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THE ECONOMY OF SMALL GAS ENGINES USING MONTREAL ILLUMINATING GAS.

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Anything written at the present time concerning the gas engine needs no apology, for the rapidity of its growth—little short of marvellous during the past decade—and the remarkable manner in which it has recently gained in scientific and popular favour places it in the front rank of those objects which command the attention of all who are interested in prime movers.

Notwithstanding the fact that most attractive thermodynamic problems and possibilities of high heat efficiences were always presented by the gas engine, its development during its early growth was neglected because of the difficulties, chiefly mechanical, that necessarily had to be overcome before it could become of practical use. Manufacturers, following the path of least resistance, strove by improving the steam engine to obtain greater economy in heat engines; and indeed obtained the desired result. But with the high pressures used at the present time in the multicylinder engines, it is obvious that, without superheating, the limit of economy in this direction has been practically reached. Accordingly, during the past ten years serious attention has been directed to internal combustion engines, and the rapidity of the gas engine's development, with its attendant success, has justified and amply repaid all work done toward its improvement. Previous to 1893, the majority of engineers were doubtful about the ultimate importance of the gas engine as a prime mover; to-day units of 2,000 to 4,000 horse-power are being constructed, while those of 1,000 to 1,500 horse-power are in operation. Growth such as this is phenomenal.

Mr. Herbert A. Humphrey* gives an interesting table, showing the gas engine horse-power installed and in process of manufacture by the chief builders of Europe and America. In England Messrs. Crossley Brothers and the Premier Gas Engine Co. have supplied, or are about to supply, 7,600 horse-power, averaging 345 horse-power per engine. On the continent four leading manufacturers have made, or have in process of manufacture, engines capable of developing 115,000 horse-power, the average unit being about 675 horse-power.

TABLE I.—Compiled from *Engineering*, September 19, 1902.

List of Gas Engines of over 200 Horse-Power. Delivered or in Hand.

Where made.	For driving Dynamos.		Engines for other purposes.		Total Engines for all purposes.	
	Total No. of engines.	Total H.P. of engines	No. of engines.	Total H.P. of engines.	Total No. of engines.	Total H.P. of engines.
England	65	20 250	16	5.350	81	25,600
Europe	126	60,105	64	62.800	190	122,905
America	47	18 600	9	14,500	56	33,100
Total	...	..	..	..	327	181,605

While the production of gas engines in America is hardly as large as in Europe, three firms in the United States have made, or are making, engines capable of developing over 33,000 horse-power in units varying in size from 300 to 4,000 horse-power.

* Recent Progress in Large Gas Engines, *Engineering*, September 19. 1902.

These figures, which do not include units smaller than 200 H.P., merely indicate how rapidly the gas engine is being developed, and how widely it is employed at the present time.

In our own country, more especially in the east, the gas engine is not used to such an extent as its popularity elsewhere would seem to indicate that it should be. Installations are not numerous, and are for the most part in small units. This may be occasioned by natural influences, which would exclude the gas engine, even granted that it is a most economical heat engine. It is probable, however, that, in addition to this, there are other reasons. In most power installations it is doubtful if the idea of using the gas engine as a prime mover is ever entertained; and while there are places where at present it is, doubtless not the best and most economical prime mover to be employed, there are just as surely others where it asserts its superiority. It is certainly worthy of serious consideration.

That there should be hesitation about installing gas engines here is not surprising. The mere fact that there is such a scarcity of information concerning the consumption of engines using Montreal illuminating gas that it is almost, if not quite impossible to arrive at the cost of running gas engines in Montreal might, in large measure, account for it. So far as the author knows, there are no authentic records on this subject, and although this cost in Montreal may be closely inferred from tests performed in other places, it certainly would be more accurate and more satisfactory to have actual figures as a guide for estimates.

The present paper is written with a desire to furnish information on this point; and, with this object in view, the tests have been made under conditions as nearly similar to those which occur in practice as it is possible to make them. They are in no sense laboratory experiments. The two engines tested form a part of the equipment of the Department of Mechanical Engineering at McGill University. For convenience, these engines will be referred to as Engine No. 1 and Engine No. 2.

Montreal illuminating gas was used in all the tests included in this paper. The average calorific value of the gas is taken as 620 British thermal units per cubic foot, and was determined by means of tests (extending over a considerable period of time) made on the Junker Calorimeter. The calorific value was not obtained on the days on which the trials were performed, but, in the calorific tests made, the variation in this value was so trifling that the average may be used with the probability of very slight error.

An analysis of the gas made February 2nd, 1892, gave the following results:—

Benzene (C_6H_6)	0.5%
Other Unsaturated Hydrocarbons (C_2H_4, C_3H_6, etc.)	5.9%
Oxygen	0.2%
Carbon Monoxide	9.5%
Hydrogen	47.0%
Methane (CH_4)	32.9%
Nitrogen (separate determination)	3.8%

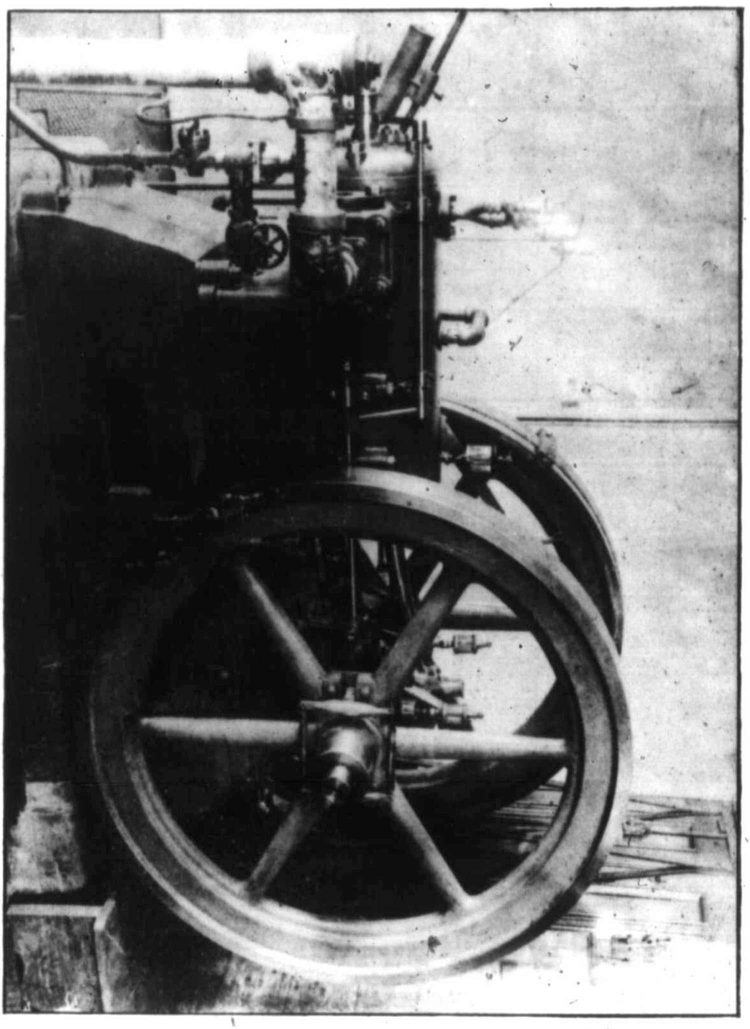
Carbon dioxide is absent, and the methane is possibly too low and the hydrogen too high.

For complete combustion one volume of the above gas requires 5.85 volumes of air, and at atmospheric pressure and at a temperature of 60° Fahr. one cubic foot weighs 0.03079 pounds.

TABLE II.—Calorific value of the gas analysed above.

Constituent.	Per cent. volume.	Calorific value per cubic foot B.T.U.	Calorific value of constituent in 1 cubic foot of gas. B.T.U.
Methane	32.9	1,065	350
Hydrogen	47.0	345	162
Carbon Monoxide	9.5	341	32
Benzene	0.5	4,000	20
Other Unsaturated Hydrocarbons	5.9	1,700	100
Calorific value of one cubic foot of gas			664 B.T.U.

If calculated from the above analysis, the theoretic calorific value of the gas will be found to be slightly higher than the value obtained from the calorimeter, and the value used in subsequent calculations. But since the analysis was made February 1st, 1902, and the calorimeter values were all made after September 25th, 1902, this amount of variation, about six per centum, is not surprising.



As stated previously, the conditions under which the trials were run were made to resemble as closely as possible those which would occur in actual practice. The method of conducting the tests was as follows:—The gas admission cock was fixed at that point, previously determined, at which the engine gave best results under all loads, and was left in this position during the series of trials. The amount of cooling water run through the engine during each trial was sufficient to prevent undue heating of the cylinder at full load, and throughout the series the flow was kept constant.

In all the trials each engine was running on its governor, and the brake load was kept as constant as possible during each trial.

The gas used was metered by means of dry meters, one on the main gas supply and one on the igniter circuit. All meters were calibrated by means of a standard wet meter after the trials and the readings were corrected.

The brake horse-power was obtained in each case by means of a brake on the fly-wheel of the engine. The load was measured on a Fairbank's weighing machine, weighing to one-eighth of a pound. Both engines were fitted with hot tube igniters, and as it is impossible with this means of ignition to have successive explosions occur at exactly the same point in the stroke, the indicated horse-power cannot be calculated with any degree of accuracy. Because of this the indicated horse-power is not included in the results, but indicator diagrams taken during each trial by means of Crosby indicators are appended. The revolutions were obtained by means of a revolution counter attached to the crank shaft of the engine. The revolutions, gas meter readings, brake loads, etc., were recorded trials were, for the most part, of one half hour duration, and the every five minutes.

The greatest error in the results, occasioned by reading the gas meter, is probably not over two per centum. The brake horse-power could be obtained on engine No. 1 to one-third of one per centum at five brake horse-power and to one-sixth of one per centum at ten brake horse-power; while the error in obtaining the brake horse-power of engine No. 2 was not greater than three-fourths of one per centum at one brake horse-power and three-eighths of one per centum at two brake horse-power.

The castings for engine No. 1 (Fig. 1) were bought from the maker, and the engine was built in the Mechanical Engineering Department at McGill University. The chief dimensions and particulars of the engine are as follows:—

Cylinder diameter.. .. .. 8.5″
Length of stroke.. .. .. 12″
Hot tube igniter
Governor of the hit-and-miss type.
Otto cycle.

The trials on this engine were all made on December 18th, 1902, and, as stated previously, the engine was run on the governor with approximately the same mixture of gas and air throughout all the trials. The engine ran continually during the series. Indicator diagrams were taken, but no explosion counter was used, and because of this and other difficulties referred to previously, the indicated horse-power is not worked out. The results and particulars of these tests made be seen in Table III.

TABLE III.—Results and particulars of trials on Engine No. 1.

Trial No.	1	2	3	4	5	6	7	8	9	10
Date of trial	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02	18 12/02
Revs per minute.	208	208	208	208	204.3	204.5	204.7	204.6	205	186.8
Load on brake	9.19	18.88	29.06	39.0	48.0	60.0	70.0	80.0	95.0	110.0
Brake horse power	0.827	1.700	2.62	3.51	4.25	5.31	6.20	7.10	8.44	8.90
Total gas per hour (cubic ft.)	199.5	201.0	221.0	224.0	263.0	260.0	244.0	250.0	262.0	268.0
Total gas per hour used by igniter (cubic ft.	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Gas per hour used in cylr. (cubic ft.)	193.5	195.0	215.0	218.0	257.0	254.0	238.0	244.0	256.0	262.0
Gas per brake h.p. per hour used in cylinder (cubic ft.)	234.0	115.0	82.1	62.1	60.5	47.8	38.4	34.4	30.3	29.4
B.T.U. per B.H.P. per minute	2420	1184	848	642	625	495	394	356	314	305

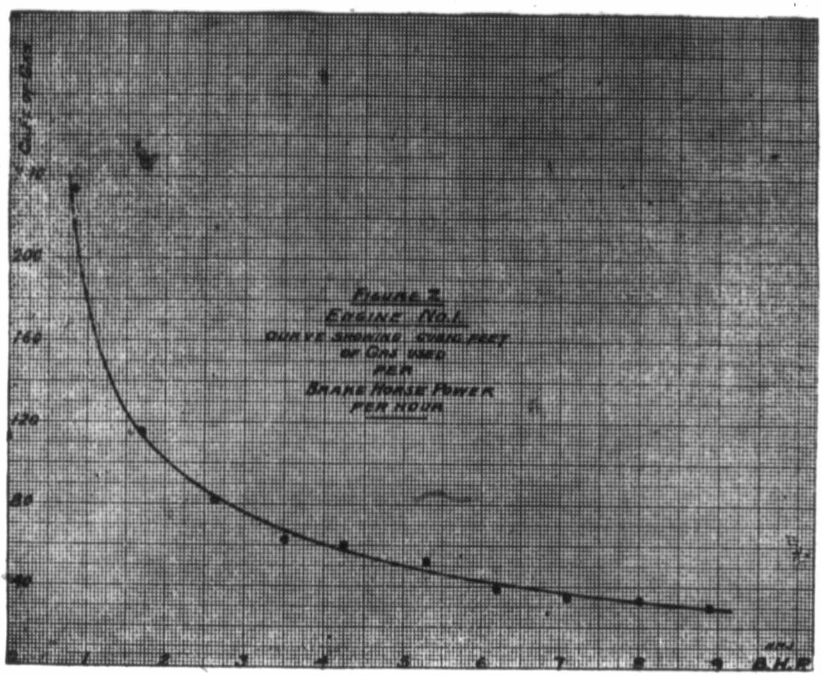


FIGURE 2
ENGINE No. 1
CURVE SHOWING CUBIC FEET
OF GAS USED
PER
BRAKE HORSE POWER
PER HOUR
200
160
120
80
40
0
1
2
3
4
5
6
7
8
9
B.H.P.

FIG. 2.

The mechanical efficiency as obtained from previous trials is, at full load, about 0.80.

These results are shown graphically in figure 2.

Engine No. 2 (see Fig.3) was built by Messrs. Crossley Brothers, of England. Its chief dimensions and particulars are as follows:—

Cylinder diameter..	7.5″
Length of working stroke..	8.4″
Length of compression stroke..	5.34″

Hot tube igniter.

Governor of the hit-and-miss type.

Atkinson's cycle.

It may be noticed in passing, that this engine has one working stroke for every revolution of the crank shaft and, in all, four strokes per revolution. Also, that the admission, compression, expansion and exhaust strokes are all of different lengths. (Fig.
expansion and exhaust strokes are all of different lengths. (Fig 4.)

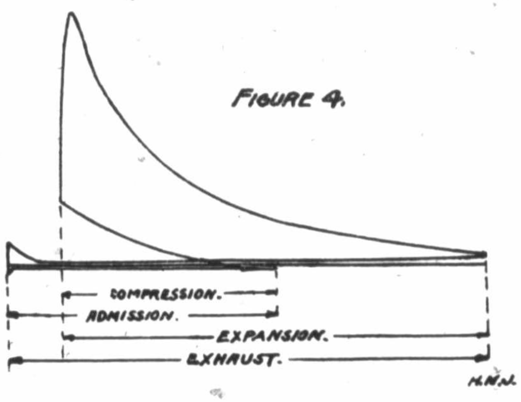


FIGURE 4.

The tests of Engine No. 2 were performed in the same manner as were those on Engine No. 1. The results and particulars may be seen in Table III.

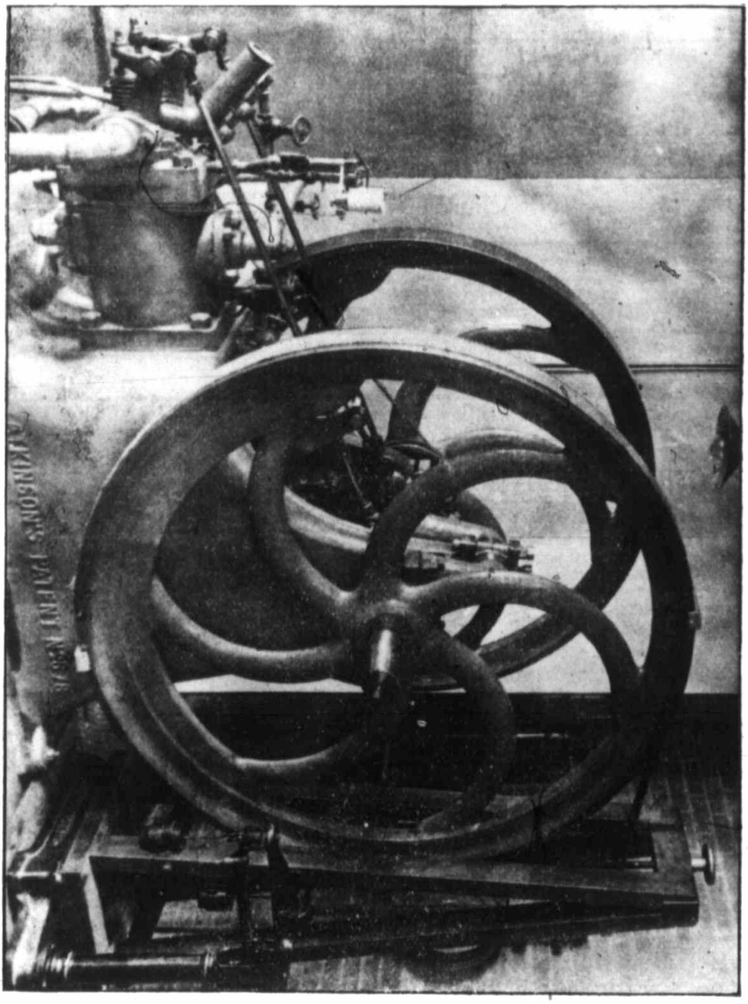

KINSON'S PATENT

TABLE III.—Results and particulars of trials on Engine No. 2.

Trial No.	1	2	3	4	5
Date of Trial	31/12/02	31/12/02	31/12/02	31/12/02	31/12/02
Revs. per minute	133	138.2	143.5	138.0	138.5
Load on brake	39.75	32.25	25.5	17.62	9.0
Brake horse-power,	2.28	1.91	1.57	1.04	0.54
Total gas per hour (cubic ft.)	95.3	92.9	90.3	86.6	80.2
Gas per hour used by igniter (cubic feet)	6	6	6	6	6
Gas per hour used in cylinder (cubic feet)	89.3	6.0	84.3	80.6	74.2
Gas per brake H.P. per hour used in cylinder (cubic feet)	39.1	46.7	56.8	85.4	165.0
B. T. U. per B. H. P. per minute	405	472	587	882	1701

Figure 5 shows these results graphically.

The mechanical efficiency of this engine is, at full load, approximately 0.70.

In all the above results the British thermal units per brake horsepower per minute are found from the gas actually used in the cylinder. The gas required for the igniter is not included as it is a constant quantity at all loads and should be considered separately.

By comparing the curves of Figs. 2 and 5 it will be seen that, when running under the most efficient load, the consumption per brake horse-power per hour is less for engine No. 1 than for engine No. 2, due probably to increased compression and size. Larger engines would show a further decrease in B. T. U. per H. P. per minute.

As the load decreases the gas per brake horse-power per hour increases very rapidly. This is indicated very plainly by the curve (Fig. 5) of total gas per hour used by engine No. 2. This curve shows that the amount of gas per hour required at 2.28 B. H. P. was only 15.1 cubic feet in excess of that required when running at 0.54 B. H. P. This small difference is partially due to the method of governing and would, no doubt, be much greater had the engine some such governing device as would make the explosion mixture of gas and air weaker at small loads than at large ones.

The figures, however, demonstrate (1) the importance of running engines of this type at approximately three-quarters to full load. (2) That the size of the units should be so chosen as to

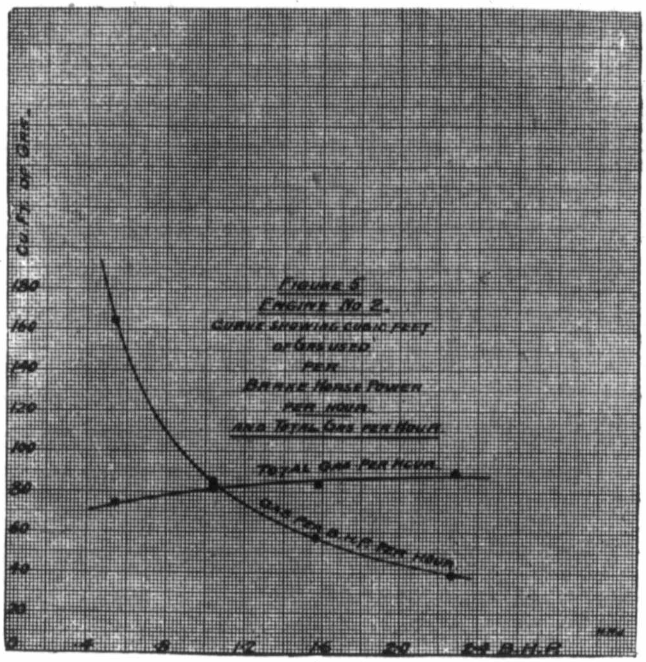


FIGURE 5.
ENGINE NO 2.
CURVE SHOWING CUBIC FEET
OF GAS USED
PER
BRAKE HORSE POWER
PER HOUR.
AND TOTAL GAS PER HOUR.
TOTAL GAS PER HOUR.
GAS PER B.H.P. PER HOUR.
CU. FT. OF GAS.
180
160
140
120
100
80
60
40
20
0
4
8
12
16
20
24 B.H.P.

FIG. 5.

make this possible and (3) that where there is a great variation in the load there should be multiplicity of units if attendant conditions do not recommend otherwise.

The cost of gas for running engine No. 1, at full load, for one hour a day for three hundred days, would be, with gas at $1.00 per thousand cubic feet, approximately $9.00 for the gas used in the cylinder, and twenty five cents for igniter gas per brake horse-power.

The amount of water necessary for cooling purposes varies with the seasons. A large number of trials performed at various times throughout the year, gives twenty gallons per brake horse-power per hour as an average quantity that need not be exceeded.

Assuming fifteen cents as the cost of 1,000 gallons of water, the cooling water would be, on this basis, ninety cents per B. H. P. for one hour a day for three hundred days. The total cost for gas and water would therefore be $10.15 for engine No. 1.

Calculated in the same way, the price of one brake horse-power for one hour a day for three hundred days would be for engine No. 2, when running at full load :—

Cylinder gas..	$11.73
Ignition gas..	.90
Cooling water..	90
Total..	$13.53

The lubricating oil will cost approximately the same as for a steam engine of the same size.

TABLE IV.—Cost of gas and cooling water for one horse-power for one hour a day for three hundred days.

	Cylinder gas.	Ignition gas.	Cooling water.	Total.
Engine No. 1	$9.00	$0.25	$0.90	$10.15
Engine No. 2	11.73	0.90	0.90	13.53

The attendance required by gas engines is a minimum and the cost for this relatively small. Very little skill and knowledge in engineering matters are demanded from the attendant since his duties are practically confined to starting, stopping and oiling.

The cost of running the above gas engines compares favourably with the cost of running steam engines of the same size.

If we assume fifty pounds of steam as the amount used per brake horse-power per hour, which is a fair value for single cylinder engines of the size in question, and six pounds of water as evaporated per one pound of coal burnt, the coal used per brake horse-power for one hour a day for three hundred days would be one and one-quarter tons. This at four dollars per ton would be five dollars. The water would cost approximately twenty-five cents at the above rate. If we consider the extra cost of boiler plant, piping, attendance, etc., necessary for the steam engine, the advantage that the gas engine has of making a much more compact and convenient plant and the fact that it can be run by others than licensed engineers, the difference between the cost of the two is slight. The gas engine cannot, however, without a gas producer, successfully compete with compound steam engines except in places where the conditions are peculiarly favourable.

In places where there is no gas supply and where the conditions do not recommend the building of a producer, an oil, instead of a gas engine may be used.

Engine No. 1 is designed for either gas or gasoline as a working substance, and it is hoped, shortly, to furnish figures giving the comparative cost of running this engine with each. Reports are favourable as to the running of oil engines. The results of tests, as may be seen from Table VI., show about the same number of B. T. U. used per B. H. P. per minute as do those of the gas engine. Assuming 310 as a fair value for the B. T. U. used per B. H. P. per minute by an oil engine, we can easily arrive at an approximate cost of fuel for an engine using kerosene oil (Canadian).

A sample of this oil, when tested in the Junker Calorimeter, gave a calorific value of 18,600 B. T. U. per pound. Taking 8.3 lbs. to the gallon, the British thermal units in one gallon are 154,380.

With oil at twenty cents per gallon the cost of oil per B. H. P. for three hundred hours would be approximately $7.20. This compares favourably with the cost of operating gas engines. The cost of gasoline will not differ much from that of kerosene oil.

Coffin * gives the following table on the comparative cost of pumping water by means of gas, gasoline, oil and steam engines:—

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* Coffin. "The Application of Gas, Gasoline and Oil Engines to Pumping Machinery." *Journal of the New England Water Works Association.* 1899.

TABLE V.—Giving comparative annual cost of pumping with different kinds of power.

	Oil Engine.	Gasoline Engine.	Gas Engine.		Steam Engine.	
Average daily pumping. Galls.	Oil at 9c. per gall.	Gasoline at 9c. per gall.	Gas at $1 per 1000 cubic ft.	Gas at 50c. per 1000 cubic ft.	Coal at $5. per ton.	Coal at $4. per ton.
50,000	$ 770	$ 735	$ 920	$ 675	$1,230	$1,160
100,000	1,250	1,200	1,580	1 035	1.740	1,600
200 000	2.200	2,050	2.815	1,820	2,525	2,300
300,000	3,085	2.875	4.000	2,510	3,130	2.850
400,000	3,920	3,640	5,140	3 150	3,700	3,350
500,000	4.745	4,400	6,270	3,780	4,200	3,790

The above prices include attendance, repairs and supplies, interest (4%), depreciation (3%) and fuel.

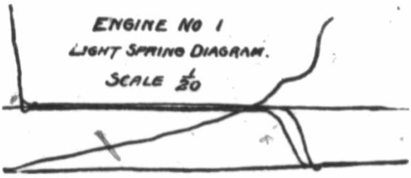
These figures indicate that in small units, at any rate, the internal combustion engine can, as far as cost is concerned, successfully compete with the steam engine; while the employment of gas and oil engines for driving electric lighting and pumping machinery, for automobiles and marine work, has long passed the experimental stage. Perhaps under no conditions does the gas engine promise more than in connection with, and when run by the gas from blast furnaces. So great has been its success already in this relation that one enthusiast has ventured to prophecy that "the day is not "far distant when iron will be a bye product of the blast furnace, "and furnaces will be primarily gas producers, while steam engines "will have to be sought for in museums." It is probable that even the most ardent supporters of the internal combustion engine do not look for this state of affairs in the immediate future. But when we realize that smelting one ton of iron supplies gas equal to 9,000,000 British thermal units and that the gas is more than three and one-half times as efficient when used in the gas engine as when used in steam boiler furnaces, and when, moreover, we bear in mind the successes of the past decade, we cannot but expect from these engines much more in the near future than has been, or is at present being accomplished.

Table VI. shows the results of tests made on gas and oil engines of various sizes. For convenience of comparison the performance in every case is expressed in British thermal units per brake horse-power per minute.

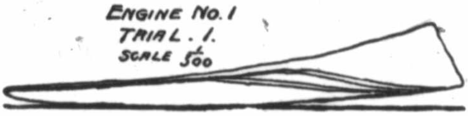
TABLE VI.—Consumption of gas and oil engines.

B. H. P. of Engine.	Authority.	Gas per B. H. P. per hour.	Calorific value of gas, B. T. U. per cubic feet.	British thermal units per B. H. P. per minute.	Remarks
90	*Trans. AM. Soc. Mech. Eng.* Vol. xxi. ..	16.74	1000	279	Natural gas
564.3	"*Engineering*" December, 1902 ..	142.0	98	232	Engine coupled to blowing cylinder. Compressor horse power given. Blast furnace gas used.
	OIL ENGINES. ..	Oil in lbs. per B.H.P. per hour.	B.T.U. per lb.		
8.57	Clerk. "*The Gas and Oil Engine*" ..	0.977	19,899	324	
7.72	Donkin. "*Gas, Oil and Air Engines.*" ..	0.840	19,700	276	American oil.
6 76	Donkin. "*Gas, Oil and Air Engines.*" ..	0.940	19,500	306	Russian oil.

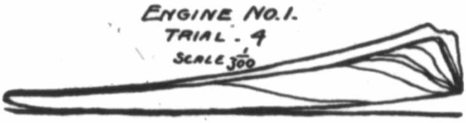
ENGINE No 1
LIGHT SPRING DIAGRAM.
SCALE $\frac{1}{20}$



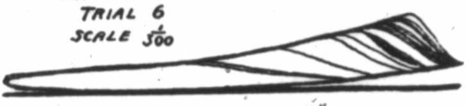
ENGINE No. 1
TRIAL. 1.
SCALE $\frac{1}{500}$



ENGINE No. 1.
TRIAL. 4
SCALE $\frac{1}{300}$

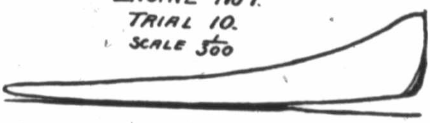


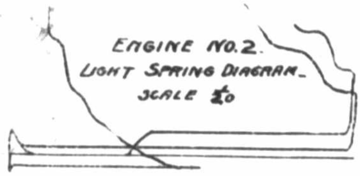
ENGINE No. 1
TRIAL 6
SCALE $\frac{1}{500}$



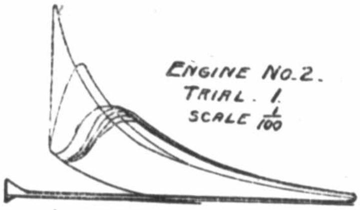
ENGINE No. 1
TRIAL 8
SCALE $\frac{1}{500}$

ENGINE No 1.
TRIAL 10.
SCALE $\frac{1}{300}$

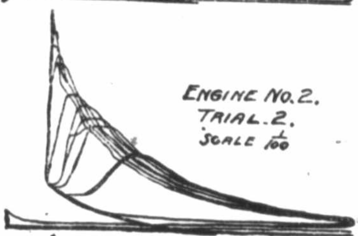




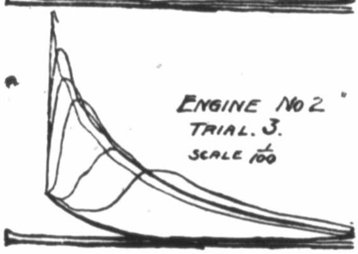
ENGINE NO. 2.
LIGHT SPRING DIAGRAM.
SCALE $\frac{1}{20}$



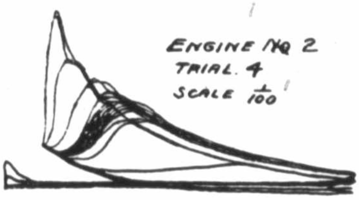
ENGINE NO. 2.
TRIAL. 1.
SCALE $\frac{1}{100}$



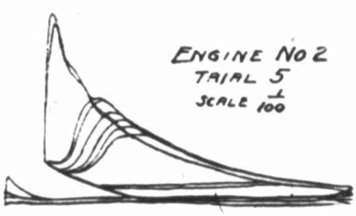
ENGINE NO. 2.
TRIAL. 2.
SCALE $\frac{1}{100}$



ENGINE NO 2
TRIAL. 3.
SCALE $\frac{1}{100}$



ENGINE NO 2
TRIAL. 4
SCALE $\frac{1}{100}$



ENGINE NO 2
TRIAL 5
SCALE $\frac{1}{100}$