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GAS, GAS ENGINES, AND GAS PRODUCERS.

By J. Seton Gray, S. Can. Soc. C. E.

(Read before the Mechanical Section, February 28, 1907.)

The thermal efficiency of a modern steam plant is about 10%, and that of a gas engine plant about 20%. This is the principal reason for the large amount of work that has been done in recent years on the gas engine.

Again, while gas can be manufactured in a gas producer for about three cents per 1,000 cubic feet, city lighting gas costs between 50 and 100 cents per 1,000 cubic feet. This explains why so much attention is being paid to the development of the gas producer for the making of power gas.

The many methods adopted for the production of power gas may be divided into three general classes:

1. When a carbonaceous substance such as coal is heated in a closed retort, gases are given off which may be collected and used for power. This method is that at present in use for the manufacture of illuminating gas.

2. If steam be blown through a mass of incandescent fuel, a combustible gas is produced. In this process the fuel is kept incandescent by a blast of air, the steaming and blowing periods being intermittent.

3. If steam and air together be uninterruptedly blown into incandescent fuel, a gas, containing hydrogen and carbon monoxide, is produced continuously. The amounts of steam and air are regulated so as to keep the fuel at a fairly constant temperature.

Gas produced by the first method, while generally of high calorific value, is costly, as already mentioned. Water gas, produced by the second method, is much cheaper; but as it contains much hydrogen is a very inflammable gas, and on this account cannot be used with the high compression pressures now employed in gas engine practice. These high pressures are necessary if a high efficiency is required of an engine.

The third method, however, gives a cheap gas, well suited for gas engine work, and will be treated more fully in this thesis.

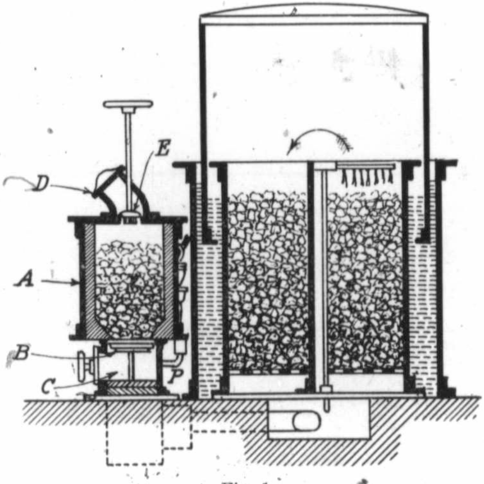
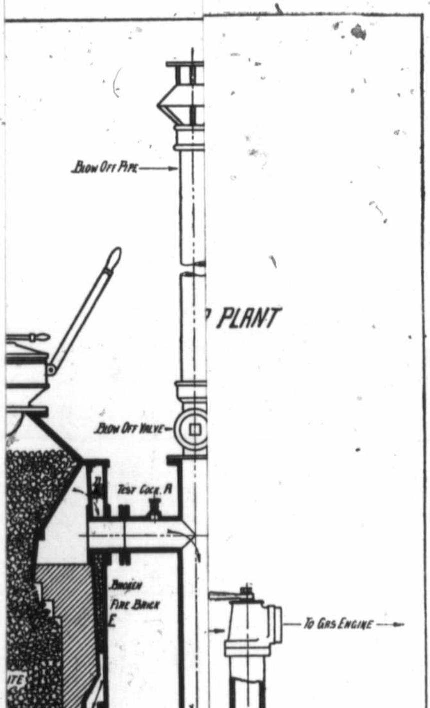


Fig. 1.

Nearly all fuels containing carbon can be used for the production of producer gas. It must be noted, however, that if the gas is going to be used in a gas engine cylinder, it must be of uniform quality. It must also contain no tar or other impurities in order to avoid trouble with the valves.

To Mr. Dowson we owe the first successful producer gas plant. His plant was designed to work with anthracite coal. This coal is non-caking, and, being nearly pure carbon, contains very few condensible hydrocarbons or tar. It is therefore an ideal fuel for the gas producer.



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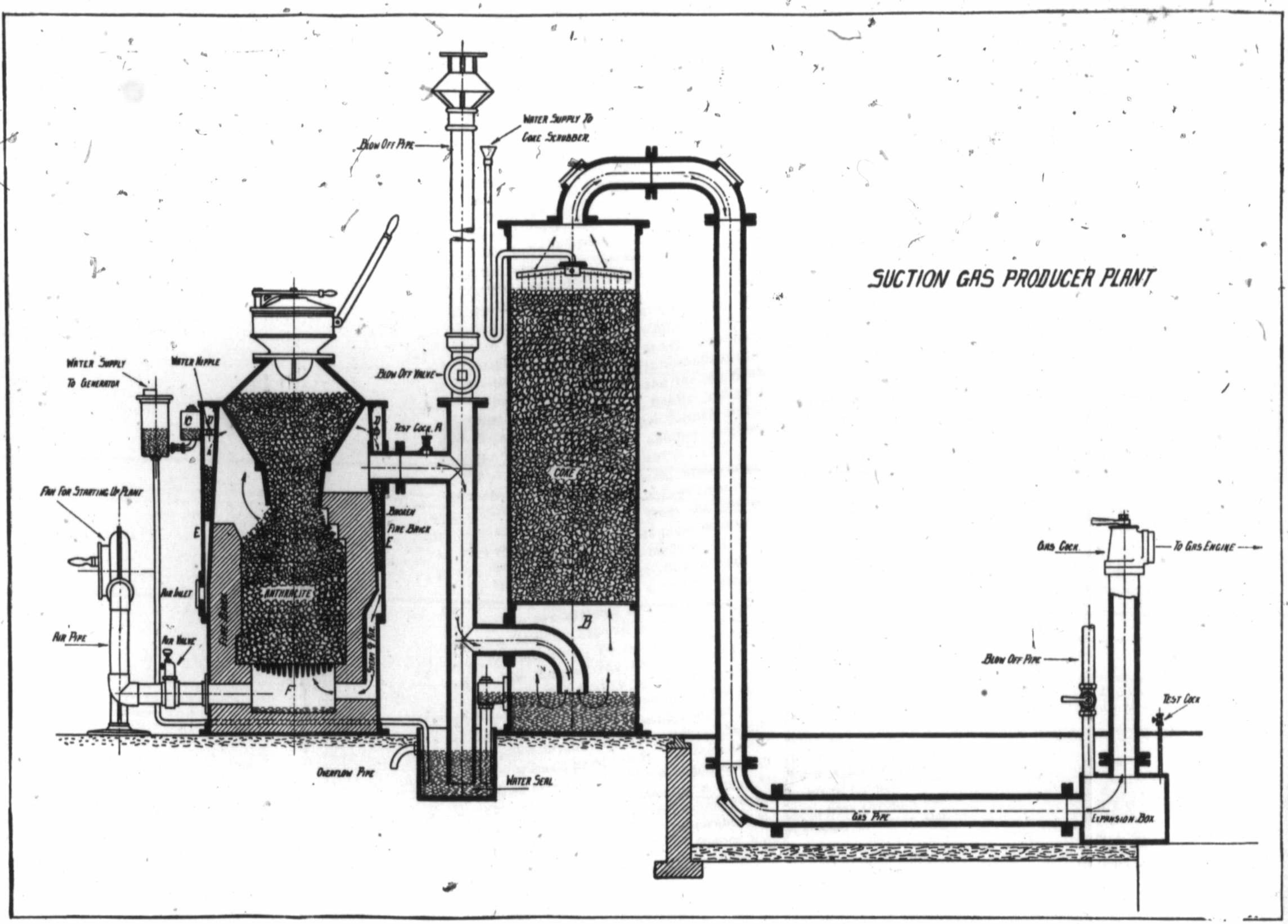

SUCTION GAS PRODUCER PLANT
WATER SUPPLY TO
COKE SCRUBBER
BLOW OFF PIPE
BLOW OFF VALVE
WATER SUPPLY
TO GENERATOR
WATER NIPPLE
TEST COCK A
FAN FOR STARTING UP PLANT
BROKEN
FIRE BRICK
AIR INLET
ANTHRACITE
COKE
AIR PIPE
AIR VALVE
OVERFLOW PIPE
WATER SEAL
GAS COCK
TO GAS ENGINE
BLOW OFF PIPE
TEST COCK
GAS PIPE
EXPANSION BOX

Fig. 2.

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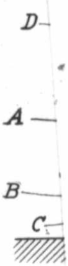

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As this producer embodies in the best way the fundamental principles necessary for the production of gas from solid fuel, it will be described here.

Fig. 1 is a diagrammatic section of a Dowson Gas Producer, taken from "The Gas and Oil Engine," by D. Clerk. As may be seen, the producer consists of a cylindrical casing A, lined with fire-brick, and having at the bottom fire bars B, above a closed ash pit C. The upper part of the generator is closed by a metal plate on which is mounted a fuel hopper D, having an internal bell valve E operated from the outside.

To begin operations, the upper cover is removed from the hopper D, the bell valve is opened; a fire is built upon the bars B, and air forced through it by the steam jet N and the pipe P. Fuel is slowly added from above till the whole mass is incandescent and fills the producer to a depth of about 18 inches at least. During this heating process, gases are given off by way of the open hopper and are ignited there. Care must be taken not to inhale this gas. (It contains much CO and is very poisonous, but when burned it is harmless.) When the fuel is incandescent the inner and outer valves of the hopper are closed, and the gas flows by a pipe through cooling and scrubbing devices, finally finding its way to the gas holder through the coke scrubber formed within it. From the gas holder the gas flows through another scrubber, as shown by the arrow, and thence to the engine.

In 1895 Renier, a Frenchman, after much experimental work with a Dowson Gas Producer, succeeded in making the engine draw its own supply of gas direct from the gas generator, without the use of a gas holder. While this plant was not a commercial success, it was the forerunner of the modern suction gas producer.

The Dowson Gas Producer has already been described. The following is a description of a suction gas producer; the difference between the two systems may be seen from the descriptions: The adjoining sketch (Fig. 2), shows the general construction of this piece of apparatus. To set it in operation a fire is built on the grate. The door at the front of the producer allows this to be easily done. A quantity of paraffine waste, or other combustible material, is placed inside the generator, and lighted. Broken wood is then added through the hopper at the top, and this is followed by coal until a bright fire is burning. The air for combustion is supplied by a small hand fan B. As soon as the fire is burning brightly the water necessary for the production of the gas is turned on.

This gas is tested by opening a small test cock A, and applying a light. If the gas burns with a blue flame it is ready for use. The gas is then allowed to enter the scrubber B, and to pass through the expansion box to the engine. Before being allowed to enter the engine the gas is again tested, and if it still burns with a blue flame the engine may be started. The hand fan is stopped as soon as the engine starts work, and thereafter the whole plant becomes automatic.

During the suction stroke of the engine a vacuum is set up in the engine cylinder. To fill this vacuum air and steam are drawn into the generator, are there turned into combustible gases, which pass through the scrubber to the engine.

For the production of the necessary steam a water supply C is fixed to the generator. This supplies water to the vaporisor D. This vaporisor is just a pipe perforated with a number of holes. Every time the engine draws gas, which it does in proportion to the load, a small quantity of water is drawn out of the vaporiser, falls on a quantity of hot refractory material E in the casing, and is there converted into steam. This steam is caught up by the current of air drawn in at the air valve. The mixture of air and gas passes round the casing to a space F under the fire bars, from whence it is drawn up through the body of incandescent fuel, where it is turned into gas. The gas passes from the generator through a water seal at the bottom of the coke scrubber, passes through the closely-packed coke, where its tar and other impurities are extracted, and then goes to the engine cylinder. A continuous stream of water is allowed to fall in a spray over the coke, whereby the gas is cooled to the normal temperature.

The theory of the chemical action that goes on in the gas producer is as follows: When air comes in contact with glowing carbon we get, first of all, the burning of the carbon to form carbon dioxide, according to the equation $C + O_2 = CO_2$. Now, carbon at a high temperature is a very strong reducing agent, so when the CO_2, already formed, comes in contact with the mass of glowing carbon through which is must pass, the CO_2, carbon dioxide, is reduced to CO, carbon monoxide, according to the equation $C + CO_2 = 2CO$. This carbon monoxide is a combustible gas, very poisonous, and can be used in the gas engine.

When steam comes in contact with glowing carbon, it is reduced by the action of the carbon to CO and 2H, according to the equation $C + H_2O = H_2 + CO$.

The producer plant last described is known as the suction plant, because it is kept in continuous operation by the suction stroke of the engine. Another plant also in common use is known as the pressure plant. A well-known example of such a plant is the Dowson plant, already described. The chemical reactions in this case are exactly similar to those already described when dealing with the suction producer. The principal differences between the two systems are that the pressure system requires a steam boiler in which to generate the steam required for operation, also, that with this system a gas holder, in which to store the gas, is required.

There is one serious objection to the pressure system which is not found in the other system. The whole producer is under pressure. If, then, there are any leaks between the producer and the engine, gas will escape. As has already been mentioned, this gas is very poisonous, and may cause the death of a careless operator. The suction producer is full proof in this respect, because the pressure in the system is less than atmospheric. If, then, there are any leaks in the system, all that can happen is that air will pass into the system through these leaks. While this will reduce the efficiency of the plant, it can do no other damage. The fact that no boiler or gas holder is required in the suction producer is a great point in its favour, because simplicity is the essence of good engineering, especially when we are dealing with a machine which is going to be put under the care of men who have no engineering knowledge or skill.

It takes only a few minutes to start up a small gas producer plant. The Highland and Agricultural Society of Scotland made some tests in Glasgow in 1905, to ascertain the time required to get an engine and producer plant to full working load, starting with the

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The following are the combined chemical and heat equations of the reactions that take place in the gas producer :—

$C + H_2O = H_2 + CO$

$1 + \frac{18}{12} = \frac{2}{18} + \frac{28}{18}$ (1) or 1 lb. C + 1.5 lbs. H_2O = .166 lb. H_2 + 2.33 lbs. CO. Now, to separate 1.5 lbs. of water into H_2 and O at the same temperature requires 11,500 B.T.U., and 1 lb. C burned to CO gives 4,400 B.T.U. ; therefore, to turn 1.5 lbs. water to water gas requires other 7,100 B.T.U., or the burning of $\frac{7.100}{4,400}$ = 1.61 lbs. of C to CO, according to the equation.

(2) 1.61 lb. C + 2 15 lbs. O = 3.76 lbs CO + 7.100 B.T.U. ; therefore, finally, by adding together equations 1 and 2 we get 2.61 lbs. C + 2.15 lbs O + 1.5 lbs. steam = .166 lb. H + 6.09 lbs. CO. Now, the heat in a lb. H = 69,000 B.T.U. ; therefore .166 lb. H_2 = 11,400 B.T.U.

also, 6.09 lbs. CO = 26,400 B.T.U.

∴ 2.61 lbs. C give a gas with 37,800 B.T.U.

1 lb. O gives a gas with 14,500 B.T.U. = the calorific value of the fuel.

Again, 1 lb. H_2 occupies 180 cu. ft., so .166 lb. H occupies 29 cu. ft.

1 lb. CO occupies 186 cu. ft., so 6.09 lbs. CO occupies 77.8 cu. ft.

or the gas from 1 lb. carbon occupies 106.8 cu. ft. and has 14,500 B.T.U. ; therefore, the calorific value of our producer gas is 136 B.T.U. per cu. ft. In practice, 12.5 lbs. coal give 1,000 B.T.U., and, with coal at $6 per ton, 1,000 cu. ft. gas costs 1.74 cents. Lighting gas from the city mains costs about 60 cents per 1,000 cu. ft., and its calorific value is only four times as high as that of producer gas.

producer empty and cold. Only two men were allowed to start each plant on trial. The results were as follows:

Builder of Plant	Capacity of Plant B.H.P.	Time to start	Remarks
Campbell Gas Engine Co.,	18	13 min.	
" " " "	8	17½ "	
Crossley Bros.	24	15½ "	
Industrial Engineering Co.,	10	..	Started but was compelled to stop because water was shut off at main.
National Gas Engine Co., ..	20	48 "	Excessive time caused by defective igniter.
" " " "	10	15¾ "	
Messrs. Tangyes, Ltd... ..	21	16 "	
" " "	12	12½ "	

These tests were all made starting with the producer cold. The average value for a small plant is about 15 minutes. But in actual practice the fire is banked up when the producer is not in operation as, for instance, when it stands over night. When this is done the engine can be running in about seven minutes from the start. According to Mr. J. Emerson Dowson, the stand-by losses due to this banking up of the fire amount, in a moderate-sized plant, to about three lbs. of coal per hour.

Comparison of Steam and Producer Plants.

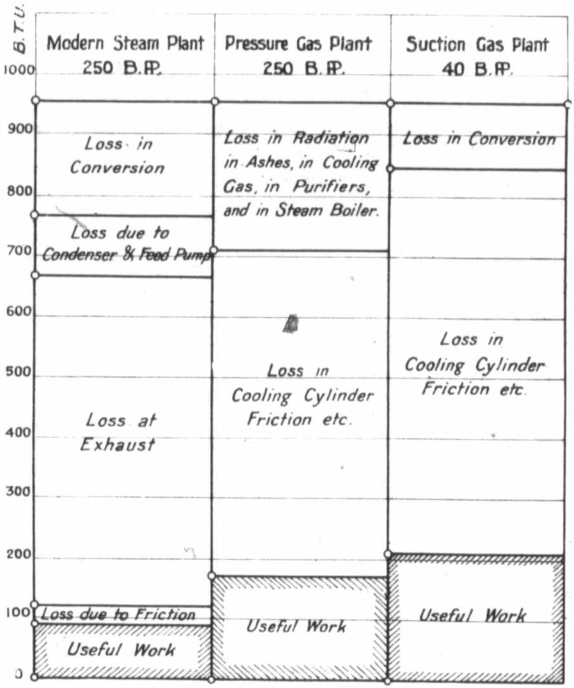
Dealing with efficiency, the adjoining diagram shows very clearly the values obtained from three characteristic plants.

Column 1 shows how the heat is used up in a modern steam plant of 250 H.P. The total heat contained in the coal was 952 B. T. U. Of this there is a loss in conversion of 20%, much of the heat in the fuel passing up the chimney. There is a further loss of 10% in the feed pump, in condensation, and in radiation. Of the remaining 70%, 57½% is lost in the engine exhaust; and after making an allowance for friction losses, we find that out of a total of 100%, only 10% is converted into actual work.

While this value of 10% may be obtained in test, in actual every-day practice the efficiency will be still less.

Column 2 shows how the heat is used up in a pressure producer plant of 250 H.P. There is, first of all, a loss of 25½% in radiation, in ashes, in gas coolers, and in steam boiler. Of the 74½% which goes forward to the engine, 33.2% is lost in cooling the engine

DIAGRAM SHOWING HOW THE HEAT IN 1 LB. OF COAL IS UTILIZED IN THREE CHARACTERISTIC PLANTS.



cylinder, 20% is lost in exhaust, and after allowing for friction we find that 18% of the available heat is given as actual work in this system.

Column 3 shows the distribution of the losses in a 40 H.P. suction producer system. It may be taken for granted that the losses in a 250 H.P. system will be smaller. Of the total heat in the coal 89% is transferred in the gas to the engine cylinder. After deducting engine losses, as in the last case, we find that 23% of the available heat is transferred into mechanical work. The efficiencies then are as follows:

Steam, 10%; pressure producer, 18%; suction producer plant, 23%.

There are one or two other points worthy of mention while dealing with the efficiency question. In a small steam plant the loss due to bad stoking is often quite considerable; in a producer plant there is very little such loss.

With regard to stand-by losses, as before mentioned, these are about three lbs. of coal per hour in a moderate-sized producer plant, whereas, according to results obtained by Mr. Dowson, this loss is about 71.5 lbs. of coal per hour in a steam plant of the same size. When we consider that most plants are idle for about 199 hours every week, we see how great will be the difference in coal bill due to stand-by loss.

This loss is small in producer plants because, since very little air is passing through the fire, when the fire is banked up in the gas generator that piece of apparatus is turned into a slow combustion furnace.

With regard to the efficiencies mentioned on the last page, there is a point of great practical interest which is too often overlooked. When we say that the efficiency of a steam plant is 10%, while that of a gas producer plant is 23%, we mean, among other things, that, for the work equivalent of 10 tons of coal, we must not only buy 100 tons, but we must also pay for the labour of handling this, and also for storage space. With the producer plant the calculations are made only on 23 tons of coal. A similar relation holds in the disposal of the ashes.

Dealing now with the problem of fluctuating loads, the following test was made on a suction producer plant by Messrs. Crompton & Co., Ltd., of London, England. A gas engine was run for four hours with a load of 10 H.P., then a load of 80 H.P. was thrown on suddenly. The plant immediately responded, and hardly a flicker was noticed in the lights supplied from this engine. It is to be borne in mind also that this was done without the use of a gas holder. This can be done by any well-designed producer plant, and is a performance that an engine working from a steam boiler would find very hard to beat.

Coming now to the problem of attendance. It is found that a complete producer and gas engine of 100 B. H.P. capacity requires the labour of one man for two hours each day, to keep it in first-class running condition. Everyone who has run a steam boiler and engine plant knows the troubles that are constantly turning up. The sanitary authorities complain that so much smoke is being thrown into the air, or the injector fails to operate, and the water begins to creep down in the water guage. The boiler has to be cleaned out twice a year; there is a large amount to be paid for insurance, for inspection, for wear and tear of fire bars and other fittings, for the repair of leaks in joints caused by the high pressure of the whole system, and, finally, there is the knowledge that some day the whole plant may take it into its head to go out by the roof.

Contrast with this the gas producer. It is clean and efficient, there is very little water to handle (¾ gallon per B. H.P., a steam plant requires 4 gallons per B. H.P.), and very little attention required. The whole system, except the engine, is subject to pressures of only a few lbs. per square inch. There is no chimney to build and maintain, nor is there any smoke nuisance. When the facts are considered that the system is cheap to instal, and also cheap to operate, one has to wonder at the slow growth of the gas producer industry compared with what it might be.

It has been argued against the producer plant that gas engines are not very good for the operation of electric generators. As an example to contradict this statement, in Granada, Spain, three single cylinder gas engines were installed rated at 80 B. H.P. each. These engines drive alternators in parallel, and have supplied the whole city with light for the last two years. Now, there are gas engines on the market in which the problem of balancing has been very carefully dealt with. If the result mentioned above could be obtained with single cylinder engines, there should be no difficulty in obtaining satisfactory operation from the modern three cylinder engines.

The following is taken from Dr. Oskar Nagel:

Several years of experience have shown that the gas power plants are fully as reliable as the best steam plants, and have the advantage of much greater economy. The following table of results of plants built in Austria and Germany, on the Koerting system, bears out his statement. It is to be noted with regard to these results that the plants are small, and were working only a short time each day, and that stand-by losses are taken into account.

Place	KW. hrs.	KW. per lb. coal	Lubric. oil per KW. hr.	Cotton waste per KW. hr.	HP. Capacity
Clausthal	219,150	.36	5.6	.558	100
Cransee	51,847	.36	5.62	.558	100
Neumarkt	125,076	.37	7.22	.442	80
Neurode	119,800	.24	3.03	1.42	160
Reichenbach	49,437	.3	6.20	.50	60
Soberheim	95,326	.36	7.36	3.50	100
Schoenberg	58,514	.35	12.8	1.30	80
Schwetz	82,312	.398	4.81	1.06	160
Walserorde	60,352	.32	8.24	2.03	70
Wienenden	71,828	.24	6.97	1.98	160
Karlsruhe	70,766	.45	5.14	1.08	100
Werden	102,716	.36	6.07	2.99	90

A few facts and figures at this point should prove of interest.

A small joiner shop was driven by a 30 H.P. motor. This motor was replaced by a 60 H.P. suction producer plant, built by the National Gas Engine Co. The electric drive cost $13.20 per week. The same work was done by the producer at $2.88 per week for fuel, $5.32 for labour, oil, etc., also interest on capital and depreciation. This shows a net saving of $6 per week. It also shows that the gas engine is going to be a keen competitor of the central station (electric).

The National Gas Engine Co. installed two complete suction plants in the south of Scotland in a factory which had been buying power from a central station. Before the installation was made the engineers in charge of the work made the following calculation of probable saving: The 160,000 units of electricity required per annum, at 3½ cents per unit, gives a power bill of $5,000 per annum. For the same power, with a suction producer, assuming one lb. coal gives one B. H.P. hr. 108 tons of coal per annum would be required. At $3 per ton the fuel for the producer costs $324 per annum. Allowing 10% for interest on capital and depreciation, $471 for labour, $120 for oil and sundries, the total expenditure is $1,881 per annum, and the saving due to the adoption of the producer plant $3,119 per annum. The cost of engine and producer plant, complete, was $6,240, the electrical equipment cost $3,360 for two dynamos, switchboard, and wiring, or the total cost of $9,660. A saving of $3,119 per annum would therefore pay for the whole plant in three years.

It is interesting to mark the effect of the perfecting of the gas producer on the gas engine industry. Messrs. Thorneycroft & Co., shipbuilders, London, England, have just fitted a number of canal barges with suction producer plants and gas engines. The results of these have been so satisfactory that they are going to try them on coasting and merchant vessels. The British Admiralty is making experiments to find what are the limitations in using it for naval work.

The greatest advantage the producer has for marine work is that the amount of coal to be carried is greatly reduced.

In a country like Canada, where farming is done on a large scale, and where the power users are so scattered as to prohibit the building of central stations for power and light, the gas producer ought to have a large and increasing use. Messrs. Tangye Ltd., of Birmingham, England, have put on the market a portable gas engine and producer plant to meet the demand of the farmers.

About ten years ago attention was drawn to the fact that a large amount of power is available in gas which is usually thrown away from blast furnaces. It had been stated on good authority that 468 H.P. may be developed per ton of iron produced per hour. In the United States of America alone there were produced in 1905 23,000,000 tons of pig iron. This is equivalent to an available power of 1,225,000 H.P.

The chief difficulty to be overcome in the use of this blast furnace gas in a gas engine is that connected with the removal of the large quantities of dust which it contains. Another difficulty sometimes met in a small plant, namely, that the gas is very variable in quality, is overcome in large plants by mixing the gas obtained from several furnaces together. However, the trouble due to this is not very great in a well-designed plant. The gas, which is very hot when it leaves the furnace, is usually cooled in the process of extracting the dust.

The quantity of dust in the gas varies greatly with the kind of ore and coal used. For instance, the Cockerill Co., Belgium, had a 200 H.P. gas engine running at their works in Seraing for three years without any special provision being made for the elimination of the dust contained in the gas. During all that time the engine never had to be cleaned on account of dust, although it was running night and day.

On the other hand, this same company, at their works in Differdingen, experienced trouble right from the start with some 600 H.P. engines which they installed. Investigation showed that the Differdingen gas contained four to five grammes of dust per cubic metre of gas, while the Seraing gas contained only from .25 g.m. to .5 gm.

Experience shows that furnaces using hematite ores give a gas containing very little dust, and what dust there is settles very easily, even in short lengths of pipe. Oollitic ores, on the other hand, give a gas containing much dust, which passes quite readily with the gas through long lengths of pipe.

There are two ways at present in use for the purification of blast furnace gases.

1. Passing the gas through scrubbers containing sawdust or coke, is exactly the same way as is done with producer gas.

2. The gas is caused to pass through a contrifugal fan. A jet of water enters the axis of the fan, and is driven outwards in the form of a fine spray. This spray of water gathers up all the dust in the gas. This latter method was tried in the Differdingen plant already mentioned, with the result that while the gas contained 4 gms. dust per cubic metre when it left the furnace, it held only .25gm. after passing through the fan, and could then be used with success in the engines.

The calorific value of this gas, as might be expected, is very variable. It may be taken that rich gas means poor operation in the blast furnace, while poor gas represents good operation therein. The average calorific value is about 110 B.T.U. per cubic feet, and an average analysis shows CO, 28%; H, 2.5%; CO_2, 7.25%; N, 61.3%.

This paper has been an endeavor to point out a few of the merits of the gas producer. The subject can only be taken up in a general way, because there are so many conditions to be met in the problem of power generation, that each case must be taken up separately, nevertheless the success of the producer, during the few years in which it has been developed, makes a thorough knowledge of this piece of apparatus necessary to anyone who pretends to be up to date in power plant work. The small producer plant has a field in sparsely-settled districts which cannot be as well met by any other existing piece of apparatus. The blast furnace engines are also growing in popularity as their operation becomes better known. As has already been pointed out, there is a great deal of power going to waste at present in existing blast furnaces. If the whole of the power from Niagara was utilized, it would only give three times the H.P. that is thrown away by the blast furnaces of the United States of America alone. From these facts one is encouraged to believe that the gas engine industry has a bright future before it, now that the gas producer has proved to be a commercial success.