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The Canadian Society of Civil Engineers.

INCORPORATED 1887.

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GAS AS A MOTIVE POWER, AND ITS RELATIVE COST.

(By W. H. Laurie, M. Can. Soc. C. E.)

Read Before the Mechanical Section 23rd March, 1905.

Gas was first introduced in the year 1793 by Murdoch, for illuminating purposes, and the first reciprocating gas engine was introduced one year later by Street, and in 1801 a second patent was taken out on a gas engine, setting forth the advantages to be gained by compressing the gas and air before entering the explosion cylinder. These two patents embodied two of the fundamental principles upon the merits of which later engines were made a practical success, although a period of sixty years elapsed from the date of these patents before a practical gas motor was made, and even then the consumption of gas per horse-power was about 100 cubic feet per hour per horse-power, six or seven times what it is to-day. It was not until 1876 that a really successful engine was produced by Otto, and from that date the gas engine has been gradually becoming a more serious competitor of the steam engine, and has within the last few years reached a stage where it has entirely out-distanced the moderate sized steam engine, owing to the high efficiency obtained from recent improvements in the details of construction together with improvements in the apparatus for generating the gas.

Gas.—Any combustible material, when subjected to a high temperature either by its own combustion, or, by the application of external heat, will be partially, or wholly converted into gas. There are three principal processes for making gas from coal, the products of which are known respectively as:—

1st.—Illuminating, or coal gas.
2nd.—Water and producer gas.
3rd.—Semi-water gas.

Illuminating Gas.—The first (illuminating, or coal gas) is usually made from bituminous coal, as that contains a larger percentage of volatile matter, and less fixed carbon than anthracite, it being only the volatile matter that is converted into gas, the fixed carbon remaining in the retorts in the form of coke.

The coal is placed (in charges from two to four hundredweight) in fire clay retorts, hermetically sealed, which have been heated to the necessary temperature for gas making (from 1,800 to 2,000 degrees). The coal is subjected to this heat for a period of five or six hours, by which time the coal will have given off all the gas it is capable of evolving.

The gas, on leaving the retorts, passes through a pipe leading to the hydraulic main, where a portion of the tarry matter is deposited, and the temperature reduced to about 140 or 150 degrees.

From the hydraulic main it is drawn off into a surface condenser, where the gas becomes cooled to normal temperature, about 60 degrees, and deposits the tar and aqueous vapor previously held in suspension.

From the condenser the gas passes to the exhauster, the function of which is to remove the gas from the heated retorts as fast as it is produced, and at the same time force it on with sufficient force to pass it through the various materials used in its purification.

From the exhauster the gas enters the apparatus intended for the abstraction of the ammonia in same, consisting usually of a scrubber, or washer, or both. The function of these devices is to remove all the ammonia and some of the carbonic acid and sulphuretted hydrogen in the gas.

From the scrubbers the gas passes to the purifiers, where the remaining impurities—carbonic acid and sulphuretted hydrogen—are abstracted by means of lime and oxide of iron. Under this process the following are the approximate results obtained from a ton of Newcastle coal, according to an authority on the subject:—

Gas (10,000 feet)..	380 lbs.
Tar (10 gals.)..	115 "
Ammoniacal liquor..	177 "
Coke (absolute)..	1,568 "
	2,240 "

Water Gas.—About 1784, Cavendish discovered that hydrogen, which had been previously known as "Inflammable Air," was one of the component parts of water, but no practical use was made of the discovery until 1824, when J. H. Ibbetson took out a patent for a special method of making illuminating gas, by passing steam through a mass of incandescent carbon; and even then no apparatus was designed that could be considered a commercial success, until about 40 years after. Among the water gas processes in use to-day, that of the Loomis-Pettibone is one of the most widely known in America.

This plant consists of two generators from five to eleven feet in diameter, and from twelve to eighteen feet in height, and steam boiler, with necessary valves, &c. The generators are lined with firebrick, with firebrick arched grates, ash-pit and flue to boiler in the bottom. They are provided with a door on top for firing and admission of air; two cleaning doors above the grate and one below the grate into ash-pit.

The vertical boiler is of the multitubular type, and of suitable size to correspond to the generators, and is connected at its base with the generators. An exhauster is connected with the top of the boiler beyond the producer valve.

In Operation.

The generators are supplied with a layer of coke about five feet thick, which is ignited at the top, the exhauster creating a downward draft; when this body of fuel is ignited, coal is charged at intervals, raising the fuel bed to about eight feet above grates, and there maintained.

Bituminous coal is generally used and is fed through the feed door in the top of the generator. Air is also admitted through the same doors and by means of the exhauster is drawn down through the grates and ash-pits of the generators, up through the vertical boiler and then to scrubbers and exhauster, from which it is delivered to gas holder.

When the exhauster has brought the fuel up to a state of incandescence, the charging doors are closed, and valves altered, so as to direct the flow of gas as desired. Steam is then turned into the ash-pit of one generator, and, in passing through the incandescent coal, is decomposed, forming gas. From the first generator the gas passes through the connecting pipes shown near the top of the generators, and down through the second generator, then into the base of boiler and up through the same, and thence, after being washed in a scrubber, is passed to gas holder.

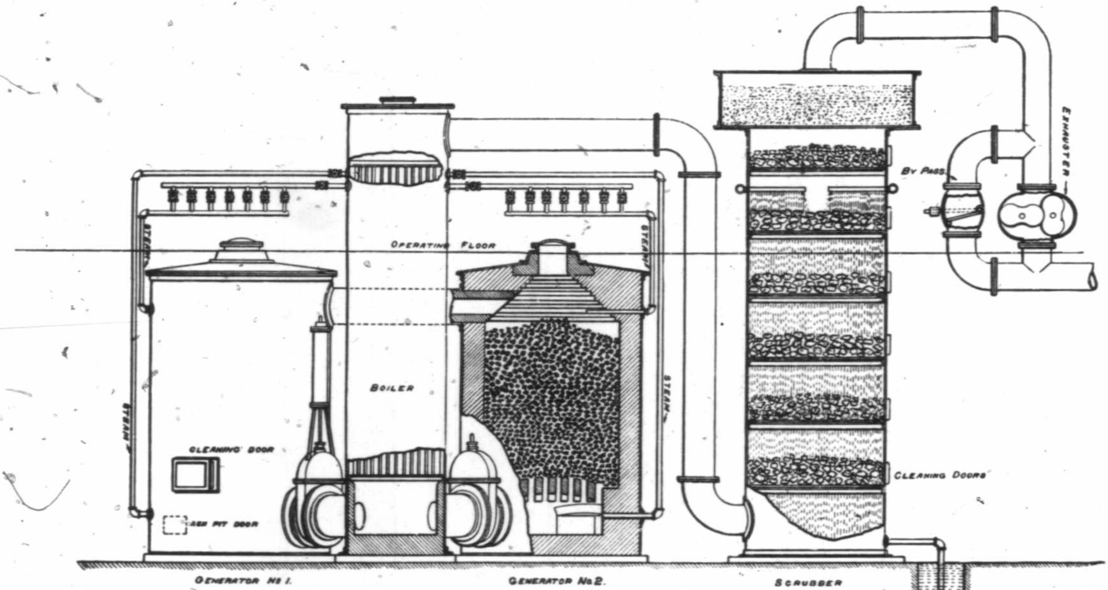

OPERATING FLOOR
STEAM
STEAM
STEAM
STEAM
BOILER
CLEANING DOOR
ASH PIT DOOR
BY PASS
EXHAUSTER
CLEANING DOORS
GENERATOR No 1.
GENERATOR No 2.
SCRUBBER

FIG. 1.

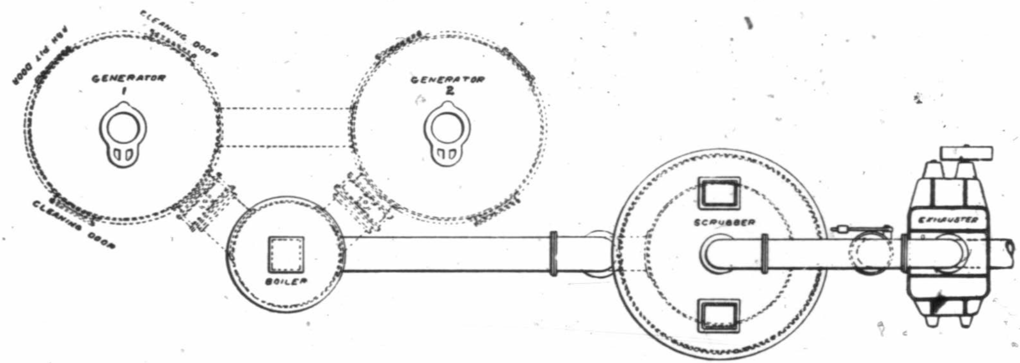

GENERATOR
1
GENERATOR
2
CLEANING DOOR
ASH PIT DOOR
CLEANING DOOR
BOILER
SCRUBBER
EXHAUSTER

FIG. 2.

Water gas is made for about five minutes, when the temperature of the fuel beds having been considerably reduced, the steam is shut off and the process reversed.

The process of making water and producer gas is alternated at intervals of five minutes or so. In making the second run of water gas the course of the steam is reversed, i.e., the steam is turned into the ash-pit of No. 2 generator and down through No. 1.

While the fires are being blasted, and during the making of water gas, the hot gases, in passing through the boiler, give up a large proportion of their heat for the production of steam to be used under generators for decomposition.

The great advantage of the double generators is that as all the gas is made to pass through the fire, the tarry matter from the coal is converted into fixed gases that can be conducted any distance through ordinary pipes, and at any temperature or pressure.

In operation, a plant, such as I have described, will produce about three volumes of producer gas to one of water gas. The production per ton of bituminous coal is about 35,000 to 45,000 cubic feet of water gas, and 100,000 to 150,000 cubic feet of producer gas.

This system is, however, more especially adapted to large power plants, and, except under special conditions, is of greater capacity than is required for small units.

Semi-Water Gas.—In order to produce a cheap apparatus for small plants, extensive experiments have been made, resulting in what is known as the semi-water gas producer. Since then a large number of different makes have been placed on the market, in sizes from 8 horse power and upwards. This is an evolution of the water gas apparatus, i.e., in the water gas plant, steam and air are supplied alternately, whereas in the semi-water plant, the steam and air are supplied at the same time, and the amount of steam so reduced in volume as not to interfere with the temperature of the fuel (usually about one pound of steam per pound of fuel consumed). The general form of apparatus comprises the following principle parts, viz.:—

1.—The producer, or generator.
2.—The saturator.
3.—The hydraulic box.
4.—The coke scrubber.

Producer.—The producer is a cylindrical steel shell lined with firebrick and fitted with a revolving grate. There is an annular space between the brickwork and the outer shell, through which the air for the combustion of the fuel passes from the saturator to the bottom of the producer., A central collecting bell is suspended from the top and keeps the fuel at a uniform level. One or two charging hoppers are provided, either in the centre or one on each side of the bell. The bottom of the producer is closed by a water seal, which permits of cleaning and removal of ashes without interruping the continuous operation of the plant. The air and steam, in passing upward through the incandescent fuel combines with the carbon in the formation of gas.

Saturator.—The saturator is a water jacketed pipe or vessel in which water is maintained at a constant level. The gas, as it passes from the producer, is hot; the saturator not only reduces the temperature, but the entering air in its passage through the saturator on its way to the bottom of the producer, comes in contact with the heated water, and picks up a certain amount of steam vapour, which on its course through the fire increases the calorific value of the gas there being formed.

In some cases the separate saturator is dispensed with and an evaporator attached to the top of the producer which supplies the necessary steam.

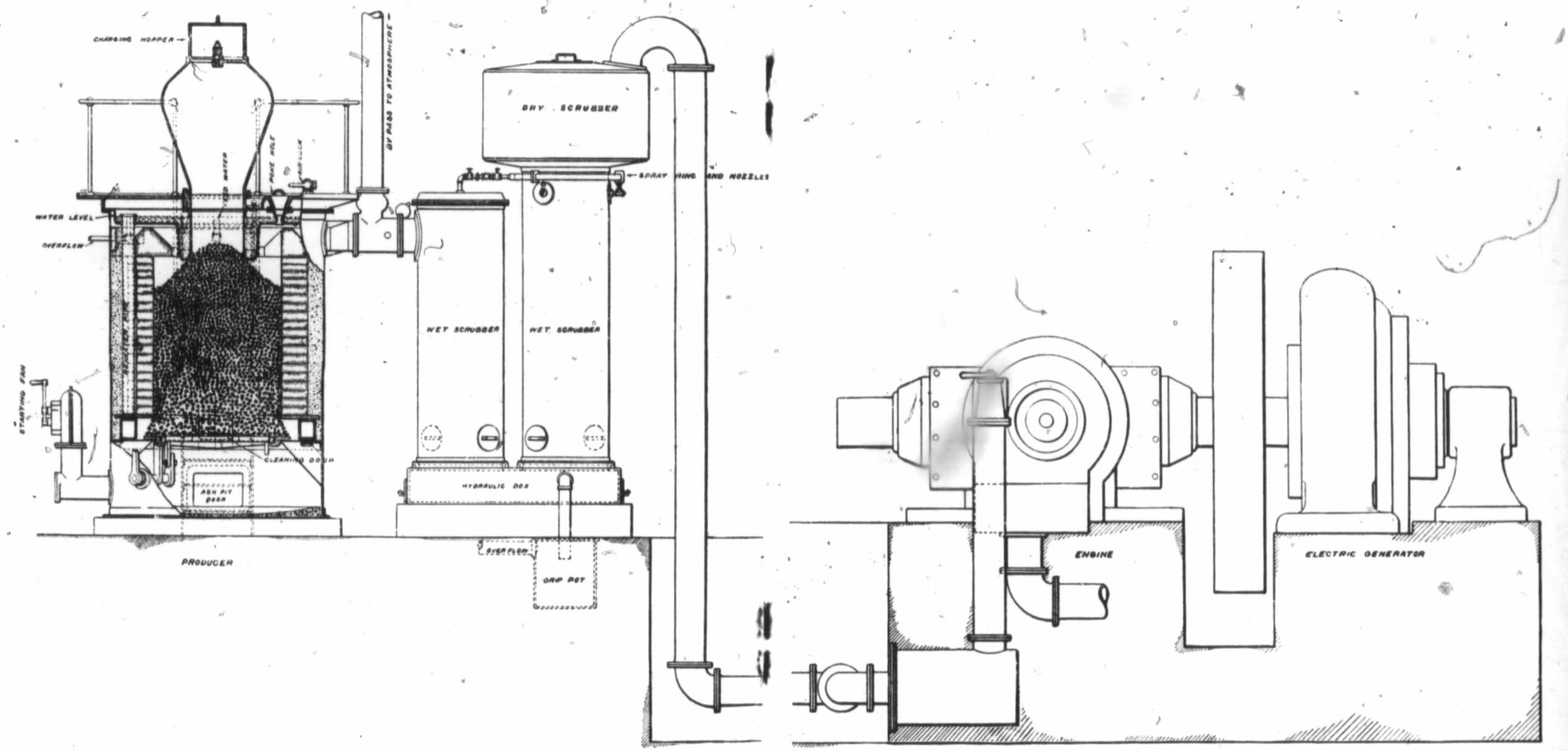
Hydraulic Box.—From the saturator the gas passes to the hydraulic box which acts as a seal and prevents the gas from backing up into the producer. It is provided with an inclined water trough which permits the removal of accumulated dust; the gas then enteres the coke scrubber.

Coke Scrubber.—This is a cylindrical steel shell filled with coke through which a small quantity of water trickles. The gas is here cleaned of any tarry products it may contain, and is cooled to atmospheric temperature, and finally, before reaching the engine, the gas passes through the sawdust scrubber.

Sawdust Scrubber.—This is fitted with trays filled with sawdust or other similar material which exposes the gas to a very large surface, and removes the last vestige of fine ash or other solid matter which may have been carried over.

Under some circumstances the sawdust scrubber is not necessary, the gas being sufficiently clean after leaving the coke scrubber for engine use.

Starting.—To start the plant a small hand blower is used, the fire is started in the generator, and coal added. The atmospheric valve is opened, and the blower used until the fuel becomes incandescent, and in a condition to give off gas (which usually takes from 10 to 15 minutes) when the atmospheric valve is closed and the gas allowed to pass through the apparatus. The engine is then started, and the production of the gas becomes automatic; the suction stroke of the engine furnishes the draft through the fuel and



CHARGING HOPPER
BY PASS TO ATMOSPHERE
DRY SCRUBBER
FEED WATER
POKE HOLE
AIR COCK
SPRAY RING AND NOZZLES
WATER LEVEL
OVERFLOW
WET SCRUBBER
WET SCRUBBER
STARTING FAN
CLEANING DOOR
ASH PIT DOOR
HYDRAULIC BOX
OVERFLOW
DRIP POT
PRODUCER
ENGINE
ELECTRIC GENERATOR

draws sufficient air and steam to combine with the carbon to keep up the supply of gas.

Fuel.—The fuel most suitable for donsumption in the semi-water gas producer is anthracite, owing to its freedom from sulphur, smoke and other impurities, and the product of a ton of coal is about 160,000 cubic feet of gas.

Of the different kinds of gas here mentioned, the illuminating gas is by far the richer, or higher in heat units, containing about 600 heat units per cubic foot.

The second in point of calorific value is the water gas, containing about 300 heat units per cubic foot.

The third is semi-water gas, containing about 150 heat units per cubic foot.

And the lowest in calorific value is the producer gas, containing about 110 heat units per cubic foot. This latter is due to the fact that the gas is obtained by a combination of oxygen and carbon, but to get the required volume of oxygen, we have to introduce four times the volume of nitrogen (as air is composed of one-fifth oxygen and four-fifths nitrogen) thereby producing a very weak or lean gas, as nitrogen has no value in heat or heat energy.

The principle upon which the producer operates is, that limiting the amount of air or oxygen admitted to the fuel to one half what would be required for complete combustion, or 1.33 pounds per pound of carbon, carbonic oxide gas is formed instead of carbonic acid gas (the latter being a product of complete combustion). As the steam passing through the incandescent bed of fuel is disintegrated, the oxygen combining with the carbon and the hydrogen remaining in the gas, very much increases its quality; owing to its high heat value and the quantity of air necessary being reduced and to the oxygen obtained from the disintegration of the steam, the nitrogen is reduced in like ratio.

In semi-water gas the heat value is increased to about 150 B.T.U. per cubic foot, and in straight water gas about 300 B.T.U. per cubic foot.

Illuminating gas, owing to its being made in air-tight retorts, is almost entirely free from nitrogen.

The following table gives an approximate percentage of the principal constituents of the four different kinds of gas:—

	Illuminating.	Water.	Semi-Water.	Producer.
Carbonic oxide..	5.7	42	25	23
Hydrogen..	46.5	48	19	2
Carbonic acid	3.1	6	6	3.6
Nitrogen.	3.7	5	49	63.5
Marsh Gas	35.7			7.4
Heat units, approx.	600	300	150	110

Relative power developed with various qualities of gas is shown in diagram, Fig. 4, in which semi-water gas at 150 B.T.U is taken as standard.

Producer gas of	110	B.T.U.	= 90 H.P.
Semi-water gas of	150	"	=100 H.P.
Water gas of..	300	"	=112 H.P.
Coal gas of	600	"	=117 H.P.

RELATIVE COST OF POWER.

In making a comparison of the costs of the various motive powers, to simplify the matter we will consider the question of fuel only, except in the case of illuminating gas, which we can only consider at its cost ($1.00) per 1,000 cubic feet.

Gasoline.—The consumption of gasoline in a gasoline engine is one-eighth of a gallon per B.H.P. hour. This at 20 cents per gallon will figure out as follows:—

.125 x 10 x 312 = 390 gallons @ 20 cents = $78.00 per B.H.P. per annum.

Illuminating Gas with the Modern Gas Engine.—A B.H.P. can be produced with from 14 to 16 cubic feet of illuminating gas, or, an average of 15 feet per hour. This would figure out as follows:—

15 x 10 (hours per day) = 150 x 312 (days per year) = 46,800 cubic feet @ $1.00 = $46.80 per annum per B.H.P.

Steam.—The average automatic high pressure engine of small powers requires from four to eight pounds of coal per hour per B.H.P., take the average six pounds; this figures out as follows:

6 x 10 (hours per day) x 312 = 18,720 lbs. @ $4.00 per ton = $37.44 per B.H.P. per annum.

Semi-Water Gas from Anthracite Coal.—The most reputable gas engine builders will guarantee their engines to develop a B.H.P. on one pound of coal in the generator; this will figure out as follows:—

1 x 10 x 312 = 3,120 lbs. of coal, $5.00 per ton = $7.80 per B.H.P. per annum.

Semi-Water Gas, from Gas Coke.—The author has recently obtained a copy of a test of an electric power plant of about 80 H.P. The fuel was common gas coke and the consumption was .92 lbs. per hour per B.H.P.; this figures out as follows:—

.92 x 10 x 312 = 2,870 lbs. of coke @ $4.00 = $5.74 per B.H.P. per annum.

Water Gas.—With large gas plants of 500 H.P. and over, the Crossley Bros. can produce a B.H.P. on .80 lb. of bituminous coal per B.H.P.; this would figure out as follows:—

.80 x 10 x 312 = 2,870 lbs. of bituminous coal @ $4.00 = $5.00 per B.H.P. per annum.

Horse Power For Different Qualities Of Gas

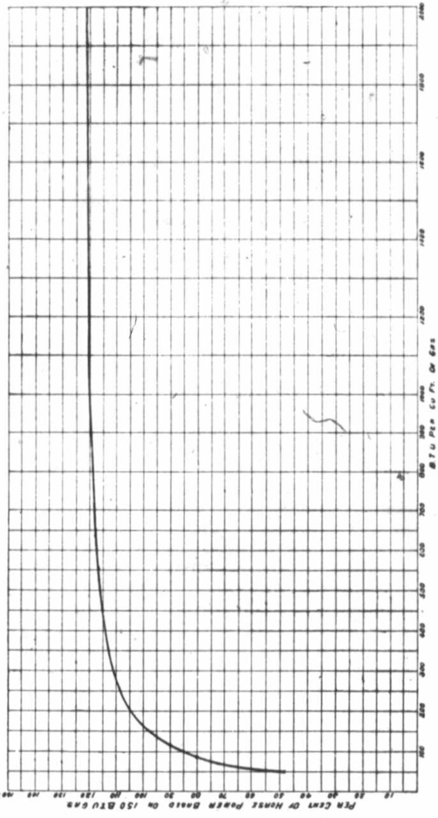


Fig. 4

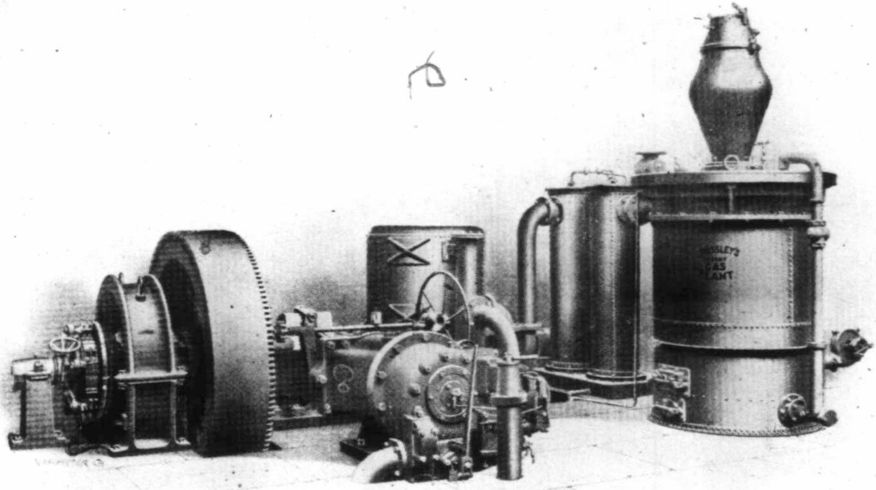


FIG. 5.

Summary.

COST OF POWER FROM VARIOUS MOTIVES PER B.H.P. PER ANNUM.

Power from	gasoline..	$78.00
" "	illuminating gas	46.80
" "	steam engine..	37.44
" "	semi-water gas.. .. .. (anthracite coal)	7.80
" "	semi-water gas.... .. .. (common gas coke)	5.74
" "	water and producer gas.. .. .. (bituminous coal)	5.00

From the foregoing it will be seen that the gas engine with a suitable gas producer will generate power at a lower rate of cost than any other source of power, although it is only within the last few years that it has been brought to its present high efficiency. Increased sizes and higher compressions are the most marked features in its recent development. These changes have necessitated material modifications of design.

Strains, due to increased heat, and higher pressures, made the operation of the large valves and the older designs an impossibility, therefore, new devices were necessary to overcome the new requirements.

Figures 6, letters A., B. and C. show the cylinder end of large engines as now made by Crossley Bros., showing improvements in the mode of constructing the main casting, water jacketed exhaust valve and cylinders. From these it will be seen that the exhaust valve box is now a separate casting, thus removing one of the main causes of fractured breech ends, which was one of the chief causes of trouble with large engines. There is no part exposed to the hot working fluids which has not got water on the other side, with the exception of the head of the inlet valve, which is kept cool by the admission of each fresh charge. This is the only satisfactory method of preventing pre-ignition, which is much more liable to occur with gases of high calorific value, containing a large percentage of hydrogen, such as illuminating gas, water gas and semi-water gas.

"The use of large engines for driving directly coupled dynamos for various purposes is rapidly coming into practice both on the continent and in the United States. In some cases, when used for special purposes, large engines are running night and day on their full output; this, of course, means a most severe test of every part of the engine; a year's run on such duty being, at least, equal to three years' ordinary work, and in one case an engine of 400 H.P. ran seven months continuously without being stopped. And there are a number of instances of large engines running 97% of the total hours of the year, the 3% including stoppages due to all causes, either affecting the engine or the electrical part of the combination."

"The requirements of the electricians for steadiness in running and accurate governing, have now got far beyond anything anticipated some years ago."

For great accuracy in the governing of large engines of the "Otto," or four stroke type, it is desirable to use four cylinders in any suitable combination, and an impulse automatically regulated by the governor; such an engine, if properly constructed, will give almost perfect regulation. In two engines tested by Mr. James Atkinson, M.I.C.E., the variation between full load and no load, was three-fourths of one per cent.

Ignition.—The hot tube ignition has proven the more satisfactory, and when suitable gas is available, it is impossible to improve on it for stationery engines. Hot metal tubes have, however, almost entirely disappeared, and long life porcelain tubes taken their place.

"When two tubes are fitted to an engine, each with its own chimney and flame, its own separate ignition valve and gear, with means of shutting off either to replace a burst tube without stopping, it looks as if there were not much room for improvement in this direction."

There are numerous instances when a suitable gas supply is not available, and electric ignition has to be used. For this purpose, unless a constant supply of electricity is to be had, small dynamo machines are considered the best.

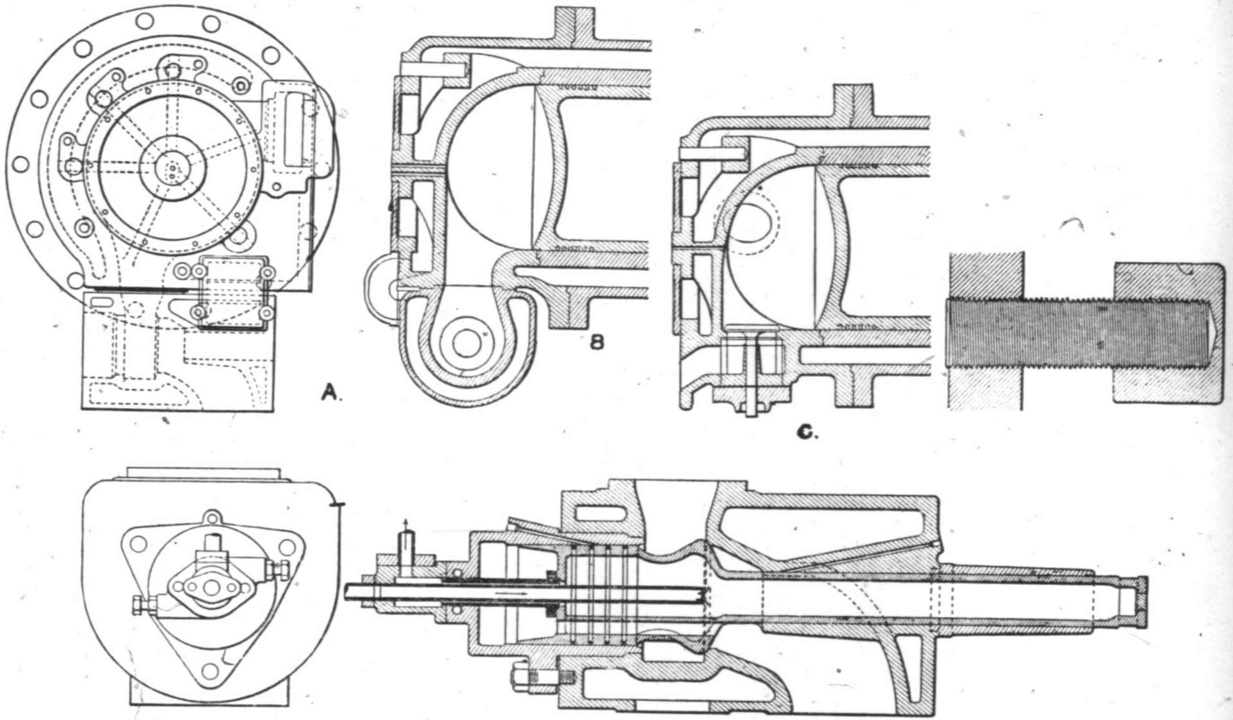


FIG. 6.