. will gasify about 4 cwt. of coal per hour, the area of the supply being about 160 sq. in. A Duff producer 8 × 10 will gasify about 10 cwt. coal per hour, giving a gasification of about 14lbs. per square foot of bottom area, and, of course, a larger amount per square foot of grate area. The area of the air supply will be about 1,720 sq. in.

The conditions which decide the best speed of gasification are many. If the air supply be too great, or if the gasification be too quick, the temperature inside the producer will become too high, and the gases will leave at too high a temperature. The gas also may be swept through so quickly that too large a quantity of carbon dioxide may be left undecomposed. The more concentrated the air supply in general, the slower will be the best rate of combustion.

Attempts have been made to increase the efficiency of the producer by super-heating the air and steam supplied, and if by this means heat which would otherwise be lost is carried back into the producer it must lead to some economy. The methods used have consisted either in circulating the air and steam through passages in the masonry of the producer or in building the producer with a double shell, so as to form an annular space in which the air and steam can circulate.

An example of this arrangement has been described in connection with the Mond producer, and another is the Boyd producer (Fig. 28A). In this the lower part of the producer has no firebrick lining, but consists only of iron plates. Outside this is another casing, and into the space D between the two the air and steam is supplied, and enters the producer by the grate F.

Shape of Producers.—The external form of the producer is not of much moment. For producers standing alone the cylindrical form is generally used, but when they can be built in blocks, as is usually the case where a large production is required, the rectangular form is most convenient, as there is less surface exposed, and therefore less loss of heat by radiation, and the block is more compact.

Sources of Loss of Heat to the Producer.—The efficiency of a producer depends on the amount of heat which is lost—*i.e*, which, being evolved in the producer, is carried away before it can be used in the furnace.

The sources of loss of heat are :—

(1) Heat carried away by the gases.
(2) Heat lost by radiation.
(3) Heat carried out by the ashes.
(4) Carbon-dioxide in the gas.
(5) Water in the gas.

Heat Carried Out by the Gas.—The higher the temperature at which the gas leaves the producer, and the larger the amount of gas per pound of fuel, the greater will be the loss of heat in the gas. It may amount to as much as one-sixth of the total heat evolved in the producer. How far this heat is actually lost will depend on circumstances. If the gas be carried hot to the furnace only, that heat which is

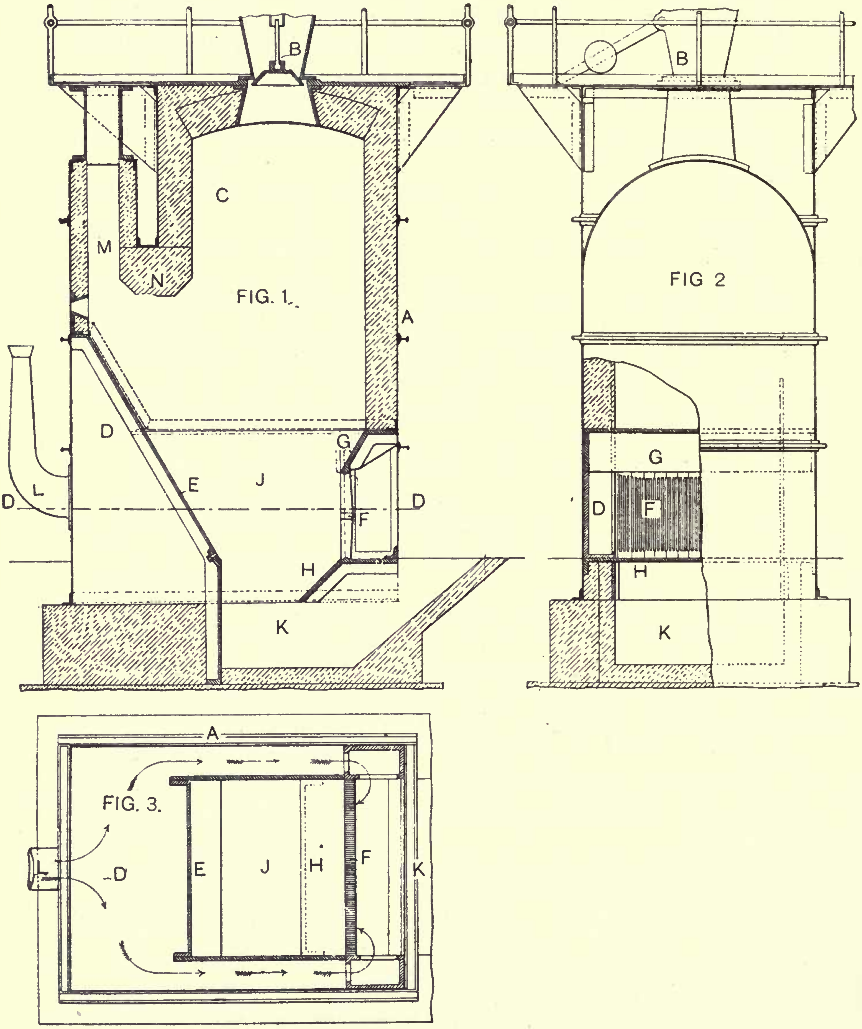


Fig. 28a.—Boyd's Gas Producer.

lost by radiation on the way can be really considered as lost. Opinions differ as to whether the gas should be used hot or cold. If the loss of heat can be prevented, by using the sensible heat in any way, a cool gas is probably best, but otherwise a hot gas is more economical. A very hot gas often leads to trouble with the valves. but much depends on the conditions of working, and whether it is desired to remove the tar or not.

Obviously, methods for reducing this source of loss will be to use the gas hot, to utilise the sensible heat of the gas in some way outside the producer, or to use such a high column of fuel that the excess of heat will be absorbed by it and thus saved in the producer.

Loss by Radiation.—No estimate can be formed of this loss ; it will always be comparatively small, and will be less in the case of producers built in blocks than in those built separately.

Heat Lost in Ashes.—This is always small in solid and bar-bottom producers, and is practically nil in the case of water-bottom producers.

Carbon-Dioxide in the Gas.—The effect of carbon-dioxide in the gas has been already pointed out, and it cannot be too strongly insisted upon that for ordinary producer gas the amount of carbon-dioxide is a measure of the inefficiency with which the producer is working. The usual cause of excess of carbon-dioxide is either a producer badly designed, so that the carbon-dioxide formed escapes without coming in contact with incandescent fuel, or, more frequently, undue cooling by the use of too much steam.

It is in the direction of reducing the amount of carbon-dioxide that the producers need improvement, and users should keep a constant check on the working in this respect.

Steam in the Gas.—The gas will always carry over the water contained as moisture in the fuel charged, but should contain no more; any larger quantity can only be due to excessive steam supply. Steam has a very high latent heat, and therefore will carry away a large amount of heat, which cannot be recovered unless the steam be condensed, a condition not likely to be met with in practice. The specific heat of steam is also very high, so that the loss of heat from excess of steam may be very considerable. When a large excess of steam is used intentionally, as in the Mond process, elaborate condensing appliances are necessary.

Sometimes when gases rich in tarry matters are used in regenerative furnaces an excess of steam may be advantageous, as it may be decomposed by the tarry matters in the regenerators yielding carbon monoxide and hydrogen. As a rule, however, too little steam is better than too much.

Quality of the Gas.—The quality of the gas depends on the fuel and the amount of steam used. No producer can be said in general to give a better gas than another, as every producer in use is capable of giving the best quality gas that is possible from a given fuel. On the other hand, some producers are much more easily worked so as to give the best gas which the fuel is capable of yielding, continuously and regularly. The principal conditions on which this depends are uniformity of distribution of air and steam, ease of regulating air and steam supply, sufficient thickness of hot fuel to decompose any carbon-dioxide formed, and uniform distribution of the fuel.

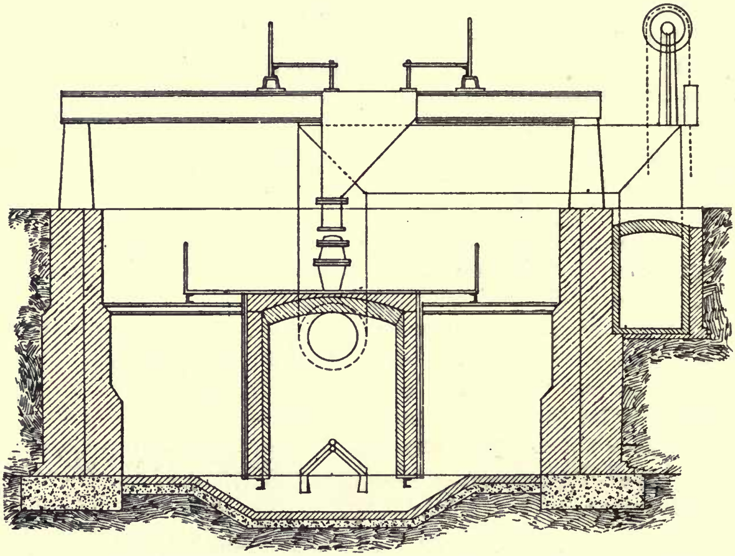


FIG. 29.—DUFF PRODUCER, WITH CHARGING HOPPERS.

Analyses of gases published by manufacturers of different types of producers to show the quality of gas produced are quite useless unless the nature of the fuel used and the exact conditions of working be fully known.

Charging Producers.—Producers are always charged by means of a hopper fitted with sliding or lowering doors, so that the fuel can be put in without admitting air. The exact arrangement of these hoppers varies much. In circular producers there is usually a single hopper in the centre, and this answers well for producers of small size, but it must always be remembered that the fuel from the hopper will form a natural slope, so that the depth of the charge will be greatest under the hopper and least farther away. For large producers two hoppers are sometimes used. For a centre-blown producer the fuel should be supplied in the middle. The finer material will thus form the middle of the mass, whilst the larger lumps will roll off towards the circumference, thus offering an easier passage to the gas near the circumference, and insuring a good distribution of air and steam.

Automatic charging is now largely used. Of the many devices the simplest consists of a rotating cylinder placed below the hopper and provided with a longitudinal opening, so that when this comes under the hopper the cylinder fills with fuel, and as it is then rotated the charge is emptied as the opening comes round over the mouth of the producer. By regulating the speed of rotation of the cylinder, the amount of fuel supplied can be adjusted.

In the top of the producer test holes should be provided by which rods can be put in to ascertain that the fuel is descending uniformly.

The tops of the producers are usually united to form a charging platform, and rails should be laid so that the coal can be brought up in bogies and charged at once into the feeding hoppers. In some cases a large supply bin is fixed above the producers with shoots leading to the various hoppers, so that the fuel can be let down at once for charging.

Ash Removal.—The removal of ash is of the utmost importance. In the intermittent producers there must be an accumulation of ash between the times of cleaning, so that the height of the zone of combustion must be continuously increasing. In water-bottom producers the ash should be removed regularly at short intervals, and care should be taken to draw the ash not only from the outer edge, but from over the whole area of the producer, for thus alone can the uniform fall of the charge and uniform combustion be secured. The ash removal is most uniformly carried out in the automatic producers.

If the fuel yields a firm clinker, it may be desirable to provide some mechanical means by which it can be broken up. The details of any such appliance will depend on the form of producer to which it is applied.

Coking Coals in Gas Producers.—Coking coals are, as a rule, unfit for use in gas producers, since on heating they become pasty, and as the volatile matter is expelled yield a solid mass, which prevents the passage of the gas. If such coals have to be used the coke must be broken up by some mechanical device. A coal which yields a very fusible clinker may also lead to trouble, unless the clinker be broken up mechanically.

In the Fraser-Talbot producer, made by the Wellman-Seaver Engineering Company, a vertical rod passes down the centre of the producer—which is of the water-bottom type—and carries two radial arms which are placed at different angles. The shaft can be rotated by means of gearing, and can also be raised or lowered by means of a hydraulic cylinder placed above, and is provided with springs which will yield if there is undue resistance to the motion of the shaft, and thus lessen the chance of fracture. The shaft is rotated very slowly—about once in 10 minutes—and the vertical motion occupies about the same time, and thus coke and clinker is very effectually broken up. To keep the shaft and arms cool they are made hollow, and a stream of water is kept constantly circulating through them.

Tar Removal.—When producer gas is made from bituminous coal it is always charged with tarry matter, the amount of which will vary with the character of the fuel. The crude tar may reach as much as 15 per cent. of the weight of the coal consumed. There will also be a certain quantity of ammonia, the amount depending on the nature of the fuel and on the amount of steam used. The nature and composition of the tarry matters depends largely on the temperature and rate of distillation.

The tar is combustible, and therefore adds to the heating power of the gas. The tarry matter is not given in an ordinary analysis of a producer gas, the analysis of the crude and washed gases being identical, because in the preparation of the sample for analysis the tar is completely removed.

The removal of the tar from a gas necessarily lowers its heating power, but it is impossible to say to what extent—possibly 10 per cent.; indeed, one manager who has had considerable experience gave it as being as much as 20 per cent. The removal of the tar also reduces or destroys the luminosity of the flame.

If the furnace be far from the producer, and the gases are cooled, there will always be some deposition of tar, though in any case, unless the gas be thoroughly washed, the removal will be far from complete. There will always be a deposit of soot and very thick tar in the mains which must be burnt up periodically.

Whether the tar should be removed or destroyed will depend on circumstances. In boiler firing and in other cases where heating by radiation is required the tar is best left in the gas, but for use in the regenerative furnace a tar-free gas is preferable, whilst for use in gas engines the gas must not only be tar free but also dust free. A tar-free gas may be obtained in three ways:—

(1) By using a material which yields no tar. This is not always easy, as even coke-fed producers may produce a small quantity of tar, so that when the gas is to be used for gas engines it must be washed to remove this and the dust.

(2) By destroying the tar. The method of doing this by passing the gas through the hot fuel has already been explained, but the tar removal by this method is generally by no means perfect.

(3) By washing. In this case the gas is usually cooled and scrubbed by passing up towers down which a stream of water is kept falling, or is washed by being bubbled through or agitated with water. In either case the removal of the tar is complete. Gas for use in gas

engines is always washed or scrubbed. When the gas is so treated it must necessarily enter the furnace cold.

Up to the present no attempt has been made to recover the tar from gas producers.

Tar Destruction.—The method of destroying the tar in the Wilson producer has already been described, and a similar method might be used in conjunction with any other producer.

Mr. Matthewman stated in a paper read before the West of Scotland Iron and Steel Institute that the method

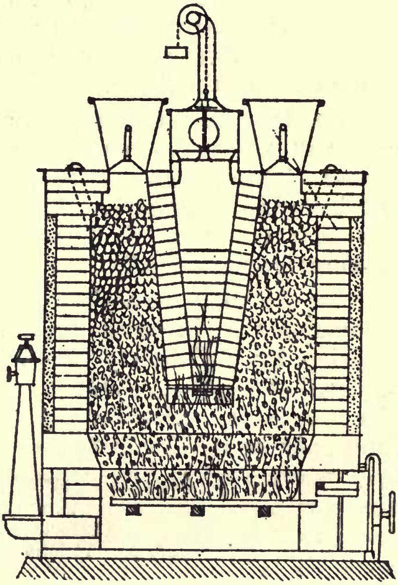


FIG. 30.—THWAITE TWIN PRODUCER.

of drawing off the gas from below the surface of the fuel merely limited the zone of combustion, that the gas found its exit by the nearest possible route, and the fresh fuel did not become decomposed to any appreciable extent until it had fallen into the route of the gaseous current. The tarry matters were therefore not decomposed, but accumulated in the closed upper part of the producer and the gas was practically the same as if made from coke.

This statement undoubtedly contains some truth, but seems to be exaggerated; the tar destruction is not by any means complete, but some of the tar seems to be destroyed.

The process has been a little modified by Mr. Thwaite in his twin producer. This is a bar-bottom producer, and the upper portion is divided into three parts by two hanging walls carried on arches thrown across the producer. The fuel is charged into the two outer spaces, and the gas is drawn off from the middle space. Although the gas is drawn off very low down, it does not seem as if the tar destruction would be any more perfect than in the Wilson form, while the gas, being drawn off near the bars, would leave the producer at a high temperature, and might carry a considerable quantity of carbon dioxide.

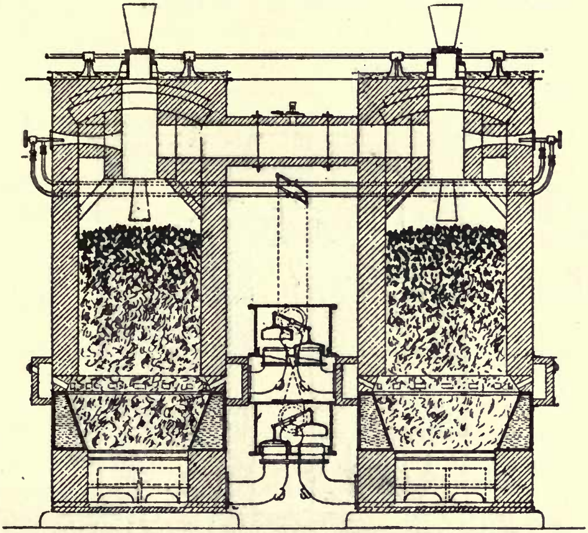


Fig. 31.—Thwaite Duplex Producer.

In the Thwaite duplex producer two producers are used side by side. They are united at the bottom and at the top by cross tubes. The bottom cross tube can be put into connection with the air and steam supply and the gas main, and is provided with valves so that the direction of the current can be changed, and thus air and steam can be supplied to and gas can be drawn off from either producer. Fuel is supplied at the top alternately to the two producers, and a steam jet is arranged so that steam can be supplied at the top of the producers. The mixture of air and steam is blown as usual into the bottom of one producer, say the left-hand one. The gas passes upwards, mixes at the top with the products of distillation, and then, together with any steam blown in at the top, passes downwards through the other producer, the steam and tarry matters being completely broken up on their way to the gas main. The current is reversed every 10 minutes or so, and the gas is said to be quite free from tar, steam, and carbon dioxide.

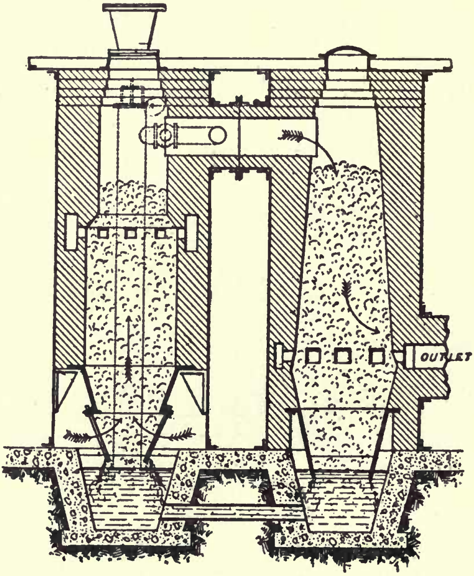


FIG. 32.—THWAITE NON-REVERSAL PRODUCER.

The Thwaite non-reversal producer is very similar, two producers being worked side by side, but the current of gas always passes in the same direction, a supply of air and steam being blown in at the top of the first producer so as to maintain the temperature in the second producer sufficiently high.

The Duff-Whitfield Producer.—This producer is the best that has yet been designed for tar destruction, and leaves little to be desired. The producer is of the ordinary Duff type except that, as greater pressure is required, the air is supplied by a fan or blower instead of by a steam jet, the steam being blown in from a boiler separately. The gas is drawn off to the mains by a pipe some distance below the top of the charge. A pipe passes from above the top of the fuel, and another from a little lower level to vertical pipes reaching nearly to the bottom of the producer, and into each of these a steam jet blows and carries the gas forward into the bottom of the producer. The suction of these steam jets draws enough of the hot gas up through the fuel to insure the distillation of the coal, and the products of distillation are thus carried round and delivered into the hottest zone of the producer, where they are completely destroyed. The gas is thus quite tar free.

Washing Gas.—A large number of different forms of apparatus have been devised for the removal of dust and tar from gas which is to be used for gas engines. The methods consist in passing the gas up towers packed with some suitable material, where it meets a descending rain of water, and thus the dust and tar are washed out, or in bubbling the gas through water, this being, as a rule, much less efficient, or, as in many modern types of plant, agitating the gas with water by means of dashers or other mechanical appliances. This is perhaps the most efficient, and at the same time the cheapest, method of bringing about the desired cleansing.

Ammonia Recovery.—The recovery of ammonia has already been discussed in connection with the Mond plant. No attempt has been made to recover the ammonia from gas producers worked in the ordinary way, as the quantity would be too small to be profitable. The method of Dr. Mond, *i.e.*, the use of a large excess of steam, could no doubt be applied to producers of almost any type, provided efficient condensing plant be provided. It has been quite successfully carried out with Duff producers.

Initial Cost.—The initial cost of the simple types of producer is small, as they are very easily built. The actual cost will, of course, vary with circumstances.

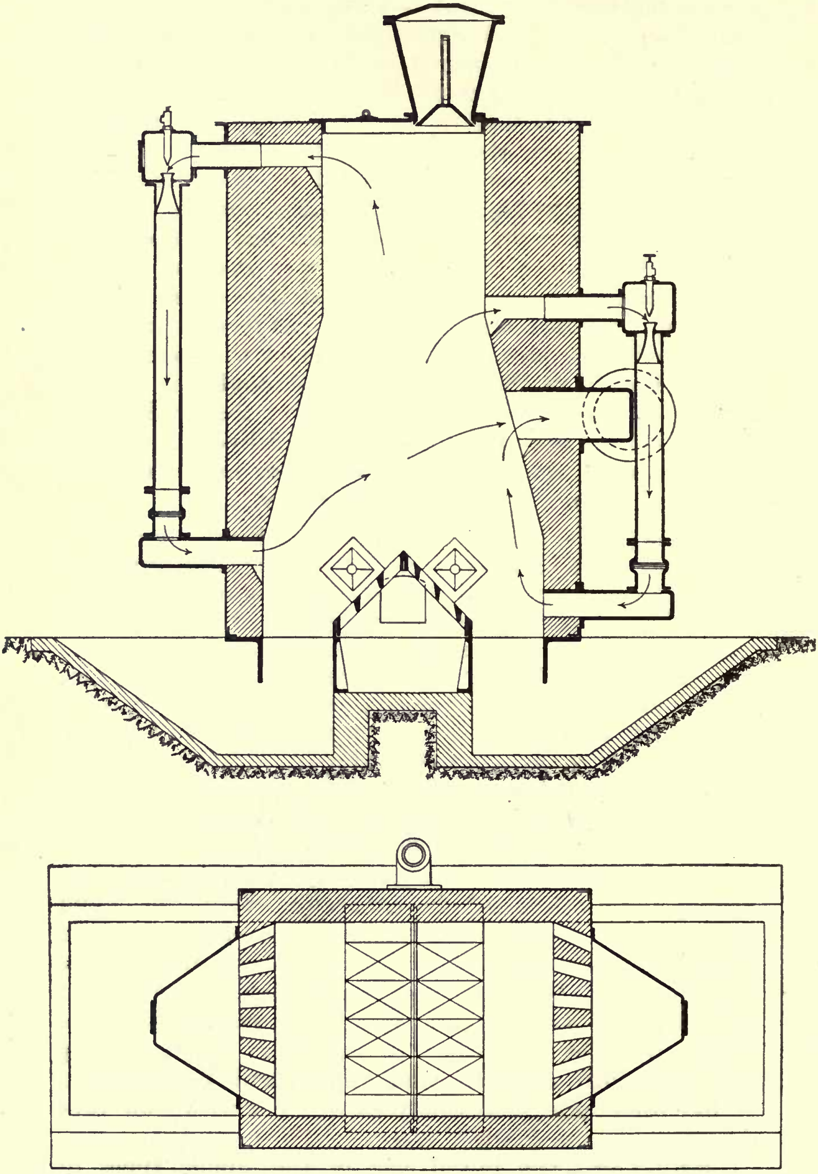


FIG. 33.—SECTIONAL ELEVATION AND PLAN OF THE DUFF-WHITFIELD GAS PRODUCER.

Cost of Labour.—The cost of labour is small, as one man can attend to two or more producers, and additional labour will only be required for removal of the ashes.

Cost of Repairs.—The cost of repairs is small in a well-built producer, but may be considerable if the producer has been badly built at the outset. A well-constructed producer should run for two years or more without needing repair.

Cost of Gas.—The cost of the gas will be made up of many items, each of which may vary considerably under different circumstances and in different localities.

Mr. F. J. Rowan has given the following estimate of the cost of gas-making in Duff producers, each producer gasifying 10 cwt. of coal per hour, and working 60 hours per week, coal at 10s. a ton yielding 150,000 cub. ft. of gas per ton, and labour costing 1s. per ton.

Coal	·80d.
Labour	·08d.
Interest and depreciation...	·20d.
	1·08d. per 1,000 cub. ft. of gas.

CHAPTER X.

USES OF GASEOUS FUEL. FIRING STEAM BOILERS. FURNACES. THE REGENERATIVE FURNACE. THE WEARDALE FURNACE. GAS KILNS. GAS ENGINES. CONTROL OF PRODUCTION.

Using Gaseous Fuel. — Gaseous fuel is available for all purposes for which solid fuel can be used, except for firing furnaces of the blast-furnace type. Its advantages, however, will not be equally marked in all cases, nor, indeed, can it be asserted that it will always, and under all conditions, have an advantage over solid fuel.

There are, in general, four purposes for which gaseous fuel may be used, and as each involves a different set of conditions and has very different requisites for success, they are best considered separately.

They are—(1) Firing boilers for steam-raising.
(2) Heating furnaces without regeneration.
(3) Heating regenerative furnaces.
(4) Working internal-combustion engines.

Firing Steam Boilers.—It must be admitted at the outset that for boiler firing gas has not proved such a success as many anticipated, though many published results will bear comparison with those obtained with boilers fed with solid fuel.

The first attempts at boiler firing by means of gas consisted in placing the fireplace outside the boiler and so enlarging it as to make it a gas producer, each boiler, therefore, having its own producer. Such an arrangement offers no advantages whatever over the ordinary methods of firing; the powerful radiation of the solid fuel is lost, and the great advantage of gas, *i.e.*, that of being able to make it at a central producing plant and distribute it as required, is not obtained. Such methods are therefore necessarily defective, and call for no further comment.

The conditions which hold in boiler heating are very different to those in the heating of an ordinary furnace. The boiler will be full of water which can never attain a high temperature, and therefore will have a very powerful cooling effect on the burning gases, and will produce a thin layer of cold gas, a zone of no combustion, all over the heating surface. The heating, therefore, will not be by contact but by radiation, and hot gases are very poor radiators.

Where gas is used, therefore, every effort must be made to increase the radiative power, and also the temperature of the flame and of the products of combustion. For the former purpose the gas should not be deprived of its tar, as a luminous flame has an enormously greater radiative power than a one which is non-luminous. The calorific power of a gas is, as already remarked, considerably reduced by the removal of the tarry matter, but the heating power, as measured by its steam-raising capacity, is reduced in much larger proportion. Washed gas is therefore quite unsuited for steam raising.

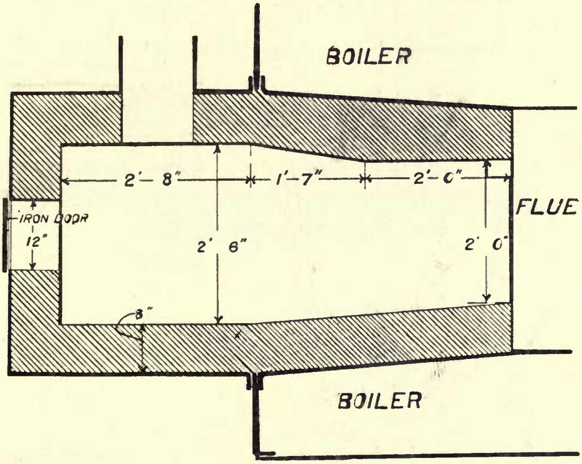


FIG. 34.—COMBUSTION CHAMBER FOR LANCASHIRE BOILER.

Producer gas has a low calorific power, and if it be burnt in a cool space such as the furnace of a Lancashire or Cornish boiler, the temperature attained will be very low, and therefore the radiative power will be very small, and the flame is very likely to be extinguished, or at least the combustion rendered incomplete. This difficulty is overcome by burning the gas in a separate brick-lined chamber outside the boiler, or sometimes within it. The brickwork then becomes heated to strong redness, and thus keeps up the temperature of the gas. An arrangement of the brickwork in such a way that it can radiate the heat directly on to the water spaces of the boiler is a very great advantage.

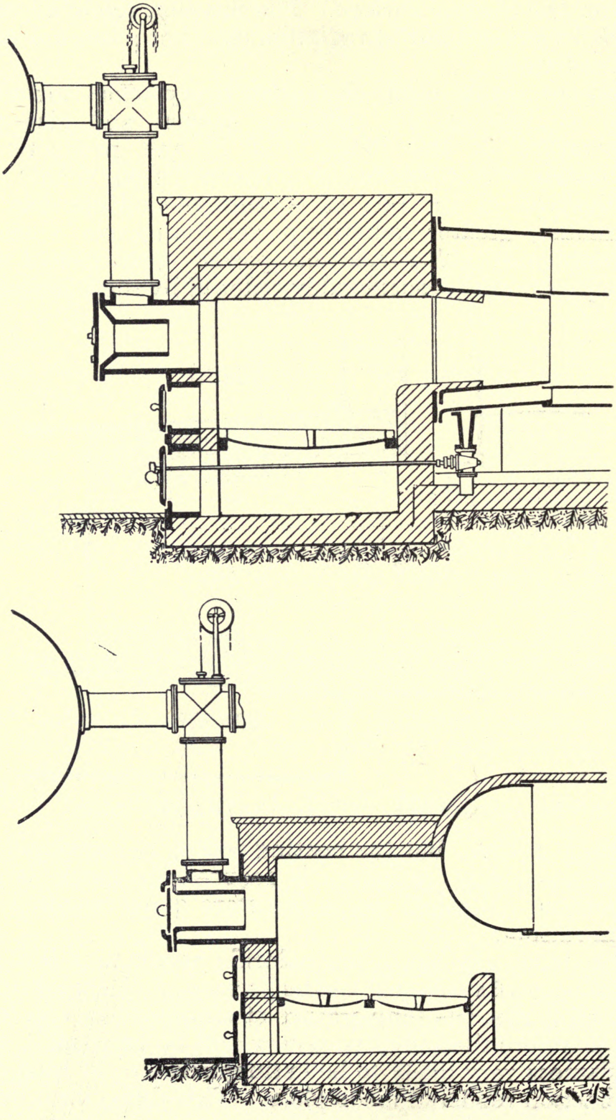


FIG. 35.—COMBUSTION CHAMBER FOR GAS-FIRED BOILER.

Fig. 34 shows a very good arrangement for burning gas in an ordinary Lancashire boiler, and Fig. 35 shows another type which is provided with grate bars, so that a fire can be lighted, and can be kept burning if required. This is, however, quite unnecessary once the brickwork has been heated up to a good red heat. In place of having a separate combustion chamber the boiler flue itself may be lined with brickwork for a length of 4ft. or 5ft. The heat transmitted through the brickwork thus becomes available for heating the water instead of being lost. Fig. 36 shows an arrangement for heating a water-tube boiler—in this case a Babcock and Wilcox—the firebrick grating becoming very hot and thus assisting in the radiation. Whatever form of boiler be used, the air must be supplied by a valve of some sort by which the supply can be regulated. Some firemen seem to think that a gas fire once started can be left to itself without any care, but this is certainly not the case if good results are to be obtained. One of the chief essentials for the successful use of gas under boilers is to burn it with the least possible excess of air, and the richer the gas the smaller the excess of air which is necessary.

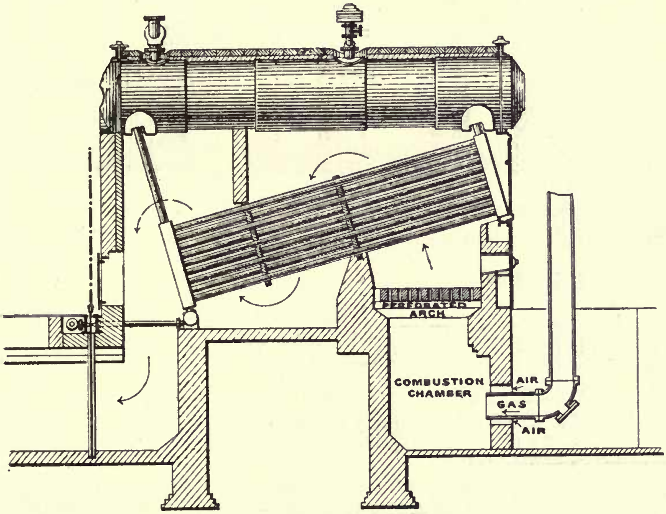


FIG. 36.—GAS-FIRED WATER-TUBE BOILER.

It is not possible to apply the regenerative system to boiler firing because the products of combustion leave the boiler at far too low a temperature. The temperature of the gases is never very high and most of the heat is necessarily taken up by the boiler itself. The waste gas may, however, be used for heating the feed water or for heating the incoming air, but intermittent systems are quite out of the question. A continuous system such as that of Gorman might be used, and an arrangement said to work satisfactorily with blast furnace gases has been introduced by Mr. Tate, of Workington. In this system the furnaces and flues are surrounded by firebrick regenerative chambers Fig. 37, which become heated by the products of combustion. The air enters the lower regenerative chamber at the front of the boiler and is made to take a tortuous course through it by means of

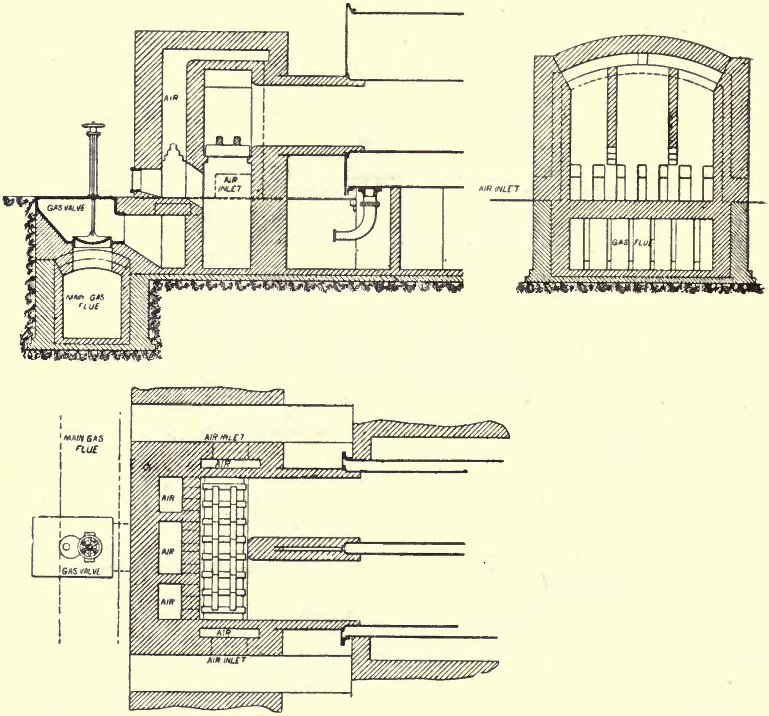


FIG. 37.

firebrick partitions; it then travels back by the side chambers, and is delivered into the combustion chamber. In one set of experiments the air had a temperature of 480° Fah., and in another set a temperature of 735° Fah. These temperatures are very low compared with those obtained in the Siemens furnace, but are high enough to be of real advantage in working the boilers. It is uncertain, however, whether greater practical effect could not be obtained by using the waste heat to heat the feed water.

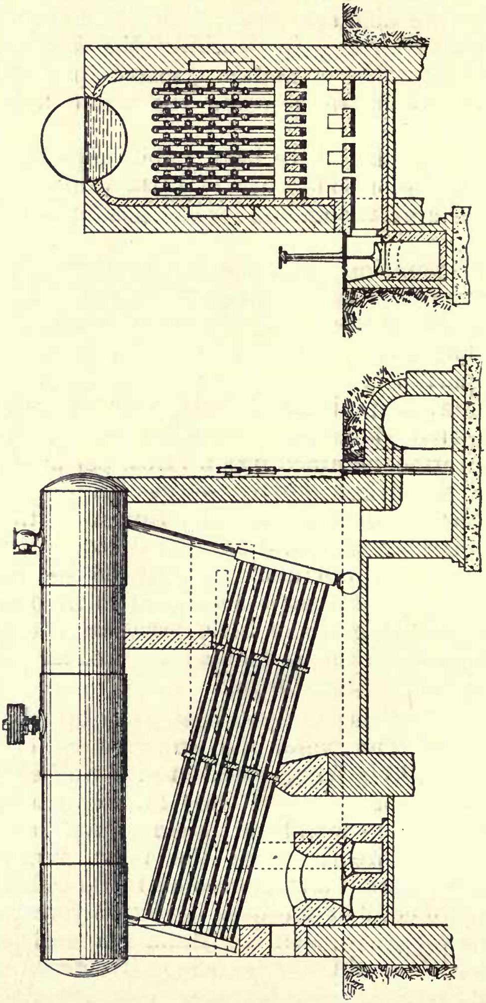
The figures that have been published with reference to the gas firing of boilers are of little value, as in many instances the arrangements for the gas firing were very crude.

The evaporation obtained has varied very much. From a large number of published figures about 5·5lbs. per pound of coal used in the producer seems to be a fair average, but the quality of the coal is of course of great importance. In some experiments made by D. K. Clark firing by solid fuel and by gaseous fuel were compared, the same coal being used in both cases. The evaporation obtained was 5·71lbs. per pound of coal with hand firing and 5·67lbs. by gas firing. In another set of experiments made by Mr. Rowan with a multitubular boiler an evaporation of 9·49lbs. per pound of coal gasified was obtained. It should be noted that comparisons with the same fuel gasified in producers or used by hand firing are of little practical value, since in almost all cases a cheaper fuel can be used for gas making than is suitable for hand firing.

Gaseous fuel has not yet been very largely used for boiler firing. The boiler the arrangement of which is shown in Fig. 38 is being satisfactorily worked with gas from a Duff producer, and blast furnace gas is largely used in iron works for steam raising. As, however, the gas is passed directly from the blast furnaces it is impossible to obtain any figures as to its efficiency, but the method of combustion used is certainly very wasteful.

The newer gases, such as Mond gas and water gas, have been little used for boiler firing. No doubt, however, they would be as satisfactory as any other non-luminous gas.

Where boilers have to be kept going singly, or all in one block, it does not seem as if gas fuel has much advantage over solid fuel, especially if automatic stokers be used; but where the boilers are scattered so that coal would have to be delivered in many places, gas might have decided advantages.



FIG, 38.—GAS-FIRED WATER-TUBE BOILER.

The advantages of gaseous fuel for boiler firing may be summed up as follows:—

(1) The fire can be kept at a uniform temperature, there being no necessity for the constant opening of the

furnaces for the supply of fuel as in hand firing, nor is the fire cooled by the addition of cold fuel. To obtain the best results, however, the boilers must receive constant attention.

(2) The gas can be generated in one place and conveyed by pipes to the boilers, wherever they may be situated.

(3) Less labour will be required at the boilers, and the labour required at the producers will be much less than that which would be required to stoke in the ordinary way. These advantages are so considerable that probably in the future gas will be much more largely used for steam-raising than it has been in the past.

Furnaces Without Regeneration.—For heating ordinary reverberatory furnaces without regeneration, gas has much the same advantages and disadvantages as for steam-raising. As the furnace itself will probably be red-hot, a separate combustion chamber is not necessary, and the products of combustion being at a high temperature may be used for steam-raising or other purposes. This method of using gas offers so few advantages that it is rarely used; indeed, in one sense the ordinary coal-fed reverberatory furnace is a gas furnace.

Siemens Regenerative Furnace.—The first and best known of the regenerative furnaces is that invented by Sir Wm. Siemens. In this, as is well known, four regenerative chambers are placed beneath the furnace, and are filled with a chequer work of fire brick. The air and gas are passed up through two of these regenerators, and the products of combustion are passed away through the other two to the chimney, the direction being reversed every hour or so. The air and gas are thus very strongly heated before they come into the furnace, and a very high temperature is produced by the combustion.

Furnaces of this character are now very largely used for many purposes, especially for steel melting, and they are now made of very large size. Indeed, at present no limit has been found to the advantageous size. The air and gas are admitted by ports. The two ends of the furnace are exactly similar. The gas ports are rectangular openings, two or three in number, and the air port is usually a long narrow opening close to the roof, and extending nearly the whole width of the furnace—at any rate, far enough to overlap the gas ports at both ends.

The gas ports are below and the air ports above, because the light gas will tend to rise and the heavier air to fall, so that perfect mixture is thus ensured, and the furnace becomes filled with a long flame extending from end to end.

In the earlier forms of furnace the roof was always built so as to dip towards the middle and to deflect the flame downwards. Mr. F. Siemens, however, contended that this is a mistake, as contact with the hot brickwork tends to induce dissociation and thus to limit the temperature which is attainable by combustion, and he suggests that the roof should be made somewhat higher in the centre so as to give enlarged space for combustion. Most furnaces are now built with the roof nearly horizontal over the main part of the furnace, but rising sharply near the ends to the air ports.

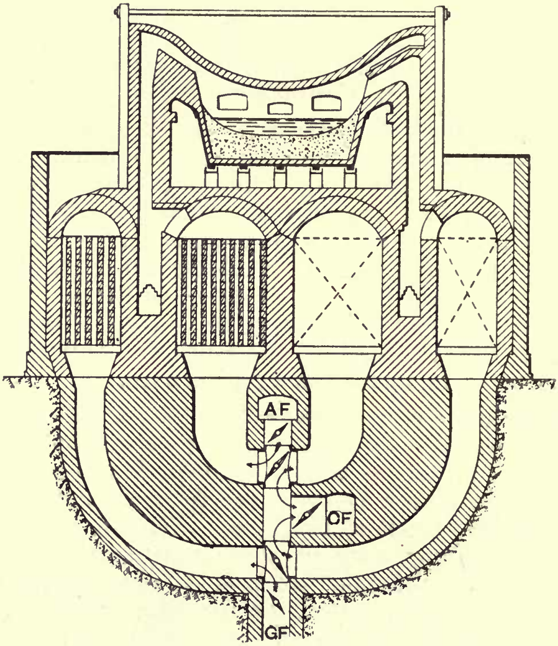


FIG. 39.—DIAGRAM OF SIEMENS FURNACE.

The essential part of the apparatus is the regenerators. These may be of any form and may be placed in various positions, but should always be below the level of the furnace floor so that the hot air and gas may tend to rise freely into the furnace. In the Siemens furnace the chambers are usually under the body of the furnace, but in some recent forms they have been put under the working platform instead, a position which has the disadvantage of

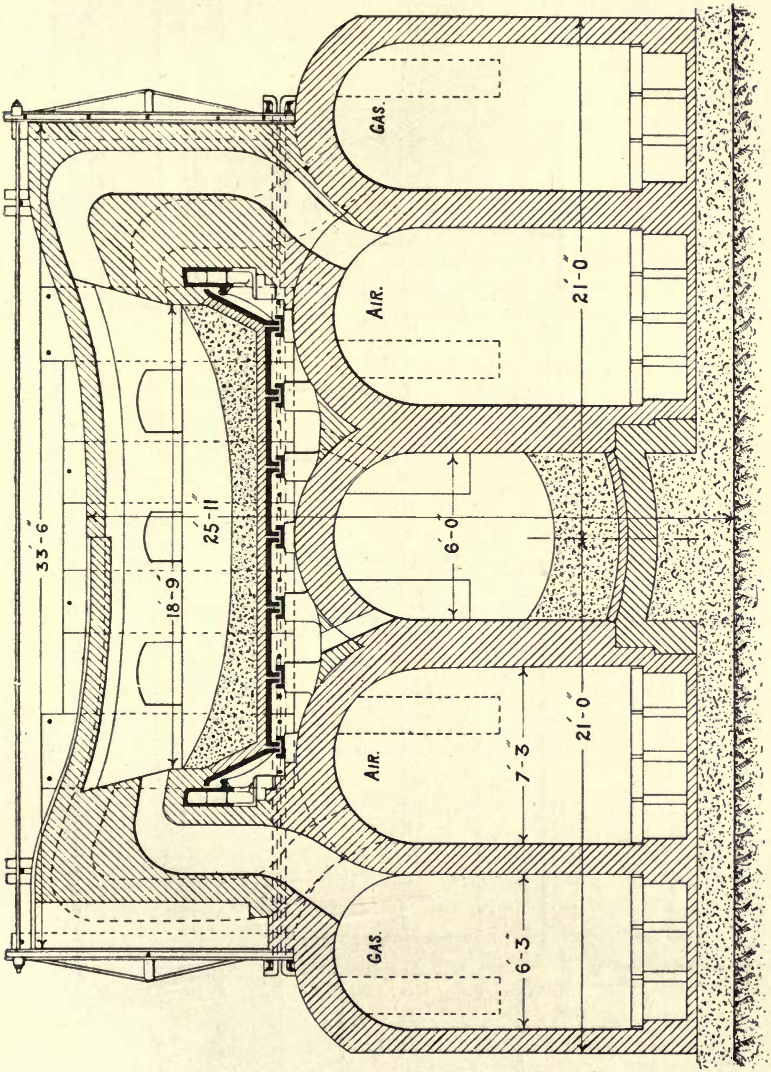


FIG. 40.—SIEMENS STEEL FURNACE (LONGITUDINAL SECTION).

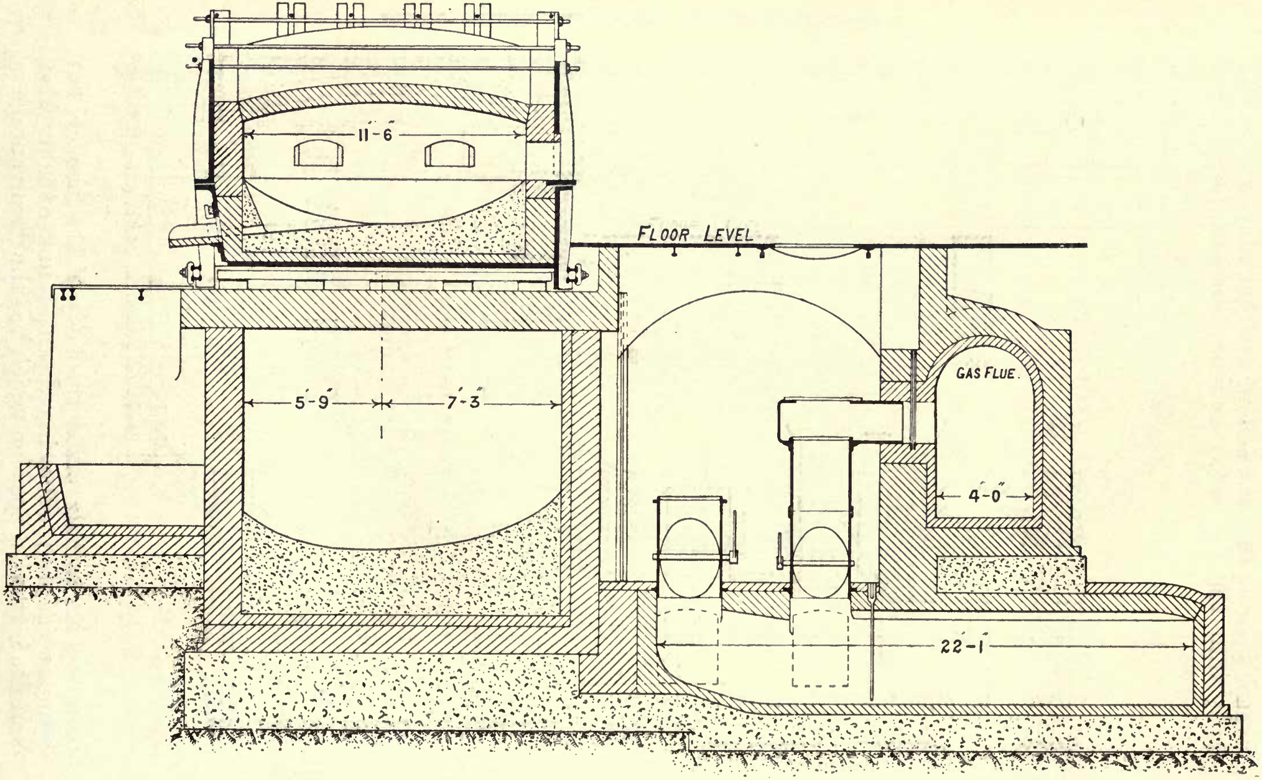


FIG. 40A.—SIEMENS STEEL FURNACE (TRANSVERSE SECTION).

making this platform unduly hot. In the Batho furnace they are placed in separate iron casings outside the furnace, but not below it, and occasionally they are put above the furnace, which is, however, the worst possible position.

The length of the regenerative chamber, *i.e.*, from back to front, is, in ordinary cases, determined by the width of the furnace, the breadth is determined by the available space under the furnace, so as to allow the flues to rise nearly vertically, so that the only dimension that can be modified is the depth.

The volume of air required for complete combustion is rather larger than that of the gas burnt, and as both should be delivered at approximately the same temperature the air regenerator is usually made somewhat larger than that for the gas. The difference may be even greater than the ratio of air to gas, because the gas is usually delivered to the regenerators at a higher temperature than the air, and therefore requires less heating. The difference in size is usually obtained by varying the width of the chamber, since the other dimensions must necessarily be uniform. No general rule is adopted. Some engineers make the chambers the same size, others make the air chamber half as large again as the gas chamber; a ratio of 4 to 5 is probably a very good one in most cases.

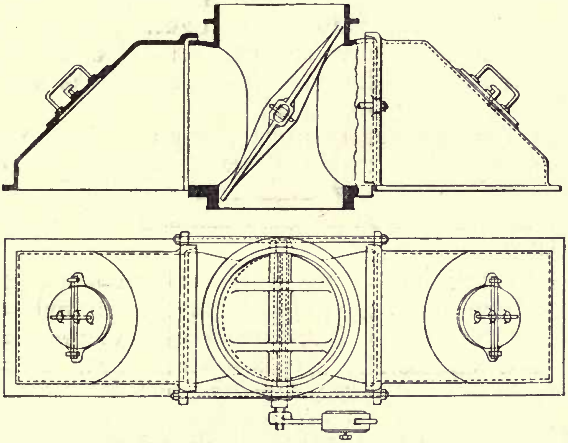


FIG. 41.—VALVES FOR SIEMENS FURNACE.

The deeper the chamber the more heat will be taken up, and therefore, as a rule, the better will be the results.

The tendency of late has been to greatly increase the depth till it has reached 16ft. or 20ft., and even this is not the limit. There is, of course, a practicable limit, due to the need for maintaining a draught. The hot products of combustion would tend to rise back into the furnace if they were not drawn forward by the chimney draught. The limit to the depth of the regenerator chamber, therefore, would be reached when this back pressure approached so near the pressure in the chimney as to interfere with the draught.

The valves are another very important part of the furnace, many forms having been designed. It is very important that the valves should be perfectly tight, or there will be great loss of gas. The usual form of valve is the simple cast-iron butterfly valve working in an iron casing.

The maximum rate of combustion will, of course, be determined by the chimney draught, which must be sufficient to carry away the products of combustion as quickly as they are formed when air and gas are being supplied at the greatest speed.

The Siemens regenerative system is by no means confined to steel making, but is applicable to any purpose where a very high temperature is required, and it is largely used in glass making and many other industries.

Gas for Regenerative Furnaces.—Any form of gas may be used. Ordinary producer gas is that in general use, but Mond gas, water gas, and washed blast-furnace gas have been used successfully. It is obvious that, in order to get the best results, the furnace must be designed for the gas to be burnt, for, among other things, the quantity of air required for combustion will vary with the nature of the gas—the richer the gas the more air being required, but at the same time the less the excess that need be supplied, an excess of but 1 per cent. being sufficient in the case of water gas.

The gas should be clean. Dust is very objectionable, as it tends to clog the regenerators and also to flux away the bricks. Tar is also objectionable. When tar is carried over into the hot chambers, it is decomposed by contact with the hot brickwork into gaseous products which pass over with the gas and solid carbon which is deposited. When the gas is reversed, the excess of air in the products of combustion burns the carbon. This produced a high local temperature which may help to flux away the bricks, and at the same time it increases the temperature of the products of combustion.

It does not seem to be much advantage to supply the gas hot to the regenerators; indeed, Siemens contended that the only result of so doing was to increase the temperature of the chimney gas. The hotter the gas is supplied, the smaller should be the gas regenerator in proportion to that for air.

The recovery and utilisation of the waste heat gives the regenerative furnace a very high degree of efficiency, far greater than can be attained in any other form of furnace.

Other Forms of Regenerative Furnace.—Various other forms of regenerative furnaces have been designed. In the furnace called the Siemens new type (Fig. 42), designed by Mr. F. Siemens and described before the Iron and Steel Institute in 1889 by Messrs. Head and Pouff,* only two regenerators are used, those for the air, the gas being sent into the furnace hot from the producer. Another peculiarity of this furnace is that the gas and air enter, and the products of combustion leave, the furnace at the same end, or rather perhaps side, it being in this case the longer dimension of the furnace. The arrangement will be made quite clear by the illustration.

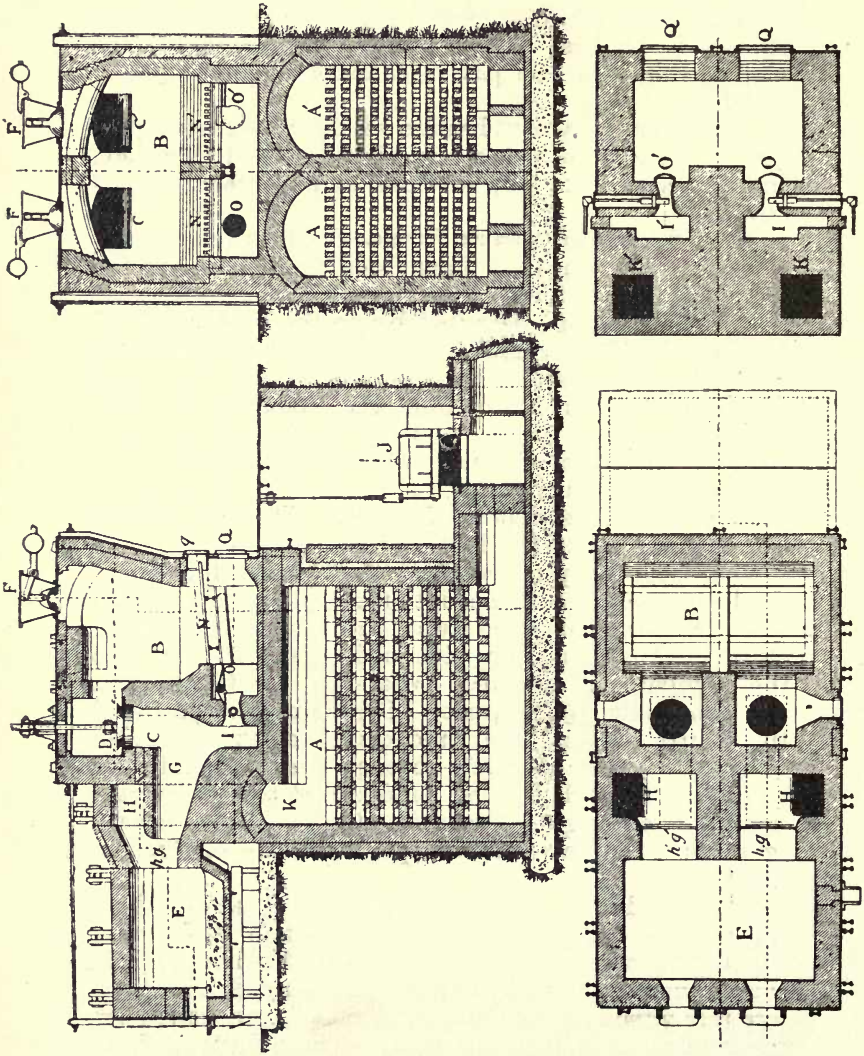
Gas from the producer B passes through the flue C′ to the gas port and thence into the combustion chamber *h′g′*. Air for combustion passes through the combustion chamber A′ by an air flue and the port H′ into the combustion chamber, where it meets the gas, and combustion takes place. The flame sweeps round the hearth E, and the products of combustion pass away by *h g* and go partly through the regenerator A, and partly through the gas producer B to be converted into combustible gas. From time to time the air regenerators and the gas from the producers are reversed as usual.

The products of combustion are at a very high temperature, and contain carbon dioxide and water vapour. These are decomposed by the hot carbon, carbon monoxide and hydrogen being formed, and therefore it is often said that the products of combustion are regenerated as well as the heat. These furnaces have at present been mainly used for heating plates, billets, &c., and similar purposes.

---

* J. I. and S. I., 1889, Vol. II.

Non-reversing Furnaces.—In the Siemens furnaces (Fig. 40) the direction of the air and gas have to be reversed periodically by means of suitable valves, and many



attempts have been made to devise a furnace in which good results shall be obtained without changing the direction of the flame. The best known of these is probably the Gorman heat-restoring furnace. In this the products of combustion are made to circulate round fire-clay tubes, through which the air passes on its way to the furnace. No data have been published from which the efficiency of the furnace can be judged, but it does not seem as if the regeneration would be very great, the heating surfaces being small, and it would be best suited for cases in which the products of combustion were not at a very high temperature.

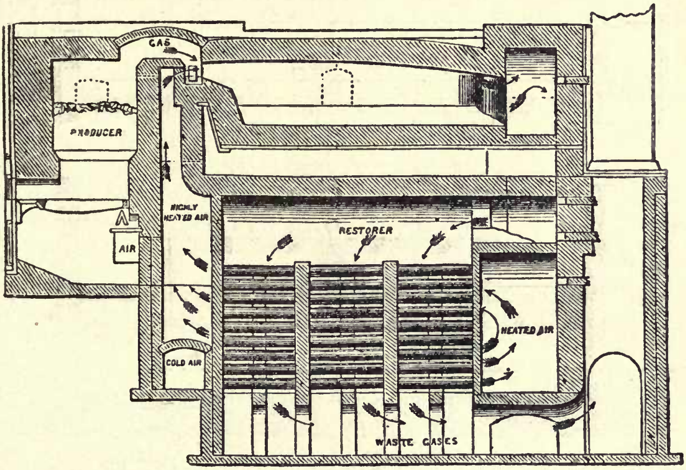


FIG. 43.—THE GORMAN FURNACE.

The Weardale Furnace.—This is the latest form of furnace with continuous regeneration, and it is being largely and very successfully used for heating bars, plates, and similar purposes. This is shown in Fig. 44.

The furnace may be of any length; that shown is 30ft. long. The gas enters from the producer by the gas main O and passes through the ports K into the space M between the two roofs of the furnace. Here it meets the hot air, which, entering by openings into the flues C, passes to the heating chamber M. Combustion takes place as the gas and air meet, and the flame passes through the opening L into the furnace, where it spreads out and forms a sheet of flame.

The products of combustion pass away by the openings D, and may be used for steam raising or any other purpose. The furnace is, of course, provided with suitable working doors arranged according to the purpose for which it is to be used. In this case a slag hole is provided at J, towards which the hearth is made to slope.

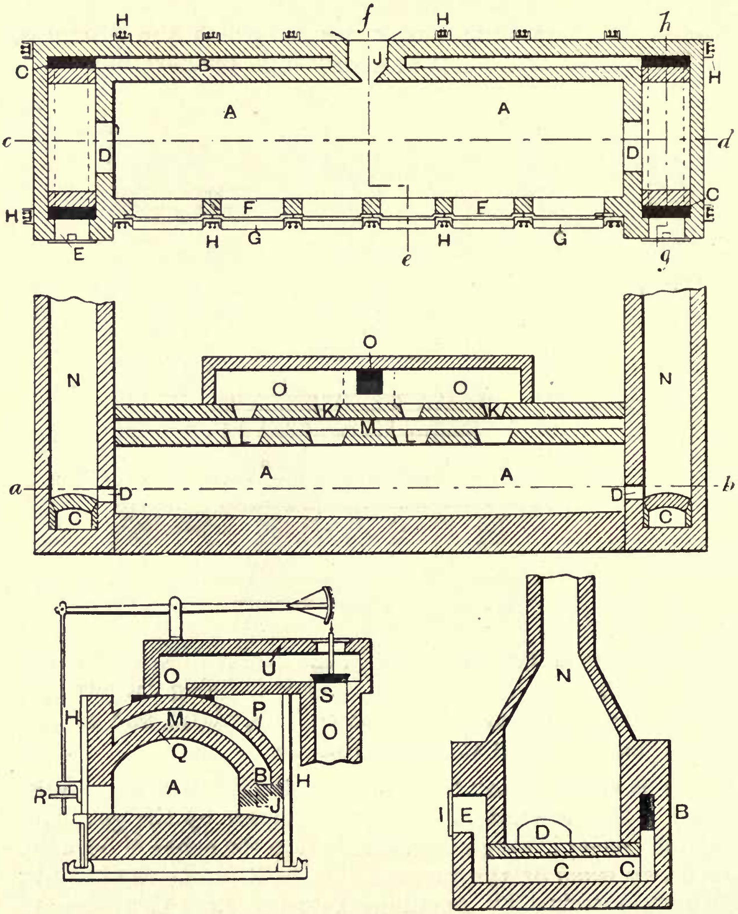


FIG. 44.—THE WEARDALE FURNACE.

The mode of lighting is as follows: After the whole of the brickwork of the furnace has been thoroughly dried by fires kept burning in the interior for a sufficient length of time—wood being the best fuel for this purpose—the gas is admitted by means of a valve, and is ignited by the fire left burning for the purpose. The process of putting gas in is a little different from that adopted in starting a melting furnace. In the case of new furnaces all the doors must be closed before the gas is admitted, in order that a through draught from the air inlets to the chimney may be established. This effectually prevents any spreading of gas between the roof arches, where it might cause an explosion. The gas invariably lights quietly, and without the slightest puff.

In one case given by Mr. Hollis a furnace with a heating chamber 34ft. 6in. by 11ft. heated 910 tons of slabs in a week, with a consumption of 2·37cwt. of coal per ton of slabs, and in another case a furnace with a heating chamber 39ft. by 7ft. heated 600 tons of slabs with a coal consumption of 2·4 cwt. per ton.

The waste heat was carried to Lancashire boilers, and gave an evaporation of 6·23lbs. of water per pound of coal consumed.

One or two other types of gas-heating furnaces may be mentioned.

The Dunnachie Kiln.—This illustrates the application of gas firing to quite a different purpose, viz., the burning of bricks or other similar articles. Regenerator chambers are not required, as the bricks serve to heat the incoming air. The kilns are built in sets of 10, in two rows of five each (Fig. 45). The gas may be made in any type of producer (at Messrs. Dunnachie's works, at Glenboig, Wilson & Duff producers are used), and enters the kiln from a flue running along the bottom or one side of the flues, the hot air being supplied just above it so that combustion takes place at once. Flues are arranged so that the gas can be sent through the kilns in any order. The flame sweeps across the kiln and through the bricks stacked in it, and the products of combustion leave on the other side. When at work there will always be two kilns cooling off, the air passing through these on its way to the kilns where burning is in progress, and being heated on its way by the hot bricks; the hot products of combustion pass through two or three more kilns which are filled with unburnt bricks which are thus heated; the other kilns are being charged and discharged. As soon

LIBR
OF T
UNIVE
O
CALIF

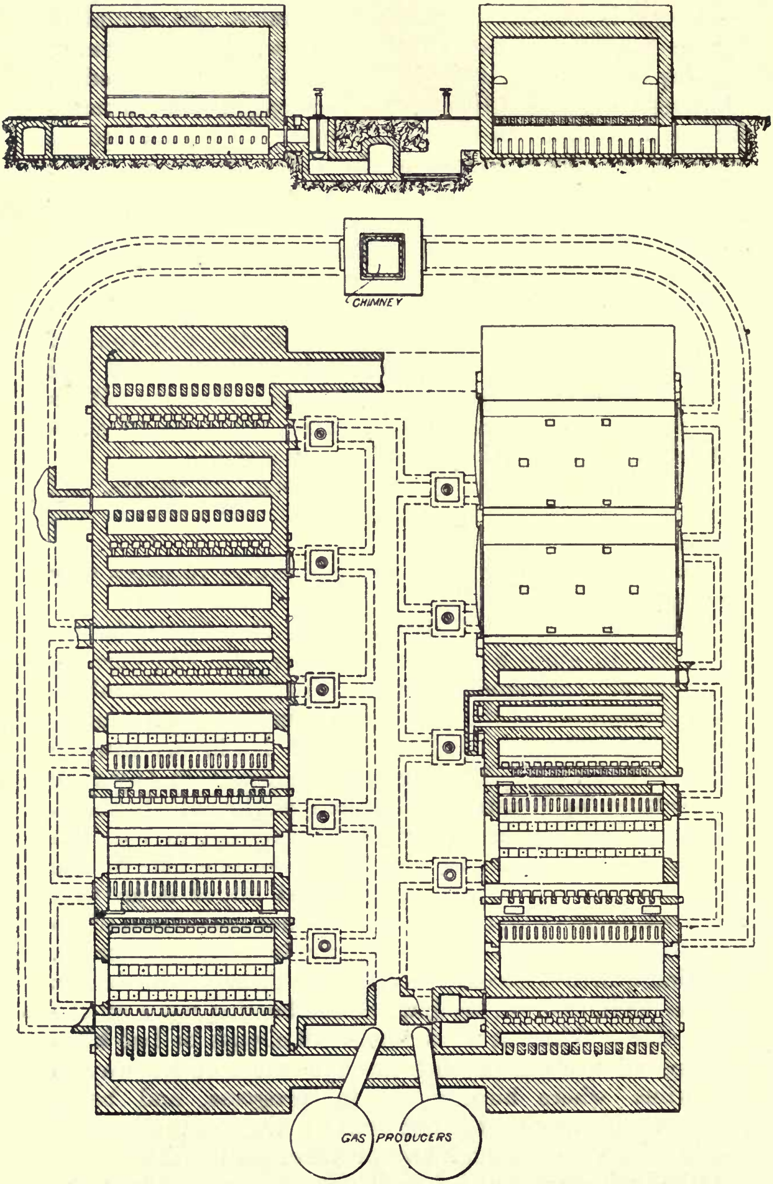


FIG. 45.—THE DUNNACHIE GAS KILN.

as the burning is complete the valves are adjusted so that the second of the two cooling-off kilns is ready for discharging, the finished oven begins to cool off, the oven which was next to the one finished becomes the one in which burning is taking place, and the bricks in the last charged oven begin to dry. The kiln is worked continuously and is found very efficient.

The Davis-Colby Gas Kiln.—This kiln (Fig. 46) is mainly used for the magnetising-calcination of hematites and other ores to be subsequently subjected to magnetic separation, but it might be used for the calcination of ores of any other kind. It consists of a shell of iron cased with firebrick, carried on a series of iron columns, the upper portion being cylindrical, the lower slightly conical. Inside this is a circular wall of masonry, perforated with a large number of openings so as to leave a narrow annular space between it and the outer wall. In the centre is a narrow cylinder of brickwork *E*, the walls of which are also perforated with a large number of openings. Thus there is in the centre a cylindrical space *E*; outside this is a broad annular space *B*, and outside this again a narrow annular space *C*. The ore is supplied to the space *B*, and is withdrawn at the bottom between the columns;

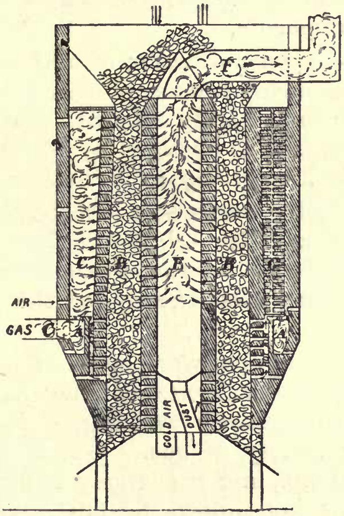


FIG. 46.—THE DAVIS-COLBY KILN

gas and air are supplied to the space *C*, combustion takes place, the products of combustion pass across *B* to *E*, and thence away to the chimney *F*.

Kilns of this type are built up to 33ft. high and 24ft. diam., with a capacity of about 8,000 cub. ft. Such a kiln will burn about 800 tons of ore per week, with the consumption of about 8 cwt. of coal per ton of ore.

It will be obvious that gas fuel can be used for a great number of purposes, and it would serve no good purpose even if it were possible to give an exhaustive list. The forms of plant described can only be taken as examples, and, of course, can be modified to almost any extent to suit special requirements.

Gas Engines.—In the conversion of heat into energy viâ steam there are so many sources of loss that the process is not likely ever to be highly efficient. This is especially the case when the heat is obtained by the combustion of gas not well suited for giving up its heat to water.

In gas engines the conversion is more direct; the gas is burnt in the cylinder of the engine, whence such engines are often called internal-combustion engines, the expansive force being used directly for the propulsion of the piston.

At first these engines were made of small size and worked with ordinary coal gas, but they have now been made and are satisfactorily working of very large size, and with every variety of gas. Gas engines are now built up to 2,500 h.p., and are largely coming into use.

The subject of gas engines is far too large to be discussed even superficially here, as a volume would be required for the purpose; suffice it to say that they give the most efficient method of utilising the energy of burning gas.

As above remarked, any form of gas may be used in suitably-designed engines. Coal gas was first used, and is still often used for small plants, but is far too costly for any other.

Gas made from coke in the Dowson producer is frequently used and is often called Dowson gas, but it is quite obvious that a similar gas might be made in a producer of any type. Gas made from bituminous coal in an ordinary producer may be used, provided the tar be destroyed or removed, and gas may be made from almost any organic refuse.

Mond gas is admirably suited for the purpose. In one test given by Mr. Humphry, a 25 nominal horse-power gas engine (Crossley Bros.), working with Mond gas, gave 8·71 h.p. with a consumption of 1·13 lbs. of slack per indicated horse-power hour; and in another case a simplex engine of 320 h.p. used ·803 lb. of fuel per indicated horse-power hour.

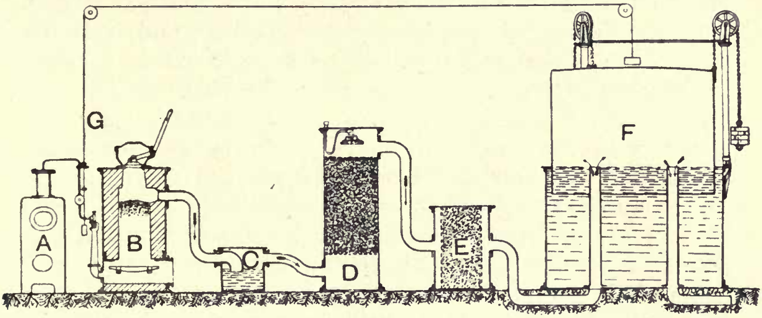


FIG. 47.—DOWSON GAS PLANT ARRANGED FOR GAS ENGINE.

For Making Gas.
A Steam Boiler.
B Generator.

For Cleaning Gas.
C Hydraulic Box.
D Coke Scrubber.
E Sawdust Scrubber.

F Gasholder.
G Governing Gear.

Water gas should also be suited for the purpose, and blast furnace gas is now being largely used in iron works for electric lighting, driving the blowing engines, and other purposes.

Conclusion.—It will be seen from what has been said that fuel gas can be used for almost all purposes for which solid fuel can be used, and generally with considerable advantage over solid fuel if the best kind of gas for the particular purpose be selected.

There is very little doubt but that the near future will see an enormous development in the production and use of fuel gas. The electric light is largely superseding coal-gas for lighting purposes, and this should lead to a large utilisation of the mains for the supply of fuel gas, and such a gas can also be satisfactorily used for lighting purposes by the adoption of well-known methods. For domestic heating, gas has undoubtedly many advantages, but the high cost of coal gas makes it too costly under most conditions, while with a good fuel gas the cost would probably be very much less than with solid fuel.

Whilst the products of combustion must always escape into the air, smoke which is due to imperfect combustion should never be produced. It does not, of course, follow that gaseous fuel is necessarily smokeless; indeed, a tar-laden gas may produce a very large amount of smoke, but even with such a gas it is much easier to regulate the combustion so as to avoid smoke than with solid fuel. Washed producer gas, Mond gas, and water gas are, however, smokeless, and it is no doubt one of these that will eventually be used, so that the substitution of gaseous for solid fuel, whilst not purifying the atmosphere altogether, would largely do away with the smoke nuisance. There are two chief characters that render the use of gaseous fuel so advantageous in most cases :—

(1) The gas can be made in any convenient place and can then be distributed by means of pipes to any spot where it is required with but little cost. Any one who has had to deal with large works where coal is brought in and distributed to a large number of furnaces will recognise at once the enormous advantage that this gives, to say nothing of the great saving of cartage and labour by concentrating the fuel at one place.

(2) Gas producer plant is far less dependent on the quality of the fuel than are solid fuel furnaces. Coal of any sort can be used, cheap slack answering admirably, provided it be not coking; indeed, strongly coking coal is the only fuel quite unfit for use in gas producers. Refuse of any kind can be used, and refuse destructors are usually gas producers, the gas being used for boiler firing or other purposes. Mr. Rowan describes an efficient form of refuse destroyer which is a modified Duff producer.

Control of Gas Production.—Gas production, like any other technical process, requires to be skilfully controlled. Many managers seem to have the idea that a gas plant once started can be left to itself, that it will run automatically, and that a labourer who clears the ashpit is quite capable of managing it. This is a great mistake, and has led to not a few failures and to an enormous amount of inefficient gas production. A skilled and trained man should always be in charge, and in an installation of any size such a man will soon save his salary, and also will produce gas of a better and more uniform quality than an unskilled man can possibly do. The production must be checked periodically by analysis of the gas as it leaves the producer, and of the products of combustion as they leave the furnaces. As this can only be done by a trained chemist, with a laboratory in which to work, it is needless to give details here. The chemist will know where he can get the information, and no amount of directions will enable an untrained man to make accurate determinations; indeed, determinations made by engineers for this and similar purposes are frequently so inaccurate as to be worse than useless.

The most important determination to be made in the gas and in the products of combustion is carbon dioxide. In the gas it should be as low as possible, under no circumstances except in Mond gas rising above 4 or 5 per cent., an excess, providing the producer be well designed, indicating an excess of steam. In the products of combustion it should be as high as possible, say 17 per cent., and excellent results have been obtained by giving a bonus to the furnace man who keeps carbon dioxide highest in his products of combustion. It is evident that either incomplete combustion or excess of air will lower the percentage of carbon dioxide.

Many forms of apparatus for determining the amount of carbon dioxide in gas have been devised for laboratory use, and are most of them quite satisfactory, though they are not suitable for use by an ordinary workman.

An apparatus has been devised by Mr. G. Craig, by which these determinations can be made regularly and with quite sufficient accuracy for all practical purposes.

The principle on which it is based is the same as that used in laboratory determinations. The gas is measured, the carbon dioxide is removed by absorption, and the gas is measured again, the difference being the amount of carbon dioxide removed; but instead of the gas being transferred to measuring and absorbing tubes, it is made to flow continuously, and is measured before it enters and after it leaves the absorbing vessel. (See Fig. 48.)

The apparatus consists of two gas meters, between which is placed an absorbing vessel containing soda lime, the meters being filled with paraffin oil instead of with water, so as to prevent the solution of the gas.

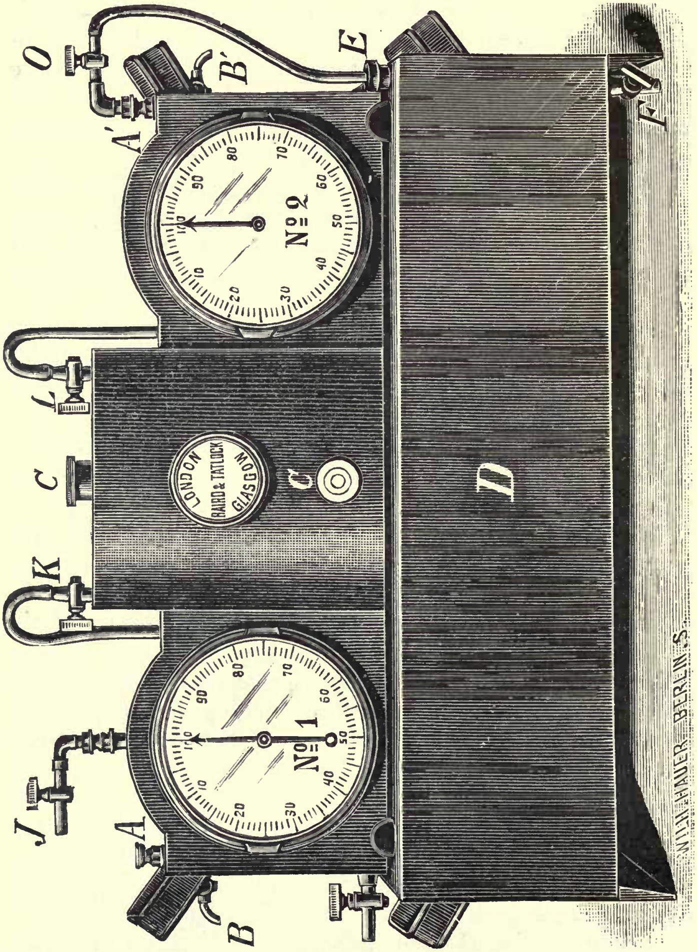


FIG. 48.—CRAIG'S GAS TESTER.

The gas to be tested enters meter No. 1 by the stop cock J and is there measured; it then flows by the stop cock K to the absorber, downwards through the soda line, then up through the escape tube and through meter No. 2, which records the amount of gas which escapes. The second dial is graduated backwards, so that the reading gives, not the amount of gas which passes, but the amount by which it falls short of the 100 volumes which has passed the first meter, that is, the percentage of carbon dioxide present. If air be passed through, the two meters will give the same reading, but if a gas containing carbon dioxide be passed the reading on the second meter will be lower.

When a test is to be made the gas is run through the instrument till it has made about two revolutions, so as to remove air and fill it with gas similar to that to be tested, and the flow is stopped when the pointer of the first meter is at 100. The pointer of the second meter is now also brought to 100, it being made loose so that it can be readily turned. The current is then started and allowed to flow till the pointer on the first dial has made exactly one revolution, and the pointer on the second dial will indicate the percentage of carbon dioxide.

It is quite evident that the gas must be at the temperature of the air. In order to insure this the gas is made to flow through a cooling tube about 15ft. or more in length and ½in. diam. The apparatus itself should be kept in a room or in a sheltered place, so that all parts of it may be at the same temperature, and it may be fitted with thermometers, by which any change of temperature may be observed.

The apparatus is shown placed on a metal aspirator, but this is not by any means essential. A suction of ¼in. to ½in. of water is all that is necessary, and this can be obtained by connecting the outlet with a chimney, the draught from which will be sufficient to draw the gas through, or any form of aspirator may be used. The amount of gas passing each revolution is about ·15 cub. ft., and the absorbing vessel contains enough soda lime for about 100 determinations.

As examples of the results obtained, the following may be useful:—

	Per Cent.
Gas from hot blast stoves	17·0
" "	16·8
" "	16·0

	Per cent.
Blowing engine boiler (gas fired)	13·5
,, ,, (air supply reduced)	14·5
Boiler	13·2
Boiler	10·75
The brickwork of this boiler was then examined and carefully pointed, and the result was	14

Assuming the composition of the gas to be about the same as that given in the examples, it will be seen that combustion in the hot-blast stoves must have been perfect, and the excess of air very slight. In the boilers fired with the same gas the excess of air was, of course, greater. Mr. Craig has made a large number of comparative experiments with laboratory apparatus. When every care was taken in the laboratory, and the gas dried over sulphuric acid before analysis, the results agreed with those given by the "tester," but if the gas was not so dried the laboratory results were invariably about ·2 per cent. lower.

APPENDIX I.

TABLE I.

Gases Saturated with Water Vapour at 760 mm. Pressure, and at Temperatures from 0° to 99° C.

Temperature t° Centigrade.	Water Vapour Tension in Millimetres of Mercury.	Grammes of Water Vapour Absorbed by 1 Cubic Metre of Dry Gas at 0° C. when Saturated at t° C. and 760 Mm.	Relative Volumes of Dry Gas and Water Vapour in a Saturated Mixture at t° C. and 760 Mm.		Total Volume of Gas and Water Vapour resulting from Saturating 1 Cubic Metre of Dry Gas at 0° and 760 Mm. to t° C.
			Dry Gas Per Cent.	Water Vapour Per Cent.	
0	4·569	4·866	99·40	0·60	1·0060
1	4·909	5·231	99·36	0·64	1·0107
2	5·272	5·620	99·31	0·69	1·0144
3	5·658	6·035	99·26	0·74	1·0191
4	6·069	6·477	99·20	0·80	1·0228
5	6·507	6·948	99·14	0·86	1·0275
6	6·971	7·448	99·08	0·92	1·0312
7	7·466	7·983	99·02	0·98	1·0359
8	7·991	8·550	98·95	1·05	1·0407
9	8·548	9·153	98·88	1·12	1·0444
10	9·140	9·794	98·80	1·20	1·0491
11	9·767	10·47	98·71	1·29	1·0539
12	10·432	11·20	98·63	1·37	1·0587
13	11·137	11·97	98·53	1·47	1·0634
14	11·884	12·78	98·44	1·56	1·0682
15	12·674	13·64	98·33	1·67	1·0730
16	13·510	14·56	98·22	1·78	1·0778
17	14·395	15·53	98·11	1·89	1·0826
18	15·330	16·56	97·98	2·02	1·0884
19	16·319	17·66	97·85	2·15	1·0933
20	17·363	18·81	97·72	2·28	1·0981
21	18·466	20·04	97·57	2·43	1·1040
22	19·630	21·33	97·42	2·58	1·1099
23	20·858	22·70	97·26	2·74	1·1148
24	22·152	24·16	97·09	2·91	1·1207
25	23·517	25·69	96·91	3·09	1·1267
26	24·956	27·32	96·72	3·28	1·1327
27	26·470	29·03	96·52	3·48	1·1387
28	28·065	30·85	96·31	3·69	1·1447
29	29·744	32·77	96·09	3·91	1·1518
30	31·510	34·80	95·85	4·15	1·1578
31	33·366	36·95	95·61	4·39	1·1650

Temp. C°.	Water Vapour.		Relative Volumes.		Total Volume.
	Tension Mm.	Grammes.	Dry Gas Per Cent.	Water Vapour Per Cent.	Gas and Water Vapour.
32	35·318	39·21	95·35	4·65	1·1722
33	37·369	41·61	95·08	4·92	1·1794
34	39·523	44·14	94·80	5·20	1·1866
35	41·784	46·81	94·50	5·50	1·1939
36	44·158	49·63	94·19	5·81	1·2023
37	46·648	52·61	93·86	6·14	1·2096
38	49·259	55·76	93·52	6·48	1·2181
39	51·996	59·09	93·16	6·84	1·2266
40	54·865	62·60	92·78	7·22	1·2363
41	57·870	66·32	92·39	7·61	1·2448
42	61·017	70·24	91·97	8·03	1·2545
43	64·310	74·38	91·54	8·46	1·2643
44	67·757	78·75	91·08	8·92	1·2753
45	71·362	83·38	90·61	9·39	1·2863
46	75·131	88·26	90·11	9·89	1·2974
47	79·071	93·43	89·60	10·40	1·3085
48	83·188	98·89	89·05	10·95	1·3208
49	87·488	104·67	88·49	11·51	1·3332
50	91·978	110·78	87·90	12·10	1·3468
51	96·664	117·25	87·28	12·72	1·3605
52	101·554	124·10	86·64	13·36	1·3742
53	106·655	131·35	85·97	14·03	1·3892
54	111·973	139·03	85·27	14·73	1·4054
55	117·516	147·17	84·54	15·46	1·4218
56	123·292	155·80	83·78	16·22	1·4394
57	129·310	164·97	82·99	17·01	1·4571
58	135·575	174·70	82·16	17·84	1·4761
59	142·097	185·03	81·30	18·70	1·4963
60	148·885	196·02	80·41	19·59	1·5179
61	155·946	207·72	79·48	20·52	1·5396
62	163·289	220·18	78·51	21·49	1·5639
63	170·924	233·46	77·51	22·49	1·5883
64	178·858	247·63	76·47	23·53	1·6152
65	187·103	262·77	75·38	24·62	1·6436
66	195·666	278·97	74·25	25·75	1·6733
67	204·559	296·32	73·08	26·92	1·7044
68	213·790	314·92	71·87	28·13	1·7381
69	223·369	334·91	70·61	29·39	1·7746
70	233·308	356·41	69·30	30·70	1·8137
71	243·616	379·59	67·95	32·05	1·8556
72	254·305	404·62	66·54	33·46	1·9002
73	265·385	431·71	65·08	34·92	1·9488

Temp. C°.	Water Vapour.		Relative Volumes.		Total Volume.
	Tension Mm.	Grammes.	Dry Gas Per Cent.	Water Vapour Per Cent.	Gas and Water Vapour.
74	276·868	461·09	63·57	36·43	2·0002
75	288·764	493·04	62·00	38·00	2·0570
76	301·086	527·88	60·38	39·62	2·1179
77	313·846	565·99	58·70	41·30	2·1843
78	327·055	607·81	56·97	43·03	2·2574
79	340·726	653·86	55·17	44·83	2·3386
80	354·873	704·79	53·31	46·69	2·4268
81	369·508	761·36	51·38	48·62	2·5245
82	384·643	824·50	49·39	50·61	2·6344
83	400·293	895·38	47·33	52·67	2·7566
84	416·472	975·45	45·20	54·80	2·8939
85	433·194	1066·5	43·00	57·00	3·0516
86	450·473	1171·0	40·73	59·27	3·2298
87	468·324	1291·9	38·38	61·62	3·4381
88	486·764	1433·4	35·95	64·05	3·6792
89	505·806	1601·0	33·45	66·55	3·9666
90	525·468	1802·7	30·86	69·14	4·3102
91	545·765	2049·7	28·19	71·81	4·7329
92	566·715	2359·1	25·43	74·57	5·2596
93	588·335	2757·5	22·59	77·41	5·9393
94	610·643	3289·6	19·65	80·35	6·8433
95	633·657	4035·4	16·62	83·38	8·1121
96	657·396	5155·2	13·50	86·50	10·017
97	681·879	7022·9	10·28	89·72	13·192
98	707·127	10760·7	6·96	93·04	19·544
99	733·160	21978·4	3·53	96·47	38·604
100	760·000	∞			∞

TABLE II.—*Properties of Fuel Gases.*

Gas.	Formula.	Sp. Gr. H = 1.	Sp. Gr. Air = 1.	Calorific Power.	Volume of Air required for Complete Combustion.	Lbs. per cubic foot at 760 mm. and 0° C.
Acetylene	C_2H_2	13·000	0·91000	11,941	11·90 times	·0734
Atmospheric Air	...	14·438	1·00000	...	......	·0807
Carbonic Oxide	CO	14·000	0·96710	2,430	2·38 times	·0781
Carbonic Anhydride	CO_2	22·000	1·51968	...	......	·1227
Ethylene	C_2H_4	14·000	0·97840	11,143	14·28 times	·0784
Hydrogen	H_2	1·000	0·06926	34,180	2·38 times	·0056
Methane.........	CH_4	8·000	0·55300	13,062	9·52 times	·0447
Nitrogen	N_2	14·000	0·97010	...	......	·0784
Oxygen	O_2	16·000	1·10521	...	......	·0893
Steam	H_2O	9·000	0·62182	...	......	·0502

APPENDIX II.

DESCRIPTION OF RECENT GAS PRODUCERS.

In the text it was not possible to describe more than a few typical examples of producers; so, for the further information of those who are interested in the details of producers, a selection has been made of what seemed the most important of the forms recently patented, so that the reader may be able to see how the principles which have been explained, in the foregoing pages have been carried out by inventors, and the direction in which improvements are being sought. It is impossible to express any opinion on the merits of most of the designs. Some of them have no doubt been put into actual use, and their practical value thus proved or disproved, but probably many of them have never gone beyond the "drawing" stage. Some may contain the germs of still further improvement.

In order to help the reader to find any information which he may desire, a list of the producers described is given below, and also a list classified according to what seems to the author to be the characteristic points of each. That this arrangement will be altogether satisfactory is not to be expected, for, unfortunately, the descriptions of inventors are not always clear enough to enable an accurate judgment to be formed as to wherein lies the improvement.

LIST OF PRODUCERS DESCRIBED.

No.	Year.	Patent No.	Patentee.
1	1897	28367	Charles Humfrey.
2	1898	20451	John Dymond.
3	1899	1574	Maurice Taylor.
4	1901	4522	Julius Pintsch.
5	1901	8449	Ludwig Mond.
6	1901	9377	Lucien Genty.
7	1901	12307	La Société Anonyme pour le Production et L'emploi de la Vapeur Surchauffée.
8	1901	14183	Maurice Taylor.
9	1901	15646	Edward J. Duff.
10	1902	17265	J. A. Herrick.
11	1901	22016	W. J. Crossley and J. Atkinson.
12	1901	26330	John Robert Taylor.
13	1902	3783	F. E. Bowman.

No.		Year.		Patent No.	Patentee.
14	..	1902	..	7613	John S. Daniels and F. L. Daniels.
15	..	1902	..	14893	John Fielding.
16	..	1902	..	15498	Walter W. Tonkin and Samuel Puplett.
17	..	1902	..	18867	Charles J. Schill and H. G. Hill.
18	..	1902	..	18892	W. J. Crossley and Thomas Rigby.
19	..	1902	..	24194	W. J. Crossley and Thomas Rigby.
20	..	1902	..	24878	W. H. Beanes and Werner Pfleiderer and Perkins, Ltd.
21	..	1902	..	25319	Joseph Emerson Dowson.
22	..	1902	..	25560	John Robson.
23	..	1902	..	26709	Alfred Wilson.
24	..	1902	..	27533	H. Riché.
25	..	1902	..	28877	G. R. Hislop.
26	..	1903	..	9818	Robert M. L. Rowe and R. Bickerton.
27	..	1903	..	12477	L. Maréchal and P. Barrière.
28	..	1903	..	12506	La Société Française de Constructions Mecaniques.
29	..	1903	..	16164	Alfred B. Duff.
30	..	1903	..	16263	J. R. George.
31	..	1903	..	25763	F. Hovine and H. Breuillé.
32	..	—	..	—	James Dunlop.

Classified List.

(1) The removal of the tar from the gases is sought in many of the inventions.

(*a*) By so arranging the upper part of the producer that the coal shall be readily distilled, and the products of distillation shall pass downwards into the fuel.

No. 1 (Humfrey), No. 5 (Mond), No. 6 (Genty), No. 7 (Surchauffée), No. 23 (Wilson).

(*b*) By returning the distillates from the top of the producer to the body of the fuel by means of an auxiliary steam jet.

No. 2 (Dymond), No. 6 (Genty), No. 14 (Daniels), No. 15 (Fielding), No. 28 (La Société Française de Construction), No. 31 (Hovine and Breuille).

(*c*) By passing the gas through a separate chamber filled with incandescent coke.

No. 24 (Riché), No. 26 (Rowe and Bickerton).

(2) Producers in which the air and steam for combustion are heated.

No. 2 (Dymond), No. 6 (Genty), No. 13 (Bowman), No. 16 (Tonkin and Puplett), No. 17 (Schill and

Hill), No. 18 (Crossley and Rigby), No. 20 (Beanes and Werner), No. 21 (Dowson), Do. 22 (Robson), No. 23 (Wilson), No. 25 (Hislop), No. 27 (Maréchal and Barrière), No. 32 (Dunlop).

(3) Producers with special arrangements for charging.

No. 12 (Taylor), No. 19 (Crossley), No. 30 (George).

(4) Producers with special arrangements for the supply of air and steam.

No. 9 (Duff), No. 10 (Herrick), No. 21 (Dowson), No. 23 (Wilson), No. 29 (Duff), No. 30 (George).

(5) Producers with special arrangements of grates.

No. 3 (Taylor), No. 7 (Surchauffée), No. 11 (Crossley and Atkinson), No. 13 (Bowman), No. 25 (Hislop).

(6) Producers raising their own steam.

No. 3 (Taylor), No. 6 (Genty), No. 13 (Bowman), No. 16 (Tonkin and Puplett), No. 17 (Schill and Hill), No. 20 (Beanes and Werner), No. 26 (Rowe and Bickerton), No. 27 (Maréchal and Barrière).

(7) Producers with arrangements for breaking up clinker.

No. 16 (Tonkin and Puplett), No. 20 (Beanes and Werner), No. 25 (Hislop), No. 32 (Dunlop).

(8) Producers with arrangements for breaking up fuel.

No. 5 (Mond).

(9) Producers in which the air and steam is supplied at top and drawn off either lower down or at bottom of producer.

No. 11 (Crossley and Atkinson), No. 21 (Dowson).

(10) Producers fed at the bottom.

No. 12 (Taylor).

(11) Producers with rotating parts.

No. 9 (Duff), No. 18 (Crossley and Rigby), No. 19 (Crossley),

(12) Producers arranged so as to allow easy replacement of parts.

No. 8 (Taylor).

(13) Producers with regulation and purification of the gas for use in gas engine.

No. 4 (Pintsch), No. 13 (Bowman), No. 32 (Dunlop).

(1) **Humfrey's Improvements in Gas Producers.** Patent No. 28367 of 1897.—The design shown in Fig. 1 has for its object to convert the dead space below the hopper into a gasifying one. The arrangement is shown applied to a Mond

producer, in which A is the ordinary inverted hopper and C a similar, but smaller sized, inverted hopper arranged below the hopper A. From the upper part of the bell C one or more tubes or passages D lead the gases collecting in the bell C to the space E in the upper portion of the gas generator above the fuel. The action of the apparatus is as follows: The air and steam entering the bottom of the gas producer

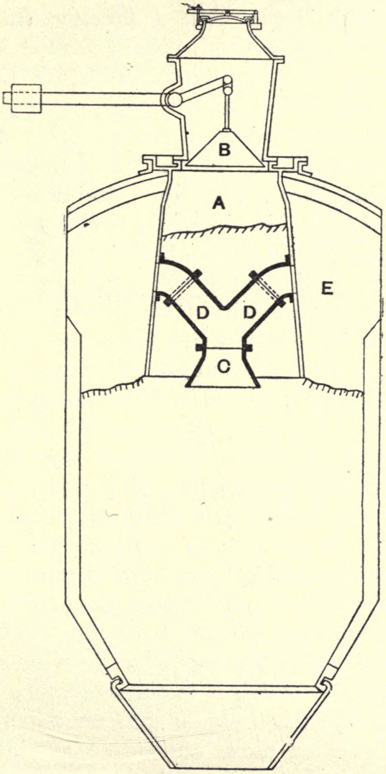


FIG. 1.—HUMFREY'S GAS PRODUCER.

pass nearly uniformly up through the mass of fuel, and are converted into permanent gas. This gas passes partly up through the bell C and partly into the space E between the sides of the main hopper or receiver A and the sides of the producer. The bottom of the bell C is placed so much lower than the bottom of the hopper A as to make the distance from the hearth of the gas producer to the surface of the fuel below C somewhat less than the distance from the hearth to the surface of the fuel between the walls of the gas generator and the hopper of receiver.

(2) **Dymond's Gas Producer.** Patent No. 20451 of 1898.—This producer, shown in Fig. 2, has for its object to insure the production of a high and uniform quality of producer or water gas. It comprises a cylindrical metal shell 1, lined internally with firebricks up to the normal height of the fuel. Above this height is provided a fireclay lining 8, which constitutes a gas superheater, and is formed with a superheating gas passage 9 that tapers in from the hopper end 3^a, the contracted part being in such close proximity to the fire that intense heat is retained therein. The outlet pipe 13 passes down to the passage 14, the gas being led up again at the opposite side through another metal outlet pipe 13^a. The outlet end 13^b of this pipe is connected to a vertical pipe 16, having at its extreme end an hydraulic valve box 17 fitted with a valve 18. This valve covers the end 16^a of gas inlet pipe 16, and is located within the box 17, which contains water that seals the valve when the same is in its lowered position, so as to then prevent escape of gas. The valve 18 serves to prevent back pressure when the generation of gas is stopped. The hydraulic valve box 17 has a continuous water supply pipe 21, and an overflow pipe 22 to keep the water seal at the required height. 23 is a pipe for leading the gas from the valve box 17 to a scrubber. The fuel hopper 3 is fitted with the two valves 24 and 25. The top of the gas generator is provided with air inlet and outlet ports 35 and 35^a respectively, the air being directed through curved passages formed by division pieces, so as to be heated by its passage between the two plates 30 and 31, after which it enters the vertical pipes 36^a, by which it is delivered into the ashpit 37 below the firebars. Each steam and air injector tube 43 is provided with one or more adjustable air inlets 44. The air injector is provided with a steam injector or nozzle 47.

(3) **Taylor's Gas Producer.** Patent No. 1574 of 1899.—The object of this arrangement, which is shown in Fig. 3, is to provide a gas producer of small weight, and without any scrubber requiring a current of water. It consists of the producer A, the fuel to which is fed through a door B and charging slide C. The fuel is supported by a grate secured to the cleaning door D. The gas issues from the producer through the pipe G, and passes through tubes H surrounded

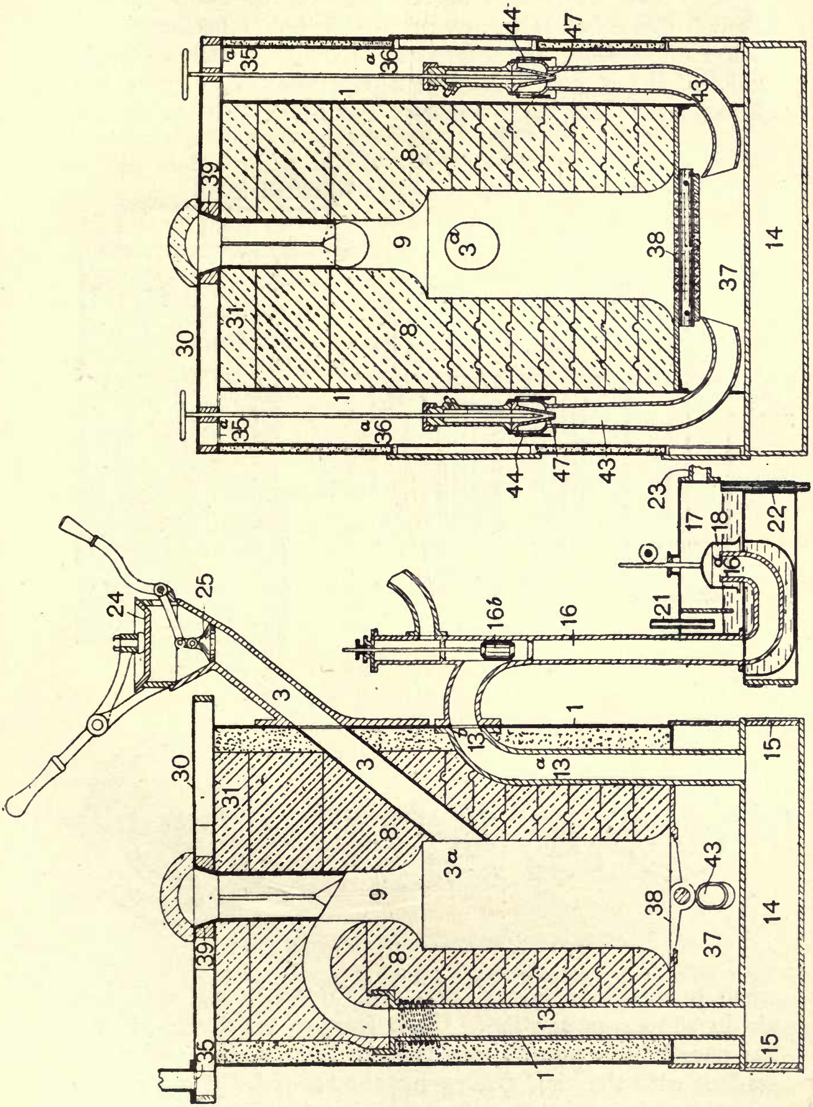


FIG. 2.—SECTIONS OF DYMOND'S GAS PRODUCER.

by the water in a tank I, which communicates with another tank having a float for maintaining the water at a constant level. Under the action of the heat of the gases passing through the tubes H the water in the tank I becomes converted into steam, and when the pressure of such steam is sufficient it will pass through a pipe J which opens into the atmosphere; and, as hereinafter described, this steam will when requisite be carried into the furnace along with the air in proper proportion. Upon leaving the tubes H the gas passes by a pipe K into tubes L, which are cooled by contact with the air. On leaving the tubes L the gas passes by a pipe N into a cleansing chamber M containing water, the pipe N terminating a little above the surface of the water; so that the gas, owing to the speed of its motion, impinges on

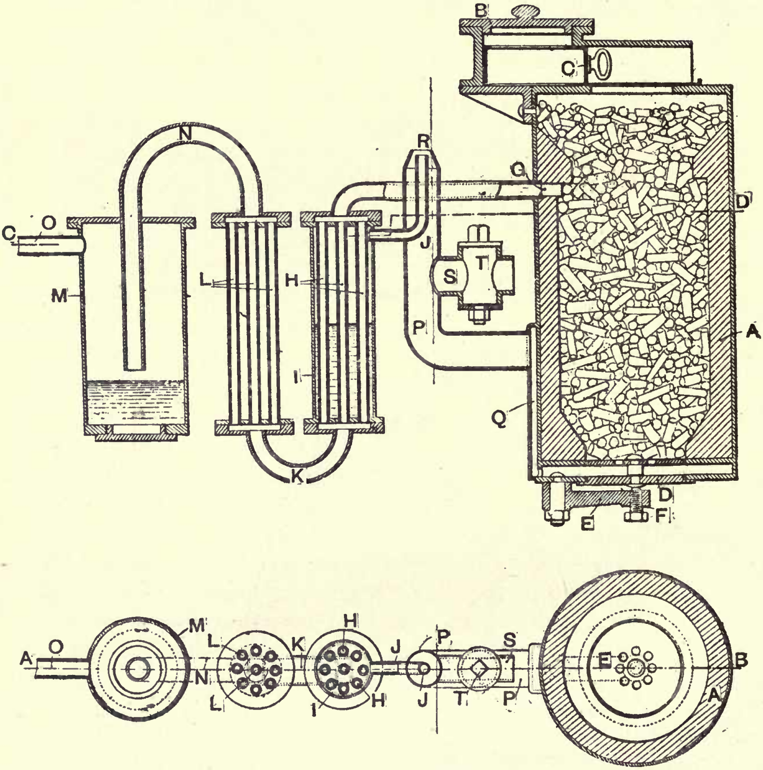


Fig. 3.—Taylor's Gas Producer.

such water, and ashes and dust contained in the gas are retained upon or in the water, while the cooled and cleansed gas passes to the engine through a pipe O. An air-and-steam supply pipe P at one end opens into a jacket Q which envelops, or partly envelops, the lower part of the gas producer, and opens under the grate at the base of the furnace. The pipe P is contracted at its upper end R. The steam under constant pressure is conveyed from the vaporiser H through the pipe J, the end of which is directed towards the orifice R, so that when the engine does not draw in gas from the gas producer the steam escapes into the atmosphere. Upon the pipe P, between the furnace of the gas producer and the point where the pipe J opens, there is an air-inlet pipe S, the admission of air being controlled by means of a cock T.

(4) **Pintsch's Gas Producer.** Patent No. 4522 of 1901.—In this apparatus, shown in Fig. 4, the generation of gas takes place at a constant pressure, but only during the suction period of the gas engine, and in exact proportion to the gas feed necessary for the said engine. The arrangement, which works at a pressure below that of the atmosphere, comprises a gas generator E, a gas engine (not shown), a pipe A leading from the gas suction chamber of the engine, and connected immediately to a pipe B which leads through a purifier C and condenser D to the top of the generator E, means for admitting air and steam to the generator, and an elastic gas rarifier inserted in the pipe connection between the engine and generator. The generator, if water gas* is required, is provided with a water tank underneath the grate F. The water in this tank

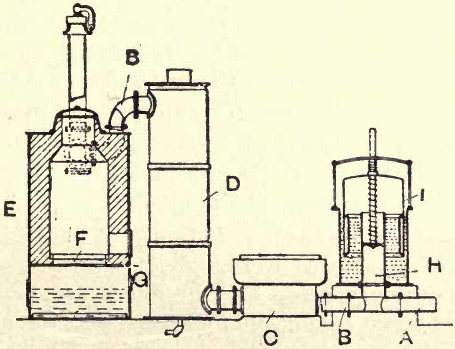


Fig. 4.—Pintsch's Generator for Supplying Gas for Power Purposes.

---

* Water gas here obviously means steam-enriched producer gas.

being heated by the heat from the grate, and thus slowly caused to vaporise, produces sufficient steam to generate the necessary quantity of gas for the suction period of the engine. Beneath the grate F an adjustable air inlet opening G is provided, so as to admit just sufficient air to the generator to retain the fire at the proper glow heat. During the suction period of the gas engine sufficient air and steam will be drawn by suction through the grate F of the generator to enable the generation of a certain quantity of gas. The suction of the engine, however, will draw the gas through the pipes B and A direct to the engine, so that the gas, the generation of which is dependent on the amount of suction of the engine, will be immediately consumed by the latter. Since, however, after the suction of the engine has ceased, a comparatively small amount of gas will still be developed, which might cause a dangerous increase of pressure, a pressure regulator is arranged in the pipe A. This consists of a vertical pipe H extending upwardly from the gas supply pipe A, and over the open end of which is arranged a small bell I which is pressed upwardly by means of a spring, so as to prevent the atmospheric air pressure from destroying the vacuum or rarification required for the proper working of the plant. If now gas is drawn from the generator E during the suction period of the gas engine, the suction will in a certain measure influence the bell I, and pull the same slightly downwards. As soon as the suction ceases, the bell will return to its normal position under the influence of its spring, and in so doing will draw the gas, developed in the generator E after the suction period has ceased, out of the generator, thus preventing the generation of gas pressure in the plant.

(5) **Mond's Gas Producer.** Patent No. 8449 of 1901.—This apparatus, shown in Fig. 5, is specially adapted for converting ordinary slack into producer gases containing a minimum of tarry condensible matters, and for obtaining as a by-product a maximum of ammonia. The body of the producer has a metal casing A lined with refractory material B, and an outer metal casing C. Air is blown at D into the annular space between the casings, whence it passes between the firebars E into the body of fuel. A central tube I, surrounded by a jacket J in which cooling water is caused to circulate, extends down below the ashpit K, and has at its bottom a side opening L provided with a door for removing such matters as may drop down the tube. The fuel is fed

through a hopper N and over a cone O, filling up the bell M and the space above it up nearly to the hopper. The gas generated in the body of the producer passes away by the

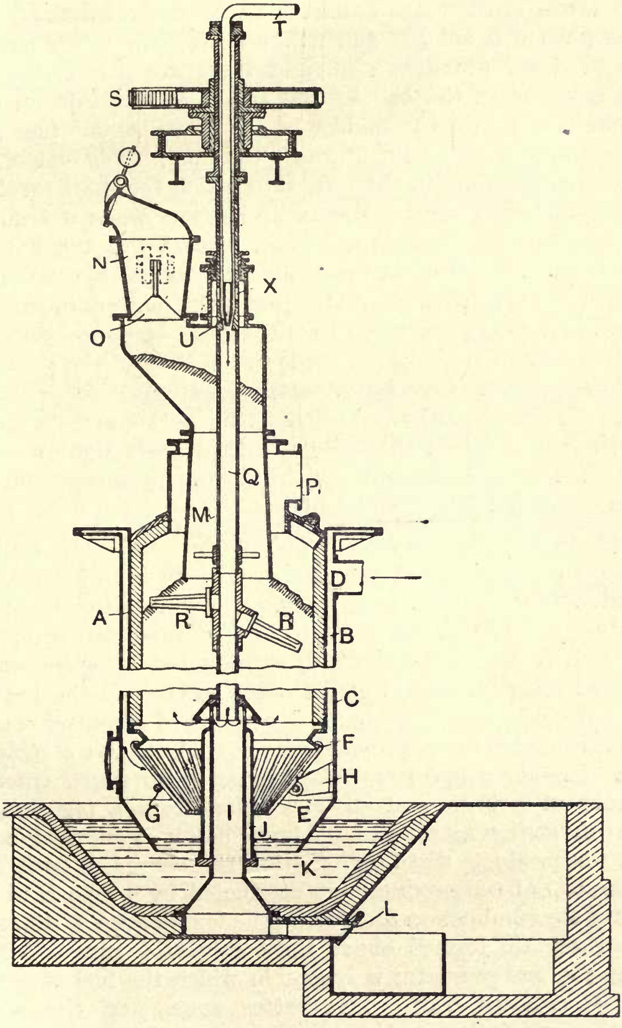


Fig. 5.—Mond's Gas Producer.

outlet P. Down the centre of the producer is passed a tubular shaft Q having agitating arms R projecting from it, and having fixed on its upper part a wheel S which is caused to revolve by a motor. Into the upper end of the shaft Q enters, through a stuffing box, a steam pipe T, which terminates in a nozzle U arranged to operate as an injector. Above the nozzle U there are lateral holes X in the tubular shaft, through which hot gas and vapours from the upper part of the producer are drawn in, and these are passed through the raw fuel in the bell by the action of the injector and forced down into the middle of the incandescent fuel at a level above the firebars, through the open lower end of the shaft and openings in the tube I, in which the shaft revolves. The agitators R serve to break up the fuel when it tends to cake. By thus drawing a certain quantity of the hot gas produced in the body of the producer through the fuel in the hopper, the quantity of volatile and tarry matters in this fuel is reduced before the fuel enters the body of the producer to such an extent that the gas made in the body of the producer is sufficiently free from tarry matters for all practical purposes, while the tarry matters distilled off in the hopper are forced by the steam jet in the hollow vertical shaft right through the mass of incandescent fuel inside the producer, and are thus converted into permanent gas.

(6) **Genty's Gas Producer.** Patent No. 9377 of 1901.—The principal object of this design (Fig. 6) is to obviate the disadvantages met in connecting gas engines directly to gas producers. The lower portion of the producer comprises the hearth A and the shaft B, surmounted by a concentric vertical retort C heated on its outer surface by the heat of the escaping gas. The hearth A consists of a central conical sole surrounded by an annular grate D. The hearth is enclosed in a chamber supporting the producer, into which enters a current of hot air and steam coming from a regenerator. The combustion zone is situated immediately above the hearth, and the products distilling off from the charge of fresh fuel at the top of the producer are conducted by a pipe E to the part of the combustion zone where the temperature is greatest. The gases are formed above the combustion zone. Higher up in the gas generator is a zone in which the fuel is heated by the radiated heat. This latter zone, and the whole upper part of the producer are surrounded by a boiler F, the water in which absorbs the heat which escapes through the walls of the producer. The produced gases circulate through the annular flue G, and then escape by a pipe H into the

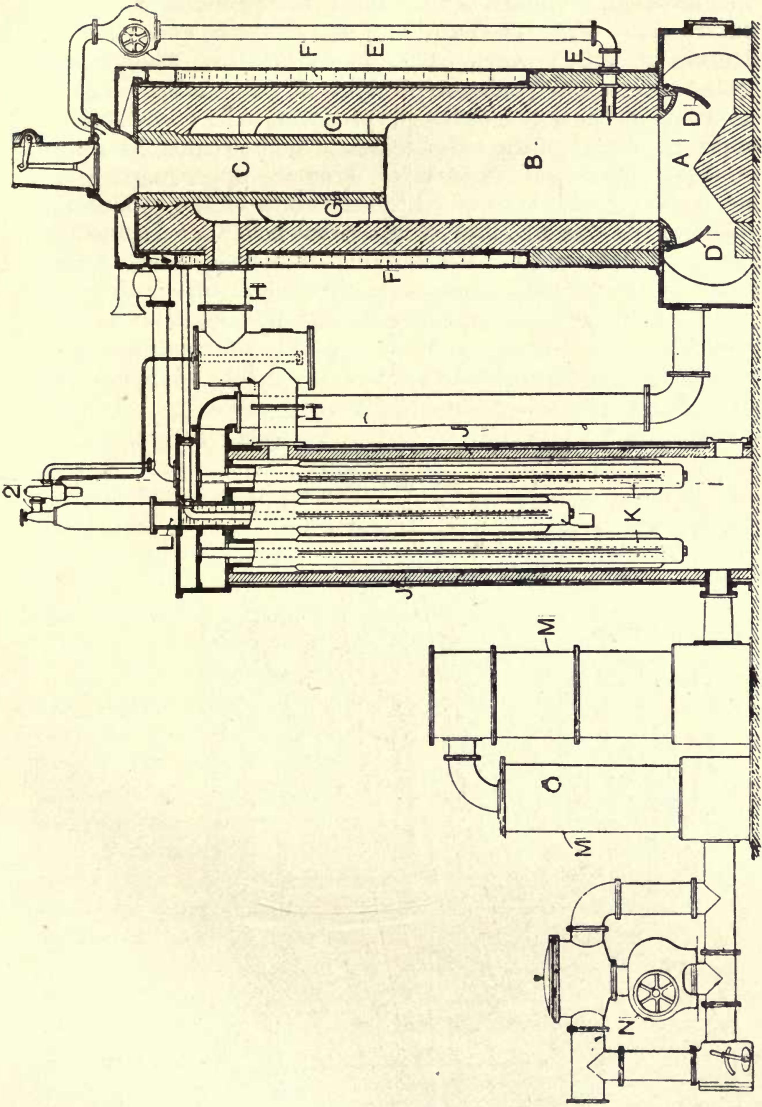


FIG. 6.—GENTY'S GAS PRODUCER.

regenerator. A suction fan I is situated in the pipe E to assist in drawing from the retort all the volatile matter, and forces these products into the hottest zone of the producer. The tarry products are decomposed, and give a deposit of carbon which burns on the hearth. The steam and other gaseous products, on meeting the gaseous current produced by the action of the gas producer, undergo reduction under the action of the red-hot fuel. The hot gases from the producer enter the regenerator J at its upper part, and heats the air that is supplied to the hearth of the producer, and also the water contained in a small boiler for producing the steam required for the working of the producer. This boiler is constituted by an externally-ribbed tube L in the centre of the regenerator. On leaving the regenerator the producer gases enter scrubbers M, and after purification pass to an aspirating arrangement consisting of a fan N supplying a constant volume of air.

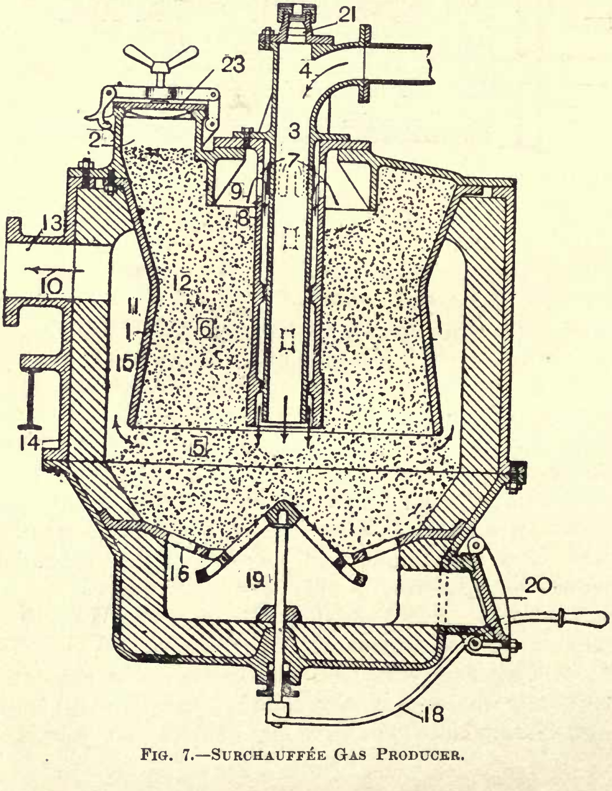


Fig. 7.—Surchauffée Gas Producer.

(7) **Surchauffée Gas Producer.** Patent No. 12307 of 1901.—This apparatus (Fig. 7) has for its object to obtain a uniform composition of the gas produced and a uniform temperature thereof, while insuring a maximum production of gas with an apparatus of comparatively small dimensions. It consists of a casing 1 to receive the fuel, and having, as shown, the form of two truncated cones meeting at their smaller ends. The casing 1 has at the top a number of charging inlets 2 closed by covers 23. The air necessary for the gasifying of the fuel is blown in by the central pipe 3 following the direction of the arrows 4; it then passes through the fuel, and burns in the zone 5, while the products of distillation from the upper layers 6 of the fuel escape by openings 7 formed in the casing 8, which surrounds the central pipe 3. These products, then following the direction of the arrows 9, pass through the combustion zone 5, where they are decomposed, and then pass as indicated by the arrows 10 into the space 11, mixed with the gases of partial combustion. The gaseous mixture thus formed heats the fuel 12, and escapes, with a composition and at a temperature practically uniform by the outlet 13. The firegrate 16 is provided at its centre with an opening which can be partially closed by a conical shaking grate, which is operated by means of a lever 18. The air supply pipe has at its top a lid 21, which serves at starting for the kindling of the fuel by petroleum or otherwise.

(8) **Taylor's Gas Producer.** Patent No. 14183 of 1901.—The object of this apparatus (Fig. 8) is to provide means whereby the refractory material and metallic parts can be readily and quickly renewed without disturbing the joints. It consists of a cylindrical chamber A provided with a cover B carrying the charging hopper C, and a supporting cylindrical base D containing the incandescent fuel chamber S. The metal ring E enclosing the refractory material F, forming the lower part of the chamber A, fits in a bored opening in the top of the cylindrical base D. The air and steam required for the production of the gas enter the ashpit G through a passage H communicating with the annular space J between a ring K and the lower part of the ring E which it surrounds, the ring K being held in position by screws M. The bottom of the ring E is closed by a washer N resting on rods O which are slightly curved. The refractory material F at the lower part of the chamber S rests on the washer N, and fits inside the ring E. A door R permits of the refractory material F,

ring K, and washer N being introduced into or removed from the producer without it being necessary to take down any other part. The refractory material S and ring E can be easily removed by removing the chamber A. When the part E has been renewed the refractory material S is placed in position, and the chamber or casing A is again bolted to the supporting base D, the annular space T is filled with grouting or a cement of refractory earth, so that the joint between the parts S, A, and E is thus secured.

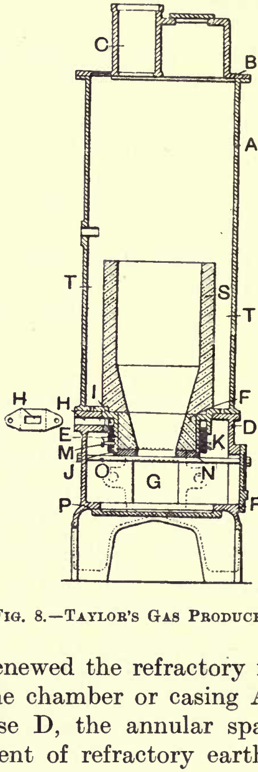


Fig. 8.—Taylor's Gas Producer.

(9) **Duff's Gas Producer.** Patent No. 15646 of 1901.—This producer, which is shown in Fig. 9, is more especially applicable where town's refuse is used as fuel, and consists of a firebrick-lined casing A fixed at its lower end to a depending tapered metal piece B which dips into a water seal C. The piece B is provided with rollers B_1 arranged to travel on a circular rail D. With this arrangement the firebrick casing A, with its depending piece B, can thus be turned round, the parts being rotated by means of a driving pinion E and circular toothed rack E_1. The casing A is

provided with a metal cover G having an inner lining G_1 of firebrick, the cover being fixed to the charging platform H, so that it does not interfere with the rotation of the vertical casing A. The cover G is provided with a depending spigot part G_2 which dips into a liquid J in a trough J_1, thus forming an effective seal. A fuel charging box K is fitted to an inlet

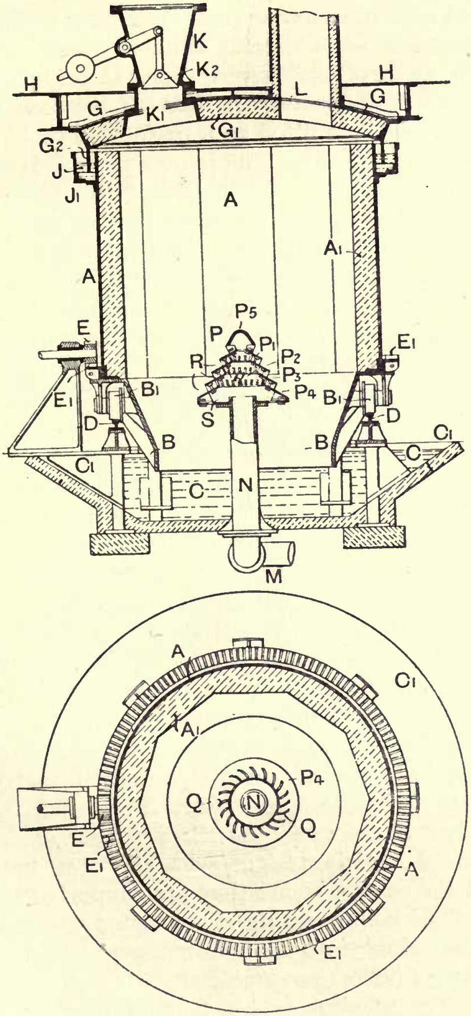


Fig. 9.—Duff's Gas Producer.

K_1, the opening at the bottom of the box being controlled by a weighted valve K_2. The gas escapes from the producer by an outlet L. Air is led from a blowing apparatus to the fuel bed by pipes M connected to a stand pipe N. On this stand pipe is mounted a cone-shaped air-distributing nozzle P, consisting of a series of sloping annular plates P_1, P_2, P_3, P_4, overlapping each other, curved vanes Q being arranged all round the annular openings R thus left between the plates. The bottom ring P_4 is fitted to a perforated plate S fixed to the stand pipe flange N. The blower piece P is surmounted by a cap or cover P_5. The action of the apparatus is as follows: After the producer has been charged with fuel, the vertical shell A is turned slowly round, and this slow rotating movement, combined with the polygonal contour of the lining A_1 of the shell, has the effect of twisting the fuel bed so as thereby to break it open, and thus feed the fuel down to the air-distributing nozzle P in an open condition. The air issuing from the blower piece P is thus allowed to distribute itself freely and uniformly through the fuel. The curved vanes Q on the blower piece P act as baffles, and impart a swirling or circular movement to the air as it issues from the blower piece, and thereby prevents the issuing air from being too directly and forcibly blown upon the lining A_1 of the producer, and also prevents the formation of adhering clinker, as well as the overheating of the shell plates.

(10) **Herrick's Gas Producer.** Patent No. 17265 of 1902.—The object of this design, shown in Fig. 10, is to provide for supplying to the mass of fuel air in large volume, but so uniformly distributed throughout the mass as to have no disrupting action upon any portion of the same by reason of its pressure, to regulate the blast as desired, and to prevent any clogging of the blast openings. Projecting through the lower portion of the casing of the producer are a series of tuyere boxes 4 having straight sides and open bottoms, and meeting at the centre, where they are supported by a hollow casing 5. This hollow casing is connected to an injector 7, whereby air is blown into the hollow tuyere boxes. The sides of these tuyere boxes are provided with slots for the escape of the air. The effective area of these slots can be varied by adjustment of sliding dampers 9. Each of the tuyere boxes has at the outer end a door 10 for cleaning purposes, and the lower portion of the casing of the producer has alongside of each tuyere box a socket 11 for the reception of a firebrick

12, on the removal of which plugs access may be had to the outer side of the tuyere boxes and their dampers for the purpose of removing ashes or cinders. The tuyere boxes being embedded in the ashes in the lower portion of the producer, these ashes close in beneath the tuyere boxes, so that no air can escape from either box without entering the mass of ashes, and then rising through the same into the mass of incandescent fuel above, the uniform distribution of the air escape opening of the tuyere boxes throughout the mass of ashes insuring a thorough dissemination of the air throughout all portions of the mass of fuel in the producer without the employment of a powerful blast; hence air in large volume can be passed through the producer, and correspondingly large volumes of gas can be produced without the employment of any such pressure as will tend to disrupt the mass of incandescent fuel.

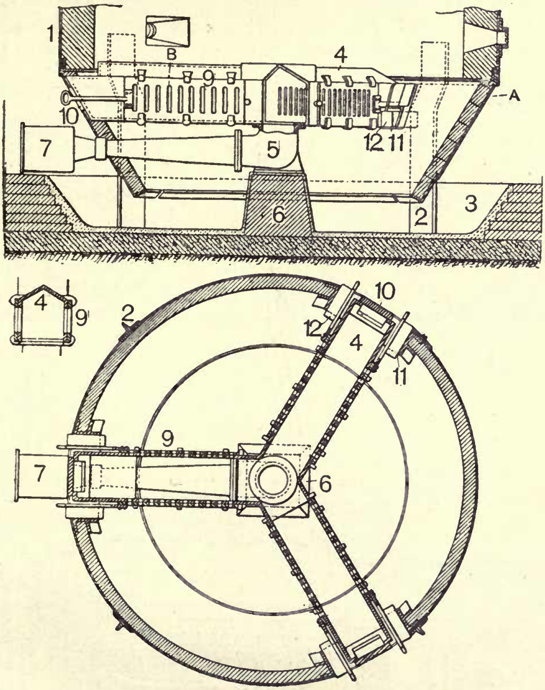


FIG. 10.—HERRICK'S GAS PRODUCER.

(11) **Crossley and Atkinson's Gas Producer.** Patent No. 22016 of 1901.—This producer (Fig. 11) has been designed for making gas of a somewhat low calorific value, such as is commonly used for driving gas engines and for heating purposes generally. An essential feature of the producer is that the fuel is introduced at the top, and is continuously consumed downwards, the air for supporting combustion being introduced at the top and the gases taken away from the bottom. The producer consists of a casing A lined with firebrick B. At the bottom the lining B is supported on a flat iron ring D, and under this iron ring is a revolving ball-

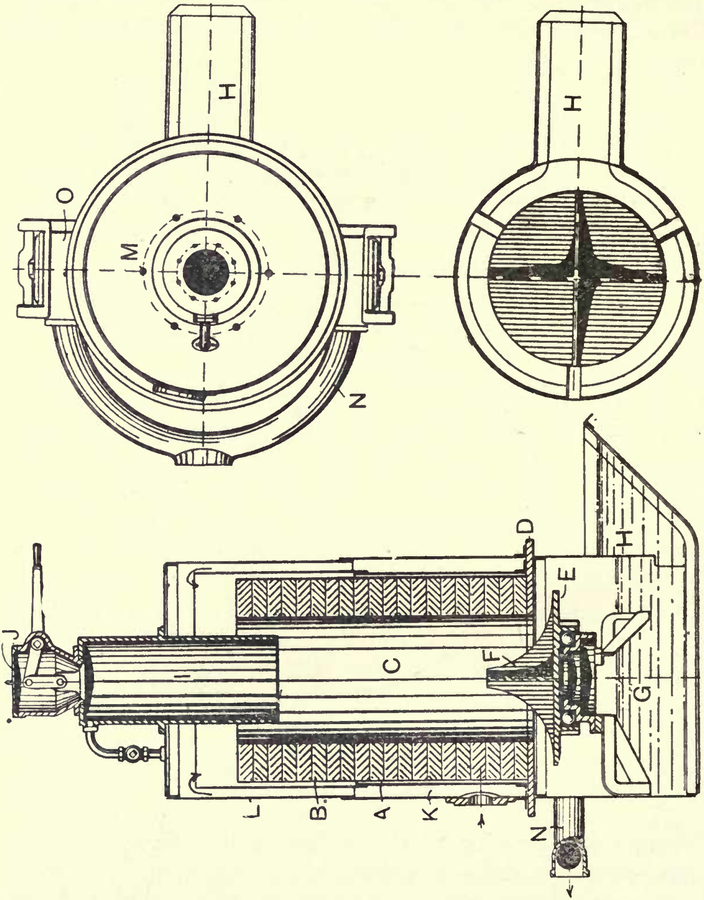
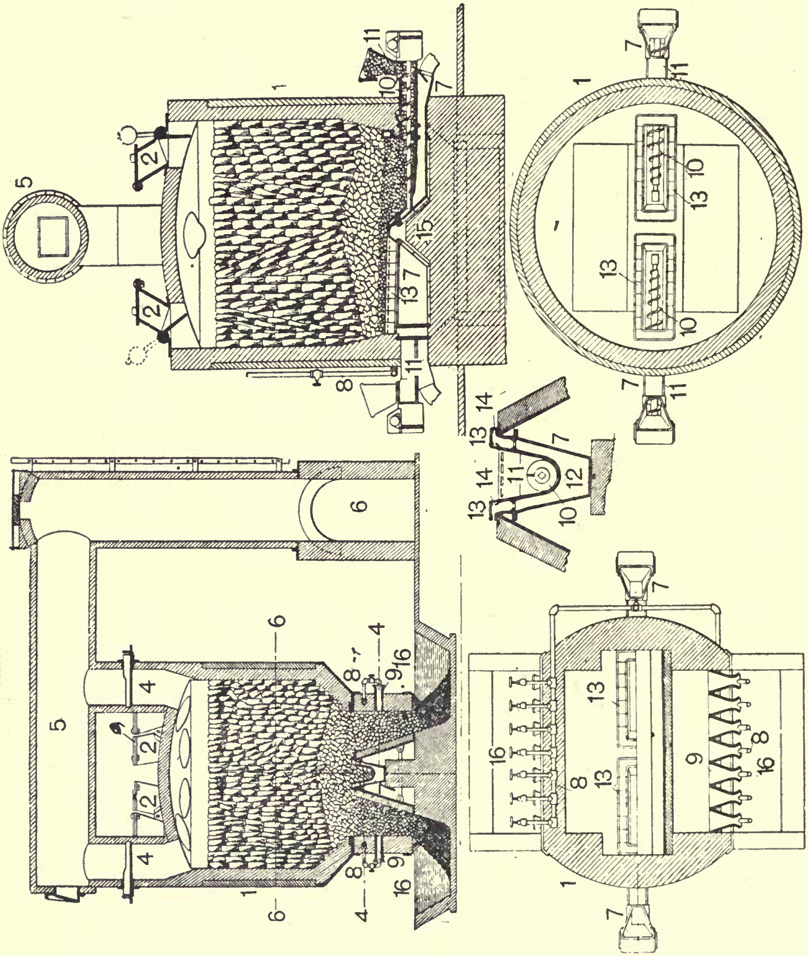


FIG. 11.—CROSSLEY & ATKINSON'S GAS PRODUCER.

bearing grate E, having ribs F on its upper side projecting into the fuel bed, a space being left between the ring D and the grate E for the passage of the gases and the ashes. At the lower portion G of the producer is a water lute which assists in keeping the grate E and the ring D from being overheated, allowing the removal of the ashes by means of the opening H, which is open to the outside without interfering with the continuous working. The fuel is introduced by means of a bell I and hopper J. The air is introduced at the lower part of an annular space K contained between the producer shell A and an outer shell L, so as to pick up heat as it rises to the top of this space. The bell I defines the active depth of the fuel, and the distance from its lower edge to the grate level requires to be suitable for the fuel used and for the size of the producer. It may be filled with fuel so as to hold a reserve, and as the fuel burns away it drops out of the bell into the producer itself. As there is no material supply of air to the fuel in the bell, it cannot burn in the bell, but can only commence to burn after passing out of the lower end. In the top plate there are a number of poker holes M closed normally with taper plugs. The gas passes away by the pipe N.

(12) **Taylor's Gas Producer.** Patent No. 26330 of 1901.—This producer, shown in Fig. 12, has for its object to produce a gas which shall be free of unstable constituents requiring subsequent removal. The walls 1 of the generator are contracted near the bottom, so as to permit the incandescent coke to be bridged over above the stokers to thereby support itself. 2 are hoppers for introducing the initial charge of fuel. 4 4 are the uptakes leading to the gas main 5. 6 is a conduit leading to a regenerative furnace for utilising the gas produced. 7 7 are the feeding devices for introducing the fuel under the bed of incandescent coke contained in the generator. 8 8 are steam pipes, and 9 9 are air openings, the parts being so arranged that the issuing steam forces into the lower parts of the generator commingled air and steam. The underfeed stoker comprises the Archimedean screw 10, the coal reservoir 11, over the sides of which the coal is elevated by the screw, an air chamber 12 surrounding the magazine, and supplied with a forced draught, tuyere blocks 13 at the sides of the fuel magazine, and connected with the air chamber 12, and openings 14 in the tuyere blocks, through which air is ejected therefrom into the generat-

ing chamber. These stokers are arranged end to end, and are placed near an abutment 15 located so as to discharge the green fuel above the point where the air and steam enter through the nozzles 8 and 9. 16 16 are



Section on line 4 4. FIG. 12.—TAYLOR'S GAS PRODUCER. Section on line 6 6.

water-sealed ashpits, into which the incombustible ash or residue descends from the generating chamber. In the operation of the device wood kindlings are first introduced through the hoppers 2 2, and on top of them coke is fed to the desired depth. The fire being lighted, and the coke brought to the required condition of incandescence, the stokers are started and green coal is continuously fed into the generator under the incandescent coke. This fuel, as it is fed upward, is converted into coke by the distillation of its hydrocarbon constituents, which, in the presence of the air issuing through the air openings 14, are decomposed, forming carbonic acid gas and hydrogen. The carbonic acid gas passing upward through the incandescent body of coke above it is converted into carbonic oxide gas before it leaves the generator. The water contained in the coal is, like the steam introduced through the nozzle 8, decomposed, producing hydrogen gas and oxygen, the latter serving to facilitate the oxidising operations which take place in the generator. The fresh coke overflows from the stoker, and passes down at the sides of the abutment 15, where it meets the incoming air and steam introduced through the nozzles 8 and 9. In the presence of the free oxygen combustion of the coke ensues and carbonic acid gas is produced, which passes upward through the incandescent body of coke above it, and is converted into carbonic oxide gas. The hydrogen which results from the decomposition of the steam passes up through the incandescent coke unchanged owing to the limited air supply.

(13) **Bowman's Gas Producer.** Patent No. 3783 of 1902.—This apparatus (Fig. 13) comprises a generator 1, lined with fireclay, and provided with an ashpit 3. In this ashpit is mounted a furnace grate 5, the position of which is controlled by a hand lever 7. Below the firebrick lining is fitted a coil 9, the ends of which are carried upward, one into the steam space and the other into the water space of a small boiler 10 provided with field tubes 11, which are suspended in a space heated by the furnace. The boiler is supplied with water through a feed pipe 12, while the surplus water passes away through a tube 13. To the top of the generator a vessel 14 is fitted, and at the top of this vessel is secured a hopper 15 for the supply of fuel. A ring of fine gauze 16 is fitted between the firebrick lining and vessel 14 to prevent coal dust, &c., passing out with the products of combustion. The air for combustion is admitted at the bottom of a chamber 17 formed round the exhaust pipe 18 of the gas engine, gills 20 being fixed upon the pipe to form baffles, and cause the air to make a tortuous passage, and so absorb the heat;

the hot air from this chamber 17 is conducted by a pipe 21 to the steam space of the boiler, and this steam space is also connected by a pipe 22, controlled by a damper 34, to the chamber 3. The space below the boiler at the upper part of the generator is connected to a pipe 23, the upper part of which forms a chimney when a damper 24 is opened, while the lower end of the pipe 23 enters a vessel 25 in which is fitted a pipe 26 with a bell-mouthed opening at the bottom, which dips

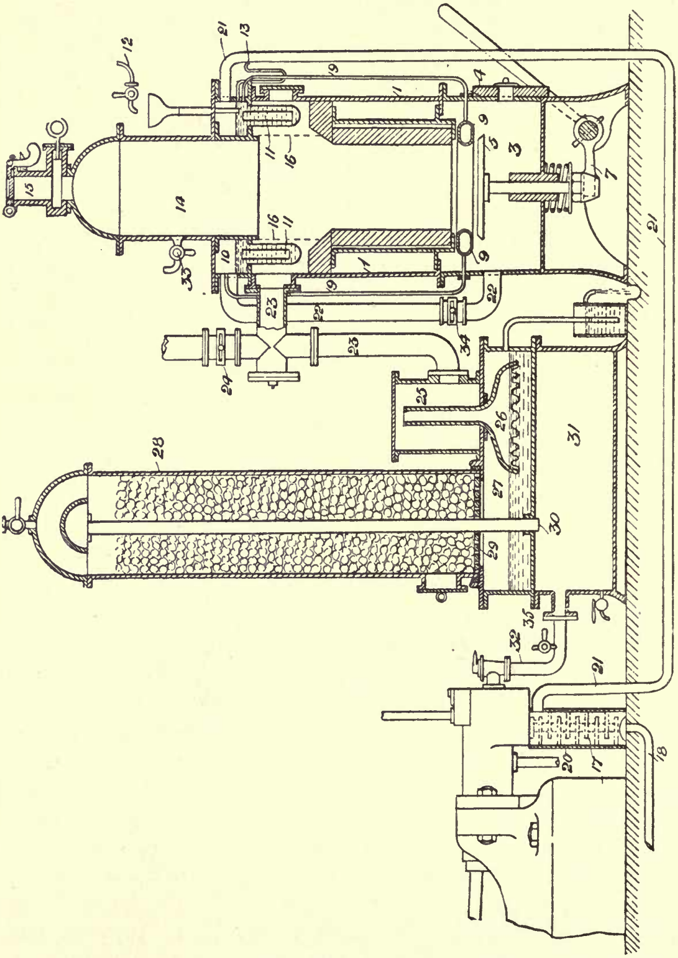


FIG. 13.—BOWMAN'S GAS PRODUCER.

slightly into water contained in a tank 27 supporting a scrubber 28, the bottom of which consists of a perforated plate 29. The scrubber is provided with a central pipe 30, which passes through the water tank 27 into an expansion chamber 31 connected by a pipe 32 to the cylinder 19 of the gas engine. When the fire is lighted upon the grate 5 it requires the aid of a blower to start the fire and raise a little steam, the damper 24 in the pipe 23 being opened to the chimney, and the damper 34 in the pipe 22 being closed. The use of the coiled pipe 9 forming an auxiliary boiler enables steam to be raised more readily. When the gas produced is rich enough to burn, which can be tested by opening a valve 33 in the vessel 14 and applying a light, the valve 24 is closed and the gas blown through the scrubber to a tap 35 on the pipe 32. When the gas burns here the gas valve on the engine is opened and the flywheel is turned to start the engine. As soon as the engine is properly started, damper 34 in the pipe 22 is opened, and the engine aspirates the gas from the generator and maintains combustion therein.

(14) **Daniels' Gas Producer.** Patent No. 7613 of 1902.—The main features of the design shown in Fig. 14 are the means provided for collecting and utilising the distilled and condensible gases from the upper portion of the producer, and the method of constructing and arranging the firebars and other fittings. At the upper end of the casing A is a feeding hopper, the inner branch F of which projects below the upper end G of the interior chamber E so as to form an annular collecting head from which the distilled gases and vapours escape by means of an opening H_1, which leads into a conduit passage H. The lower end of this collecting conduit H is joined to a feeder branch K which delivers the distillates and gases to the lower portion of the firegrate within the zone of combustion. This branch K is formed with slots through which the distillates are delivered, and through which the steam for decomposition in the interior of the gas producer passes. The branch K also forms a support for the firebars. Steam is introduced through a nozzle J for the creation of an induced draught in the conduit H. Within the interior of the producer is arranged the projecting ring-like collector D for leading to the gas outlet passage. The firegrate is formed of rocking bars L and O, carried on central spindles M, operated by hand levers N. The rocking bars I are made to intermesh on their inner ends with projecting bars Q formed upon the bearer member K.

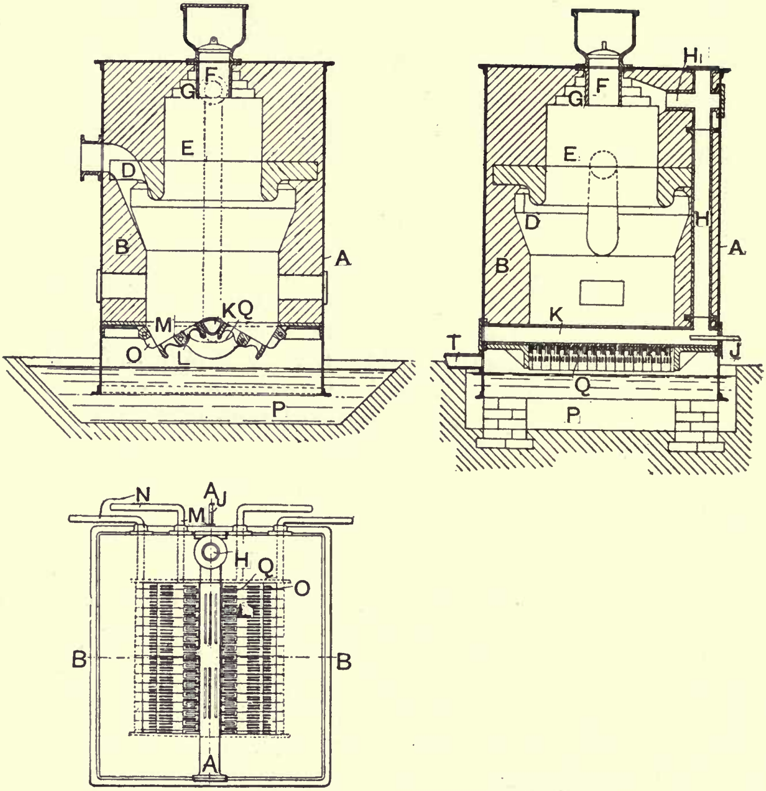


Fig. 14.—Daniel's Gas Producer.

(15) **Fielding's Gas Producer.** Patent No. 14893 of 1902.—The object of this design, shown in Fig. 15, is to enable gas producers to be worked with open tops into which the fuel may be charged at all times, and so that at any time pokers or stirrers may be introduced into the centre of the fire. A is a hopper into which the coal is fed, B is an enlarged extension forming a feed chamber through which the coal descends into the body of the fire C. D is an annular space in connection with which there is fitted an outlet E through which are drawn off the vapours formed by the heating of the coal in the feed chamber B. F is a steam injector which draws off the vapours and discharges them into the body of the fire at G. Since a slight vacuum will be produced in

the annular space D, there will be a slight suction of air through the coal in the hopper A, and this air will be delivered with the vapours into the body of the fire at the

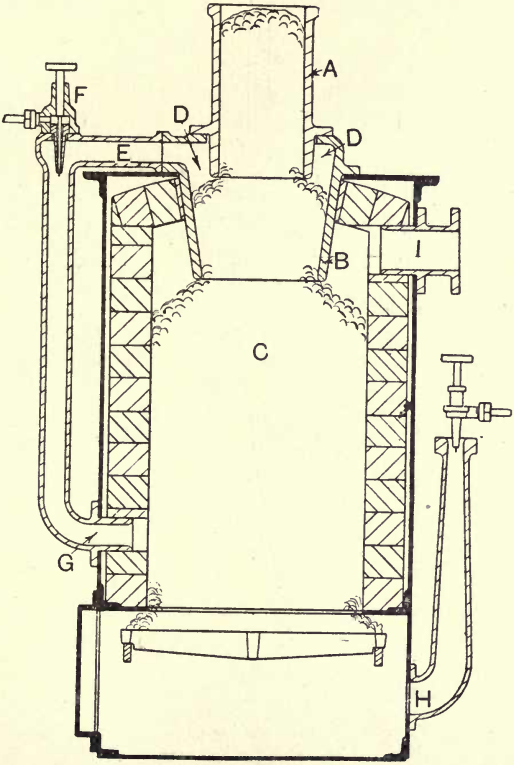


FIG. 15.—FIELDING'S GAS PRODUCER.

point G. H is the ordinary air blast supply, for supporting combustion, the air being supplied either by an injector or by a fan. I is the gas outlet.

(16) **Tonkin & Puplett's Gas Producer.** Patent No. 15498 of 1902.—This producer, shown in Fig. 16, comprises a chamber B provided at the top with a fuel hopper C, the latter being fitted with an internal bell valve E. Below the hopper is a conical retort F projecting into the chamber B, and provided with ribs. The bell valve E is attached to a rod G. This rod projects downwards into the retort, and is used as

a poker E_1. The hot gas leaving the producer through the passage A is transferred to the cold incoming air blast, and cooled by means of the heat interchanger K, in which the

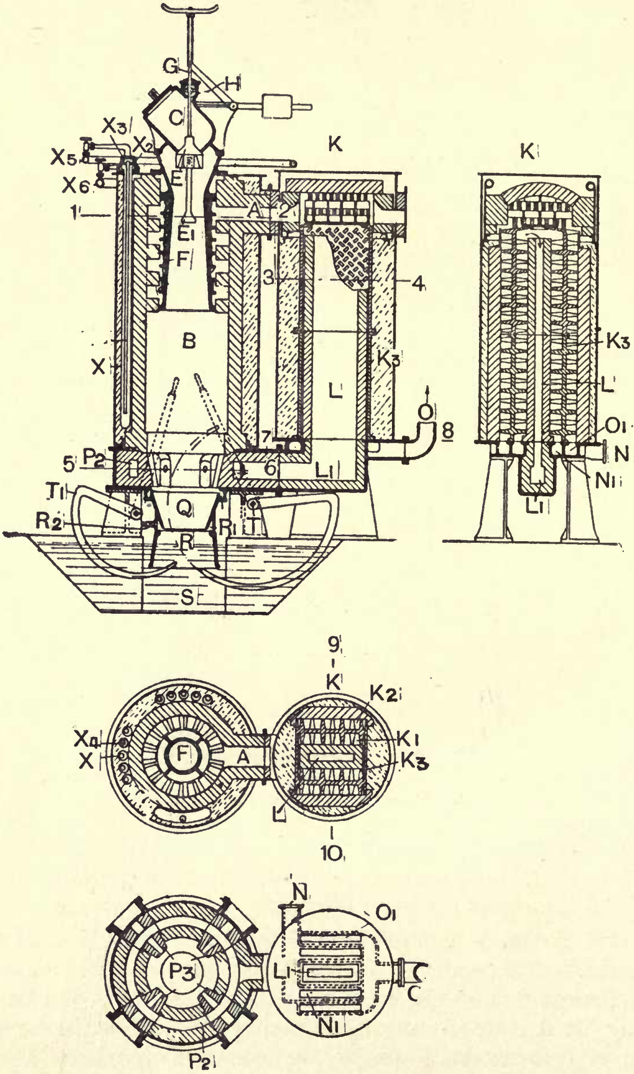


FIG. 16.—TONKIN & PUPLETT'S GAS PRODUCER.

cold air and hot gases pass in opposite directions through the two flues K_1 and K_2. This interchanger consists of a rectangular chamber K_3, the sides of which are provided with projecting ribs. The upper end of this chamber is closed by a cover, and is enclosed along with the projecting ribs within walls forming two flues K_2, down which the hot gas passes. A vertical pipe L extends nearly to the top of the chamber K_3, and communicates at the bottom with the passage L_1, which conveys the hot air down to the annular passage P_2. The passages N_1 formed in the base of the heat interchanger communicate between the air inlet N and the lower part of the inside flues K_1. Similar passages O_1 convey the cool gas from the flues K_2 to the gas outlet pipe O. The heated air blast is introduced through the nozzles P_3. A conical ring Q is fitted at the bottom of the producer, to which is attached an extension ring R which dips into the water seal S. In the upper part of the conical ring Q is an opening extending all round the chamber. Through this opening steam is introduced which rises up the inside of the walls of the chamber B, and cools the fuel next to the brickwork, and so breaks up the clinker. A second annular air passage R_1 is formed between the two rings Q and R, through which air is supplied in order to burn any fuel that may have escaped the main hot-air blast. Poking devices T_1, which move in a curved path, are fitted to the shafts T. To obtain a supply of steam for working the air blast, water is supplied to the tubes X, arranged in openings in the brickwork surrounding the chamber B. This brickwork, being at a high temperature, furnishes the necessary heat for generating the steam.

(17) **Schill & Hill's Gas Producer.** Patent No. 18867 of 1902.—This producer, shown in Fig. 17, is particularly applicable to small installations. The top of the generator is equipped with a steam-raising and heat-storing device consisting of a mass of cast iron 5, within which a tubular coil of wrought-iron pipe 6 is embedded, and the mass of iron is perforated at 7 to allow of the passage of the products of combustion. The coiled pipe 6 is connected by means of a branch pipe 8 with a water supply under pressure. The delivery end of the coiled pipe 6 is connected to a steam drum 9, fitted with a regulating valve 12 which controls the delivery of steam through a pipe 13 to a jet 14. Immediately above the steam nozzle 14, and within the chimney 15, is fitted a movable valve 16. A gas holder is provided to

receive the gas as produced, and the top of the gas holder is connected by mechanism with the valve 16 in such a way that when the holder is raised to its utmost limit the valve is opened, and when it has sunk to its predetermined limit the valve is closed, both movements being automatic. The lower part of the generator is provided with an outlet for clinker or ashes, this being sealed by a water lute 20. The air inlet 21 is provided with a clack valve 22 opening inwards, and from the annular chamber 21 the air passes downward through the curved pipes 23, becoming highly heated by the products of combustion from the generator. The heated air issuing from the pipes 23 enters an annular chamber 24, and flows downward through a pipe 25, and enters the generator through a series of radial openings 26 connected by an annular passage 27. There is an outlet 28 for gas which passes a non-return seal (not shown) on its way to the

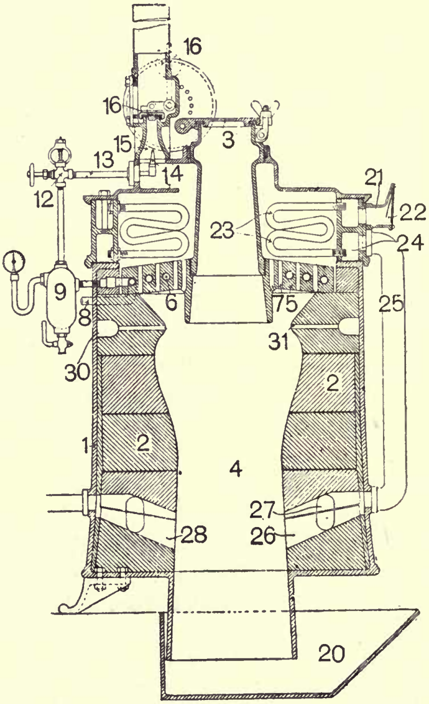


Fig. 17.—Schill & Hill's Gas Producer.

gas holder. There is also a supplementary air supply admitted through a clack valve opening inwards to an annular passage 30, whence it passes through radial passages 31 to the interior of the generator.

(18) **Crossley & Rigby's Gas Producer.** Patent No. 18892 of 1902.—This producer (Fig. 18) consists of a casing A lined with firebricks B placed inside a casing C which is carried lower than the casing A and enclosed so as to form a water lute. The top of the producer is arranged with a central bell E for collecting the gases. The fuel is fed into the producer by means of charging hoppers G arranged to drop the fuel into the space between the outside of the hanging bell and the lining of producer. A reservoir of fuel is so obtained, and being in contact with the outside of the hot collecting pipe, the fuel is heated during its descent to the actual working level of producer. The brickwork lining of the casing rests upon a plate fixed to the bottom of the casing,

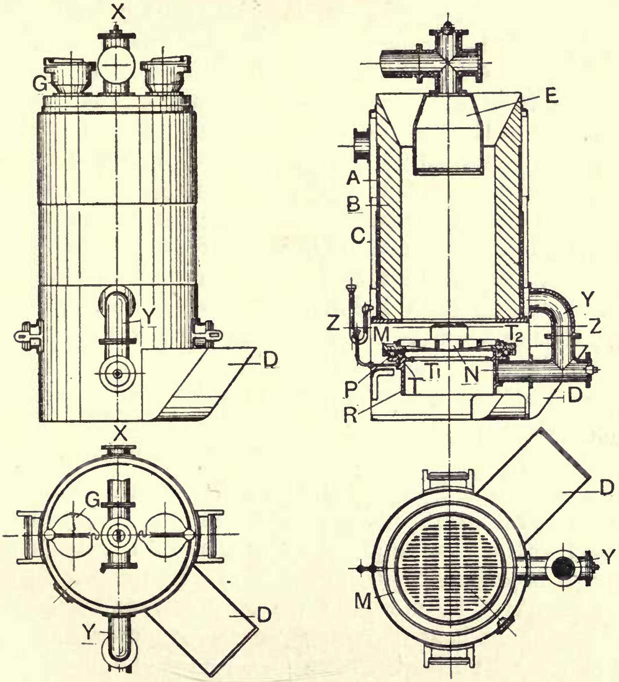


Fig. 18.—Crossley & Rigby's Gas Producer.

LIBRARY OF THE UNIVERSITY

and a few inches below this plate is fixed the revolving table M, in which is fixed the firegrate N. This table is somewhat larger than the diameter of the brickwork, and is supported upon balls P, which enable it to be easily moved. The air, or air and steam which is passed into the producer, is superheated in the annular spaces between the two casings, and is brought by the pipe Y into the cylinder previous to entering the fuel bed. On the upper portion of the cylinder are arranged two concentric cylindrical vertical rings T and T_1, which project upwards a few inches, and the space between the rings is filled with sand. On the bottom side of the firegrate table is arranged the cylindrical vertical ring T_2, which is immersed in the sand contained in the space between the lower rings, and forms a sand seal which is not affected by the heat of the fire. As the lower portion of the cylinder is sealed in water, any air, or air and steam, passed into the cylinder can only escape upwards. The grate is arranged in the form of single parallel firebars, secured so as to revolve with the table. The grate being flat, and the gas being taken away in a central position from the upper portion of the producer, the tendency is for the bulk of the air, or air and steam, to pass upwards more through the middle portion of the fuel than the outer diameter next the brickwork. In this way less clinker is produced near the lining of the producer, and as a consequence a poorer class of fuel can be used than is usual, and a gas of high heating power is obtained.

(19) **Crossley & Rigby's Gas Producer.** Patent No. 24194 of 1902.—This arrangement, shown in Fig. 19, has been designed with a view to producing gas from bituminous coals free from objectionable tarry vapours. The fuel is distilled in the retorts A by means of the sensible heat of the gases and the radiant heat of the fuel in the producer, the caked residue being afterwards fed into the producer and consumed there. The retorts are arranged with hollow, spiral castings B, which close the bottom end. Screw tackle is arranged so that the casting B may be rotated independently of the screw. When charging a retort the valve face of the casting B is tightened in its place, and fuel admitted into the retort is projected downwards into the spaces between the spirals by turning the capstan C in the right direction for this operation. When discharging a retort the casting B, in the first place, is lowered a distance by means of the tackle, and the capstan, in the second place, is turned in the same direction to that

when charging. The coked fuel in the retort A is thus projected downwards, and broken up by the spirals. The volatile gases given off from the green coal in the retorts A is conducted by way of the pipes E and F to the lower portion of the fuel bed of the producer. When a charge has been completely distilled in a retort the gas outlet therefrom is shut off temporarily by means of the dampers G. The coke or residue is broken up into suitable sections by the spiral D, and is dropped out of the retort into the producer. A fresh charge is fed into the retort through the door, which is then secured, and the damper G again opened. The fuel, after passing through the retorts, will not cake a second time, and is

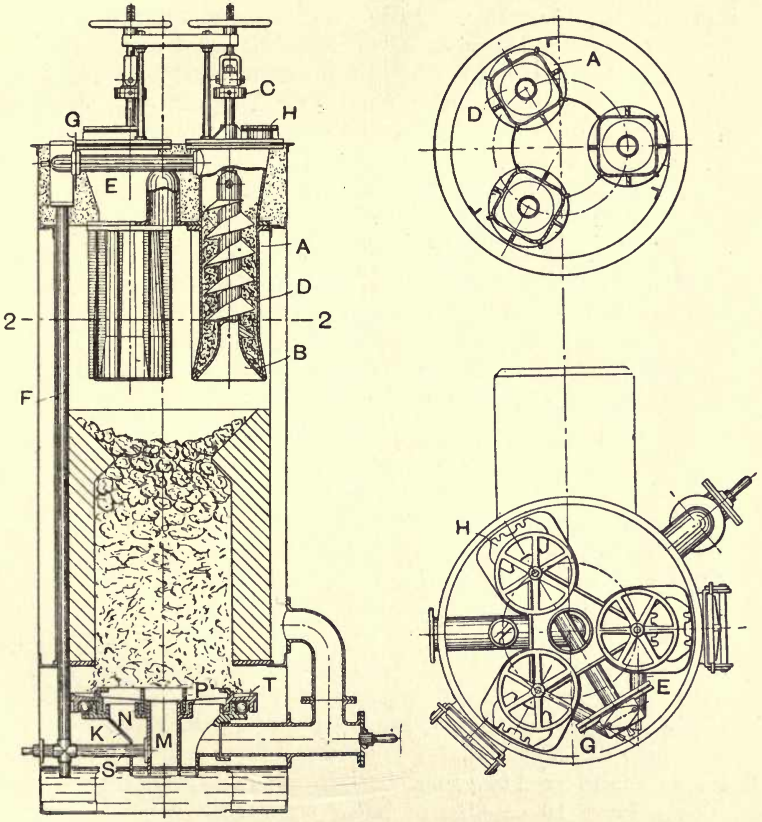


Fig. 19.—Crossley's and Rigby's Gas Producer for Bituminous Coal.

thus very suitable for use in the producer, and the gas produced is more uniform than that obtained in the usual manner. The firegrate T is of the rotary type, and is carried by a ring K, the lower portion of which is immersed in water. In addition, a second ring M is arranged concentrically inside the other, and is also immersed in the water. The upper portion of the inner ring is arranged with an annular groove N, which contains sand or water. On the underside of the firebars is arranged the vertical ring P, which is immersed in the sand or water. Connection is made to the inner ring by the pipe S passing through the outer chamber. The air and steam necessary for the gasification of the fuel is contained in the outer chamber, and the volatile gases and vapours are led from the retort to the inner chamber M. They are kept separate, but enter the fire through the same bars.

(20) **Beanes & Werner's Gas Producer.** Patent No. 24878 of 1902.—The object of this design (shown in Fig. 20) is (1) to improve the construction, working, and durability of producers, (2) to equalise the temperature of the gas passing therefrom, and (3) to utilise waste or surplus heat to increase the quantity and improve the quality of the gas produced. To admit of ashes and clinker being broken up and removed, the lower end of the producer is provided with a hopper-shaped metallic ring 2, the lower end of which is provided with a centrally arranged tubular extension 6 that dips into a water seal 7. The ring 2 with its extension 6 is provided with lateral wings 9 that serve to divide the air space below the ring and above the water seal into two portions, one of which, viz., 10, forms a closed air chamber into which air, or air and steam, is or are led through passages 11, and the other of which, viz., 10_a, is open to the external atmosphere through a large opening 10_b in the front of the producer. A tubular carrier 12 that dips into the water seal 7 is supported by a pair of bent lever arms 13 fixed to a rock shaft 14, the shaft being provided with a lever 16 capable of being oscillated. Held by the tubular carrier 12 is a hollow metal fuel support 17 provided around the side with ports. The portion of the tubular extension 6 forming part of the closed air chamber 10 is formed with openings 18, through which air can pass into the fuel chamber 1. By the construction described, the most active combustion, it is claimed, will take place in the centre of the fuel, the rapid destruction of the wall of the producer will be prevented, and any clinker formed will rest upon the

metal portions at the bottom of the fuel chamber. When it is desired to break up clinker resting on the ring 2 and central fuel support 17, the rock shaft 14 is oscillated by means of the hand lever 16. By turning the rock shaft to a greater extent, the tubular carrier and fuel support can be caused to move downward out of the tubular extension 6, and into the water seal, so as to permit ashes and clinker to fall freely into the receptacle below. The fuel above the ashes and clinker is at this time supported by a temporary grate composed of metal bars 20 that are inserted across the lower part of the fuel chamber 2. After the ashes and clinker have been removed, the tubular carrier is returned to its normal position, and the temporary grate bars withdrawn. To enable the gas to pass away from the gas producer at an

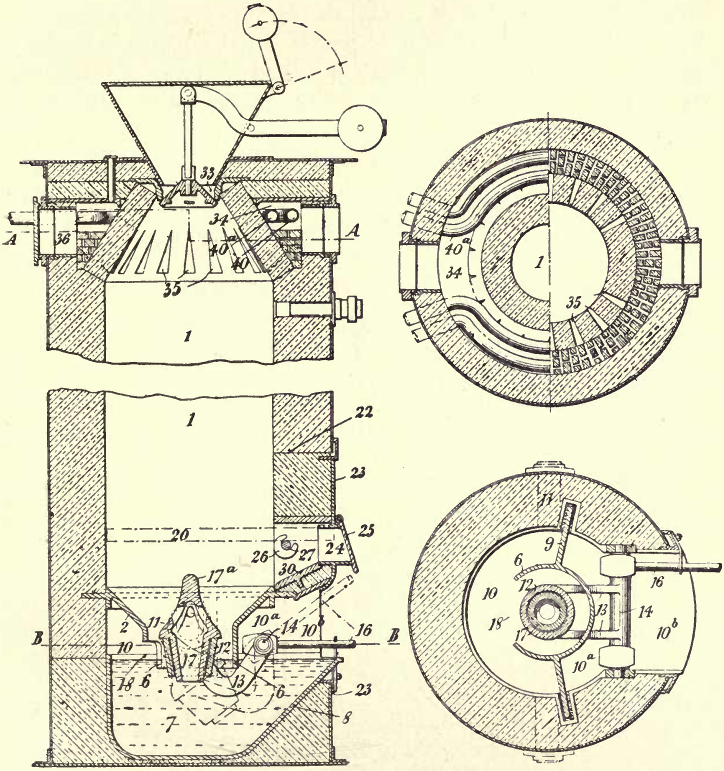


FIG. 20.—BEANES & WERNER'S GAS PRODUCER.

approximately uniform temperature, the upper part is constructed with a regenerator chamber 34 that communicates through openings 35 with the upper part of the fuel chamber, and is provided with brickwork arranged chequerwise. The regenerator chamber is provided with pipes 40, through which air is led on its way to the closed air chamber 10 at the bottom of the producer, so that excess of heat from the escaping gas can be utilised to heat the air on its way to the fuel chamber 1. The regenerator chamber may also be provided with pipes 40_a into which a small stream of water is led and converted by surplus heat into steam that is mixed with the air and led to the fuel chamber to increase the quantity and quality of the resulting gas.

(21) **Dowson's Gas Generator.** Patent No. 25319 of 1902.—In this apparatus air, or steam and air, are made to enter the gas generator at or near the top and the bottom thereof,

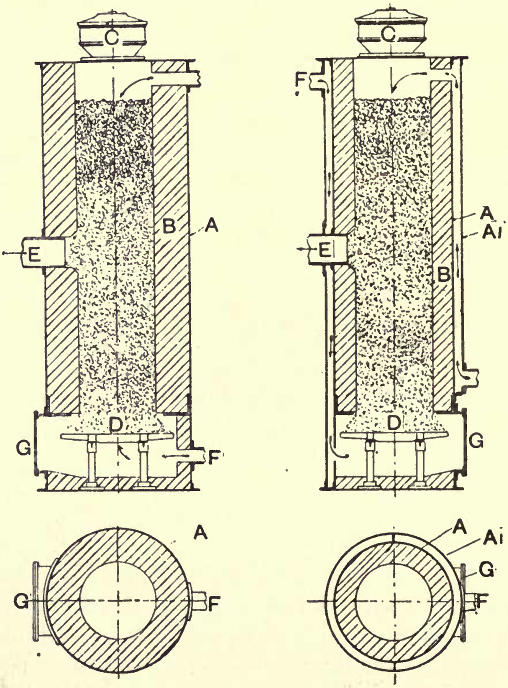


Fig. 21. Fig. 21a.

Dowson's Gas Generator.

there being a gas outlet about half-way up the generator, through which the gases from the upper and lower parts of the generator pass out. In this way the fuel in the lower part of the generator is worked by an up draught, while that in the upper part of the generator is worked by a down draught. The gases formed in the lower and upper parts of the generator then pass outwards through the outlet. This way of working a gas generator is, the inventor claims, especially suitable where the gas is made from bituminous coal or other fuels containing hydrocarbons, as the portion of the fuel which is not converted into gas in the upper part of the generator is made into gas as and when it reaches the lower part thereof. The air required for producing gas in the generator is forced into it by a pump or blower, a jet of steam, or any other suitable means. The generator may be surrounded by an air jacket, so that the air to be used may be heated before it comes in contact with the fuel. In the accompanying illustrations Fig. 21 represents one arrangement of gas generator, and Fig. 21A another arrangement. In Fig. 21 there is an outer casing A, lined with firebricks B, feeding hopper C, grate D, gas outlet E, and inlets F F for air or steam, and air door G. In Fig. 21A there is an inner casing A and outer casing A_1 with air space between the two casings. There is a firebrick lining B, feeding hopper C, grate D, gas outlet E, and inlets F F for air or steam, and air doors G. Any suitable feeding hopper or arrangement of firegrate may be used.

(22) **Robson's Gas Producer.** Patent No. 25560 of 1902.—This producer is shown in Fig. 22. Around the lower portion of the coal-feeding hopper 6 is cast an air jacket 13 to which a fan 14 is connected by duct 15. The jacket 13 is also intersected by four air pipes 16. The outside ends of the pipes are connected to the top of an inner vertical annular casing 3—4. Four oblong apertures 19 are cut below the air pipes, which permit the hot gases from the producer fire to pass into the cover. To the bottom of each pipe is attached a small dish 18. A little water is kept dropping into each dish, and is vaporised by the hot gases in which they are enveloped. The air from the fan is first heated in the coal hopper, and becomes mixed with the steam as it passes out of the dishes, and it drives this forward into the inner casing 3—4, where it is further heated. From the bottom of the casing it enters two pipes 25 which are connected

at opposite sides to a circular passage 23 round the interior of a cast-iron ring grate 21 which carries the firebars 22. Having received additional heat from the grate, the air and vapour now pass out by two segmental slots 24 through the metal on the inside of the ring and on opposite sides just below the firebars. These firebars run longitudinally to the air slots, so that the air and steam will pass up into the fire from between the ends of the bars. The steam and hot air now enter the shaft 26, which is encircled by a firebrick lining 27. Having passed through the fire, the gas now

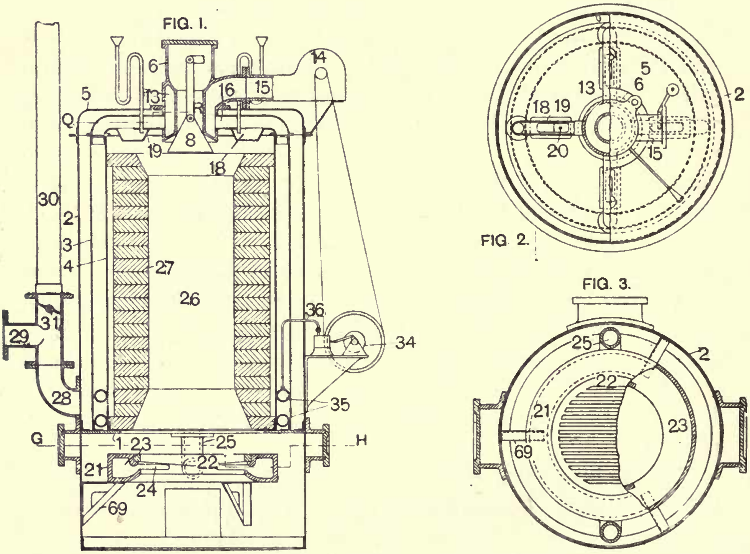


FIG. 1.
FIG. 2.
FIG. 3.

Fig. 22.—Robson's Anthracite Gas Producer Plant.

formed passes through the four apertures 19 in the top plate, and into the cover 5; from there it passes down between the outside 3 of the inner casing and the outside shell 2. At the bottom of the outer casing is fixed to the producer shell a pipe 28 with two branches 29 30, one of which, 29, is connected to a hydraulic box, and the other to a chimney passing through the roof of the producer-house. A throttle valve 31 is fitted to the chimney, which must be opened to give ventilation to the fire when the plant is not working, and to maintain the flow of the hot gases down the outer casing which keeps the inner one warm.

(23) **Wilson's Gas Producer.** Patent No. 26709 of 1902.—This producer, shown in Fig. 23, is provided at its lower portion with an air tuyere 2 of inverted V section that extends centrally across it, and is open at the bottom, and with laterally arranged and upwardly extending grates 3 arranged at opposite sides of the tuyere 2, and at the back of which are air supply passages 4, the arrangement being such that air supplied to the central tuyere 2 will be caused to issue from its open bottom and pass up each side thereof into the fuel, whilst air admitted to the passages 4 will be simultaneously

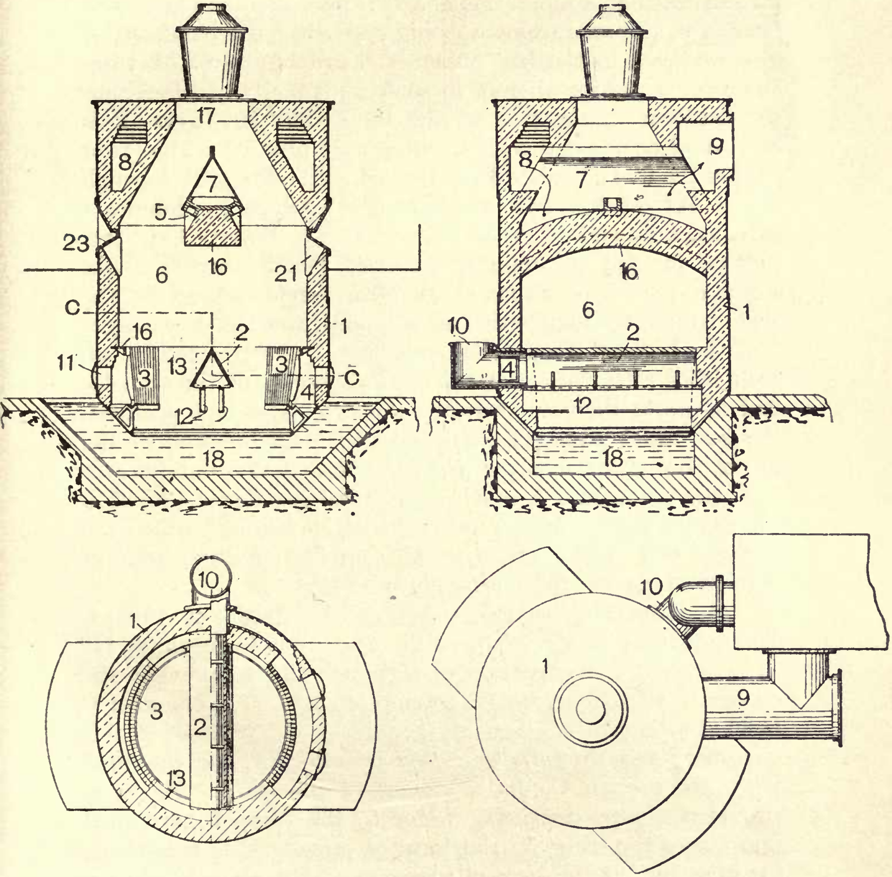


Fig. 23.—Wilson's Gas Producer.

delivered into the fuel through each of the two side grates 3, the result being that the air will be distributed amongst the fuel in an advantageous manner, and cause the combustion thereof to take place in a regular and uniform manner. 5 are gas outlets arranged in the upper portion of the producer, and opening into a flue 7 of inverted V section, which communicates at its ends with an annular flue 8, and is provided with an outlet branch 9, the arrangement being such that the combustible gas produced in the fuel chamber 6 can be drawn off from the central portion thereof in such a manner as to facilitate the uniform combustion of the fuel. The air tuyere 2 is connected at one end with an air supply pipe 10. The lower part of the fuel chamber 6 is provided with a lining 13 through which extend the two air channels 4 which communicate with the inlet end of the air tuyere 2. The lining 13 at parts thereof located at opposite sides of the air tuyere 2 has segmental portions removed therefrom and replaced by the grate bars 3, through which air can pass from the air passages 4 at the back of them. The cross flue 7 is supported by an arch 16 of refractory material. At each side of the arch 16, and at parts thereof between its central and end portions, the gas outlet passages 5 are provided. In the wall at the top of the producer is the annular flue 8 that communicates with the cross flues 7, and has a lateral gas outlet branch 9 which may be connected to a regenerator through which the hot gas can escape and heat air supplied through another portion thereof to the air supply pipe 10.

(24) **Riche Gas Producer.** Patent No. 27533 of 1902.—The object of the design shown in Fig. 24 is to insure as far as possible the destruction of the tars and to prevent the clinker from clogging up the column of coke. The chamber B is filled with raw fuel through the inlet A. The base of this chamber forms the furnace, closed by a door J, and provided with an ashpan D_1 and an overflow pipe C_1. At A_1 is provided a pipe delivering water to the trays B_1, arranged one above the other in the form of steps. E_1 is the nozzle, for injecting, at the base of the column, the air required for combustion. At the side of the chamber B is arranged a high vertical shaft E filled with coke through the hopper K. At the top of this column is a pipe I for the evacuation of the gases. Between the chamber B and shaft E is arranged a horizontal passage D, at the point F of which air is injected. This passage D compels the columns of raw fuel and coke to

spread at their bases and form inclines closing the ends of the passage or chamber D. The gas producer is started by blowing in an excess of air through the nozzle E_1 until the column of coke E has become incandescent. Then the air supply through E_1 is adjusted for normal working. Water is injected at A_1 if the fuel does not contain a sufficient amount of moisture of its own. The gaseous mixture produced at the base of the column in the chamber B reaches the passage D at a high temperature ready for passing through the coke column in the shaft E. The gaseous mixture receives, however, at F additional air, which destroys the greater part of the tars by partial combustion and dissociation. The velocity of the gases in the passage D is reduced on account of its large cross section, so that dust is deposited therein. As the tars are burned in the horizontal passage D before they reach the purifying column of coke, the latter is never

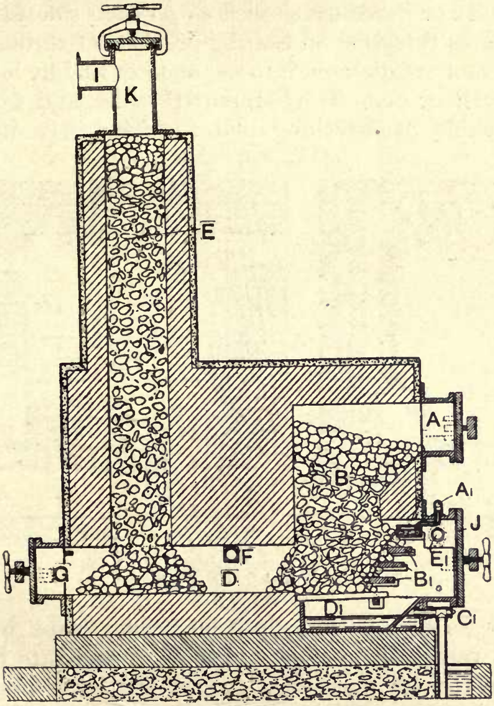


FIG. 24.—RICHÉ GAS PRODUCER.

contaminated by either dust or clinker. Its purpose is to transform steam and carbonic acid into combustible gases, while the unburnt, or portion of the tar not dissociated, is transformed into permanent gases. The carbon resulting from the dissociation helps to maintain the purifying column.

(25) **Hislop's Gas Producer.** Patent No. 28877 of 1902.—The object of this design, shown in Fig. 25, is for the purpose of gasification of slack and also for continuous working. The apparatus comprises a brickwork producer chamber A, having on each side, or centrally as well as on each side, inclined or curved grates B resting on bearing brackets C, through which air and steam are directed into the mass of fuel by blowers H, and a hearth or plate D to support the fuel, and which may be a movable or swivelling plate. When in a horizontal position it forms a practically solid hearth plate, but when turned up vertically on edge, as shown, it serves to break up and loosen the ash and burnt fuel at the lower part of the producer chamber. The usual water and ashpans E may be provided under the inclined grate bars or gratings B, or a water base of any form may be provided, and under each of the grate bars horizontal beams F may extend throughout the length of the producer, and serve not only to support the gratings, but also seal the space under the swivelling base-plate D, so as to exclude ingress of air there when blowers are employed. The producer may be constructed with passages M for the inflow of air or air and steam at the crown of the chamber, and with passages N for the outflow of gases near

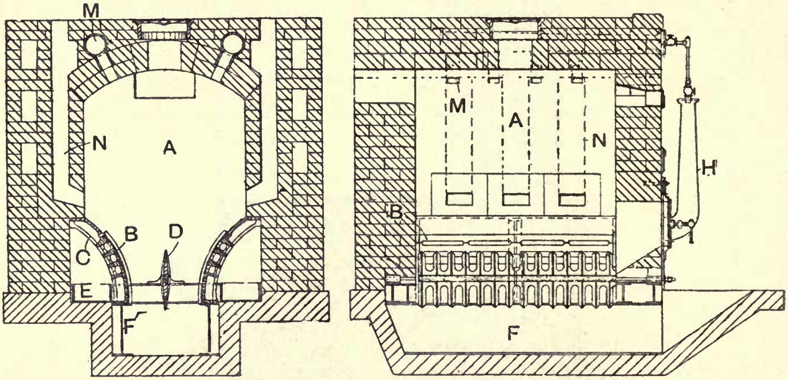


Fig. 25.—Hislop's Gas Producer.

the bottom during the period while the coal being gasified is yielding up its volatile matters. The outlet of the gases from the producer may also be reversed by the use of dampers or valves connected to these passages.

(26) **Rowe & Bickerton's Gas Producer.** Patent No. 9818 of 1903.—The object of this design, shown in Fig. 26, is to increase the efficiency and to discharge the producer gas free of tarry matter. The producer comprises a casing B lined with firebrick A. A pipe K passes downwards as far as the lower plate M, where it is bolted to another pipe N. The pipe K also carries at its upper end a short cylindrical extension O of greater diameter than the pipe K. Within this extension O, and on the flange H, rests the lower end of a pipe P surrounded with firebrick. This pipe P passes upwards about as far as the throat of the producer. A pipe Q extends downwards from the top plate C, and the lower end of Q is inserted into the upper end of P. A guard S is provided, as shown, to prevent coal from gaining access to the interior of the pipe P. The gases rising from the fuel pass

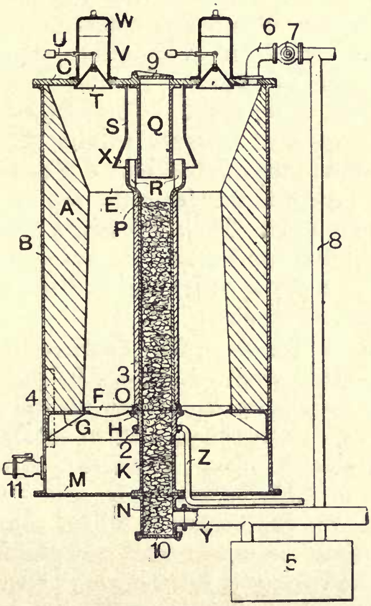


Fig. 26.—Rowe & Bickerton's Gas Producer.

into the annular space X between the guard S and the top of the pipe P, and thus gain access to the interior of the pipe P. This pipe is filled with coke which is kept in an incandescent state by the heat from the partially-burning fuel around the pipe P. The tarry matter is removed by the carbon from the gases, which pass away clean from the lower end of the pipe N by means of the pipe Y. If the gases entering the pipe P contain water vapour or carbon dioxide, the carbon in the retort will act upon these so as to produce hydrogen and carbon monoxide. Water enters the producer by a pipe Z, which discharges the water to a ring 2 arranged below the firebars. The water trickles from this ring down the pipe K, and the heat in this chamber is sufficient to vaporise the amount of water which it is desirable should enter the producer in the form of steam. The discharge pipe Y has a branch leading to a water seal 5. This acts as a safety valve to prevent any excessive pressure within the gas producer due to an explosion in the discharge pipe Y or its connections. A gas discharge pipe 6 is led from the top of the producer. 11 is the air supply pipe. The air is forced into the producer by a fan, blower, or steam jet, and the gas is sucked from the discharge pipe by a fan or pump, or by the engine using the gas during its suction stroke.

(27) **Marechal & Barriere's Gas Producer.** Patent No. 12477 of 1903.—This producer, shown in Fig. 27, has been designed for the manufacture of a poor gas in large quantities from all sorts of combustibles, and is constructed on the principle of the blast furnace. It consists of three principal parts: (1) The crucible or hearth in which the ashes and clinkers collect; (2) the boshes in which combustion takes place; (3) the shaft or stack which contains the charge of combustible and the exit for the gas. The lower part or crucible is composed of a brickwork foundation A A which supports the entire apparatus. On this foundation rests a plate B which serves as a support for the boshes. The chamber below the plate contains a U-shaped boiler D, which furnishes the steam necessary for the production of the gas. This steam is injected at the base of the column of the incandescent combustible, or fuel, through a series of small nozzles E. The boshes G are made of refractory bricks, in which is formed an annular chamber H, from which pass superposed rows of tuyeres I, which deliver heated air from a regenerator to the incandescent combustible. These tuyeres extend across

to the outer wall, and are closed by small clay plugs F; this arrangement has for its object to allow the combustible to be stoked from the sides. On the boshes is arranged the double truncated shaft K. This shaft has a double wall forming a water-jacket; its inner wall M is furnished with a series of ribs N, which serve to direct the gases towards the centre. The shaft is closed by a cover O having a peripheral

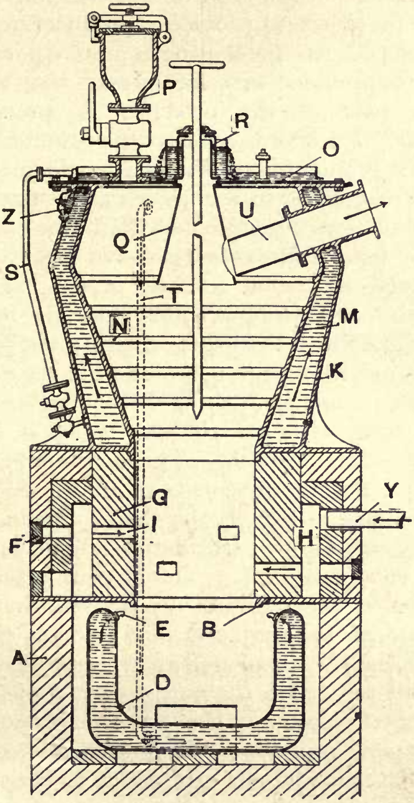


Fig. 27.—Maréchal & Barriere's Gas Producer.

flange and a number of openings suitable for charging devices P. At the centre of the cover is fixed a truncated bell Q projecting into the interior of the stack, and through which bell the gas is exhausted. Above this bell is an opening through the cover, which is kept closed by a lid R of glass or mica with waterseal, so that the working of the operations may be observed. The tank formed by the cover communicates through a pipe S with the lower part of the water-jacket of the shaft K, and the upper part of this latter communicates in its turn through a pipe T with the lower part of the boiler D in the crucible. The gases leave the producer through the pipe U.

(28) **Gas Producers.** Patent No. 12506 of 1903.—This invention, by La Société Française de Constructions Mécaniques, Paris, has for its object to provide a producer for use in the manufacture of poor gas, for heating or motive power purposes. The producer is provided with means such that the temperature in any part of the producer is prevented from exceeding 1,200° or 1,300° C., so that the fusion of the residue resulting in the production of clinker is avoided. This result is obtained by supplying to the lower part of the combustion chamber air diluted with gas mixed with the air in such proportion that (its temperature being taken into account) the gaseous products and solid residues of the combustion do not attain such temperature as would cause the production of clinker. The gas which is used for diluting the air in accordance with this invention is that produced in the gas producer, the proportion of such gas being greatly in excess of that which would form with the air with which it is mixed an entirely combustible mixture. The accompanying vertical sections show a few arrangements of the producer. In the arrangement shown in Fig. 28 the shaft is made narrower at its lower part A than above, this narrower part being followed by a gradual enlargement B. The mixture of air and gas is kept in motion by the action of a fan C drawing gases from the upper part of the producer and forcing them into a passage or passages, such as at D, which opens, or open, into a space immediately below the narrow part A of the producer shaft. Fig. 28A shows another arrangement of the lower part of the gas producer. The two arched spaces E. which cause the fuel and ash or residue to spread and form inclines, are diametrically opposite each other and above the openings for the introduction of the mixture of air and gas which enter by the passages D. In the arrangement shown in Fig. 28B the producer receives, from an external apparatus, the gaseous mixture required to maintain the combustion, and is provided with only one lower arched space G, leaving on each side thereof a passage for the descent of the fuel and ash or residue, the circulation of the mixture

of air and gas being effected by a compressed-air injector or injectors, F.

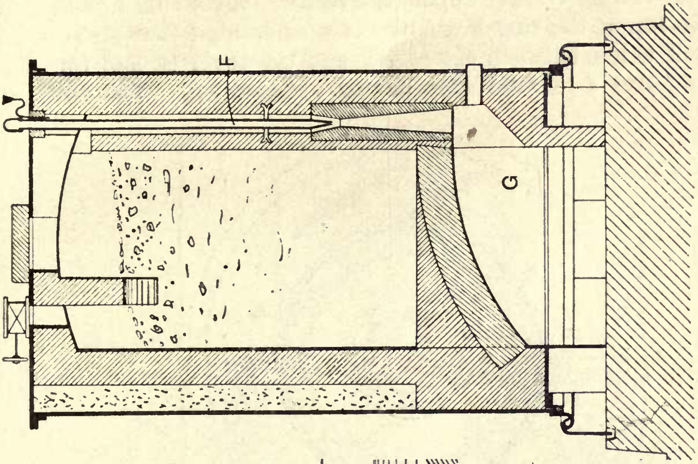


FIG. 28B.

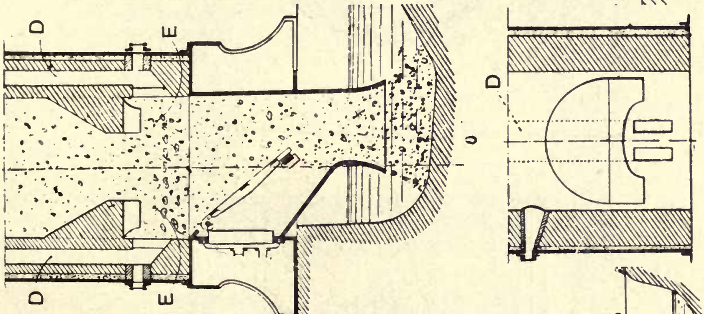


FIG. 28A.

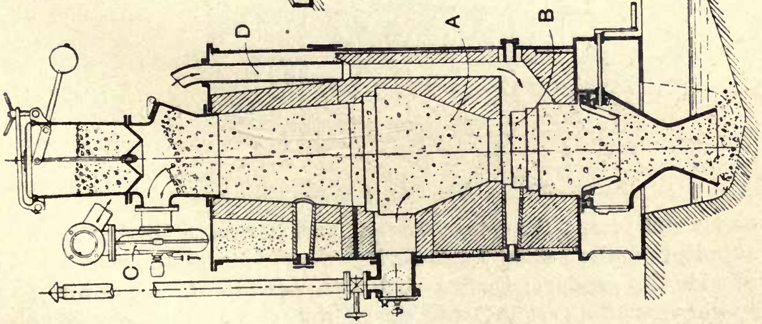


FIG. 28.

LA SOCIÉTÉ FRANCAISE IMPROVEMENTS IN GAS PRODUCERS.

(29) **Duff's Gas Producer.** Patent No. 16164 of 1903.—This invention relates to a method of distributing the air, or air and steam, to the fuel in gas producers. In the centre

of the trough B (Fig. 29) is built a casing C upon which is superposed a ring of vertical gratings D. On the top of this ring of gratings D there is placed a conical louvre ring F, and on the top of the ring F a cover G is so secured that an air space J is left between the ring F and the cover G, and the whole forms a louvred cone having a closed top. The air, or air and steam, for combustion or gasification of the fuel is supplied to the casing C through a duct K, communicating outside the producer shell A with a blower pipe L. The air passes from the casing C into the producer, both through the gratings D and the air space J. The duct K is provided with a door M, through which a rake can be inserted to clean out any residues which may become deposited in the casing C.

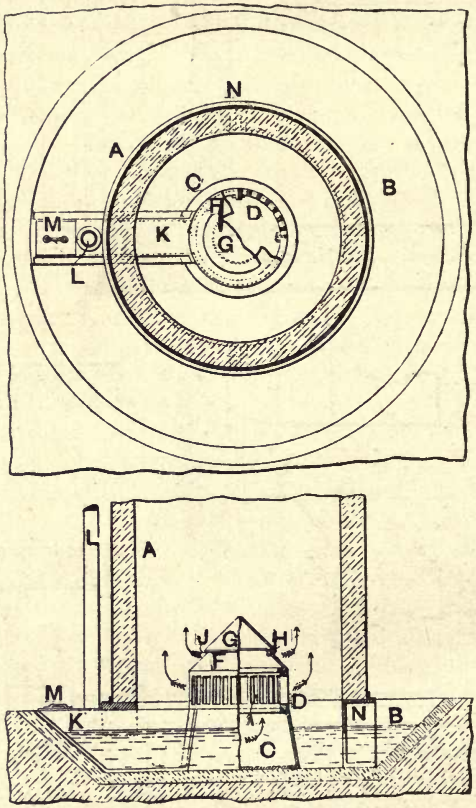


FIG. 29.—DUFF'S IMPROVEMENTS IN GAS PRODUCERS.

The streams of air, or air and steam, issuing from the two blowers at the same time act consecutively upon the fuel as the latter moves downwards, the upper conical blower delivering air to light up the fuel to incandescence, while the lower grating causes the air to act upon the fuel with a fine distribution.

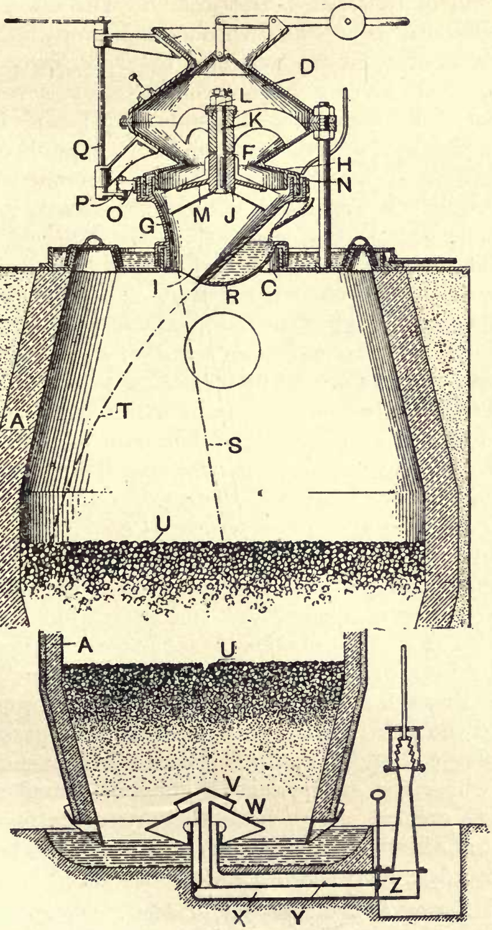


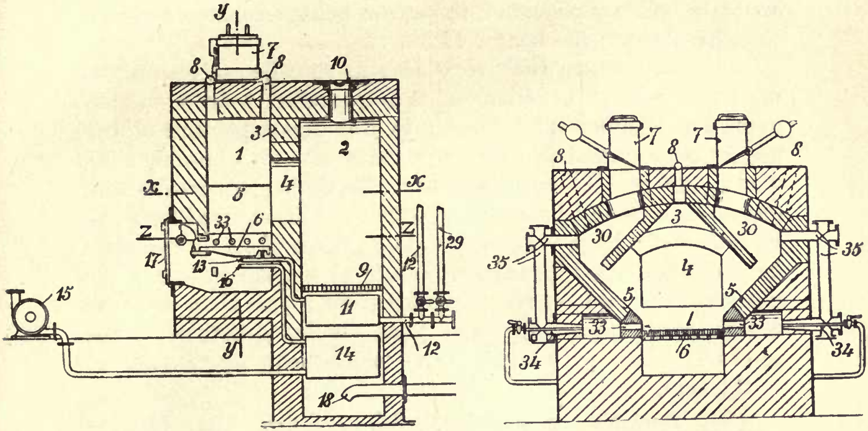
FIG. 30.—FEEDING MECHANISM AND AIR SUPPLY APPARATUS FOR PRODUCERS.

(30) **George's Gas Producer.** Patent No. 16263 of 1903.—This invention relates to the construction of fuel-feeding mechanism and air supply apparatus for gas producers. The

feeding mechanism is shown in Fig. 30, and has for its object to provide means for the uniform and even distribution of the coal to the heating chamber. It comprises a chamber D provided with an opening F, through which coal is delivered to a rotating coal distributor G. The chamber D is provided with a flange H extending over and covering the upper end of the coal distributor G. The lower end of the coal distributor is provided with a smaller opening I eccentric to its axis of rotation, whereby the side walls of the coal distributor are given a varying inclination to a vertical plane. The coal distributor G is suspended by means of a central hub J which is attached to a spindle K capable of turning in a bearing L supported concentrically in the chamber D. Projecting from the hub J is a disc M slightly inclined from a horizontal plane, and larger than the delivery opening F, with an annular space between the edge of the disc M and the inner walls of the coal distributor. The coal distributor is provided with ratchet teeth N, which are engaged by an actuating pawl O carried on an arm P of an oscillating shaft Q. The lower end of the coal distributor is provided with a dish-shaped flange R extending over and covering the opening C in the top of the heating chamber, and adapted to contain water by which the mouth of the coal distributor is cooled. The joints between the coal distributor and the top of the heating chamber and between the coal distributor and the coal magazine are water sealed to prevent the passage of gas. The proper distribution of air to the bottom of the heating chamber is accomplished by the apparatus shown in the lower view, Fig. 30, and consists of the conical hoods V and W, one placed above the other, with the upper hood V supplied with air through an air passage X, while the lower hood W is supplied with air through an independent air passage Y, with the passages X and Y controlled by a common sliding damper Z, by which the air passage Y may be closed and the air passage X opened, or vice versâ, thereby regulating the relative amount of air which passes upward through the bed of coal U over the edges of the two hoods V and W.

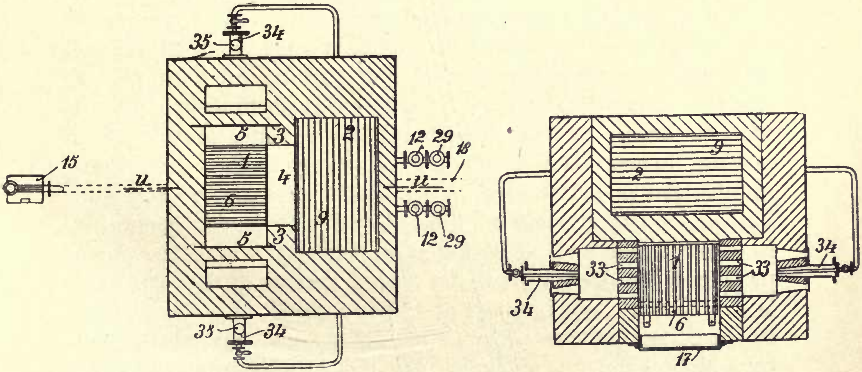
(31) **Hovine & Breuille's Gas Producer.** Patent No. 25763 of 1903.—This producer is shown in Fig. 31. It comprises two chambers, the gas generator 1 and the regulating chamber 2, separated by a partition 3, and in open communication with each other through opening 4. The sides 5 of the gas generator are inclined, and at a certain distance from the

bottom of the ashpit a grate 6 is fitted. At the top of the apparatus are arranged charging devices 7 and apertures 8 for poking the fuel. The chamber 2 is provided with a grate 9 to support the pieces of non-flaming fuel filling the chamber 2. A tight-closing plug 10 enables the charging to be effected whenever necessary. Below the grate 9 are arranged separate heating apparatus. One of them, 11, serves for superheating steam admitted through the pipe 12 and passing under the grate 6 through a pipe 13; and the other, 14, serves to heat the atmospheric air blown in by the fan 15. At the bottom of the regulating chamber, and below the heating apparatus,



Sectional Elevation.

Section on line YY of Fig. 1.



Sectional Plan.

Section on line ZZ of Fig. 1.

FIG. 31.—HOVINE & BREUILLE'S GAS PRODUCER.

is the end of a pipe 18 connected to a fan which continuously exhausts the gas generated and discharges it through a pipe into the holder. Steam required for the generation of gas is supplied during normal working by the exhaust from the engine, through the pipe 12, which discharges it into the heater 11. To provide the required quantity of steam at starting a separate boiler is provided, the steam being admitted through the pipe 29 into the heater 11.

In cases where fuel very rich in volatile substances is used the regulating chamber 2 is provided with a supplementary chamber 30 arranged in the upper portion of the gas generator near the inlet for the fuel. This chamber 30, where the fuel is subjected to a beginning of distillation, enables gaseous hydrocarbons, which are disengaged by it, to be collected ; they are exhausted by means of steam injectors 34, and discharged through orifices 33 above the grate 6 of the gas generator among the incandescent fuel, so that they are decomposed, heat and fixed gases being generated. The conduits 35 withdraw the preliminary products of distillation.

(32) **Dunlop's Self-contained Self-regulating Gas Plant.**—This plant, shown in Fig. 32, is intended to produce from bituminous slack a gas suitable for use in gas engines without the necessity of any attention further than that of filling the generator completely with fuel and turning on a supply of water. It consists of a metal shell with an inner shell lined with firebrick. At the lower end is a rocking grate with a poking finger. The shells are so arranged that free communication is established at all times between the top and bottom of the generator. Placed centrally in the generator is a water-jacketed collecting pipe, through which the gases produced are drawn off to be cooled and washed. The fuel is supplied by two hoppers at the top, and the water supply to the collecting pipe jacket is regulated by a cock, and sealed by a siphon pipe, as shown. The collecting pipe jacket is in free communication with the top of the generator, the upper end of the collecting pipe being closed by a lid, through which the condition of the fire may be observed, or through which the fire may be started by a piece of cotton waste soaked in petroleum. This lid is kept off during such time as the generator is being got into working order. From the collecting pipe the gases pass to a tubular heat interchanger, shown at the side of the generator, the gases passing downwards, inside

the tubes, which are in two lengths telescoping each other. The water overflowing from the collecting pipe jacket passes by a siphon seal to the top of the heat interchanger, and, flowing over the upper ends of the tubes, descends in a film inside the tubes along with the gases. At the same time a regulated quantity of steam is mixed with the gases as they leave the collecting pipe, the pinching screw and locknut shown at the top of the collecting pipe hood forming a readily adjustable means of insuring this result. The film of water

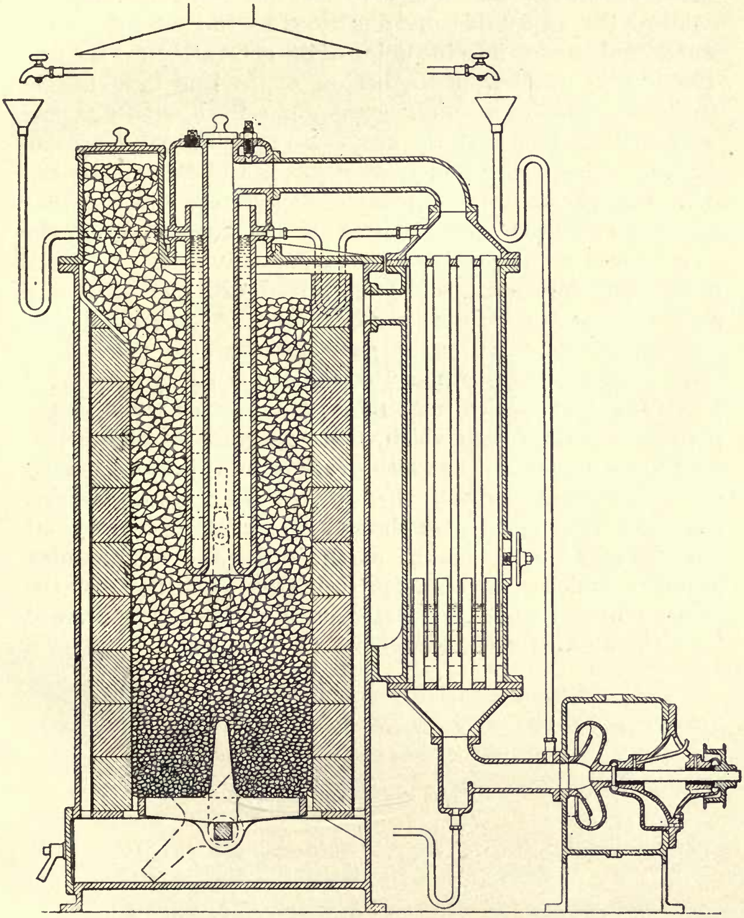


FIG. 32.—DUNLOP'S SELF-CONTAINED SELF-REGULATING GAS PLANT.

descending the tubes of the heat interchanger is trapped between the tubes at the bottom, and so maintains a constant level of water in the heat interchanger, and at the same time effectively seals the tubes, so that they are free to expand or contract without escape of gas. Around the outside of the tubes passes the air supply to the gas generator, the air entering the adjustable opening close to the surface of the water, and passing into the lining of the generator near the top. The surplus water from the bottom of the heat interchanger passes away through a siphon seal, and a fresh supply of cold water enters along with the gases into a centrifugal cooler and washer. This cooler and washer consists of an exhaust fan driven by the engine at a moderate speed sufficient to relieve the engine of the work of drawing the gases through the generator, &c. The construction is specially designed for the purpose of condensing the steam mixed with the gases, and for removing any tarry vapours or other condensible hydrocarbons that may have passed over along with the gases. For these purposes the periphery of the fan is surrounded by a U-shaped ring, which maintains a water seal around the periphery, and through which all the gases must pass on their way to the engine. The water overflowing this seal is spread out in a sheet around the ring, so that after passing the seal the gases must again pass through water before leaving the fan chamber by the branch at the top. The fan chamber provides sufficient storage for supplying each cycle of the engine's operations. The water passing the fan is drained from the bottom of the chamber by a siphon seal.

APPENDIX III.

BIBLIOGRAPHY.

THE descriptions of the various forms of gas producers are scattered through the various engineering journals and the records of the Patent Office, and a list of such, whilst it would be very long, would be of little interest or use ; and no reference is made therefore to papers which are merely a description of some new form of gas producer.

The papers mentioned below deal with the principles and problems of gas production and the use of gaseous fuel, and most of them are well worth study. In some cases, where the author has not had access to the papers themselves, reference is given to a published abstract, and only papers printed in English, and which are likely to be fairly accurate, are given. Abstracts of most of the foreign papers appear in the Journal of the Iron and Steel Institute and in the Journal of the Society of Chemical Industry.

The papers are arranged, as far as possible, chronologically, so that they will give an idea of the development of the use of fuel gas.

No attempt has been made to prepare a complete bibliography of the subject, but only to give references to such papers as are likely to be of use. Those of special importance are marked with an asterisk.

Books dealing with the subject of Fuel, and incidentally with Gaseous Fuel :—

METALLURGY. By John Percy, M.D., F.R.S. Vol. I. Introductory; refractory materials and fuel. London : Murray. 2nd edition, 1875.

At the time this volume was published gaseous fuel was only just coming into use, so that but little space is given to it. Ekmans and Siemens producers and furnaces are described.

GASEOUS FUEL : INCLUDING WATER GAS. By B. H. Thwaite, F.C.S. London : Whittaker & Co., 1888.

Contains information relating to the production and application of gaseous fuel.

FUEL AND ITS APPLICATIONS. By E. J. Mills, D.Sc., and F. J. Rowan, C.E. London : Churchill, 1889.

Contains all the information available up to the date of publication.

FUEL AND REFRACTORY MATERIALS. By A. Humboldt Sexton, F.I.C., F.C.S. London : Blackie & Sons, 1897.

A handy book dealing with the whole subject. Most modern books on the metallurgy of steel and on gas engines contain sections on gas production.

ABBREVIATIONS USED.

J. = Journal of the Iron and Steel Institute.
W. = Journal of the West of Scotland Iron and Steel Institute.
C.E. = Minutes of Proceedings of the Institution of Civil Engineers.
M.E. = Minutes of Proceedings of the Institution of Mechanical Engineers.
A. = American Institution of Mining Engineers.
C.I. = Journal of the Society of Chemical Industry.

Papers dealing with the subject of Fuel, and incidentally with Gaseous Fuel:—

A New Construction of Furnace Specially Applicable where Intense Heat is Required. By W. Siemens. M.E., 1857, 103. Collected Works, Vol. I., 62.

On a Regenerative Furnace Applied to Glasshouses, Puddling, Heating, &c. By W. Siemens. M.E., 1862, 21 and 40. Collected Works, Vol. I., p. 81.

On a Steam Jet for Exhausting Air, &c., and Some Results of its Application. By. W. Siemens. M.E , 1872, p. 97. Collected Works, Vol. I., p. 141.

On the Use of Coal Gas as a Fuel. C.I., 1881, p. 39. Collected Works, Vol. I., p. 177.

On the Regenerative Gas Furnace as Applied to the Manufacture of Cast Steel. By W. Siemens. Journal of the Chemical Society, 1868, p. 279. Collected Works, Vol. I., p. 209.

Gas Producers. By F. J. Rowan. C.E., LXXXIV., p. 3.

On the Most Recent Results Obtained in the Application and Utilisation of Gaseous Fuel. By W. S. Sutherland. J., 1884, Vol. I., p. 72.

On a Modified Form of the Siemens Producer. By John Head. J., 1885, Vol. I., p. 126.

Water Gas for Metallurgical Purposes. By A. Wilson. J., 1888, Vol. I., p. 86.

Gaseous Fuel. By Sir Lowthian Bell. J., 1889, Vol. II., p. 139.

A New Form of Siemens Furnace. By J. Head and M. P. Pouff. J., 1889, Vol. II., p. 256.

Water Gas in the United States. By A. C. Humphreys. J. (abs.), 1889, Vol. II., p. 360.

Mond Gas. (Address of President at Annual Meeting of the Soc.C.I.) By L. Mond. C.I., 1889 (VIII.), p. 503.

Fuel Gas. By G. W. Goetz. A., Vol. XVIII.; J. (abs.), 1890, Vol. I., p. 243.

FUEL GAS AND SOME OF ITS APPLICATIONS. By Burdett Loomis. J., 1890, Vol. II., p. 275.

PHYSICAL AND CHEMICAL EQUATIONS OF THE OPEN-HEARTH PROCESS. By H. H. Campbell. A., XIX. (1889), p. 128.

GAS FURNACES. By B. Dawson. M.E., 1891, p. 47.

GAS PRODUCERS. By R. Booth. Society of Civil and Mechanical Engineers, 1891. J. (abs.), 1892, Vol. I., p. 342.

FUEL GAS. By A. Kitson. Journal of the Franklin Institute. Vol. CXXXII., p. 424. J. (abs.), 1892, Vol. II., p. 387.

GASEOUS FUEL. By G. Ritchie. W., Vol. I., p. 117.

RECOVERY OF BY-PRODUCTS FROM PRODUCER GAS. By A. Gillespie. W.

MOND PRODUCER GAS APPLIED TO THE MANUFACTURE OF STEEL. By J. H. Darby. J., 1896, Vol. I., p. 144.

THE EFFICIENCIES OF GAS PRODUCERS. By C. J. Jenkin, B.A., C.E. (1895–96), CXXIII., p. 328.

THE MOND GAS PRODUCER PLANT AND ITS APPLICATION. By H. A. Humphrey. C.E., CXXIX. (1897), p. 190.

THE WEARDALE FURNACE. By H. W. Hollis. J., 1897, Vol. I., p. 56.

COMPARISON OF GAS PRODUCERS. By F. L. Slocum. C.I., Vol. XVI. (1897), p. 420.

ON THE USE OF BLAST-FURNACE GAS FOR A MOTIVE POWER. By A. Greiner. J., 1898–1, p. 21.

FUEL FOR GAS PRODUCERS. By C. W. Bildt. A., 1898; J. (abs.), 1898, Vol. I., p. 401.

THE USE OF BLAST-FURNACE AND COKE-OVEN GASES. By E. Disdier. J., 1899, Vol. I., p. 143.

THE MANUFACTURE AND APPLICATION OF WATER GAS. C. Dellwik. J., 1900, Vol. I., p. 119.

POWER GAS AND LARGE GAS ENGINES FOR CENTRAL STATIONS. By H. A. Humphrey. M.E., 1901, p. 41.

WATER GAS. President's Address to the Eighteenth Annual Meeting of the Society of Chemical Industry, 1899. C.I., Vol. XVIII., p. 642.

GAS PRODUCERS. By A. Wilson. W., Vol. VIII. (1901), p. 135.

DUFF PRODUCERS AND AMMONIA RECOVERY. By F. J. Rowan. *Iron and Coal Trades' Review*, Vol. LXII., p. 68.

PRODUCER GAS AND ITS APPLICATIONS. By F. J. Rowan. A series of articles in the *Iron and Coal Trades' Review*, 1901, reprinted in pamphlet form.

WATER GAS. By G. Lunge. Mineral Industry, Vol. IX., p. 148. J. (abs.), 1901, Vol. II., p. 395.

GASES FROM WOOD FOR THE MANUFACTURE OF STEEL. By J. Douglas. J., 1902, Vol. I., p. 287.

GAS PRODUCERS. By J. E. Dowson. Journal, Franklin Institute Vol. CLII., p. 275. J. (abs.), 1902, Vol. I., p. 484.

PRESIDENTIAL ADDRESS TO THE INSTITUTE OF ENGINEERS AND SHIPBUILDERS, SCOTLAND. By W. Foulis. 1901.

USE OF PRODUCER GAS. By F. J. Rowan. Institution of Engineers and Shipbuilders. 1902.

INDEX.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

STEVENSONS,

PRESTON.

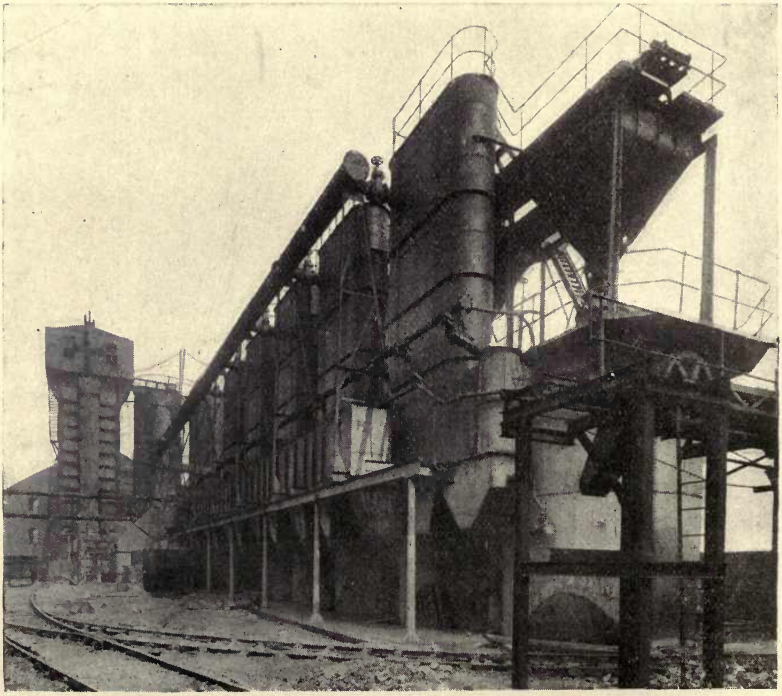
GAS PRODUCING PLANTS

. . WITH . .

AMMONIA RECOVERY

(DUFF'S PATENTS).

ARMSTRONG, WHITWORTH, MANCHESTER ..	**40,000 H.P.**
W. BEARDMORE & CO., GLASGOW	**20,000 H.P.**
,, ,, ,, DALMUIR	**10,000 H.P.**
UNITED ALKALI CO., FLEETWOOD	**10,000 H.P.**



The

"DAWSON" PATENT GAS PRODUCER

Manufactured by

STEVENSONS, LIMITED,

PRESTON.

For Prices and Particulars apply to

ROBERT BOOTH,

Successor to Bernard Dawson,

110, CANNON STREET,

LONDON, E.C.

50/-

THE WATCH FOR ENGINEERS.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

In Black Oxydised Case.

Non-Magnetic.
Chronograph Action.
Flyback Instantaneous.
Super Finished.
Full Jewelled.
Improved Regulator.
Sound Timekeeper.

The Scientific Publishing Co., 53, New Bailey Street,
Manchester, England.

THE "MECHANICAL ENGINEER"

Pocket Calculator.

Invaluable to ENGINEERS,
DRAUGHTSMEN, STUDENTS,
And all who have
Calculations to make.

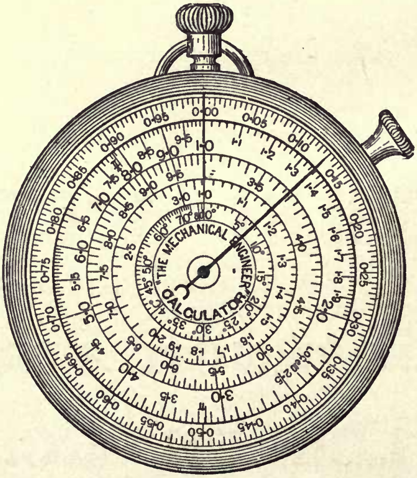
PRICE:

*In Handsome
Nickel Cases,
With Full
Instructions,
Same Size as
Illustration,*

7/9 Post Free, United Kingdom.
9/- Post Free, anywhere abroad.

*Large Size
(2½in. dial),*

12/9 Post Free, United Kingd'm
15/- Post Free, anywhere abroad.



*An Accurate and
Reliable
Instrument.*

*It is only
necessary to turn
two nuts, the
instrument does
the rest.*

*Saves no end
of
time and worry.*

The Scientific Publishing Co., 53, New Bailey Street,
Manchester, England.

THE HORSEHAY Co., LTD.,

HORSEHAY, R.S.O.,
SHROPSHIRE,

Sole Makers of the **WILSON** *Patent Gas Plant,*
For Power and Heating Purposes.

Plants of 100 B.H.P. and upwards at work in this country and abroad, making gas free from tar, from common bituminous slack, for driving gas engines.

Prices, Specifications, and guarantees will be promptly furnished upon receipt of enquiries.

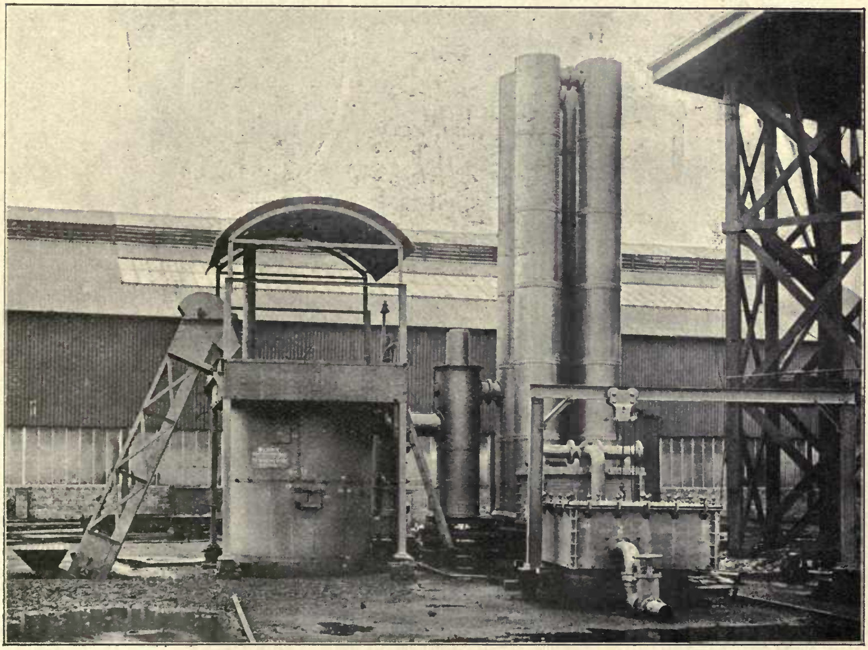


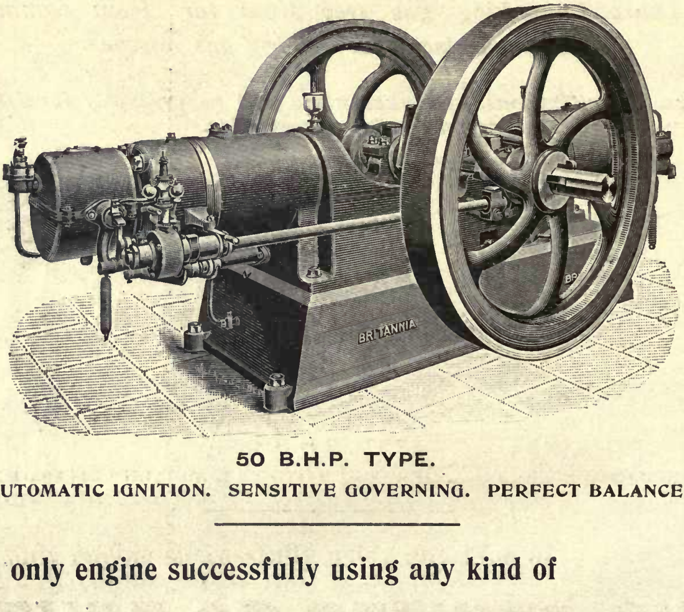
Illustration shewing a Wilson Patent Bituminous Power Gas Plant, made by the Horsehay Co., Ltd., and supplied to Messrs. Matheson & Co., for the Rio Tinto Co., Ltd., Spain. Engineers, Messrs. Duff, Bruce, & Co., Westminster, S.W,

"BRITANNIA"

SAFETY AUTOMATIC

OIL ENGINE

$\frac{1}{4}$d. per B.H.P. per hour.



50 B.H.P. TYPE.

AUTOMATIC IGNITION. SENSITIVE GOVERNING. PERFECT BALANCE.

The only engine successfully using any kind of

CRUDE OR REFINED OIL

without alteration or constant cleaning.

THE

BRITANNIA ENGINEERING CO., Ltd.

Britannia Works, COLCHESTER, Eng.

GAS PLANTS

Duff & Whitfield Patents.

2,500

GENERATORS

IN DAILY USE

FOR HEAT OR POWER.

FURNACE WORK A SPECIALITY.

W. F. MASON, Ltd.,

ALMA WORKS,

LEVENSHULME, MANCHESTER.

The Metallurgy of Iron and Steel.

By . . .

A. HUMBOLDT SEXTON,

Professor of Metallurgy in the Glasgow and West of Scotland Technical College, Past President West of Scotland Iron and Steel Institute.

COMPRISES OVER

600 Pages of Text and 200 Illustrations,

and has been prepared to meet the want for a book which, in one volume of moderate size, shall cover the whole field of the metallurgy of iron and steel.

CONTENTS.

Introductory—Sources of Iron—Pig Iron—Preparation of Materials for the Smelter—Chemistry of the Blast Furnace—Thermal Phenomena of the Blast Furnace—The Blast Furnace—The Air Supply—The Hot Blast—Blast Furnace Slag—Calculating Charges—Construction of the Blast Furnace—Blast-furnace Practice—Utilisation of By-products—History of Pig Iron—The Foundry—Malleable Iron—Puddling—Other Methods of Preparing Malleable Iron—The Forge and the Mill—Steel—Production of Steel Direct from the Ore and from Malleable Iron — Production of Steel by Partial Decarburisation of Pig Iron—The Bessemer Process—Chemistry of the Bessemer Process—Thermal Phenomena of the Bessemer Blow—Working the Bessemer Process—Bessemer Plant—The Basic Bessemer Process—Plant for the Basic Bessemer Process—Modifications of the Bessemer Process—Historical Notes on the Bessemer Process—The Siemens or Open-hearth Process—The Siemens Process Plant — The Basic Open-hearth Process—Modification of the Open-hearth Process—Appliances Applicable to all Processes—Working Mild Steel—Casting Mild Steel—After Treatment of Iron and Steel—Special Steels—Structure of Iron and Steel—Testing Iron and Steel—Rusting and Protection of Iron and Steel.

Price - 16/6 post free.

The Scientific Publishing Co.,

53, New Bailey Street, MANCHESTER, England

The Power-Gas Corporation, Ltd.,

39, VICTORIA STREET, LONDON, S.W.,
and STOCKTON-ON-TEES.

Producer-Gas Specialists, and Manufacturers of

PRODUCER-GAS PLANT
FOR
POWER and HEATING
WITH OR WITHOUT AMMONIA RECOVERY.

UNDER

MOND,
DUFF and
TALBOT

PATENTS.

Economy in Fuel!

CROSSLEY'S
GAS
PLANTS

Work with Common Bituminous Slack,
Anthracite Coal, or Coke.

FOR GAS ENGINES, OR
FOR HEATING PURPOSES.

Prices, References, and Full Particulars on Application to

CROSSLEY BROS., LTD.,
Openshaw, Manchester.

THWAITE
POWER AND FUEL GAS GENERATORS.

The Thwaite Gas Generators pioneered the use of gas generated from bituminous coal for driving Gas Engines.

The Gas Production is effected by the only cycle of operations that will secure the fixation of the volatile hydrocarbons.

THE THWAITE GAS GENERATORS will produce Power Gas from **ANY KIND OF COMBUSTIBLE SOLID FUEL.**

The Gas is of the greatest possible chemical uniformity. There is no necessity for the use of steam.

The Thwaite Cupola Fluid Slag Type of Generator provides gas identical with that produced by Blast Furnaces.

Suction Plant for using either fixed Carbon or hydrocarbonaceous fuel.

Plant for utilising Coke Oven Gas for power purposes, to secure the most economic results.

THE
Thwaite Power Gas Syndicate,

. . . 29, Great George Street, . . .
WESTMINSTER, LONDON, S.W.

Telephone No.:	Codes:	Telegrams:
708 WESTMINSTER.	A.B.C., and McNEIL'S.	"CALCINATOR," LONDON.

BOOKS FOR ENGINEERS.

Fowler's Mechanical Engineer's Pocket Book

A thoroughly reliable and up-to-date work for Mechanical Engineers, Foremen, Draughtsmen, Students, &c. Universally acknowledged to be the best Pocket Book. **Price 1/9, post free.**

Fowler's Electrical Engineer's Year Book.

Specially compiled for Electrical Engineers. Comprises 600 pages of Rules, Tables, and Data dealing exclusively with electrical matters. **Price 1/9, post free.**

Testing of Engines, Boilers, and Auxiliary Machinery.

A treatise on the methods and instruments used in testing and experimenting with engines, boilers, and auxiliary machinery.
By W. W. F. PULLEN, Wh.Sc., Assoc.M.Inst.C.E., &c. ***Price 15/6, post free.***

Metallurgy of Iron and Steel.

This Work has been prepared to meet the need for a book which, in one volume of moderate size, shall cover the whole field of the Metallurgy of Iron and Steel.
By Prof. A. HUMBOLDT SEXTON, F.I.C., F.C.S. ***Price 16/6, post free.***

Testing and Strength of Materials of Construction.

A treatise on the methods, machines, and instruments used in the testing of materials of construction.
By W. C. POPPLEWELL, M.Sc., Assoc.M.Inst.C.E. ***Price 10/10, post free.***

Commercial Management of Engineering Works.

A comprehensive work dealing with the best methods of conducting the commercial side of an engineering establishment.
By FRANCIS G. BURTON. ***Price 12/10, post free.***

Indicator Diagrams.

A treatise on the use of the indicator and its application to the steam engine.
By W. W. F. PULLEN, Wh.Sc., Assoc.M.Inst.C.E., &c. ***Price 6/4, post free.***

Tables and Data.

For the use of Engineering Students. Gives a large number of tables frequently required by students in the laboratory in convenient form.
By W. W. F. PULLEN, Wh.Sc., Assoc.M.Inst.C.E., &c. ***Price 4/3, post free.***

The Combustion of Fuel.

With special reference to smoke prevention. Contains numerous illustrations of mechanical stokers, forced draught furnaces, and refuse destructors.
By W. W. F. PULLEN, Wh.Sc., Assoc.M.Inst.C.E., &c. ***Price 3/8, post free.***

The Construction of Foundry Patterns.

An elementary manual for Engineering Students and Apprentices.
By HERBERT AUGHTIE, A.M.I.Mech.E. ***Price 5/4, post free.***

The Slide Rule and Watch Calculator.

A work dealing with the capacity and method of using the slide rule or its later development, the pocket or watch form of calculator. ***Price 1/1, post free.***

Steam Engineering.

A treatise on boilers, steam, gas, and oil engines, and supplementary machinery, with instructions for carrying out numerous simple experiments.
By W. W. F. PULLEN, Wh.Sc., Assoc.M.Inst.C.E., &c. ***Price 4/5, post free.***

Lathes, Screw Machines, Boring and Turning Mills.

A practical treatise on the design and construction of turning machines, including lathes, automatic screw machines, boring and turning mills and their accessories.
By THOMAS R. SHAW. ***Price 15/6, post free.***

Modern Locomotive Practice.

A treatise on the design of steam locomotives.
By C. E. WOLFF, B.Sc., A.M.Inst.C.E. ***Price 10/10, post free.***

Compressed Air.

A treatise on the theory and practice of pneumatic power transmission.
By WILLIAM C. POPPLEWELL, M.Sc., A.M.Inst.C.E. ***Price 7/10, post free.***

Practical Testing of Dynamos and Motors.

A treatise on the methods and instruments used in the testing of continuous current dynamo machinery. By CHARLES F. SMITH, Wh.Sc., A.M.Inst.C.E, A.M.I.E.E. ***Price 5/4, post free.***

THE SCIENTIFIC PUBLISHING CO., **58, New Bailey Street,**
MANCHESTER, England.

THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW

AN INITIAL FINE OF 25 CENTS

WILL BE ASSESSED FOR FAILURE TO RETURN THIS BOOK ON THE DATE DUE. THE PENALTY WILL INCREASE TO 50 CENTS ON THE FOURTH DAY AND TO $1.00 ON THE SEVENTH DAY OVERDUE.

JUN 4 1941

LD 21-100m-7,'40 (6936s)

d-so net

Sexton

141384