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“The Efficient Working of Gas Plants for Engines.”

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THE rapidly extending use of gas power has opened a wide and comparatively new field of investigation. The thermodynamic problems connected with the gas-engine alone are extremely interesting, and although they are complicated and difficult they are in gradual course of solution by some of the best experimenters in this and other countries. Less attention has been given to the plant which supplies the engines with gas, and in this Paper the Author proposes to deal with some of the theoretical and practical considerations on which its satisfactory working depends, as well as with the heat efficiency of some gas plants in use for engine work.

In general, the gas plant is to the gas-engine what the boiler is to the steam-engine, and it is at least as important to consider the efficiency of the gas plant as that of the boiler. It may even be more important to consider the former than the latter, since the gas produced is almost of necessity subject to greater variation in the qualities which give it driving-power than is the case with steam. The object of the gas plant is to transform solid fuel into gas suitable for working an engine, but it must not be supposed that this transformation can be effected without the loss of some of the heat energy in the solid fuel; it is necessary to pay toll on the way, in the process of making the gas. To determine the heat efficiency of the plant, account must be taken of all the fuel consumed in the apparatus used for making the gas, and the percentage of the total heat energy of the fuel consumed which is available in the gas finally passed into the holder should be calculated. Some writers have been content to give a chemical analysis of the gas, or its calorific power determined by a calorimeter, without ascertaining the calorific power of the fuel from which it was made; others have given the calorific power of the gas without stating the temperature and pressure on which the calculations of

heat value were based; again, it has been thought sufficient to determine the efficiency of the "producer" alone, even in plants which require an expenditure of fuel in a boiler as well as in the producer; while some writers have neglected to give the volume of gas produced per unit of fuel consumed. The Author considers it important that all experimenters should adopt one and the same basis of comparison, and he submits that the only true basis is a balance-sheet of the heat units, such as is now usually adopted in considering the heat efficiency of a gas- or steam-engine.

From the practical point of view, the plant should be compact and easy to work, it should produce gas as quickly as it can be consumed, its first cost should not be excessive, and it should not involve a serious charge for repairs. Apart from these considerations, it is all-important that the gas produced should be suitable in quality, not merely for an hour, but for several hours consecutively, and for this the best working conditions for each type of plant must be known, and it must be ascertained how far they can be maintained. Further than this it must be known what kind of fuel can be used in each plant, so as to yield a gas sufficiently strong and sufficiently clean for engine work. In producers used for furnace work, *i.e.*, where the gas is taken direct from the producer to the combustion chamber of the furnace, the gas is usually made with bituminous or semi-bituminous coal, and the tarry vapours distilled off in the producer mix with the gas and enrich it, and all are burnt in the furnace. For engine work it is essential not to have condensable tarry vapours with the gas; otherwise the valves will be clogged and other troubles will ensue. For this reason nearly all the producer-gas now used for engine work is made from anthracite or coke; there is a notable exception which will be dealt with later. It is unfortunate that these heat-giving hydrocarbon vapours cannot be used in engines, as gas mixed with them usually has a higher calorific power than gas made from anthracite or coke. If, however, the object be to consider what kind of producer-gas is suitable for engine work, or to compare the gas made in different engine-plants, it is necessary to consider not only its heating or explosive power, but also its freedom from tar and other impurities.

Another important point to be considered is how far the maximum production of a producer can be reduced, without injuriously affecting the quality of the gas. This is too often lost sight of, and the following instance is instructive. At the power-station of the waterworks at Bâle, exhaustive trials of Otto engines driven with generator-gas were made by Professor E. Meyer of

the Technical High School in Hanover.¹ The gas was made from ordinary gas-coke, and the first trial was with one generator serving an engine developing about 100 brake-HP. From a calculation based on the results he obtained, Professor Meyer concluded that only 54 per cent. of the steam sent into the generator was decomposed, and that 46 per cent. was wasted, although he believed that the quantity of steam used was normal. From this he concluded that the currents of steam and air passed through the fuel too quickly, and were not long enough in contact. He therefore made another trial with two 100-HP. generators working together, but each working slowly so as to produce gas for about 50 HP. only. In this way the currents of steam and air traversed the fuel more slowly than in the first trial, and he hoped to decompose a larger percentage of steam and obtain better gas. This hope was not realized, the calorific power of the gas obtained being lower in the second trial than in the first, while the consumption of fuel and steam was considerably greater. In the case of a single generator the average of five determinations gave 1,196 calories per cubic metre by calorimeter,² and 1,203 calories per cubic metre by gas analysis, whereas with two generators working at half-power the average was 1,163 calories per cubic metre by calorimeter and 1,082 calories per cubic metre by analysis. It is also noteworthy that in the first case the gas left the generator at a temperature of 650° C., and in the second case at 530° C. Professor Meyer thought this proved that the speed with which the steam and air passed through the fuel in the trial with a single generator was not too high, and he came to the general conclusion that it is better to use one generator alone rather than to work two together for a given production of gas.

To work a generator of moderate size with coke, at half-power continuously, would necessarily be attended with certain drawbacks. The fire in each generator would be at a lower temperature, while the radiating surfaces of two generators would be double those of one. In the trials referred to, the quantity of steam admitted to each generator does not appear to have been well proportioned, but exact details are not given. The boiler-pressure seems to have been about the same in both trials, but it is not stated whether or not the nozzles of the steam-jets were reduced

¹ "Zeitschrift des Vereines deutscher Ingenieure," vol. xl. 1896. "Moteurs à Gaz," vol. iii., Professor Witz.

² To express calories per cubic metre in B.T.U. per cubic foot, multiply by 0.1124.

in the second trials. It is known, however, that the steam consumed with two generators was 65.4 kilograms per hour, against 52.8 kilograms with one generator, although it was believed that the quantity allowed for the latter was excessive.

As was to be expected, the trials showed clearly that under the conditions of working adopted, one generator at full-power gave better results than two generators at half-power; but Professor Meyer's final conclusion that one generator is better than two for a given production cannot be accepted as correct. For instance, if he had compared one generator of 100 brake-HP. with two smaller generators of 50 brake-HP. each, he would doubtless have obtained different results. All the generators would then have worked to something like their maximum production, and if they had been worked properly in other respects they would in all probability have made gas of equal quality. The fact of two or more generators being worked together does not in the least affect the quality of the gas, provided the plant is suitably arranged, and the Author has designed many plants which are working satisfactorily with two or more generators. At the cocoa factory of Messrs. Van Houten and Sons, near Amsterdam, there are eight generators all working together and feeding one gas-holder through one connecting-main. At Messrs. Crossley's works there are two generators of about 300 HP. each, which have worked together for years, and the calorific power of the gas made varies very little, the average in a day's run being as high as 1,552 calories per cubic metre at standard temperature and pressure.¹ There is, in fact, no more difficulty in working two or more generators together than in working a bench of coal-gas retorts. The simple explanation of Professor Meyer's non-success would appear to be that in the first trial the fire was not dense enough or deep enough for the quantity of steam used, and that in the second trial the generators were worked at half-power, when less heat would be developed and less steam would be decomposed.

With an anthracite fire in the generator, the maximum production of gas in small generators can be reduced 30 per cent., and in large generators it can be reduced 30 per cent. to 50 per cent. without altering appreciably the quality of the gas; but experience has shown that with a coke fire, which is less dense than anthracite, it is not well to reduce the maximum production by more than one-third. The depth of the fire depends a good deal on the size of the generator and on the nature and size of the fuel. Formerly the Author used, almost exclusively, anthracite nuts or

¹ 0° C. and 760 mm.

cobbles, in pieces about $1\frac{1}{2}$ inch to 3 inches cube, and with this the fire was 3 feet to 6 feet in depth, according to the size of the generator. More recently he has used anthracite peas, which pass through $\frac{3}{4}$ -inch and over $\frac{3}{8}$ -inch or $\frac{3}{16}$ -inch screens, and these are usually 5s. to 6s. a ton cheaper than nuts. With peas the fire is 2 feet 6 inches to 4 feet deep, according to the size of the generator. When coke is used, the Author prefers to have it in pieces about $\frac{3}{4}$ inch cube, and the depth of the fire should be 3 feet to 6 feet or 7 feet, according to the size of the generator. When anthracite or coke is used, the removal of clinker is troublesome in all generators, especially if a high steam-pressure is used. When the plant is worked in the day-time only, the Author's practice is to rake the fire and remove the clinker once a day, usually the first thing in the morning, before gas is made. When it is necessary to keep the plant working continuously night and day, as in a flour mill for instance, the fire is raked through suitable stoking-holes in the doors of the generator, and the clinker is drawn out once a week. In some other types of plant the clinker is allowed to accumulate for 24 hours or 36 hours, when the working of the generator is stopped for 3 hours or more to remove the clinker and make up the fire. In a few plants, various modifications of rotary grates are used, but they are not entirely satisfactory. They discharge the clinker which is on the grate itself, but they do not thoroughly remove the clinker which adheres to the brick lining of the generator; they also cause a good deal of small anthracite to fall down with the ash and clinker into the bottom of the generator. Another type of rotary grate will be referred to later. When bituminous coal of fair quality is used there is not so much clinker as with anthracite, and various kinds of grate will serve; but at present a large Mond plant is the single good instance of a plant yielding gas clean enough for engine work when bituminous coal is used. With the smaller Mond plants, the tar difficulty has not yet been got over.

In small generators it is desirable that fuel should be put into the generator in small quantities and at tolerably frequent intervals; but in large ones it is sufficient to put in fuel every 30 minutes or 45 minutes when the plant is working hard. Longer intervals may be allowed when the rate of production is reduced. One writer has recently stated that when fresh fuel is put in the generator it raises the quality of the gas, and has more influence on it than the depth of the fire; but it would be a mistake to accept this as a general rule. With bituminous, or semi-bituminous coal, hydrocarbons are given off soon after the new coal is put into

the hot generator ; but this is not the case with anthracite or coke, and the Author is of opinion that with any kind of fuel it is essential to maintain the requisite depth of fire to insure not only the decomposition of the steam, but especially the reduction of the carbon dioxide.

It has naturally occurred to designers of gas plants to feed the generator with fuel automatically. Where gas is made on a large scale, and where the rate of production of a generator is constant, an automatic feed can be used ; but for a plant of moderate size, which serves one or more engines with varying loads, there would be an element of risk in trusting to a mechanical feed. In a generator for 100 or 200 brake-HP. the body of fire is small, and if too little or too much fuel were put on, the quality of the gas would suffer ; and if the load on the engines varied greatly, the mechanical feed would have to be regulated by the fireman. Practically, this means that with a plant of this size the attendant must be present, and as he is there it is better that he should put on the fuel and be responsible for it ; for the outputs mentioned, the weight of fuel would not exceed 1 cwt. to 2 cwts. per hour. In some places it is a convenience to have a large hopper over the top of the generator, so that coal may be let in at intervals.

Generator gas is made rapidly, and in a moderate-sized plant it usually leaves the generator at a temperature of about 500° C. Special attention must therefore be given to the cooling of the gas, so that when it leaves the gas-holder its temperature should not be higher than that of the surrounding air. In a plant serving over 500 brake-HP., as at Messrs. Crossley's Works, for instance, gas is consumed at the rate of something like 42,000 cubic feet per hour, and it will be readily understood that to bring this down from 500° C. to 15° C., or thereabouts, without an excessively large or costly plant, is not easy. It is, however, desirable for the good working of the engine that the charge of gas admitted to the cylinder should be cool, so that a given volume may contain as much energy as possible.

As to the calorific power of the gas, it should be considered bad for engine work unless it gives at least 1,200 calories per cubic metre, at standard temperature and pressure. It should also contain not less than 15 per cent. of hydrogen to insure fairly prompt ignition in the cylinder. Carbon monoxide is comparatively slow to ignite, especially when surrounded by a large body of nitrogen and other inert gases ; it therefore needs the presence of hydrogen, and it is for this reason that the Author has always endeavoured to get as high a percentage of this gas as possible. In the gas made

in the Dowson apparatus it is usually 18 per cent. to 20 per cent. by volume.

The foregoing remarks go to show that there are several practical considerations to be taken into account, and with these in view, it will now be well to consider briefly the distinguishing features of the leading types of plant used for making gas to drive engines. Broadly speaking there are three types, viz. :—

A.—Producer with jet of superheated steam forcing in air, *e.g.*, the Dowson plant.¹

B.—Producer without steam-jet, and with blower to force in air, *e.g.*, the Lencauchez and the Mond plants.²

C.—Producer without steam-jet and without blower, the air being drawn into the producer by a suction-pump attached to the gas-engine, *e.g.*, the Bénier plant.

Type A.—Producer with jet of superheated steam forcing in air.—This type is used much more than any other; it is usually provided with an independent boiler with superheating tubes, and a jet of steam at a pressure of 30 lbs. to 60 lbs. per square inch (according to the size of the producer) is used for the double purpose of supplying the steam to be decomposed, and of carrying in an induced current of air, to maintain combustion of the fuel, and to promote a high temperature while the chemical reactions are taking place. In practice, about 90 per cent. of the steam produced in the boiler is decomposed in the generator, the remainder being lost. It should also be noted that the percentage of hydrogen in the gas is not strictly a measure of the quantity of steam decomposed, as some of the hydrogen is derived from the coal in the generator. By close attention to various details the Author is able in practical work to decompose about $\frac{3}{4}$ lb. of steam for each pound of anthracite consumed in the generator, and he is able to do this without having more than 4 per cent. to 6 per cent. by volume of carbon dioxide in the resulting gas. It is sometimes remarked that there cannot be a gain in raising the percentage of hydrogen, if at the same time the carbon dioxide is proportionately increased, and this point is worth considering. Supposing a sample of gas to have the following composition by volume :—

	Per Cent.
Hydrogen	15
Carbon monoxide	27
Carbon dioxide	4
Nitrogen, etc.	54

the calorific power of this gas at standard temperature and pres-

¹ Minutes of Proceedings Inst. C.E., vol. lxxiii. p. 311, and vol. cxii. p. 2.

² *Ibid*, vol. cxxix. p. 190 *et seq.*

sure would be 1,289 calories per cubic metre. If the hydrogen were increased 5 per cent., a gas of about the following composition by volume would probably result:—

	Per Cent.
Hydrogen	20·0
Carbon monoxide	22·8
Carbon dioxide	6·5
Nitrogen, etc.	50·7

This would have a calorific power of 1,314 calories per cubic metre, and at first sight there would appear to be little gain in raising the percentage of hydrogen if there were a proportionate rise in the carbon dioxide, but a certain increase of hydrogen materially assists the prompt ignition of the charge in the cylinder of the engine, and for this reason alone it is important to secure as much hydrogen as possible without having more than 6 per cent. of carbon dioxide. Ordinary producer-gas, as used for furnace work, in which there is about 24 per cent. to 27 per cent. of carbon monoxide, but only 6 per cent. to 10 per cent. of hydrogen, cannot be used for engine work because it is too weak and too sluggish to ignite promptly, even when the percentage of carbon dioxide is low.

In Appendix I are given the results of all the trustworthy trials of Dowson plants which the Author knows of, apart from mere trials of the fuel consumption per HP., when working with engines. From this summary it will be seen that the average calorific power of the gas was 1,432 calories per cubic metre, at standard temperature and pressure, while the average heat efficiency of the plant was 78·9 per cent., being in one case as high as 81·1 per cent. and in another 82·7 per cent. With an efficiency of 80 per cent., the loss of heat may be accounted for approximately as follows:—

	Per Cent.
Loss in boiler	7
Steam not decomposed in generator	1
Unburnt anthracite lost in ashes ¹	2
Sensible heat of gas lost in cooling, scrubbing, etc., and in radiation from generator.	10
Total	20

In Appendix II are given the results obtained with two other plants of Type A.

Type B.—*Producer without steam-jet, and with blower to force in air.*—In the Lencauchez plant² there is no boiler, the gas being made

¹ In all the trials of this plant, 2 per cent. of the fuel has been treated as lost with the ashes, except where this loss was known definitely.

² Minutes of Proceedings Inst. C.E., vol. cxxix. p. 191.

by forcing air from a blower into the gas generator, and there saturating it with moisture before it enters the fire. When good gas has been produced, the blower is driven by the engine, but when there is no gas it is driven by hand-power. Some of these plants are working in France, and a few have been tested for fuel consumption per HP., but none appear to have been tested thoroughly as to their heat efficiency, etc. Professor Witz refers to this plant in his "*Moteurs à Gaz*," but seems doubtful about the heat value of the gas. Mr. Bryan Donkin also mentions it,¹ and gives the following as the composition of the gas by volume, but the analyst is not named:—

	Per Cent.
Hydrogen	20·0
Olefiant gas	4·0
Oxygen	0·5
Carbon monoxide	21·0
Carbon dioxide	5·0
Nitrogen	49·5
	<hr/> 100·0 <hr/>

This would give a calorific power of 1,858 calories per cubic metre. The heat value of the coal from which it was made is not given, nor the yield of gas for a given weight of fuel.

The Mond plant has been fully described and illustrated in an interesting Paper communicated to the Institution by Mr. H. A. Humphrey.² This plant was devised primarily for the recovery of ammonium sulphate, and the combustible gas obtained during the process was, so to speak, a by-product. At first all the gas was used for heating some large furnaces, but afterwards trials with a gas-engine showed that it was suitable for that purpose, and several engines are now working with it at the chemical works of Messrs. Brunner, Mond & Co. A recovery plant of this kind can only be worked on a large scale, night and day, one producer making sufficient gas for 2,000 HP. It is, therefore, not a plant which can be used merely for power purposes on a moderate scale, but it has the great merit of being the only plant working with ordinary bituminous coal, which yields gas clean enough for engine work. The tar is removed by an extensive system of washing and scrubbing.

In this plant there is no boiler, but a certain amount of steam is taken from other parts of the works, and all the air required (about 1,500 cubic feet per minute) is sent into the producer by a

¹ "Gas, Oil, and Air Engines," p. 238.

² Minutes of Proceedings Inst. C.E., vol. cxxix. p. 190.

blower, driven by an independent engine. The heat value of the coal used in the producer was 7,225 calories per kilogram,¹ and this weight of coal when gasified was estimated to yield 4·69 cubic metres of gas at standard temperature and pressure, having a calorific value of 1,385 calories per cubic metre. If this estimate is correct, the heat efficiency of this plant is 79 per cent. when calculated on the same basis as that of the other plants referred to.

It has been proposed to work a plant of this type without the recovery of ammonium sulphate, and if this were done it would be nearly on the same lines as the Lencauchez plant; but in the latter anthracite coal is used for engine work. In the Mond gas there is as much as 16 per cent. by volume of carbon dioxide, but this is partly compensated for by the hydrogen, which is as high as 29 per cent.

Type C.—Producer without steam-jet or blower.—In this plant there is no steam-boiler or air-blower, the air being drawn into the producer by a suction-pump attached to the engine. The quantity of air drawn in varies with the volume of gas consumed, and as it is governed by the engine itself there is no storage of gas in a holder. The latter is dispensed with altogether, the gas plant consisting merely of a producer, a washer, and a scrubber. The fire-grate is of special construction, and in it water is vaporised, and this water-vapour mixes with the air before the latter enters the fuel column. The idea is ingenious, but the results obtained have not been encouraging. The plant is fully described by Professor Witz,² who made careful trials of it in December, 1894, with an engine of about 15 brake-HP.

The first trial was with English anthracite of good quality, of which the heat value was assumed to be 8,000 calories per kilogram. The gas contained 0·3 per cent. of oxygen and only 0·8 per cent. of carbon dioxide, and by calorimetric bomb it gave 1,149 calories per cubic metre at standard temperature and pressure. The engine developed 27·6 indicator-HP., but only 14·59 brake-HP., while the consumption of anthracite was 714 grams per brake-HP.-hour. A second trial was made with ordinary gas-coke in the generator, of which the heat value was estimated at 6,800 calories per kilogram. The gas contained 0·3 per cent. of oxygen and 1·53 per cent. of carbon dioxide, while its calorific power was as low as 1,035 calories per cubic metre. The engine developed 14·7 brake-HP. and the consumption of coke

¹ To express calories per kilogram in B.T.U. per pound, multiply by 1·8.

² "Moteurs à Gaz," vol. ii. p. 89, and vol. iii. p. 186.

was 752 grams per brake-HP.-hour. These results were obtained with full load on the engine, and it is probable that the gas would have been still weaker if the load had been much reduced, as the temperature of the fuel most favourable for making gas would not have been maintained. There is the further disadvantage that if there were two or more engines in a factory, it would in most cases be inconvenient and wasteful to have a set of gas plant for each engine, and it would seldom be possible to work two or more engines from one producer without a gasholder.

The Author has not included water-gas plants among those which are suitable for engine work, chiefly because the producers of such a plant must be worked intermittently, with frequent reversals, and this necessarily causes the quality of the gas to vary considerably. The weak gas which is blown off as waste also adds seriously to the fuel consumption.

In all the foregoing calculations the calorific values of the generator-gas have been based on the following heat values:—

	Calories per Cubic Metre.
Hydrogen	3,070
Marsh gas, CH_4	9,550
Olefiant gas, C_2H_4	14,970
Carbon monoxide, CO	3,070

The calorific power of the fuel, where this was not tested by calorimeter, was calculated from the formula

$$80\cdot8 C + 345 \left(H - \frac{O}{8} \right) + 25 S,$$

where C, H, O, and S represent the percentages of carbon, hydrogen, oxygen, and sulphur in the fuel. One cubic metre of CO , CO_2 , or CH_4 contains 537·6 grams of carbon, and 1 cubic metre of C_2H_4 contains 1,075·2 grams of carbon. All the calculations as to calorific power are also based on the standard temperature and pressure of 0°C . and 760 millimetres, and all the steam derived from the combustion of the fuel or gas is treated as condensed. It is sometimes said that the steam should not be treated as condensed—in other words, that its latent heat should be deducted from the total heat value of the fuel or gas. Professor Meyer, for example, adopts this basis in his calculations. It should, however, be remembered that in stating a balance-sheet of the heat units, on the one side should be given all those in the solid fuel consumed, and on the other side the total heat units which the gas derived from it is capable of yielding, when burnt to the best advantage. When the hydrogen in the gas is burnt, steam is

produced, and the latent heat of this steam is available for heating purposes; the latent heat of the steam should therefore be included in the heat units derivable from combustion of the gas. It happens that in the present gas-engine the exhaust products leave at a high temperature, so that the steam formed on combustion of the hydrogen in the cylinder is not condensed; but if there were complete expansion this would not be the case. The present loss of the latent heat of the steam is due entirely to the engine, and should not be debited to the process of making the gas. Professor Witz and other well-known authorities fully accept this view; and to prevent confusion, and in order that an exact comparison may be made of all the examples given, all the heat values have been worked out on the basis of the latent heat of the steam produced on burning the fuel or gas being available. If this were not done it would be impossible to determine correctly the heat efficiency of the gas plant, apart from that of the engine. The point might be emphasised by taking the case of water-gas, in which there is usually about 50 per cent. of hydrogen. The volume of steam produced on combustion of this gas is much greater than in the case of generator-gas, which usually contains about 20 per cent. of hydrogen, and obviously it would be wrong to treat the latent heat of the steam produced on combustion of 50 per cent. of hydrogen as of no value in calculating the calorific power of the gas. To go a step further, if the plant produced hydrogen only, the loss would be still greater. In this connection it may be well to refer to a Paper by Mr. C. F. Jenkin,¹ in which the efficiency of gas-producers and the heat efficiency of the gas produced are fully dealt with. In this Paper Mr. Jenkin adopted a "figure of merit" based upon the heat of combustion or calorific power of the gas, divided by the weight of carbon it contained; and if he had proposed to restrict the use of this figure of merit to gas made without a steam-jet, or without air from a blower (as in the old type of Siemens producer), no great objection could be taken. But where steam is produced in an independent boiler and then forced into the gas-producer for the purpose of raising the percentage of hydrogen, it cannot be correct to determine the heat efficiency of the plant without taking account of the fuel burnt in the boiler. The figure of merit can be used to compare the gas made in two or more producers (without the use of steam or air under pressure) working with similar coal and under similar conditions, or it can be used to compare the gas made in one

¹ Minutes of Proceedings Inst. C.E., vol. cxxiii. p. 328.

producer at different times; but it cannot be used to compare the gas made in one or more producers with varying qualities of coal. In the case of water-gas, where a large quantity of steam is used, the objection to the use of Mr. Jenkin's method of computing a figure of merit would be still stronger. It should also be noted that the tests and calculations required to arrive at a balance-sheet of all the heat units involved are in no way simplified by adopting the proposed figure of merit, and for the reasons stated it is decidedly better to adopt the balance-sheet in all cases. It is correct and cannot mislead. It is not always possible to analyse the gas, and for practical purposes it is more convenient to use a calorimeter to determine its heat value, and when engineers test engines they should also test the gas with a calorimeter, so that they may know the heat value of the fuel they are using. At the same time, it is desirable that the calorific power of the fuel should be determined, as well as the yield of gas from a given weight of fuel, so that the heat efficiency of the plant may be determined.

In these notes the Author has discussed some of the theoretical and practical considerations which affect the working of gas plants used for engine work. He has also endeavoured to collect the most trustworthy data obtainable, and in conclusion he thinks he cannot do better than quote the following remarks of Professor Witz, who is a recognised authority on all matters connected with gas-power. He says,¹ "The future of gas-engines will depend to a great extent on the progress made with the production of generator-gas; the question is to make this gas rich enough, to produce it in a simple way, to maintain uniformity of quality, and to keep down the working cost." Again,² "There is a perfect relation between the calorific power of a gas and the mean pressure of the indicator diagram . . . It would therefore be a mistake to try to make an apparatus produce much gas of poor quality; it would be better to work to a good average of about 1,300 calories. This conclusion is of great importance."

¹ "Moteurs à Gaz," vol. ii. p. 14.

² *Ibid*, vol. iii. p. 39.

APPENDIX I.—TABLE A.—TRIALS OF DOWSON GAS PLANTS.

Number of Trial.	1	2	3	4	5	6	7	8	9	10	Average.
A.—Calorific value of generator fuel, . . . calories per kilogram	8,420	..	7,600	7,520	..	..	8,300	8,200	8,000	8,200	8,034
B.—Calorific value of boiler fuel, . . . calories per kilogram	..	..	7,000	7,200	..	..	7,200	7,200	7,000	7,200	7,133
C.—Fuel consumed in boiler per kilogram of fuel consumed in generator, kilograms	0.5 cubic metre of gas.	..	0.17	0.17	..	..	0.12	0.18	0.16	0.14	0.16
D.—Heat of fuel consumed in boiler per kilogram of fuel consumed in generator, calories = $B \times C$	930	..	1,130	1,220	..	..	860	1,300	1,120	1,000	1,089
E.—Total heat in 1 kilogram of fuel consumed in generator + fuel consumed in boiler, = $A + D$	9,350	..	8,790	8,740	..	..	9,160	9,500	9,120	9,200	9,123
F.—Gas produced per kilogram of fuel consumed in generator, cubic metres ¹	5.0	..	5.02	4.74	..	..	5.34	5.04	5.07	4.88	5.01
G.—Calorific value of gas, . . . calories per cubic metre	1,420	1,350	1,420	1,360	1,430	1,487	1,384	1,463	1,451	1,552	1,432
H.—Heat in gas produced, = $F \times G$	7,100	..	7,130	6,450	..	..	7,390	7,370	7,350	7,570	7,194
I.—Heat lost in process, = $H - G$ calories	2,250	..	1,660	2,290	..	..	1,770	2,130	1,770	1,630	1,929
K.—Heat efficiency of plant per cent. = $\frac{G}{H} \times 100$	75.9	..	81.1	73.8	..	..	80.7	77.6	80.6	82.3	78.9
Composition of gas produced by	18.73	..	17.0	16.67	24.0	..	16.5	19.8	15.3	17.5	18.19
Hydrogen . . .	0.62	..	2.0	..	..	..	1.0	1.3	1.4	2.1	1.40
Carbonic oxide . . .	25.07	..	23.0	27.50	22.5	..	25.4	23.8	27.6	26.5	25.17
Carbonic acid . . .	6.57	..	6.0	8.40	7.5	..	4.8	6.3	3.9	4.4	5.98
Oxygen . . .	0.03	..	..	0.90	..	..	1.2	..	..	..	..
Nitrogen, etc. . .	48.98	..	52.0	46.73	46.0	..	51.1	48.8	51.8	49.5	49.36

¹ At 0° C. and 760 millimetres.

TABLE B.—TRIALS OF DOWSON GAS PLANTS.

No. of Trial.	Date of Trial.	Locality.	B.H.P. of Gas-Generator.	Fuel used.		Authority.	Remarks.
				Generator.	Boiler.		
1 {	1883 { January }	Battersea	8	Anthracite	None	Prof. W. Foster, F.C.S., London.	Small anthracite from Gernant, South Wales: see Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 319. There was no boiler, steam being produced in coil heated by gas consumed at rate of 100 cubic feet per hour.
2 {	1885 { November }	Rouen, France	10	"	Gas coke	Prof. A. Witz, Lille.	Anthracite from South Wales. Neither fuel nor gas analysed. Calorific power of gas determined by calorimetric bombs.
3 {	1889 { July }	Schwabing, Germany	60	"	"	Mr. F. Uppenborn (on behalf of Municipality).	Anthracite from Kohlscheid, Germany. It was assumed to contain 85 per cent. carbon.
4 {	1890 { January }	Canale, Italy	40	"	"	Dr. C. Monaco, Turin.	Anthracite from Kohlscheid: for analysis see Minutes of Proceedings Inst. C.E., vol. cxii., p. 34.
5 {	1890 { April }	London	10	"	"	Dr. Langer, London.	No details given as to fuel used or yield of gas.
6 {	1890 { September }	Rouen, France	100	"	"	Prof. A. Witz, Lille.	Anthracite from South Wales. Neither fuel nor gas analysed. Calorific power of gas determined by calorimetric bombs.
7 {	1894 { June }	Sabadell, Spain	120	"	"	Prof. A. Witz, Lille.	Anthracite from Great Mountain Colliery, South Wales. It contained 90 to 92 per cent. of fixed carbon, and 1 to 2 per cent. of ash.
8 {	1897 { February }	Basingstoke	40	"	"	Mr. G. C. Jones, F.C.S., London.	Small anthracite peas from Gwaun Cae Gurwen Colliery, South Wales.
9 {	1898 { April }	Millwall	250	"	"	Mr. G. C. Jones, F.C.S., London.	Anthracite peas from South Wales. During the trial gas was made for 190 B.H.P. Calorific power of gas calculated from analysis was 1,451 calories and by calorimeter 1,448 calories per cubic metre.
10 {	1898 { March }	Openshaw	300	"	"	Mr. G. C. Jones, F.C.S., London.	Anthracite cobbles from Emlyn Colliery, South Wales. Calorific power of gas was calculated from analysis and confirmed by calorimeter.

APPENDIX II.

160 BRAKE-HP. PLANT.

TRIAL AT BÂLE, SWITZERLAND, BY PROF. E. MEYER, OF THE TECHNICAL
HIGH SCHOOL IN HANOVER, APRIL, 1896.

This plant is of the same type as the preceding ones, although of foreign make, and the trial is of special interest as ordinary coke from the gas-works was used in the generator, as well as in the boiler. The first trial was with one generator serving about 100 brake-HP. The coke was analysed by Dr. E. J. Constam, and had the following composition :—

	Per Cent.
Carbon	87·72
Hydrogen	0·81
Oxygen and nitrogen	0·43
Sulphur	0·72
Ash	9·70
Moisture	0·62
Total	100·00

From this Dr. Constam calculated that the heat value was 7,338 calories per kilogram (steam not condensed); he also made two determinations of the heat value of the coke by calorimeter, and found it to be 7,202 calories per kilogram with steam not condensed, and 7,247 calories with steam condensed.

One kilogram of coke gasified in the generator and 0·11 kilogram consumed in the boiler yielded 4·74 cubic metres of gas at 0° C. and 760 millimetres. The gas was analysed by Dr. Wolf, and eight samples, taken at intervals of about an hour, had the following average composition by volume :—

	Per Cent.
Hydrogen	7·0
Marsh gas, CH ₄	2·0
Carbon monoxide	27·6
Carbon dioxide	4·8
Nitrogen, etc.	58·6
	100·0

The calorific power of the gas, calculated by Dr. Wolf from the above analysis, was 1,190 calories with steam uncondensed, and 1,254 calories with steam condensed, and by calorimeter 1,202 calories per cubic metre, with steam uncondensed, and 1,265 calories with steam condensed, at standard temperature and pressure. The heat efficiency of the plant was 73·8 per cent.

150 BRAKE-HP. PLANT.

TRIAL AT THE JERSEY CITY TERMINUS OF THE ERIE RAILROAD, U.S.A.,
JUNE, 1899.

The producer of this plant has a steam-jet, but, unlike the other producers referred to, it has no fire-bars, the combustible fuel resting on a thick bed of ashes through which the steam and air are blown. The cast-iron base which

supports the ashes and fuel is turned round three or four times a day, to discharge the clinker, &c. The railway officials tested the working of the plant, while the makers—Messrs. R. D. Wood & Co., of Philadelphia—analysed the gas.¹ Small anthracite was used in the producer and in the boiler, and it is stated that about 93 per cent. was consumed in the former, and this would leave only 7 per cent. for the boiler, which appears rather low for the quantity of steam required. The anthracite used had the following composition :—

	Per Cent.
Carbon (fixed)	78·32
Volatile matter	7·50
Moisture	1·62
Ash	12·56
Total	<u>100·00</u>

Assuming the anthracite to have had a heat value of 8,000 calories per kilogram the results may be given as follows :—1 kilogram of anthracite consumed in the generator and 0·08 kilogram in the boiler yielded 5·13 cubic metres of gas at 0° C. and 760 millimetres. The composition of the gas by volume was as follows :—

	Per Cent.
Hydrogen	18·3
Marsh gas	2·4
Oxygen	0·4
Carbon monoxide	17·2
Carbon dioxide	8·6
Nitrogen, &c.	53·1
	<u>100·0</u>

The calorific power of the gas, calculated from the above analysis, is 1,321 calories per cubic metre, at standard temperature and pressure.

It will be seen that the gas made in this plant is not quite as good as that made in the plants referred to in Appendix I, and it is inferred that this is chiefly due to the absence of fire-bars, which facilitate the passage of steam and air through the fuel, and promote a high temperature in the fuel column.

¹ *American Engineer*, November, 1899.