MODERN ENGINES

AND

POWER GENERATORS

180 Brake Horse-Power 4-Cylinder "Fielding" Gas Engine.

Modern Engines

and

Power Generators

A PRACTICAL WORK ON PRIME MOVERS
AND THE TRANSMISSION OF POWER
STEAM, ELECTRIC, WATER, AND HOT AIR

BY

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"ELECTRICAL INSTALLATIONS" "ELECTRICAL DISTRIBUTION BY ALTERNATING CURRENTS AND
TRANSFORMERS" "PHOTOGRAPHIC AND OPTICAL ELECTRIC LAMPS" AND NUMEROUS
SCIENTIFIC ARTICLES AND PAPERS ON MECHANICAL AND ELECTRICAL ENGINEERING

WITH MANY HUNDRED ILLUSTRATIONS

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PREFACE TO VOLUME II

IN this Volume the Heat Engine, in which the working fluid is a true gas or air, is described in all its forms.

The simple " hot air " engine is described in its only useful types for small powers. It has still a field of usefulness, especially for water raising. The constant pressure gradual combustion type of internal combustion engine has, in the Diesel Engine, come again to the front; whether it is to be the permanent standard type or not, it has considerable scientific interest. We have also to note the new water piston engine of Vogt's invention. This is a remarkable departure from common practice. The gas or internal combustion turbine is of vast interest, and is briefly referred to; many advanced engineers are engaged on the problem, but little is known of results obtained.

Internal combustion Marine Engines for small powers are common, but no serious attempts have been made to introduce it for mercantile or naval shipping on any scale —its uses at present being mostly for pleasure or sporting purposes in launches. But the time is ripe for greater things. Gas can now be made with certainty, safety, and cheapness in gas producers. And these producers present no difficulties in the way of their application to marine propulsion by gas engines. The significant fact to engineers is that less than 1 lb. of common bituminous slack coal can do the work of 2 lbs. of the best Welsh steam coal, and a horse-power obtained for one-twentieth of a penny per hour. This opens up a new field for the gas engine of enormous magnitude.

Large gas engines are now common enough on land working with producer gas and furnace gases with satisfactory results.

The mode of action and general design of gas and oil engines of different makes are all very similar, the difference is only in details; out of all the classes in use it should be possible at this date to eliminate a number of them and come to some standard designs, embodying the good points of all of them.

The larger engines are more likely to arrive first at a standard type, the market for large powers is rapidly growing. No branch of manufacturing engineering business offers a more brilliant future than that of the internal combustion prime mover, not even electrical engineering. The internal combustion engine is a prime mover,— electrical engines are only power transmitters, replacing belts, pulleys, and shafting.

The growth of the internal combustion engine, and the gas producer, providing gas at a very cheap rate, has been very slow but very sure. And at this moment no steam plant of any design or make can produce 1 horse-power-hour at the same low cost as the gas producer and engine. And the difference will be greater still in favour of gas when the turbine is perfected.

This part of the work is therefore of great interest to all engineers and those concerned about the fuel supply of the future.

The questions regarding 4-stroke or 2-stroke engines compared with each other have yet to be settled ; also the question between the gradual introduction and combustion of the fuel at very high compression or the compression to moderate extent and subsequent explosion has also to be settled.

The Author inclines to the idea that gradual combustion of fuel with moderate compression of pure air and a 2-stroke cycle will prevail for oil engines of large powers. This subject will be still further considered in next Volume.

Many thanks are due to the various firms for information and illustrations of their engines, readily and willingly given regarding their specialities.

Next Volume will deal with Prime Movers on Wheels ; Portable, Traction, Road and Rail Locomotives, and Motor Cars ; with Coal, Petrol, Oil as fuel, and Steam, Gas, and Electricity as the working medium.

RANKIN KENNEDY.

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CHAPTER I

INTERNAL COMBUSTION FLUID PRESSURE HEAT ENGINES

In Volume I. the fluid momentum or impulse engines are dealt with, in which the heat is utilised by the expansion of the fluid freely, producing a high velocity of the fluid itself, and the momentum of the fluid at the high velocity is converted into an impulsive force by impact upon vanes or blades, or upon other fluids.

It is equally economical whether momentum or pressure produces power. In the pressure engines the fluid is admitted behind a movable piston in either a hot or cold condition. In the first case it may be steam from a boiler or hot gases from a furnace. Under pressure the fluid presses the piston and moves it a certain distance, when the supply of fluid is cut off and the expansion of the fluid completes the stroke of the piston; at the end of the stroke the fluid is released and escapes.

In the second case gas is enclosed in a cylinder; heat is applied to the external surface of the cylinder; the gas expands and moves a piston through some distance. The gas is then displaced into a cooling cylinder, called a refrigerator; it contracts upon cooling; the piston returns, and the gas is again heated, expanded, and the piston lifted again. This is a type of engine in which the fuel combustion producing the heat occurs outside the working cylinder and piston.

In another type of engine air and fuel mixed together in proper proportion for complete combustion are admitted to a cylinder behind a piston and then ignited. The combustion produces a sudden rise in pressure, which propels the piston.

In a modified form the latter type is now made successfully to work upon a different cycle. Air is compressed behind a piston to such a pressure that it becomes nearly red hot. At the end of the compression fuel is injected and ignites, maintaining the pressure as the piston moves forward and the gases expand.

The student of thermodynamics has a vast amount of work before him in the science of heat; but the engineer, after all, has been little assisted in perfecting heat engines by the scientific theoretical treatment of the expansion of gases by heat.

James Watt laid down the conditions for successfully employing expanding gases in a cylinder to produce power, and no improvements since made have in any way advanced us beyond the fact that the gas expands, and, in doing so, pushes the piston

along, and becomes itself reduced in temperature by an amount of heat absorbed in order to maintain its increasing volume.

The relations between heat pressure and volume of gases may be here briefly examined from an elementary point of view.

First, then, let us take a non-conducting cylinder and piston, as in Fig. 2, 1 square foot in area of bore, and suppose the piston so small in weight that we may neglect its weight.   Let the piston stand in the cylinder 1 foot from the bottom.   The pressures on each side of the piston will be equal to the atmospheric pressure = 14.7 lbs. per square inch, or 14.7 × 144 = 2116.8 lbs. total.

Air expands $\frac{1}{273}$ part of its volume for every degree Centigrade of temperature rise; hence if we apply heat to the cylinder until the air below the piston rises to 273° from 0° C., the experiment starting from zero, evidently its volume will be doubled and the piston raised 1 foot high against the 2116.8 lbs. of atmospheric pressure.   Work equal to 2116.8 foot-lbs. has been done.

The thermal units required to raise the temperature from 0° to 273° is equal to the weight of air × 273 × specific heat of air at constant pressure.   In this case the heat only increases the volume and does not increase the pressure, and the temperature remains constant.   Some engines, we shall see, work on this principle.   At 0° and atmospheric pressure 1 cubic foot of air weighs 0.081 lb., and at constant pressure the specific heat of air is 0.237; hence 0.081 × 273 × 0.237 = 5.241 thermal units.

And these units have been used up as follows :—

      1st. Raising the temperature of the air 273°.

      2nd. Lifting the 2116.8 lbs. 1 foot high.

Now, we want to know the value of these two effects—How many units were expended upon the first and second?   If we can find this out we would then know how many foot-lbs. of work can be done by 1 thermal unit—a very important result.

A thermal unit is the quantity of heat required to raise 1 lb. of water 1° Fahr. in Britain, or 1° C. in metrical units.   Joule determined the mechanical equivalent for both scales by experiment, and found it equal to 772 foot-lbs. in Fahrenheit scale and 1390 foot-lbs. in Centigrade scale.

To return to our experiment, it will be easily seen that if we begin again with air at 0° C., and the piston fixed so that it cannot move at 1 foot from the bottom of the cylinder, and apply heat to raise the temperature of the air to 273° as before, that we will have no work done, but all the heat expended on raising the temperature of the air only.

The air is kept at constant volume and its pressure rises.   Under these conditions the specific heat of the air is 0.168—much less than it was under constant pressure. The thermal units expended now are equal to 0.081 × 273° × 0.168 = 3.715.   This quantity of heat must therefore have been expended wholly in raising the temperature of the air from 0° to 273° C.; hence in the first experiment we got—

    1st . . . 5.241, for internal + 2116.8 foot-lbs. external work

    2nd . . . 3.715,   ,,   + 0   ,,   ,,

    3rd . . . 1.526, lift   2116.8 foot-lbs. external work.

So that one thermal unit produces work equal to $\frac{2116.8}{1.526} = 1387$ foot-lbs.

ABSOLUTE TEMPERATURE

If a gas contracts $\frac{1}{273}$ of its volume for every degree Centigrade through which its temperature is lowered, it is evident that it would vanish altogether at a temperature of − 273° below zero (this temperature has been called the absolute zero).   The diagram Fig. 1 illustrates this in Fahrenheit's scale, in which the absolute zero is −460°. BZ is the temperature scale; F, freezing-point; B, boiling-point.   By careful experiments we know the ratio of the volume of air at F to the volume at B = $\frac{1}{1.3665}$; there-

fore it we draw, at right angles to BZ, two lines BA and FE proportional to the volumes of the air at these temperatures, and then join AE and produce it to cut BZ at a point X, this point will be equal to 492 equal degrees or divisions of the line BZ; showing the contraction of the air to nothing at 460° below F.

Naturally, contraction to nothing is physically impossible. As a matter of fact, the air first liquefies on reducing its temperature and then freezes solid, so that we may presume it would still be a solid at absolute zero. However that may be, it is very convenient to reckon gaseous volumes and pressures from absolute zero; so that if t = temperature from F, or thermometer zero, and r = absolute zero, then $r = t + 460°$ Fahr. scale, and $r = t + 273°$ C. scale.

The law of expansion of gases by heat is then: "*The product of the pressure and volume of any gas is proportional to the absolute temperature*"; or, in a formulæ—

$$PV = C \times r; \text{ or } C = \frac{PV}{r}$$

where C is a constant depending upon the kind of gas expanded.

FIG. 1.—Diagram of Absolute Temperature.

ISOTHERMAL AND ADIABATIC EXPANSION

To understand these terms we may return to our simple cylinder and piston experiments, and suppose we have a cylinder and piston as shown in Fig. 2, with a diagram alongside of it. The piston is, as before, 1 square foot in area, and 1 foot from end of the cylinder, and there fixed. The temperature of the air, to begin with, is zero = 0° C.; we now heat the air to 273° C. without allowing the piston to move. The pressure will rise from 2116.8 lbs. per square foot to 4233.6 lbs., or 29.4 lbs. per square inch.

If we now release the piston it will be pushed forward, and the air will expand, falling in pressure as shown by the curved line in the diagram. This is the curve of pressures found by drawing verticals from each of the equal divisions of the stroke 2, 4, 6, . . . 12, and marking them off in height corresponding to the pressures P at these points found by formulæ, and joining their upper ends by the curve, PV = a constant, or $P = \frac{\text{Constant}}{V}$.

Then at the point 6 the pressure on the piston is 2 atmospheres, and its volume = 3 divisions; hence PV = 2 × 3 = 6; at point 6, $P = \frac{6}{6} \times 2 = 2$.

Then at point 8, $P = \frac{\text{Constant}}{V} = \frac{6}{8} \times 2 = 1.5$

,,   ,,   10, P =   ,, $= \frac{6}{10} \times 2 = 1.2$

,,   ,,   12, P =   ,, $= \frac{6}{12} \times 2 = 1$

$$3 \overline{)\ 3.7}$$

Approximate mean pressure   . 1.23

By adding the several pressures and dividing by the number of divisions taken,—namely, 3,—we get the average pressure, 1.23 atmospheres.

This is approximate only. There are several rules for obtaining the mean pressure from diagrams of work. A common plan is to measure by a suitable scale the length of the ordinates half-way between each on the volume line. Add these pressures and divide the sum by their number. The indicator diagrams will receive more attention later on. Meanwhile we notice that as the piston rises the gas expands, and we know that if it is supplied with heat sufficient as it expands to maintain the temperature constant at 273°, that it will take so many thermal units = 1.526 to expand it to twice the volume. This is isothermal expansion, in which the gas or air is supplied with heat sufficient to keep its temperature constant while it expands. The piston rises 1 foot, at which height the internal pressures balance the external. The work done is as before.

V is the volume swept out by the piston at the different points represented by the
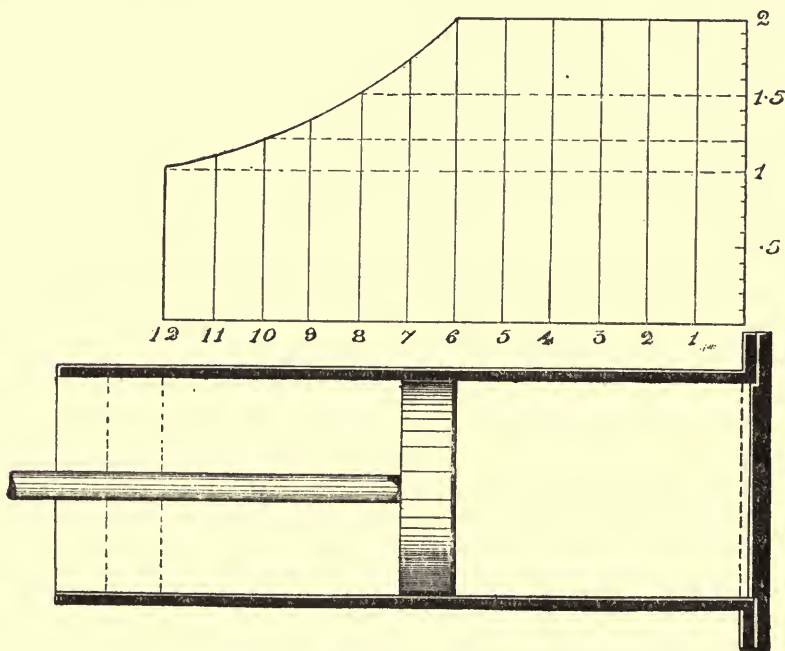
Fig. 2.—Expansion of Gas.

distances. For example, let us divide the cylinder into 2 inches and the pressure into atmospheres. Before release of the piston, P = 2116.8 lbs. And suppose we cut off the heat supply at the moment we release the piston, the temperature of the air will fall as it expands; for the gas absorbs heat in order to exist at greater volume, and this heat it takes from itself.

A rough idea of this physical fact may be pictured in the mind by imagining that heat exists in gases in two forms—first, sensible heat, measurable by a thermometer; and second, latent heat, which exists as a spring or cushion between the gas molecules.

If a gas expands, these cushions absorb more heat in order to enlarge; when a gas is compressed, heat is squeezed out of the cushions. It is evident, then, that if the gas expands and pushes the piston forward, and no heat is supplied while expanding, that the mean pressure will be less than that we have just calculated when the heat is supplied and the temperature maintained constant, and the curve will fall more rapidly; this is adiabatic expansion. The student will now understand isothermal and adiabatic curves of expansion. He will also note that they are entirely theoretical, and could only

be obtained in actual engines if we could use cylinders and pistons absolutely non-conductors of heat—a physical impossibility. The curves are valuable, however, as guides to what actions occur in expanding gases.

HOT AIR ENGINES

Turning to actual engines, and including in that term external and internal combustion engines, and excluding steam engines, a few elementary considerations are necessary before proceeding further.

There are two types of external combustion hot air engines. I distinguish between external and internal combustion engines by the test whether the fuel is burned in the working cylinder immediately behind the piston, or burned outside of the cylinder. In the former case the gases are admitted cold into the working cylinder, and heated by internal combustion; in the latter case the gases must enter through a valve after being heated by external combustion in some other vessel than the cylinder. Hence the so-called furnace gas engines should not be classed as internal combustion engines.

Diagram Fig. 3 shows the principles of the furnace gas engine, in which the air is pumped into and consumed in an external combustion chamber or fire. The back end
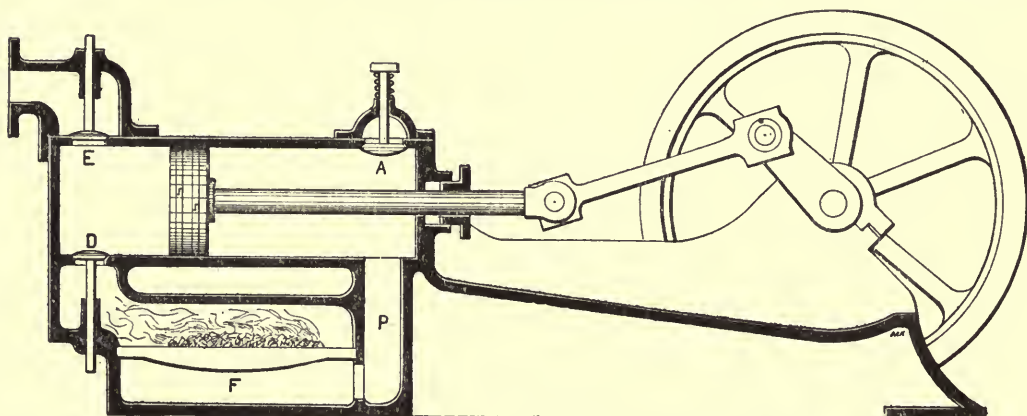
FIG. 3.—Furnace Gas Engine.

of the cylinder is the working end, the front end the pump P, and between the two the combustion chamber F. The pump piston is smaller in area than the working piston, and, as the pressure is constant, the power obtained is that due to the difference in area of the pistons multiplied by the pressure. If one piston has 100 square inches area, and the other 50 square inches, and the pressure 20 lbs. per square inch, we get $100 - 50 \times 20$ = 1000 lbs. pressure for available work. The working end has a valve D for inlet of the hot gases and an exhaust valve E. The pump has also an inlet for air A and an outlet P into the furnace.

We see in this model diagram the weak spots in this engine. First, the necessity for a valve D to let in the hot gases to the working piston. No valve has yet been found to stand a heated mixture of furnace gases for any length of time. Second, a furnace working under pressure presents many difficulties, so that only low pressures are practical; hence the engine must be bulky for its power. These objections apply to piston engines, but when this system is applied to turbine engines the valve difficulty disappears, for no inlet valve is required, and the low pressure can also be improved, as shall presently be shown. But as a hot air engine with reciprocating machinery it is of little present value, except for pumping water in country districts, where its extreme simplicity is a great consideration.

The other type of engine is represented by diagram Fig. 4. In this engine no

valves are necessary, the same air being used over and over again, any leakage being made up by an automatic valve or pump.
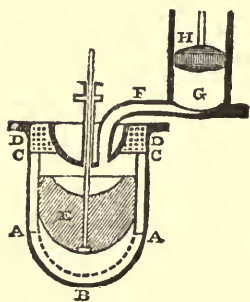

FIG. 4.—Diagram of Hot Air Engine.

To show the general nature of the apparatus by means of which the air is so treated, Fig. 4 is a vertical section of the principal parts of the air engine improved by Mr. James Stirling. DCABACD is the air receiver, or heating and cooling vessel ; G is the cylinder, with its piston H. The receiver and cylinder communicate freely through the nozzle F, which is at all times open while the engine works.

Within the receiver is an inner receiver or lining of a similar figure, so far as it extends, namely, from B to CC. The hemispherical bottom of this lining is pierced with many small holes, and the space between it and the bottom of the outer receiver is vacant. From AA up to CC the annular space between the outer receiver and its lining contains the regenerator, being a grating composed of a series of thin vertical oblong strips of metal or glass, with narrow passages between them. The inner surface of the cylindrical part of the lining, from AA up to CC, is turned, and the plunger E moves vertically up and down within it, fitting easily, so as to leave the least space possible without causing perceptible friction. This plunger is hollow, and filled with brick dust, or some such slow conductor of heat.

The space from CC to DD between the barrel of the receiver and the concave part of its cover, and above the upper edge of the lining, contains the *refrigerator*, which consists of a horizontal coil of fine copper tube, through which a current of cold water is forced by a pump, not shown in the figure.

There is an air compressing pump, not shown, which forces into the nozzle F enough of air to supply the loss by leakage.

The hemispherical bottom ABA of the receiver forms the heating surface which is exposed to the furnace.

The effect of the alternate motion of the plunger E up and down is to transfer a certain mass of air, which may be called the *working air*, alternately to the upper and lower end of the receiver, by making it pass up and down through the regenerator between AA and CC. The perforated hemispherical lining of the bottom of the receiver causes a diffusion and rapid circulation of the air as it passes into the lower end of the receiver, and thus facilitates the convection of heat to it, for the purpose of enabling it to undergo expansion, during which expansion it lifts the piston H. The descent of the plunger causes the air to return through

FIG. 5.—Stirling's Hot Air Engine.

the regenerator to the upper end of the receiver. It leaves the greater part of the heat corresponding to the range of temperature $\tau_1 - \tau_2$ stored in the plates of the regener-
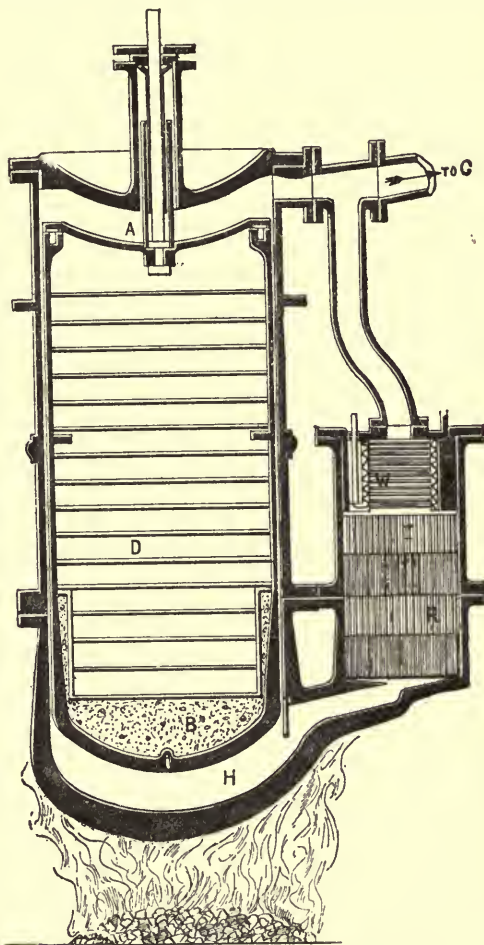
ator. The remainder of that heat (being the heat wasted by the imperfect action of the generator) is abstracted by the refrigerator, which also abstracts the heat produced by the compression of the air when the piston H descends. The heat stored in the regenerator serves to raise the temperature of the air, when, by the lifting of the plunger E, it is sent back to the lower end of the receiver.

The mechanism for moving the plunger E is so adjusted that the up-stroke of that plunger takes place when the piston H is at or near the beginning of its forward stroke, and the down-stroke of the plunger when the piston H is at or near the beginning of its back-stroke.

In a later patent a regenerator and heater and displacer is shown, as in Fig. 5. This engine worked with high pressure air up to 150 lbs. per square inch, and leakage was constantly made good by a small pump. C is the pipe to working cylinder, A the
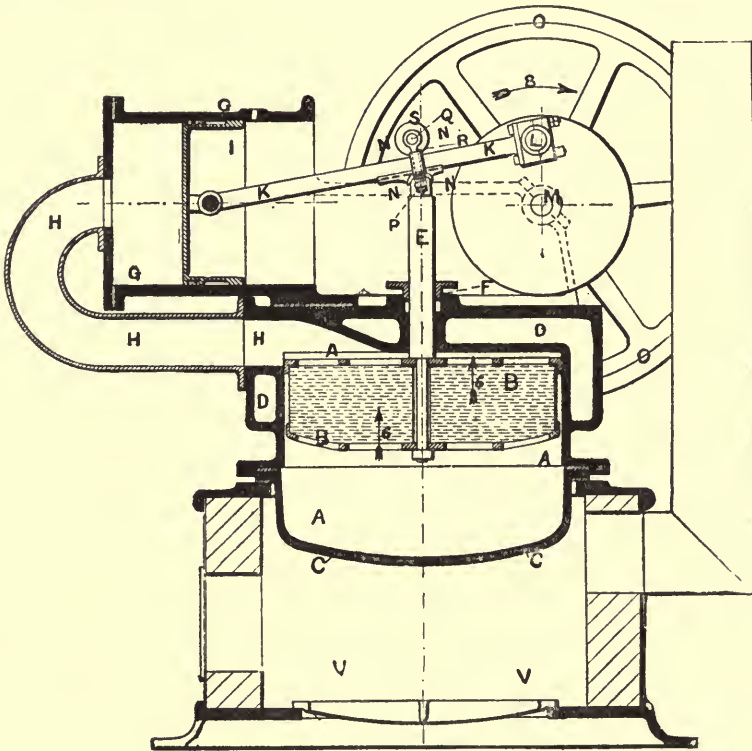
FIG. 6.—Robinson's Hot Air Engine.

cold end, and H the hot end of the displacer cylinder. The regenerator R consisted of bundles of thin sheet iron, and a refrigerator W consisted of copper pipes with circulating cold water.

The more modern form, as made by Messrs. Robinson, Manchester, has been more successful, especially for small motors. The section of this engine is shown in Fig. 6, a vertical section of the improved hot air engine. A is the air chamber in which the displacer or regenerator B is worked. C is the heater forming the lower part of this chamber. D is a jacket or water space through which water or other fluid circulates to keep the upper part of A cool, or a coil of pipe may be used as described hereafter. A rod E or its equivalent is connected to the displacer or regenerator, and this rod works air-tight through the gland F or its equivalent. G is the working cylinder in communication with the chamber A by the pipe or passage H, so that the variations of pressure in A act upon the piston I working in the cylinder. The piston I is con-

nected by a connecting rod K to the crank or disc pin L and shaft M. The upward or downward movement of the crank pin L is communicated to the displacer or regenerator B by means of the connecting rod K, the head N, and the rod E, whilst at the proper times the horizontal movement of the piston I drives the crank pin L, shaft M, and fly-wheel O.

The connecting rod K works through the head N; this head N is jointed into the rod E by the pin P, and a pin Q with adjustable bolts R or their equivalent connect a friction pulley or its equivalent S into the head N to run or roll upon the connecting rod K to reduce friction.

A coil of pipe may be used at D to cool the upper part of the chamber A.

V (Fig. 6) is the fire-grate shown with fire bars, but a burner may be used for liquid or gaseous fuels.

The displacer or regenerator B is formed as a metal casing, preferably of iron or steel, with openings in it for the passage of air in the directions as shown by arrows 6, and this casing is filled with wire gauze, or other suitably perforated material, through which the air will pass and lose its heat on the down-stroke and take up heat on the up-stroke.

Fig. 7 is a vertical section of a means for preventing the engine from running at an excessive speed. H represents a part of the air passage as described with reference to H, Fig. 6. W (Fig. 7) is the light valve, which is normally open as shown, but if the speed of engine rises the speed of the air in the passage H becomes great enough to move the valve W, so that it stops or contracts the passage H at each stroke of the engine, as shown by its position, indicated in dotted lines in Fig. 7. The speed of the engine is thus prevented from rising too high.
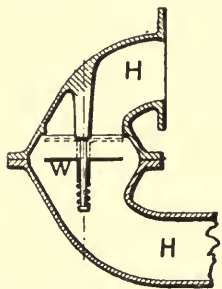
The action of the engine is as follows. The heater C (Fig. 6) is heated by the fire in the grate V or other suitable means.

Assuming the engine to be in the position shown in Fig. 6, the displacer or regenerator is now at about its highest point, and the air in the lower part of the chamber A is now heated and expanded, and the working piston I is now performing its outward stroke in the direction of the arrow 8.

FIG. 7. — Method of Governing Robinson Engine.

When the piston I has completed its outward stroke the displacer or regenerator B will have been lowered to the position as shown, owing to the downward motion of the crank pin L and the connections described; and when the piston I has half completed the return or inward stroke, B will have arrived at the bottom of the stroke, and by its descent it takes up heat from the air and consequently contracts the air, and the piston I is caused to complete the inward stroke by the momentum of the fly-wheel. B is now being raised, and in its ascent it gives up heat again to the air, causing it to expand and drive the piston I forward again. B is raised to the position shown. I completes its outward stroke, and the action is repeated as before.

The first type of hot air engine referred to in Fig. 3 has been further developed by burning the fuel as it enters cold through the inlet valve. It thus becomes an internal combustion engine, in which the fuel is burned in the cylinder and heats the air during a third of the stroke, and then the fuel and air are cut off, the rest of the stroke being performed by expansion. The pressure is constant during combustion, and the combustion gradual, not explosive.

Almost the earliest oil engine known, the Brayton, was made on this principle. It was also experimented on by Foulis of Glasgow, and the Diesel engine belongs to this class. The difficulty seems to have arisen from the fact that the gases, air, and coal gas, or air and oil gas, were first mixed and then pumped into the cylinder, a wire gauze screen being depended upon to prevent the back firing of the mixed gases.

Back firing, however, did occur, and mis-firing as well.

A method for working engines on this constant pressure system which requires no wire gauze screens and ensures ignition at every stroke has been devised on the same principle as the gas turbine described in Volume I. of this work. In this engine the fuel gas and air mix as they enter the cylinder and burn immediately, being ignited by electric sparks, and thus the two chief difficulties are overcome in this type of engine.

The engine is shown in Fig. 8 in diagram. It has two pistons, the front one acting as a pump for compressing air. The air is compressed into a receiver, and the petrol contained in another vessel connected to the air receiver, so that both are under the same pressure, beginning with the air and petrol under pressure, and the ignition plug sparking the pistons at their inmost position. We turn on the air and petrol. As the mixture enters by the valve D it is ignited and expanded, pressing the piston forwards. When about one-third of the stroke is completed the mixture of oil and air is cut off, and the remaining part of the stroke completed by expansion of the gases. Meanwhile the pump piston has been drawing in air through valve A ; on the return
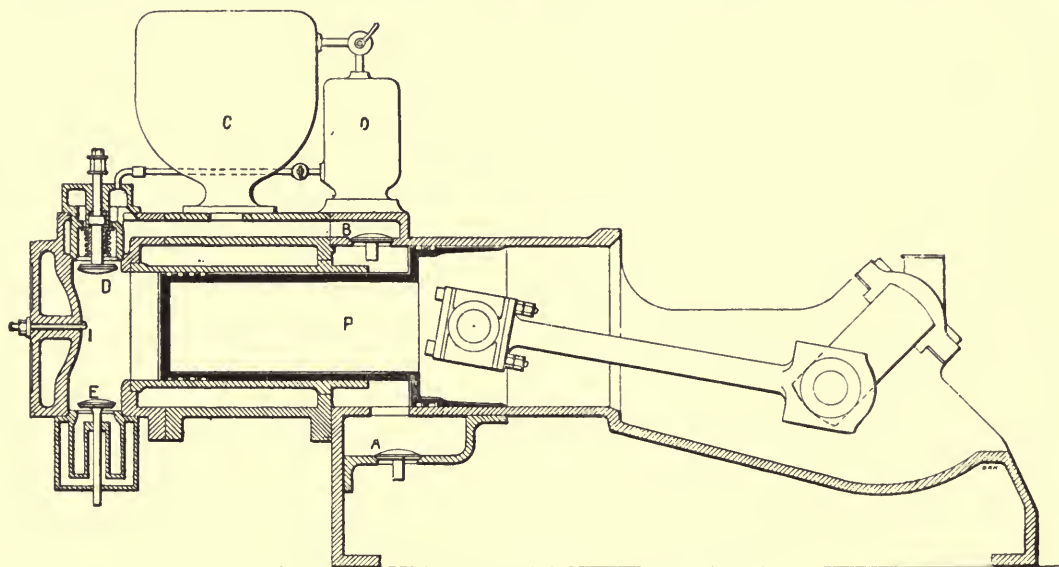
Fig. 8.—Gradual Combustion Engine.

stroke this air is compressed through valve B into the receiver C, and the exhaust expelled from the working cylinder through E, and then the same cycle is repeated. This design provides a constant pressure engine working on a 2-cycle system.

The Diesel engine operates on somewhat the same principle, only the air is compressed in the working cylinder, and the compressed fuel admitted by the valve to burn in the compressed air and supply the heat to do the work of expanding the gas.

The next type of engine is that in which the mixed fuel and air are drawn into the cylinder and fired by a flame or spark, the explosion forcing the piston up, and then, on the return stroke, expelling the exhaust. The gases are again drawn in for about a fourth of the stroke, again fired and exhausted. In this simple engine there is no compression. It was brought out by Bisschop and manufactured by Messrs. Andrews, Stockport, and proved an excellent little motor for small powers ; in fact, it still survives in spite of all modern developments. It represents excellent design, as shown in Fig. 9. The long piston rod is guided in the tubular guide G, which is slotted to allow the connecting rod to pass. The crank is nearly at right angles to the connecting rod at the moment of explosion, and the piston rod at the moment nearly parallel with the

connecting rod. The piston is travelling at considerable velocity when the explosion occurs, so that the shock is very much softened. I had one, about a quarter of a horse-power, which worked some tools for years without the least trouble. All it required was an occasional clearing out of the cylinder, as carbon collected in the lower end, choking the gas and air passages.

The air and gas are drawn in by suction through simple clack valves, which shut when the explosion takes place. The exhaust is discharged through a piston valve worked by an eccentric and lever. So far as the author is aware it is the only gas engine working at atmospheric pressure before ignition which has survived. By a slight modification of the gas valve it can run by petrol.

Fig. 9.—Bisschop Gas Engine.

Compression of the fuel and air before ignition was early suggested, and at first attempts in this direction the air and gas were compressed in one cylinder, and introduced into the other cylinder to do the work. It was clearly seen that much more power could be obtained from the engine working at greater pressures.

Beau de Rochas, a French engineer, first laid down the correct principles on a scientific basis necessary for the best results from internal combustion engines. He pointed out that the surface of the piston and cylinder should be the smallest possible with the greatest volume of contents. The volume increases as the cube, while the surfaces increase as the square of the dimensions, so that the proportion of cooling surface compared with the volume is less the larger the cylinders. In fact, it is found that above certain dimensions it is difficult to keep the temperature in the cylinder below the safe limit. Next, he advocated high piston speeds. This is an absolute necessity in internal combustion engines, for the pressure rapidly falls after the explosion, due to the rapid reduction in temperature. In this respect it is doubtful whether the common practice of firing the mixture in the cylinder when the piston is on the dead point is quite correct, for the time lost between the ignition and the expansion of the gases as the piston gains velocity affords an opportunity for a great loss of heat by conduction, whereas if the ignition occurred when the piston had acquired some velocity forward less loss would occur.

High compression is an advantage. It is, however, limited in engines in which the mixed fuel and air are together compressed, for the heat of compression permanently fires the mixture when compression is carried too far. But if the air and fuel are separately compressed, as in the Diesel engine and in the constant pressure engine

referred to in Fig. 8, compression may be carried to any practical extent. Compression of weak mixtures renders them more readily explosive.

Beau de Rochas then designed the 4-stroke cycle. First, suction drawing in the mixed fuel and air ; second, compression of the charge ; third, ignition at the dead point, and subsequent expansion and doing the work ; fourth, exhausting the spent gases. This far-seeing inventor was ahead of his time. No engines were made for or by him, and his patent was allowed to drop for want of support, and his only reward was a charitable pension of 500 francs from a Parisian scientific society, while others later on made huge fortunes out of this invention.

Very early Barnett, an engineer of Brighton, devised an engine working on a two-cycle system. The charge of fuel and air is compressed by a pump and blown into the cylinder when the piston is at the outer end of its stroke, and exhaust ports uncovered by the piston in that position. The incoming fresh charge sweeps out the burnt gases. The gases are then compressed on the in-stroke and fired at the dead point. This system was patented by Barnett in 1838.
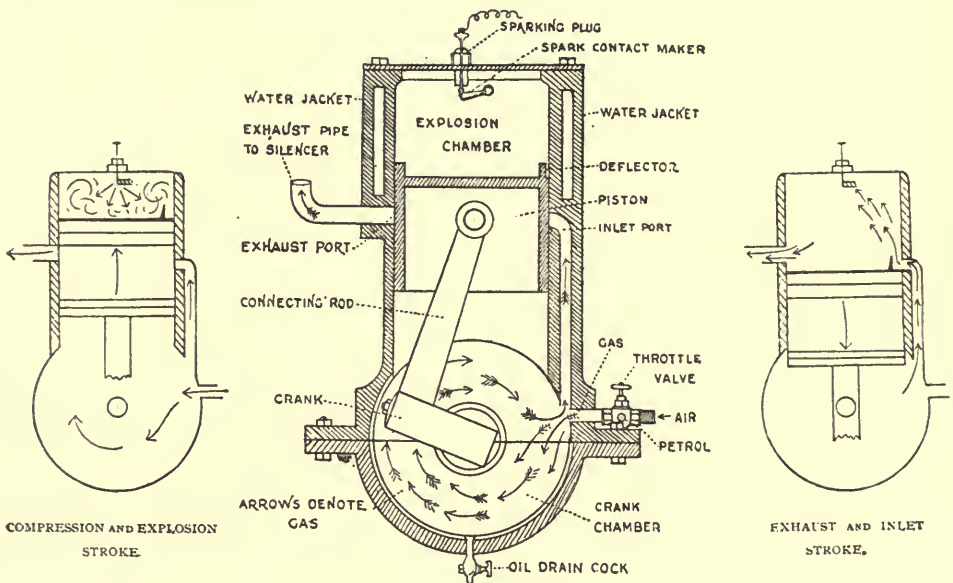
FIG. 10.—Simple Compression Engine.

This 2-cycle engine was again designed by a Mr. Holt in a patent of 1884, in which it is shown that it can be worked by only one valve. The crank is enclosed in a gas-tight case. The piston in its inward stroke draws in fuel and air into the crank case, and on its outward stroke slightly compresses this mixture in the crank case, as shown in Fig. 10. When the piston arrives at the end of the out-stroke it uncovers the exhaust port and the gas and air inlet. The compressed gases then enter and sweep out the burnt gases. The next stroke inward compresses the gases, and they are fired by sparking plug, and then expand doing the work.

It has some drawbacks in this simple form, but for small powers it is much used.

All the foregoing descriptions apply more particularly to gas and petrol engines, or light spirit oil engines, in which the volatile oil vaporises at ordinary temperatures.

In order to use heavy mineral oils it is necessary to gasify the oil, in order to make a combustible mixture with air.

Gasification of heavy oil may be carried out in two ways for gas engine driving. First, we may make the gas from the oil in the way gas is made from coal, by distillation in retorts, and then use the gas in an ordinary gas engine of any of the aforementioned

types.   Or secondly, we may construct the engine with a " vaporiser," which is simply considered as a special retort attached to the engine, in order to gasify the oil in small quantities as required for each stroke.

This principle is shown in Fig. 11.   The retort is shown at the end of the combustion chamber on the cylinder C.   The oil trickles down over a spiral of sheet metal, and part of the air is drawn through the retort to help in vaporising the oil.   In some arrangements all the air is drawn through the retort.   And in one arrangement the gases are compressed into the retort to such an extent that they ignite spontaneously and keep up sufficient heat in the retort for gasifying the oil.   It is usually necessary to heat up the retort at first starting, but after that it is either kept hot by the exhaust gases or by the internal combustion.
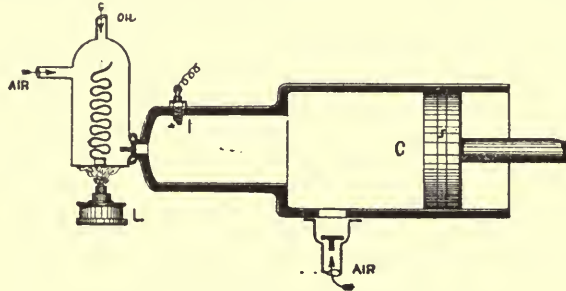
FIG. 11.—Oil Engine with Vaporiser.

At present the spirit oil engine is all the vogue for motor cars and launches, but to most engineers it is apparent that the heavy crude oils must be used where economy is necessary.   The oil engine for commercial work must consume cheap oils in either of the two methods here referred to.   There can be no doubt that such engines will prevail in the future, not only for road vehicles but also for marine purposes.

We now arrive at the question of gas producers other than public supply.   Gas for power purposes can be made from coal, coke, and other materials in special producers, and now there are many very convenient plants for cheap production of power gas.

Air in a limited quantity passed through incandescent fuel or carbon is only partially combined with carbon, and forms carbon monoxide—a combustible gas, but largely
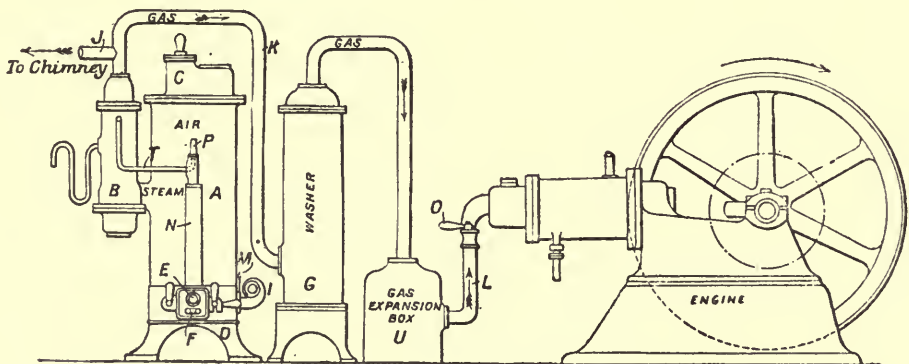

FIG. 12.—Gas Engine and Suction Producer.

diluted with nitrogen, so that its value is only about 112 B.Th.U., or a sixth of the power of coal gas.   A better method consists in passing steam into red-hot carbon. The steam decomposes the oxygen combining with the carbon, and the hydrogen coming off as gas.   The carbon and oxygen form carbon monoxide also as gas, consisting of about 50 per cent. hydrogen and 44 per cent. carbon monoxide, and 6 per cent. of other gases.   This is a good gas for power purposes.

Another system coming much into favour consists of an apparatus which works continuously while the engine runs, and, as the gas is drawn by suction of the engine from the gas generator, there is no tendency for escape of gas, as it is below atmospheric

pressure. This apparatus is made by Messrs. Taylor & Co., Paris. The description and illustrations are from their London agents, Messrs. C. Horne & Sons.

It is shown in Figs. 12 and 13,—Fig. 12 is a general view of the arrangement of the different parts; and Fig. 13, a section through the generator.

The action of the apparatus is, briefly, as follows. Air and steam are drawn by means of the suction of the engine piston through a mass of incandescent anthracite coal, and the gas thus formed passes first through a washer, then to an expansion box, and from there direct to the engine. The necessary steam is supplied from a vaporiser, through which the products of combustion from the anthracite pass immediately after leaving the furnace.

The producer itself is composed of two cylindrical portions A and B (Figs. 12 and 13), A being the generator in which the combustion of the fuel and the decomposition of the steam are effected, and B the vaporiser which produces the steam necessary for the formation of gas.

On the top of the generator is the hopper C, through which the fuel is introduced.

While the hopper is being filled its bottom part is closed by means of the slide R, which is moved by the lever S.

The interior of the generator is lined with fire-brick, and the incandescent fuel does not come in contact with any metal work.

At the bottom of the generator there is a door D (Fig. 12), which is used when the fire is lighted and when the cinders are removed. At E there is also a small mica window, through which the state of the fire may be seen; F is a door for the introduction of a fireiron. The method of working the apparatus is as follows :—

The door D being opened, some wood is introduced through the hopper C, at the top of the apparatus, and is lighted through the door D. As soon as the wood is lighted anthracite coal is put in through the hopper C, and the fire is blown up by means of the little hand fan I (Fig. 12). During this operation a cock on the branch J is open,

FIG. 13.—Section of Generator.

and the gases are allowed to pass to the chimney. As soon as it is required to start the engine the cock on J is closed, and the gases pass along the pipe K to the washer G.

The hot gases from the generator passing through the vaporiser B, which is filled with water up to the level of the bent pipe at the side, soon raise the temperature of the water to a point at which steam is given off. The steam passes along the pipe T (Fig. 12) to the top of the tube N, and down below the fire in the generator A. In its passage from the vaporiser to the generator it receives air through a cock at P, and is decomposed during its passage through the incandescent fuel in the generator.

The washer G is filled with coke, and has water running through it. During its passage through the washer the gas leaves behind it the dust and impurities that it
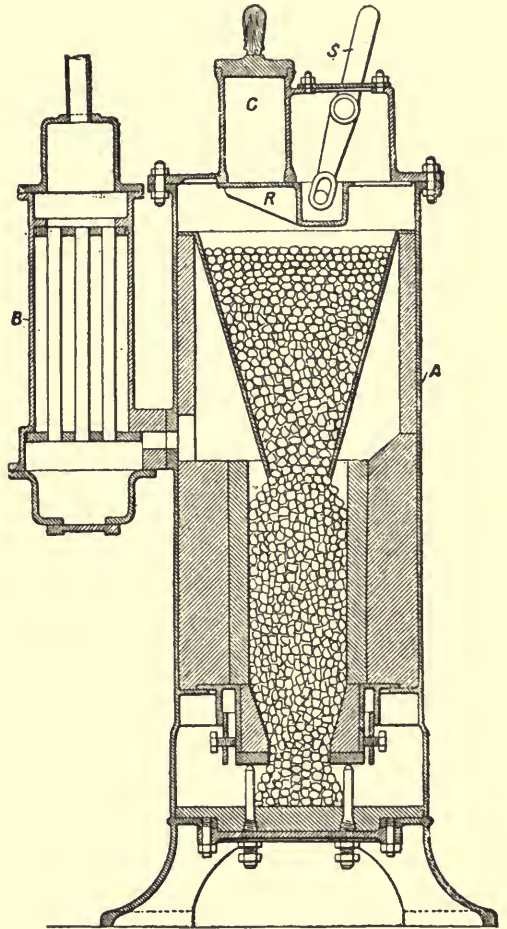
contains. From G it is conveyed to the expansion box U, and from there passes along the pipe L to the engine.

The pipe L is provided with a cock O, which is closed while the fan I is working, but which is opened when the cock on the branch J to the exhaust is closed.

If a light be applied to the gas issuing from the cock on L, as soon as J is closed the gas will burn, and the colour of the flame will indicate the time when the engine can be started. The starting is actually accomplished by closing the cock on L, stopping the fan I, and giving a few turns to the fly-wheel of the engine. When the fan is stopped the slide M is closed so as to shut off the admission of air through the fan.

The operation requires from ten to fifteen minutes from the time the fire is lighted to the starting of the engine.

The advantages of this generator are that it can be fitted to any existing oil or gas engine; it is extremely simple; there is no fear of explosion; it has no gas reservoir (the gas being produced automatically every revolution of the engine); and it can be put in anywhere without any advance of insurance rates being made. Very high economy is also claimed for it; it is said to run any good modern gas engine at a maximum cost of $\frac{1}{4}$d. per brake horse-power per hour. This is with anthracite costing 33s. per ton, and is for a 60 brake horse-power engine; with engines of less power the consumption is rather more.

There are many gas producers now in the market, and there seems a large future for them, especially for marine purposes, colonial, and agricultural work.

The construction of carburetters, vaporisers, gas producers, gas engine starters, and igniters, and their operation are detailed in the next chapters.

Having traversed the order in which the internal combustion and hot air engines originated, we can more particularly classify them thus :—

1. Hot air engines of two kinds—(a) and (b).
   (a) is the engine in which the fuel is burned in one vessel, heating the air which passes into the working cylinder with the products of combustion.
   (b) An engine in which the same body of air is heated, expanded, cooled, and contracted alternately, by shifting it from a hot to a cold chamber and back again.

2. Constant pressure internal combustion engines, in which the fuel and air are ignited and burn gradually as they enter the working cylinder.

3. Explosion engines drawing in air and fuel cold during a portion of the stroke, then ignited with a sudden rise of pressure, driving the piston.

4. Explosion engines compressing the fuel and air mixture in a pump, admitting the compressed mixture at the end of the out-stroke, blowing out the burnt gases from the previous charge, filling the cylinder with a fresh charge, compression in the working cylinder on the in-stroke, firing at the dead point, expanding and working on the out-stroke.

5. The well-known Beau de Rochas cycle, 4-stroke, on which most modern engines are worked.

Then we have to class them again according to the fuel employed—

1. Coal gas engines, supplied from ordinary gas lighting mains.

2. Producer gas engines, worked by water gas, wood gas, blast furnace gas.

3. Oil gas engines, worked by gas made from crude heavy oils in retorts.

4. Oil gas engines, worked by cheap, crude heavy oils, gasified or vapoured in a small retort or vaporiser on the engine cylinder.

5. Petrol and spirit engines, worked by air carburetted by injected or evaporated spirit or volatile oils.

They are all of importance and mostly in the evolutionary stages, and very likely in a few years' time only two or perhaps three common types will be evolved as some approach to a standard form,—if the gas or oil internal combustion turbine does not, in

the meantime, come up out of the unknown and render all further work on reciprocating engines futile.

PRACTICAL TYPES OF ENGINES

The first one to notice is of the furnace gas description, and was made to some extent in America under the name of the Bucket engine. It was proposed by Sir George Cayley, and has received a good deal of attention from time to time by inventors. It is not of great importance, so that only one of them is described in order to make the work more complete. The author in his apprenticeship days had some considerable experience with one of this class of engine. The chief difficulties arose from dirt and ashes in the cylinder, carried over by the furnace gases; also great wear of the valves, due to the hot gases passing them.
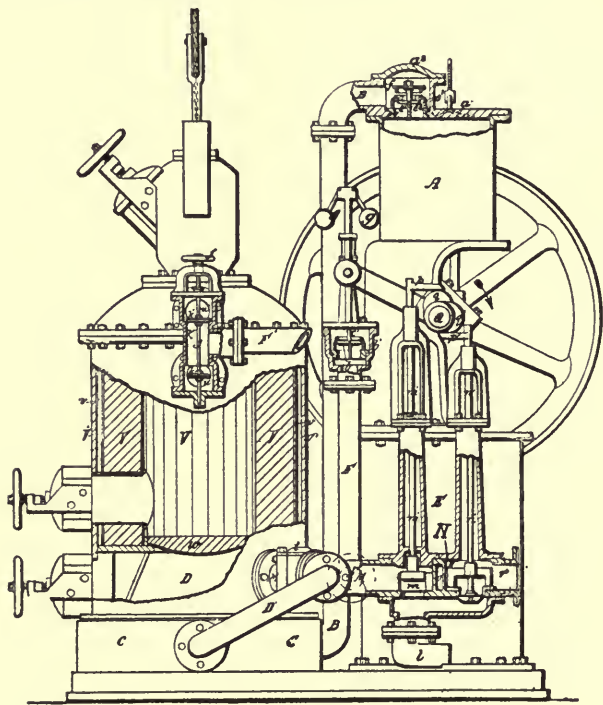
FIG. 14.—Side Elevation, partly in Section.   FIG. 15.—End View.
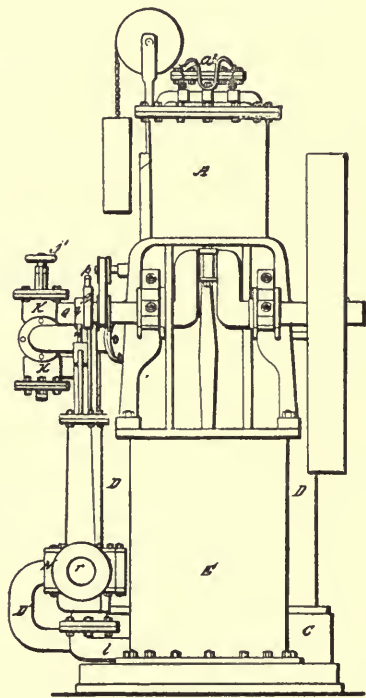
Furnace Gas Engine.

The engine here described is one patented by Long, of Bristol, and is fairly representative of the class. Fig. 14 is a side elevation partly in section, and Fig. 15 an end view. A is the air pump, and E the working cylinder. The pistons are connected by two piston rods, with a connecting rod between working the single crank. The inventor lays great stress upon a reservoir of air to be placed between the pump and furnace, also upon the arrangement of the valves.

As the piston of the air pump A descends the air is admitted by the ordinary air valves a^1 (Fig. 14) to the pump cylinder, and is pumped thence as the piston ascends, through the valve a, situated in the chamber a^2, conveniently carried on the cover of the pump A, and by the pipe B into the receiver or reservoir C, which may be conveniently situated below the retort D, as shown. By thus storing the air a constant and regular supply is afforded for actuating the piston in the working cylinder E, and hence spasmodic and irregular working of the engine is obviated.

The valve is of annular form, and is provided with two seats, e and e^1, the double seating being fitted into the cover of the air pump A, and surmounted by the fixed guard f, the top of which is dotted or perforated. The wings e^2 of the valve seating serve as guides for the valve. At Fig. 14 the valve a is shown closed.

As the piston of the air pump A ascends, the valve a is forced upwards from the seats e, c^1, and the air passes out below and above it to the pipe B. After contact of the valve with the guard f, such air as has not otherwise escaped passes out through the perforations in the top of the guard. By discharging the air below and above the valve the latter is constituted an equilibrium valve, and a shortened vertical travel suffices for the discharge of the air.

The force of impact between the valve and its seats is lessened, and noise is consequently reduced. The valve presents a small bearing surface to the compressed air reacting upon it from the receiver or reservoir C.

From the retort D the air is led by the pipe D^1 to the valve chest N, and circulates round an air space o therein, as hereinafter further mentioned.

By the pipe F, which opens into the valve chest at a point on the opposite side to that at which the pipe D^1 is connected, the air is conducted from the valve chest N to the retort D.

In the pipe F is an equilibrium valve b contained in the chamber b^1, and operated by the governor g (Fig. 14).

The governor spindle c takes at its lower end into a socket formed in the upper end of the spindle c^1, the lower end of which is secured to the valve b. Towards its upper end the spindle c^1 is connected to one end of a lever, is pivoted to the governor bracket, and provided at the other end with a balance weight, the normal tendency of which is to maintain contact between the bottom of the socket of the valve spindle c^1 and the lower end of the spindle c, thus enabling the governor to operate the valve. Between the fulcrum of the lever and the balance weight is a regulating screw.

By turning a nut accordingly, the weight may be tilted to close the valve b and arrest the working of the engine independently of the governor g.

From the valve b the air passes through the pipe F^1 to the conical valves k and k^1 enclosed in the chamber K, secured to the side of the retort D. The valves k, k^1 are fixed on the same spindle j, and are raised or lowered by turning the hand-wheel j^1 accordingly.

The valve k controls the admission of air through the port u, which communicates with the space v between the lining V and the casing V^1 of the retort. This space v extends to below the grate w.

The valve k^1 controls the admission of air through the port u^1, which communicates direct with the central chamber of the retort.

Thus the air may be directed to pass into the retort either above or below the fire, and accordingly the degree to which it is heated and expanded may be thus further regulated, and the working of the engine thereby controlled.

The valve m, by which the air is admitted to the working cylinder E, and the valve n, through which the air is exhausted therefrom, are enclosed in the valve chest N, connected to the cylinder E by the throat l.

The valve spindles m^1 and n^1 are furnished towards their upper ends with the tappets p and p^1.

On the driving shaft Q are carried the cams q and q^1.

The valve m is caused to rise by the cam q acting upon the tappet p, and thereby lifting the spindle m^1.

The heated air conducted from the retort D through the pipe M passes into the cylinder E through the throat l and impels the piston upwards.

A spiral spring having one end secured to the spindle m^1 and the other to the engine
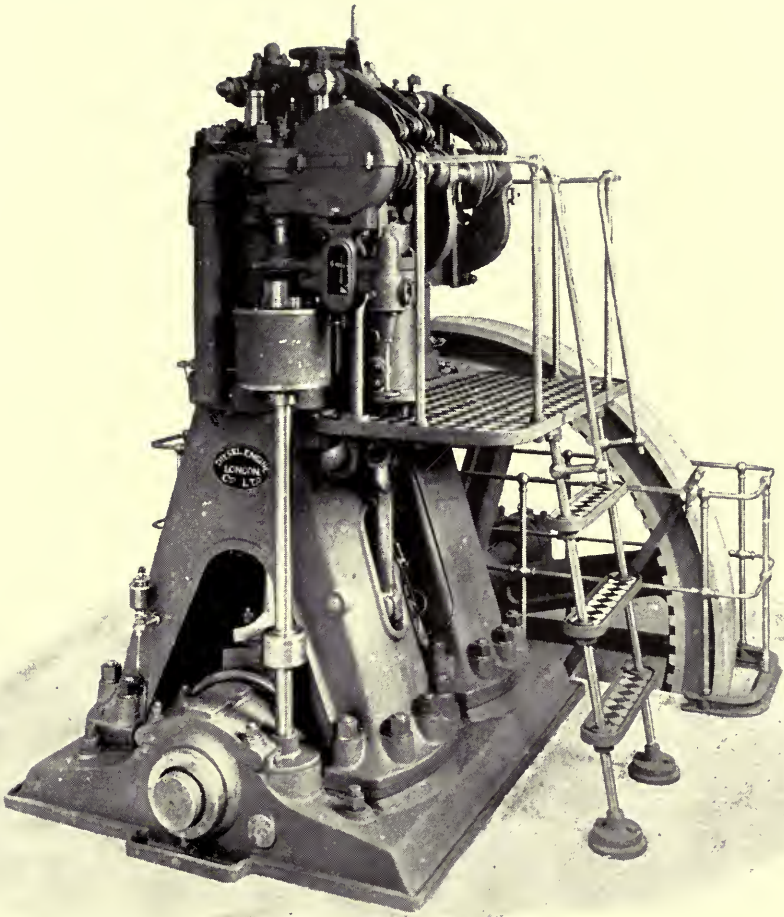
PLATE I.—80 BRAKE HORSE-POWER DOUBLE CYLINDER DIESEL ENGINE.

framing may be employed to maintain contact between the underside of the tappet p and the cam q.

In the continued rotation of the cam q the valve m is lowered and the air supply cut off. When the piston has reached the end of its upward stroke the valve n, which opens downwards, is depressed by the cam q^1 acting on the tappet p^1 formed on the spindle n^1, and the spent air issuing from the cylinder E by the throat l escapes at the valve n, and thence through the outlet $\imath$.

A spiral spring (not shown in the illustrations), having one end secured to the top of the spindle n^1 and the other to the engine framing, is employed to raise the valve n into its seat before the valve m is opened to readmit air to the underside of the piston of the working cylinder E. The cam q^1 governs the upward motion of the valve n. Anti-friction rollers may be fitted in the tappets p and p^1 to bear upon the cams q, q^1. By the arrangement and operation of the valves as above described the throat l is prevented from being unduly heated, and the valves are prevented from being suddenly forced into their seats by the compressed air. Noise arising from this latter cause is consequently lessened, and tear and wear reduced.

Should a vacuum occur in the working cylinder E the valve n opens and destroys it.

The admission valve m is partially surrounded by an air space o, to which cold air as it passes from the reservoir C to the governor valve b is admitted as hereinbefore mentioned. The valve m is thus kept cool.

The passage of cinders from the retort D to the valve chest N is prevented by a perforated screen placed over the mouth of the supply pipe M, in which is also fitted a door t, whereby ready access is obtained to the pipe for cleaning the same.

This class of engine, on tests, gave an indicated horse-power on the working cylinder of 40, while the pump indicated 21, leaving 19 horse-power for external work, the

FIG. 16.—Indicator Diagram Furnace Gas Engine.

mean pressure being 18 lbs. only. The brake horse-power was about 14, and it took about 3 lbs. of coke to work it per brake horse-power.

This engine belongs to the class in which the fuel is burned in the air at a constant pressure without explosion, and the chief trouble with it has been to get valves to work under these conditions. The pressure also is very low, and cannot well be increased. An indicator diagram from this type of engine with the pump diagram superposed upon it is shown in Fig. 16. The area enclosed between the two curves represents the available power.

We have already referred to Stirling's engine, in which the same air is alternately heated and cooled by an external furnace, and which belongs to Class I. Many fairly good working engines have been made on this system, and some are still on the market and doing good useful work. There are three makes of these engines—the Rider, the Robinson, and the Bailey engines. The Rider and Bailey engines are designed for water raising, for which purposes they are very successful, the cold water being passed through the cooler of the engine rapidly, and constantly affords an efficient refrigerator.

The Rider engine is shown in section, Fig. 17, complete in Fig. 18, and with the furnace open, showing how a new pot can be replaced, as they burn out in use by oxidation caused by the furnace gases. Referring to the sectional view, the mode of working is made clear thus :—

The compression piston C first compresses the cold air in the lower part of the compression cylinder A into about one-third its normal volume, when, by the advancing or upward motion of the power piston D, and the completion of the down-stroke of the
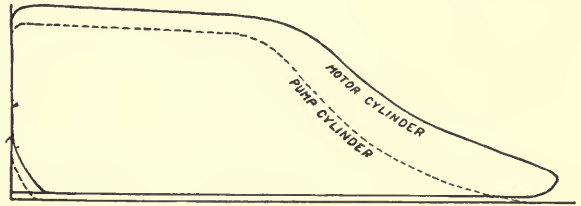
compression piston C, the air is transferred from the compression cylinder A, through the regenerator H, and into the heater F, without appreciable change of volume. The result is a greater increase of pressure, corresponding to the increase of temperature, and this impels the power piston up to the end of its stroke. The pressure still remaining in the power cylinder and reacting on the compression piston C forces the latter upward
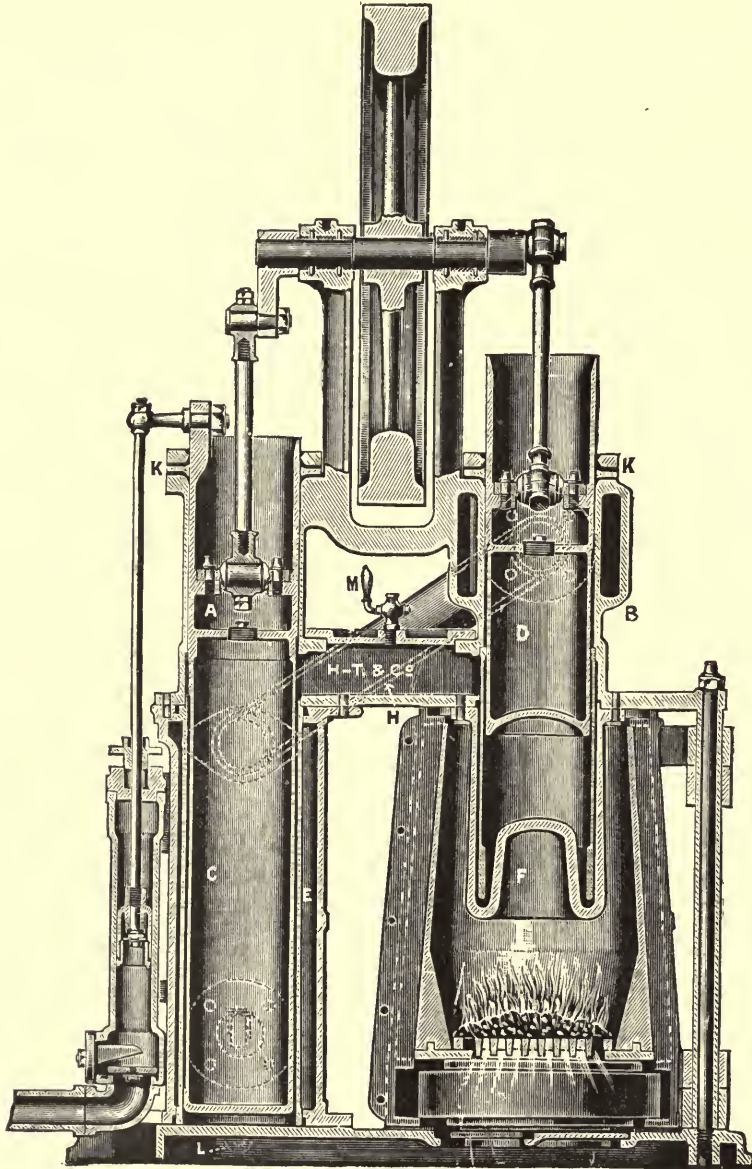

FIG. 17.—Rider Engine. Vertical Section.

till it reaches nearly to the top of its stroke, when, by the cooling of the charge of air, the pressure falls to its minimum, the power piston descends, and the compression again begins. In the meantime the heated air, in passing through the regenerator, has left the greater portion of its heat in the regenerator plates, to be picked up and utilised on the return of the air towards the heater. This process recurs at each revolution. The lower portion of the compression cylinder A is kept cold by a current of water which

circulates through the cooler E, which surrounds the lower portion of the cylinder. In pumping engines the water which is pumped answers this purpose. The heater F should be kept at a dull red heat by a steady fire (of coke generally) which is underneath it. The furnace is of the simplest kind, similar to an ordinary greenhouse stove. There are no valves or stuffing boxes to get out of order. The packings K are simple discs of leather; those on the hot side are kept cool by the water which circulates round the upper portion of the cylinder, so that there is no danger of overheating them.

The same air is used continuously, as there is neither influx nor escape, the air being merely shifted from one cylinder to another.

L is a simple check valve, which admits the air when the engine is started, and also supplies any slight leakage which may occur. It is generally placed at the back of the engine, at the lower part of the compression cylinder.

M is a small brass air cock on the regenerator, the opening of which stops the machine by releasing the pressure.

The makers, Messrs. Hayward, Taylor, & Co., have made and sold about 1000 of
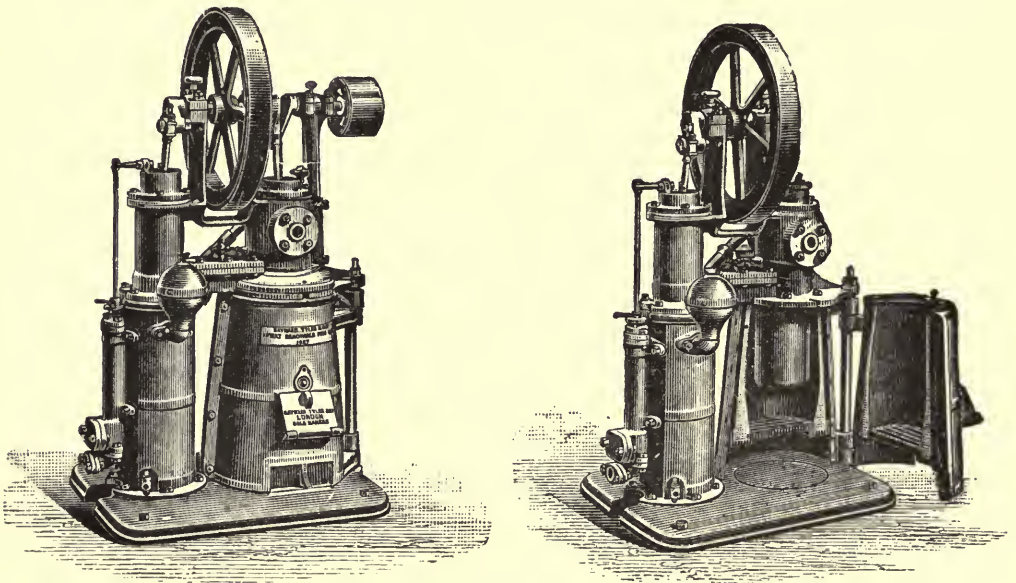
Fig. 18.—Rider Engine.

this type of engine. The cost of working is one penny per 1000 gallons of water raised 80 feet high; and as 1000 gallons weigh 10,000 lbs. raised 80 feet, we get 800,000 foot-lbs. of work done by this simple engine for one penny expended on fuel and oil. Their popularity is largely owing to their simplicity, safety, convenience in working, and economy.

For powers up to 1 horse-power they are often preferable to any other form of engine for water-raising.

The $\frac{1}{2}$ horse-power engine, which is the size most generally used, will raise 600 gallons an hour 70 feet high, or 220 gallons an hour 180 feet high.

For suctions not exceeding 25 feet the pump is attached to the engine, and is included in the price; this fact must be borne in mind in comparing with other motors, to which the price of a suitable pump has to be added.

The furnace is stoked like an ordinary house-stove or greenhouse furnace, requiring only a moderate heat to develop the power of the engine. The management is therefore readily understood by gardeners or indoor servants. There are no valves or small parts difficult to understand.

The most convenient fuel is small coke, but anthracite coal or wood may be employed. The engine requires only a few feet of iron chimney, or the chimney-pipe may be led into any ordinary house chimney.

In Rider's engine there are two cylinders and pistons, with a regenerator between them, and so also in Robinson's engine we have two cylinders and pistons, as shown in Fig. 6 in section.

Several engines have been made with the two pistons working in one cylinder, as shown in Figs. 19, 20, and 21, a German invention.

The engine here represented is fitted with two pistons in one cylinder, namely, a driving piston and a displacer. The motion of both the driving piston and the displacer is guided by means of cross-heads and slide bars, and the stroke is regulated by means of a double crank of unequal throw, the driving piston having about one-fourth more stroke than the displacer, which has in consequence a higher speed than the driving piston. The piston rod d, of the displacer a, passes through the piston b by means of a stuffing box, and the piston rod of the driving piston b forms the guide bars for the displacer rod d.

The air between the driving piston b and the displacer a is, when the engine moves forward, forced towards the hot air chamber through the chamber c^1, as indicated by the
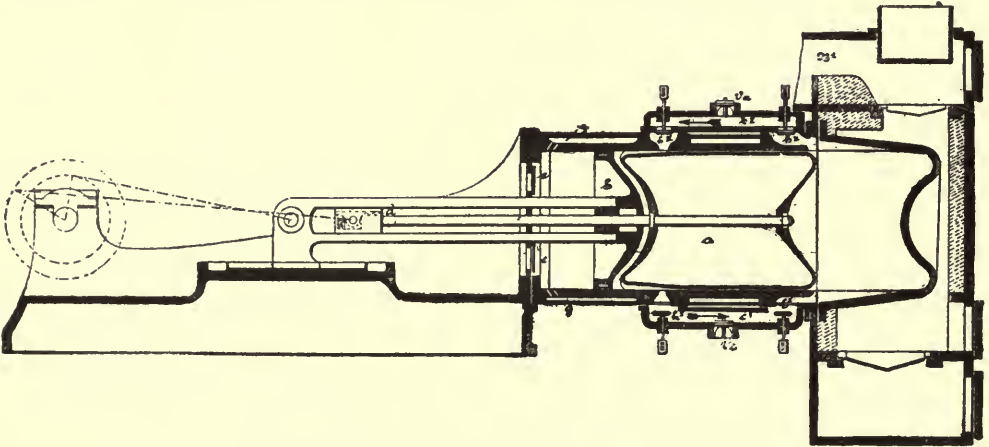
FIG. 19.—Single Cylinder Engine.   Two Pistons.

arrow, during the forward movement of the displacer. The throttle valves h^1 of the chamber c^1 are kept open by the valve gear, and the throttle valves h^2 of the chamber c^2 are closed by the valve gear.

During the return movement of the displacer a the throttle valves h^1 of the chamber c^1 are closed by the valve gear, and the throttle valves of the chamber h^2 are kept open, so that the air can only circulate as indicated by the arrows.

To increase the heating surface, an air heating apparatus of any kind may be placed in chamber c^1.

To increase the cooling surface a cooling apparatus of any kind may be enclosed in chamber c^2.

As the chambers c^1 and c^2 are connected with the interior of the engine only during their respective periods of work, it is possible to increase the heating or the cooling surface, reducing thereby the dead space or clearance to one-half.

In chamber c^1 a valve Vi is fixed, which opens, self-acting, inwardly only, and which therefore remains closed during the expansion of the air and the forward movement of the driving piston b.

In chamber c^2 a valve Va is fixed, which opens, self-acting, outwardly only, and which therefore remains closed during the backward movement of the driving piston b.

The piston rod ot the displacer a is fixed to its crosshead by means of a clutch.

The method of controlling the motion of the piston a through the governor, and the method of disconnecting the crosshead, is the same as that usually or ordinarily employed.

When the driving power is excessive and the engine runs too fast the governor throws out of gear the displacer a, so that it remains at a standstill at its dead centre within the hot air chamber.

The heat now accumulates in the hot air chamber and in the displacer. As soon as the excessive power is spent in the fly-wheel the speed decreases, the governor attains its normal position, the crosshead clutch gears up the piston rod, and the displacer a recommences its action.

During the momentary standstill of the displacer a the two chambers c^1 and c^2 open alternately as described. During the forward movement of the driving piston b fresh outer air is admitted through the valve Vi behind the piston, which at the backward movement of the driving piston b is allowed to escape through the valve Va, by which means is effected a cooling of the interior or working cylinder.

Instead of valves for shutting off the chambers c^1 and c^2, the construction may be simplified by means of turn cocks k^1 and k^2, as shown in Fig. 21.

FIG. 20.—Governor Connections.

To regulate the action of the separately fixed valves Vi and Va when the cocks k^1 and k^2 (Fig. 21) are not applied, valves A and B (Fig. 19), which open in opposite directions, are fixed in such a way that the closing of these latter will counteract the action of the former.

The counter-valves may be opened or closed by means of levers, and a sliding collar D, fitted with suitable projections or cam upon the shaft C; after every
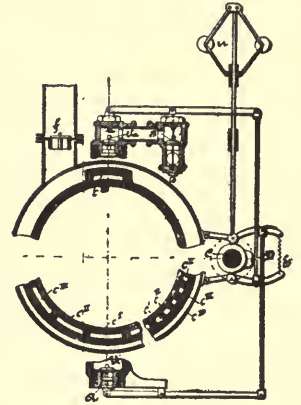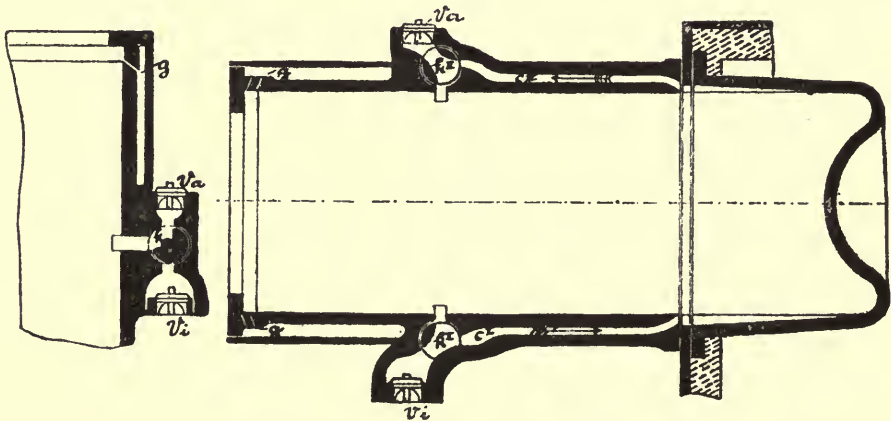

FIG. 21.—Cylinder Heater and Valves.

opening they are closed again by means ot spiral springs E. The collar D can be moved sideways by the governor of the engine, so that the counter-valves A and B may be thrown into and out of gear by means of the projections or cams of suitable shape upon the collar D. To distribute the air equally when it passes from the driving cylinder to the hot air chamber, or from the hot air chamber into the driving cylinder, a number of small passages or chambers c^1 c^2 c^3 c^4 and c^5 (Fig. 20) may be arranged around the circumference.

The interior of the cylinder in front of the piston b serves at the same time as an air pump. During the backward or return movement of the driving piston b the outer
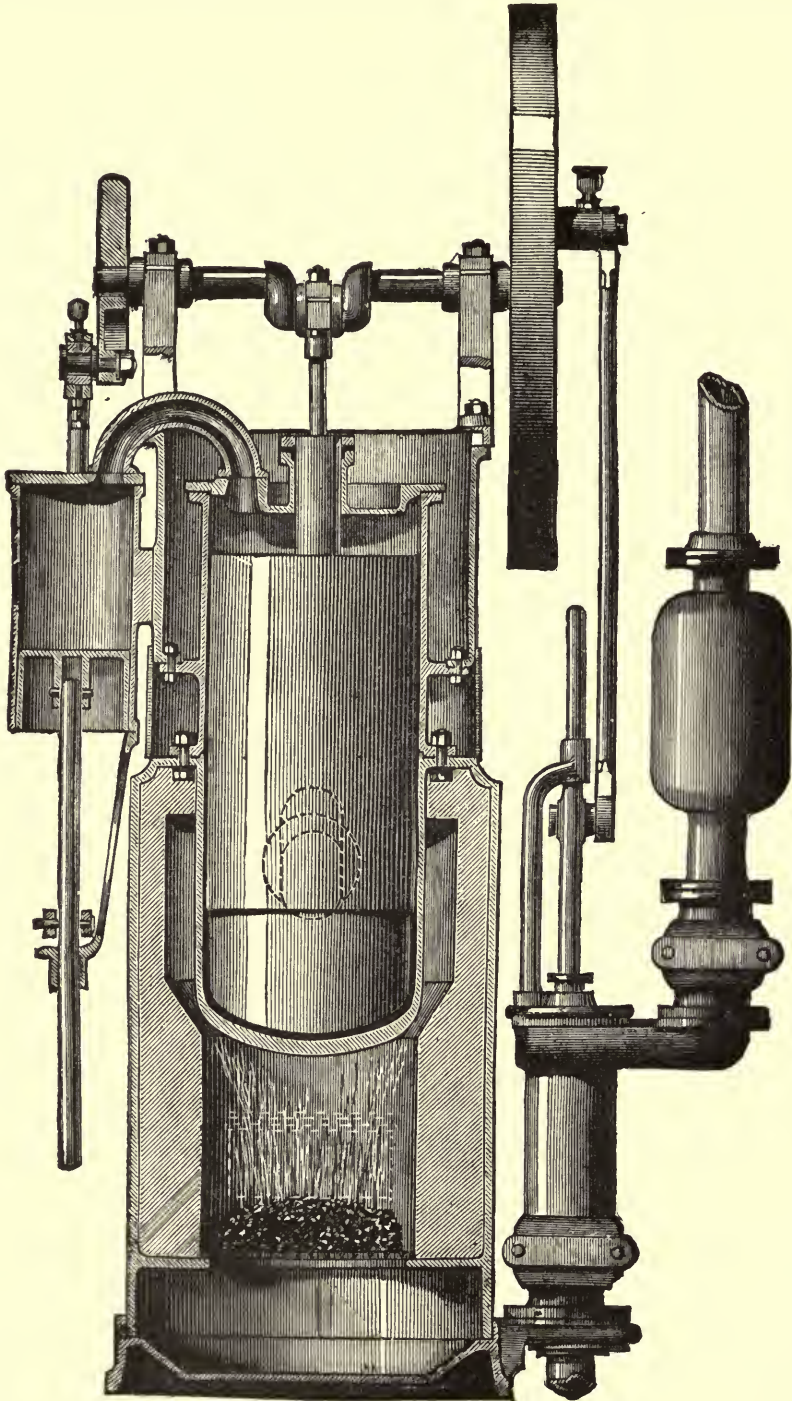

FIG. 22.—Bailey's Engine. Vertical Section.

air enters through the valves e fixed in the cylinder cover, and opening self-acting inwardly.

During the forward movement of the driving piston *b* these valves *e*, in the cylinder cover, close self-acting, and the air contained in the cylinder is forced to blow through the holes *g*, drilled in the inner circumference of the cylinder into the space between the latter and its jacket towards the exhaust pipe.

In the exhaust pipe a valve *f* (Fig. 20) is fixed, opening self-acting outwardly, which prevents the air from returning. By this continual circulation of the air during the working of the engine the outer covering or jacket of the cylinder is kept cool.

Bailey's engine is shown in Figs. 22 and 23. A horizontal and vertical type is made. In both there is one cylinder and two pistons—a working piston and a displacer. The two types are recommended for different applications.

1. The vertical engine, for pumping up to ¼ horse-power. This class offers advantages for export and for use where space is of importance. It requires no brickwork, and can be easily started by any one of ordinary ability.

2. The horizontal engine of ½ horse-power, for driving all kinds of machinery and for pumping. Brickwork can be erected in a day by any ordinary brick-setter to instructions, which are sent with each engine.

The object of the large stove in this pattern is to enable a large supply of fuel to be put on the fire, which produces very slow combustion, and therefore the fire does not require quite so much attention as is the case with the vertical pattern engines.

Where an engine is required for pumping and also for grinding or other power purposes, the horizontal pattern is recommended.

Bailey's patent horizontal hot air engine consists of a cylinder closed at one end by a steel pot, and at the other

FIG. 23.—Bailey's Horizontal Engine.

by a piston. The steel pot is fixed within the stove, whilst the cylinder is surrounded by a water jacket. Once set in motion, it requires no attention beyond oiling once or twice a day.

The engine is kept at work by the alternate heating and cooling of the air within the cylinder; the air being caused to travel backwards and forwards by a loose fitting piston within, which is worked by the engine from the outside by means of a piston rod passing through the front or driving piston. The air being used over and over again, there is thus no exhaust and consequent smell of burning oils, etc., and there are no valves whatever to wear out or stick fast, causing expense and stoppages.

The stove is provided with a roomy fireplace, holding enough fuel to keep the engine going from three to six hours without stoking. The furnace will burn almost any fuel—coke, coal, peat, wood, sawdust, spent tan, riddled cinders, etc., and, as it consumes its own smoke, it needs no attention during the intervals of firing.

Thus it will be seen that the attention required is so simple and of such a light
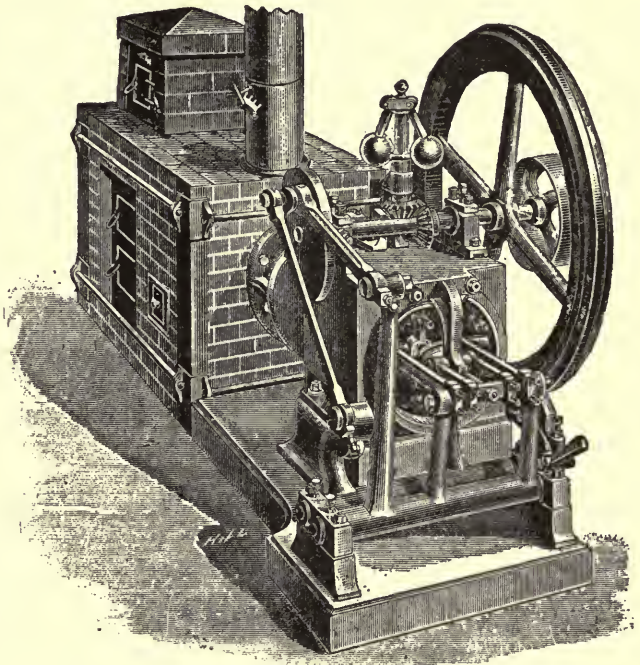
nature that any intelligent lad, labourer, gardener, or domestic servant may learn to work it in a few hours, with the assistance of printed instructions, and attend to it without material interference with his other occupation.
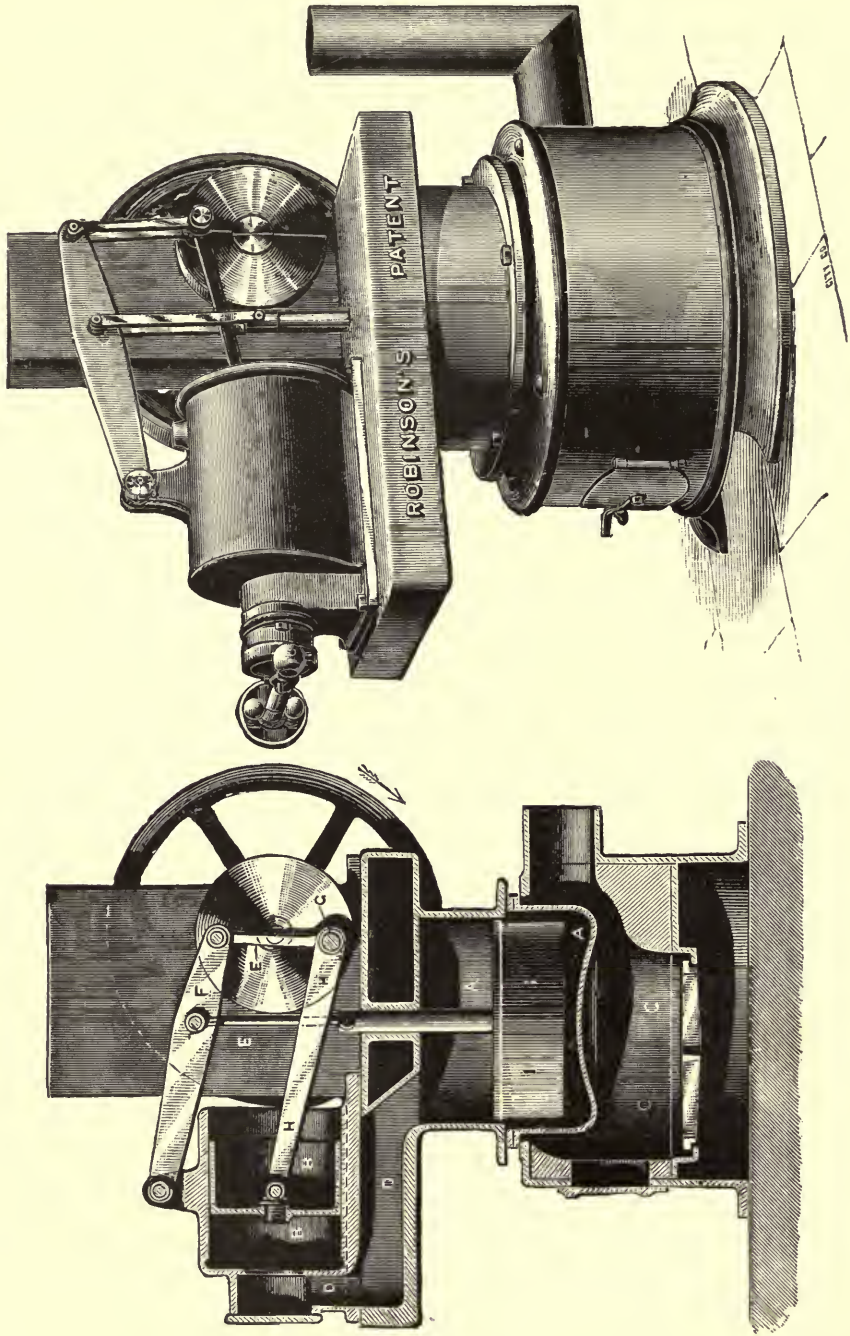

FIG. 24.—Robinson's Engine.

In Robinson's engine we have an exceedingly useful little prime mover for small powers. It runs on with almost no attention whatever with an oil or gas burner. It is shown in section already (Fig. 6); and further in two complete views (Fig. 24).

The displacer piston is hollow, and acts also as the regenerator, it being filled with strips of metal or wire gauze. An engine with a 10-inch piston uses about 40 lbs. of coal per hour, giving $\frac{2}{3}$ of a horse-power at 170 revolutions per minute.

For many household purposes, pumping water or air, it is a valuable machine, perfectly safe and not easily disabled.

In all these hot air engines the power is limited. Air is a bad conductor of heat, and when heated by external furnaces the heat spreads through the mass of air by "convection," which is a slow process. The bottom of the displacer chamber has to be very large and kept red hot, so as to heat rapidly the air entering. But this high temperature soon leads to failure, and the bottom has to be often replaced.

In the Rider engine the maximum pressure is about 20 lbs. per square inch, the speed about 140 per minute, The 1 horse-power engine takes about $4\frac{1}{2}$ lbs. of coke per indicated horse-power, or about 9 lbs. per brake horse-power per hour. An engine with a cylinder $6\frac{3}{4}$-inch bore and $9\frac{1}{2}$ inches stroke, at 140 revolutions gives about $\frac{1}{4}$ horse-power on the brake.

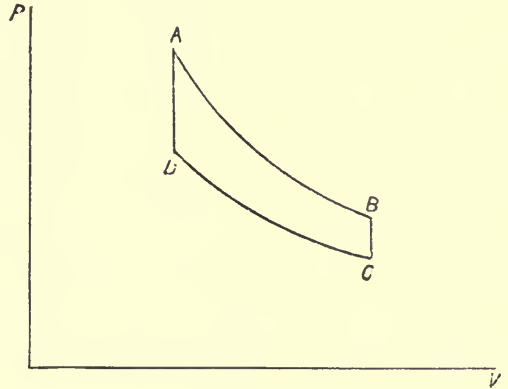Fig. 25 is an indicator diagram of these displacer engines.

FIG. 25.

ERICSSON'S ENGINE

This engine receives and rejects the heat at constant temperature; it is shown in Fig. 26.
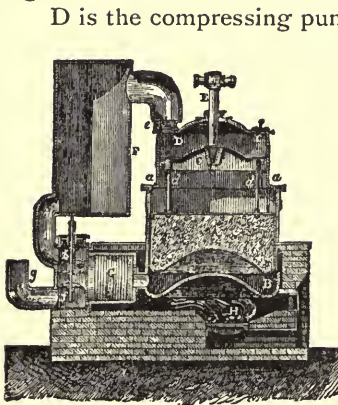
D is the compressing pump, being a cylinder standing on the cover of the working cylinder. C is the piston of the compressing pump, connected with the piston A by three or by four piston rods, of which two are shown and marked d. The space below the piston C, and above the piston A, forms one continuous cavity, communicating freely with the external air through the holes a. E is the upper piston rod, by which the pistons C and A are connected with the mechanism. That rod traverses a stuffing box in the cover of the compressing pump.

The compression of the air takes place in the upper part of the compressing pump. The air enters through the admission clack c, is next compressed, and is then forced through the discharge clack e into a receiver or magazine of compressed air F.

FIG. 26.—Ericsson's Engine.

G is the regenerator, being a box containing several layers of wire gauze, which are traversed by the air when it enters and leaves the working cylinder.

b is the induction valve, and f the eduction valve, both worked by the mechanism of the engine. When b is opened, air is admitted from the receiver F through the regenerator into the cylinder, and lifts the piston A. After a portion of the stroke has been performed b is shut, and the admission of air cut off; the remainder of the stroke of the piston A is performed by the expansion of the air.

An engine was built in America on this plan which gave 300 horse-power. It had

four working cylinders, each 6 feet stroke by 14 feet diameter ; the speed was 9 revolutions per minute, and the mean pressure slightly over 2 lbs. per square inch.

We need not dwell upon this class of engine further. Having described all the types and illustrated the practical forms in the market, we will pass on in next chapter to the large and growing class of internal combustion engines in which the gases are heated instantly by explosion or combustion in, or as they enter, the working cylinder.
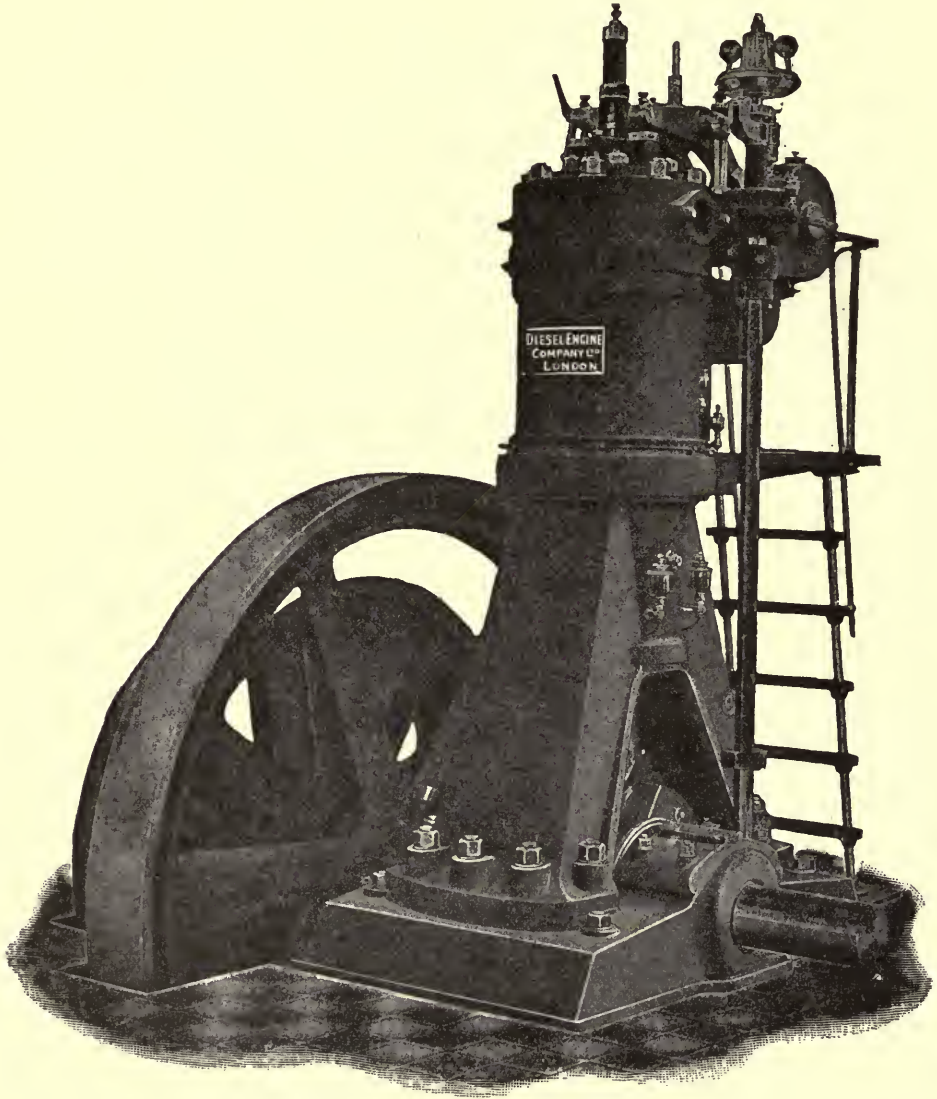

FIG. 26A.—Single Cylinder Diesel Engine, as described pages 30 to 40, and shown in section, (Figs. 31 and 32).

CHAPTER II

CONSTANT PRESSURE INTERNAL COMBUSTION ENGINES

THIS class of engine has not until recently been developed so highly as the explosion type, although it was really a successful engine before the latter came into vogue.

The system has some theoretical advantages, arising from the gradual combustion of the fuel, of working silently and smoothly, like a good steam engine, and giving a similar diagram. The fuel and air are pumped into the cylinder under a constant pressure, and ignited as they enter from the beginning of the out-stroke. Thus the expansion due to the heat of combustion is utilised at constant pressure, for the increasing volume of the cylinder as the piston sweeps forward prevents a rise of pressure. At about half stroke the gas and air, or oil and air, are cut off, and the remainder of the stroke completed by expansion, according to the laws of gases expanding, so that at the end of the stroke the pressure is only slightly above that of the atmosphere. The return stroke drives out the spent gases, and the cycle is repeated. A crank at right angles to the working crank operates a pump which draws in the gaseous or liquid fuel and air, and compresses them, thoroughly mixed, forcing them into the cylinder on the out-stroke.

The diagram (Fig. 27) shows the indicator curves of the power stroke and the pump stroke superposed.

It is a mistake to pump gas or oil and air mixed together in a separate pump, and then to force them into a combustion chamber. No

FIG. 27.—Diagram of Gradual Combustion Engine.

wire gauze or other separator can in every case prevent back firing of the mixture, and thus cause danger and trouble.

If the constant pressure engine is to be a success, the fuel and air must be compressed separately, and mixed as they enter the cylinder for combustion.

This is done in the Diesel engine and in some other oil engines, and can be carried out simply by other types. As an example we may refer to an oil engine, shown in diagram (Fig. 28), somewhat altered by the author in order to work it as a 2-stroke cycle with constant pressure gradual combustion.

The engine pumps air up to 40 or 50 lbs. pressure. This air enters the working cylinder through a valve, which has also a few openings for admission of the oil, as shown ; and the oil is maintained at the same pressure as the air by a connecting pipe connecting the oil vessel to the air inlet. This oil vessel is closed air-tight. At the end of the exhaust stroke the air and oil valves are opened, and the air and oil flow in
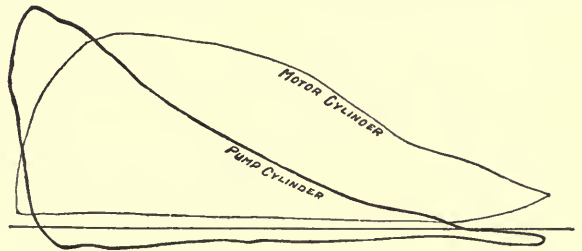
mixed ready for consumption.   They are ignited by a hot tube or sparking electric plug, and expand, driving the piston forward for about half the outward stroke.   The fuel and air are then cut off, and the remainder of the stroke completed by expansion.   At the end of the out-stroke the exhaust valve is opened, and the piston drives out the spent gases on its inward stroke.   The cycle is then repeated.

In a short time after starting, the combustion chamber is hot enough to ignite the fuel and air as they enter.   This type of engine has some advantages for marine propulsion, for it can be started by compressed air alone.   It gives an impulse every
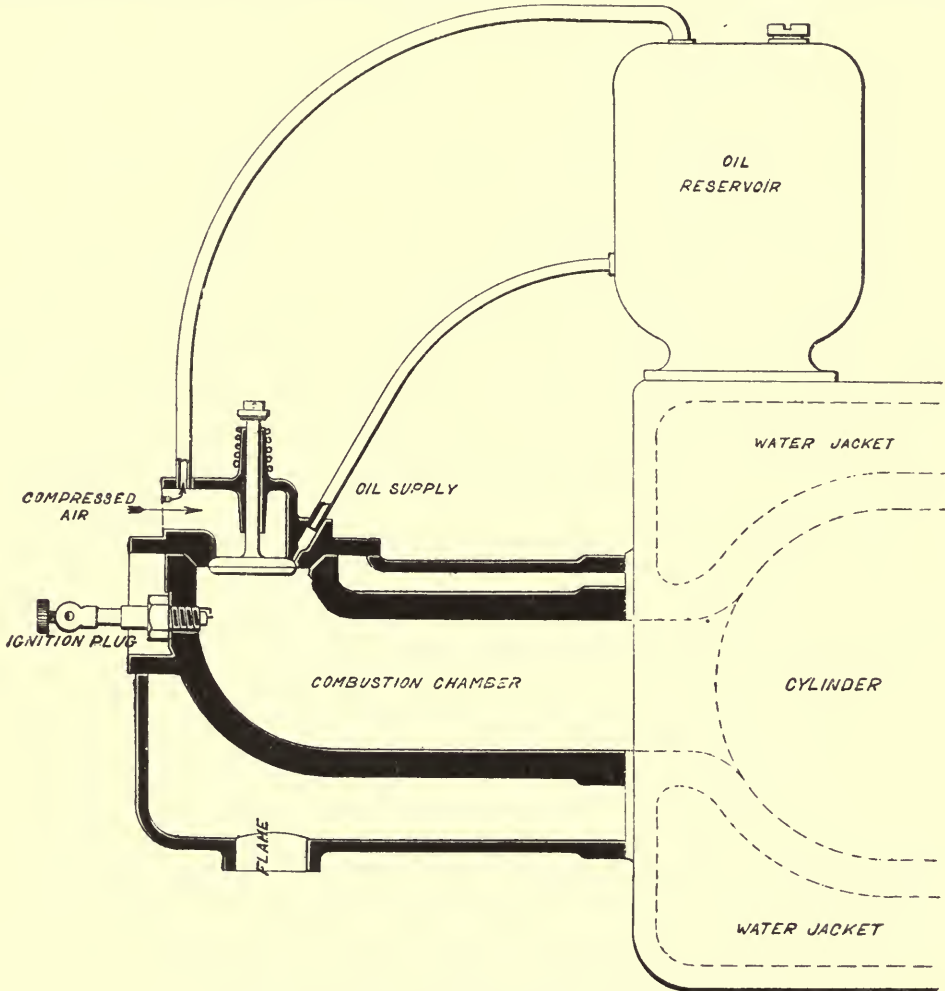
FIG. 28.—Diagram of Gradual Combustion Engine.

revolution in one cylinder ; and with four cylinders all the steady turning motion of two pairs of cranks at right angles can be obtained.

Fig. 29 represents an elevation of this form of constant pressure engine, at one time made by Simon of Nottingham with the pump driven from one end of the crank shaft.   For marine purposes it is built vertical, with four cylinders.

The ordinary Diesel engine works upon a 4-stroke cycle, and therefore requires no separate pump.   Pure air is drawn into the cylinder on the first out-stroke.   This air is then compressed on the in-stroke to a much higher degree of compression than usual. At the end of compression stroke the pressure is raised to about 35 to 40 atmospheres, and

its temperature raised by the compression to a dull red heat.   Fuel finely divided into spray is then injected under high pressure, and burns as it enters the red-hot air.   There is a large excess of air, so that the fuel is completely burned, and the heat generated does the work, by expansion in the cylinder, without rise of pressure.

In the Akroyd engine of one type the oil is gasified in a chamber opening into the working cylinder.   Into the working cylinder air is drawn during the suction stroke, and the oil is drawn into the hot chamber.   On the compression stroke the air is compressed into the oil chamber, in which it combines with the oil gas, and this is arranged to take place just as the crank passes the dead centre.   In this engine, unlike the Diesel and the others referred to in this chapter, the whole of the fuel is in the combustion chamber before ignition occurs.   It is therefore more of an explosive combination than a gradual one.   However, by slight modifications it could be made to give a gradual combustion.

The Foulis engine will illustrate the first type in which the mixed fuel and air pass through a separating gauze screen, and burn as they enter the working cylinder.   The mixture is pumped in by a pump on the engine under 40 to 60 lbs. pressure.   The ignition
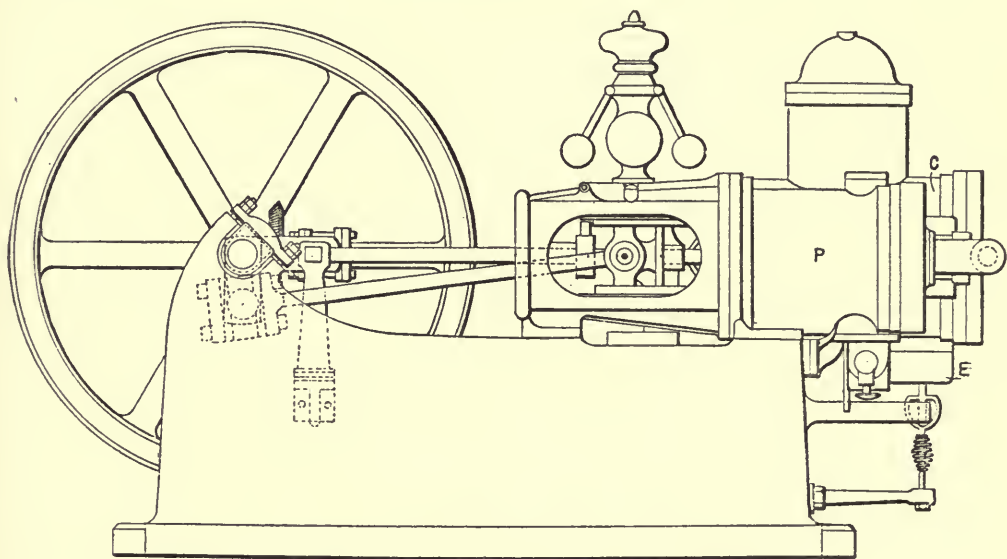

FIG. 29.—Simon's Constant Pressure Engine.

is made by a flame kept burning in the passage into the cylinder, or by a hot piece of fire clay, or it might be by electric spark as shown in Fig. 30.   C is the cylinder end, and F is an incandescent clay igniter, kept hot by the engine's working fluid entering at A.   The wire gauze separator is shown at G, and fire clay plug P reduces the area of inflow, so that the gases enter A with considerable velocity, and so tends to prevent back firing of the mixture.

The mean pressure in this class of engine was about 30 lbs. per square inch.   The pump absorbed about one-third of the indicated horse-power in the working cylinder. The idea of gradual combustion of the fuel as it enters the cylinder is a good one, and eventually some one was bound to succeed with it.   In fact, the diagram shown above in Fig. 28 illustrates a modification of the Brayton-Foulis engines consuming oil, which gradually burns as it enters the cylinder through a vaporiser.   There is no back firing possible in this design.   It, however, requires an air pump, like that in the Clark engine, shown in sectional plan (Fig. 45).   It then works as a 2-stroke engine.

Adopting the 4-stroke cycle, the air pump is dispensed with, but a fuel pump is still necessary to inject the fuel at the beginning of the working stroke.   For this

purpose, instead of using a separate pump when oil is the fuel, it may be kept under pressure, as shown in Fig. 28, a small valve being worked by the engine at the commencement of each working out-stroke. The pressures in the cylinder and oil reservoir are then sure to be equal, and the reservoir of oil, being raised some feet above the combustion chamber, produces sufficient extra pressure to inject the oil. The valve A then works simply as the air inlet on the suction stroke.

The Diesel engine realises this type of motor in a very perfect manner, by carrying the compression of the air far enough to fire the oil or gas as it enters. Besides the features already explained, in an engine of this kind the fuel may be any raw cheap hydrocarbons, and the governing of the engine is highly economical, for the fuel admission may be "cut-off" at any point of the stroke, much as it is done in an automatic cut-off steam governor.

As this engine may be taken at the present moment as an example of the higher development of the internal gradual combustion reciprocating engine, it will be fully described here from papers and illustrations kindly supplied by the makers, and from extracts from the *Engineer* of 30th May and 13th June 1902 ; also from Mr. H. Ade Clark's (Yorkshire College, Leeds) paper of July 1903.

The actual Diesel engine has the following cycle of operations :—

1st stroke takes in air alone at atmospheric pressure and temperature.

2nd stroke compresses this air to a high pressure (35 atmospheres or 500 lbs. per square inch), and to a temperature of about 1000° Fahr. This compression is neither isothermal nor adiabatic, since the operations are conducted in a water-jacketed conducting cylinder.

3rd stroke is the working stroke, during the first part of which the combustion of the fuel is carried on at constant pressure for a period which is determined by the amount of oil to be sprayed in, which quantity is controlled by the governor. The second part of this stroke is approximately an adiabatic expansion.
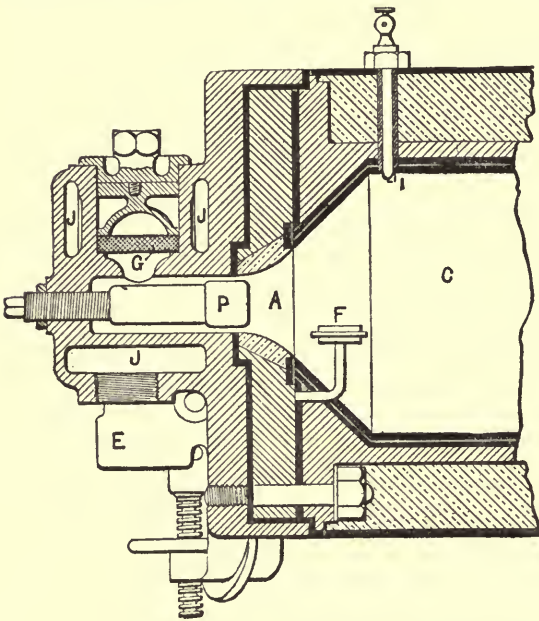

FIG. 30.—Brayton and Foulis type.

4th stroke exhausts the gases.

80 BRAKE HORSE-POWER DIESEL ENGINE

This size of engine is made by the Vereinigte Maschinenfabrik, Augsburg, and Carels Frères, Ghent. In Fig. 31 is illustrated a longitudinal section and Fig. 32 a transverse section of the engine, with standard arrangements of piping for petroleum, lubricating oil, cooling water, air-blast, starting air and exhaust ; in fact, all the engine connections except the water-cooling tanks, when such are used.

The engine is of the vertical type, with a strong cast-iron A frame, the upper part of which forms the outer wall of the water jacket ; into this upper part is fitted a cylinder of special close-grained cast iron. The cylinder cover is deep and hollow, being thoroughly water-jacketed ; in the transverse section will be seen two
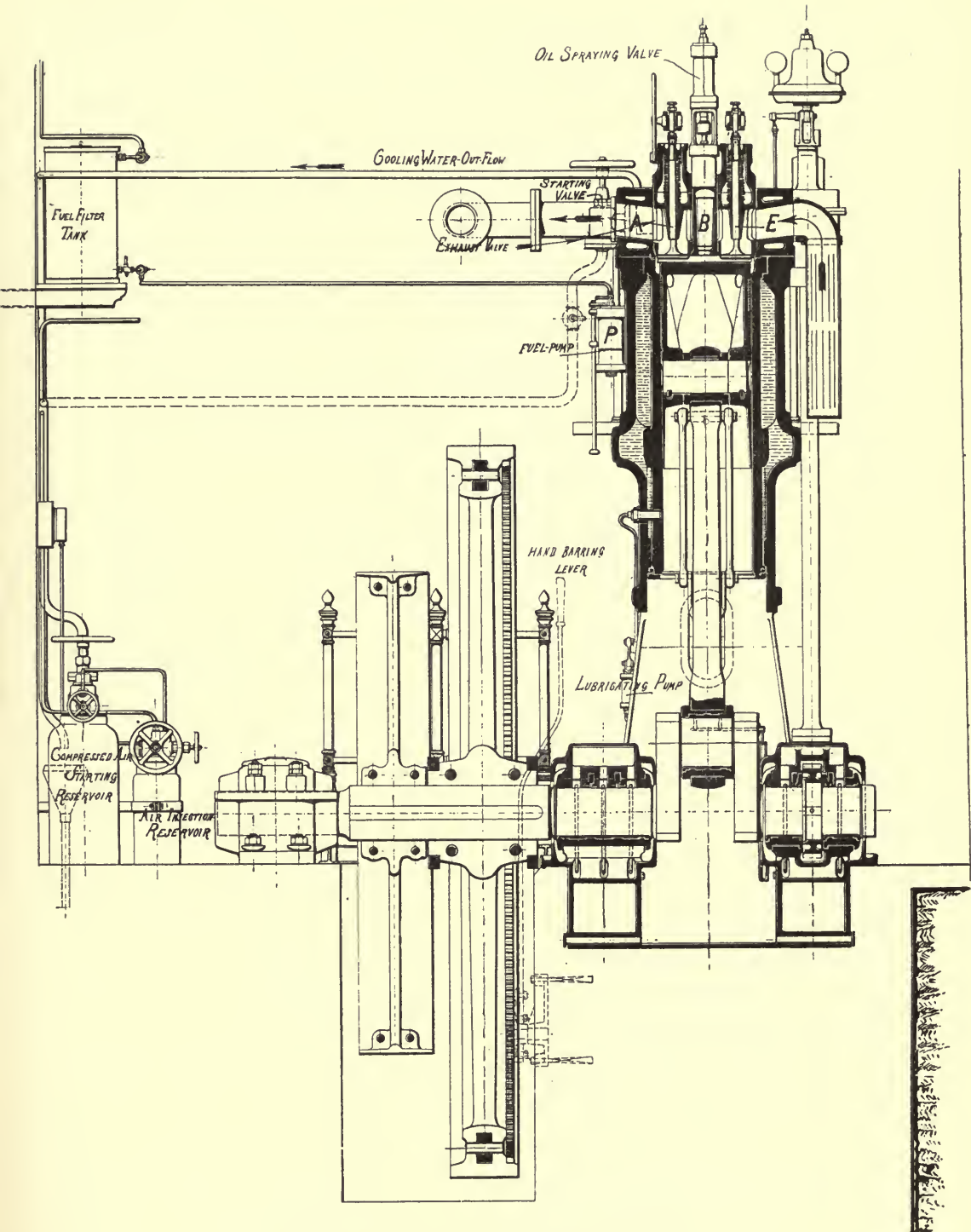
OIL SPRAYING VALVE

COOLING WATER-OUT-FLOW

STARTING VALVE

FUEL FILTER TANK

A   B   E

EXHAUST VALVE

P

FUEL-PUMP

HAND BARRING LEVER

LUBRICATING PUMP

COMPRESSED AIR STARTING RESERVOIR

AIR INJECTION RESERVOIR

FIG. 31.—Diesel Engine.   Longitudinal Section.

valves—the central one is the oil-sprayer, the other is the starting-valve, which may be made to act as the suction valve for the air pump. In the longitudinal section three valves are seen in the cover; in the centre is the oil sprayer (for details see Fig. 33). On the right is the air inlet, and on the left is the exhaust valve. The oil-spraying valve opens upwards or outwards, and the others open downwards or inwards;
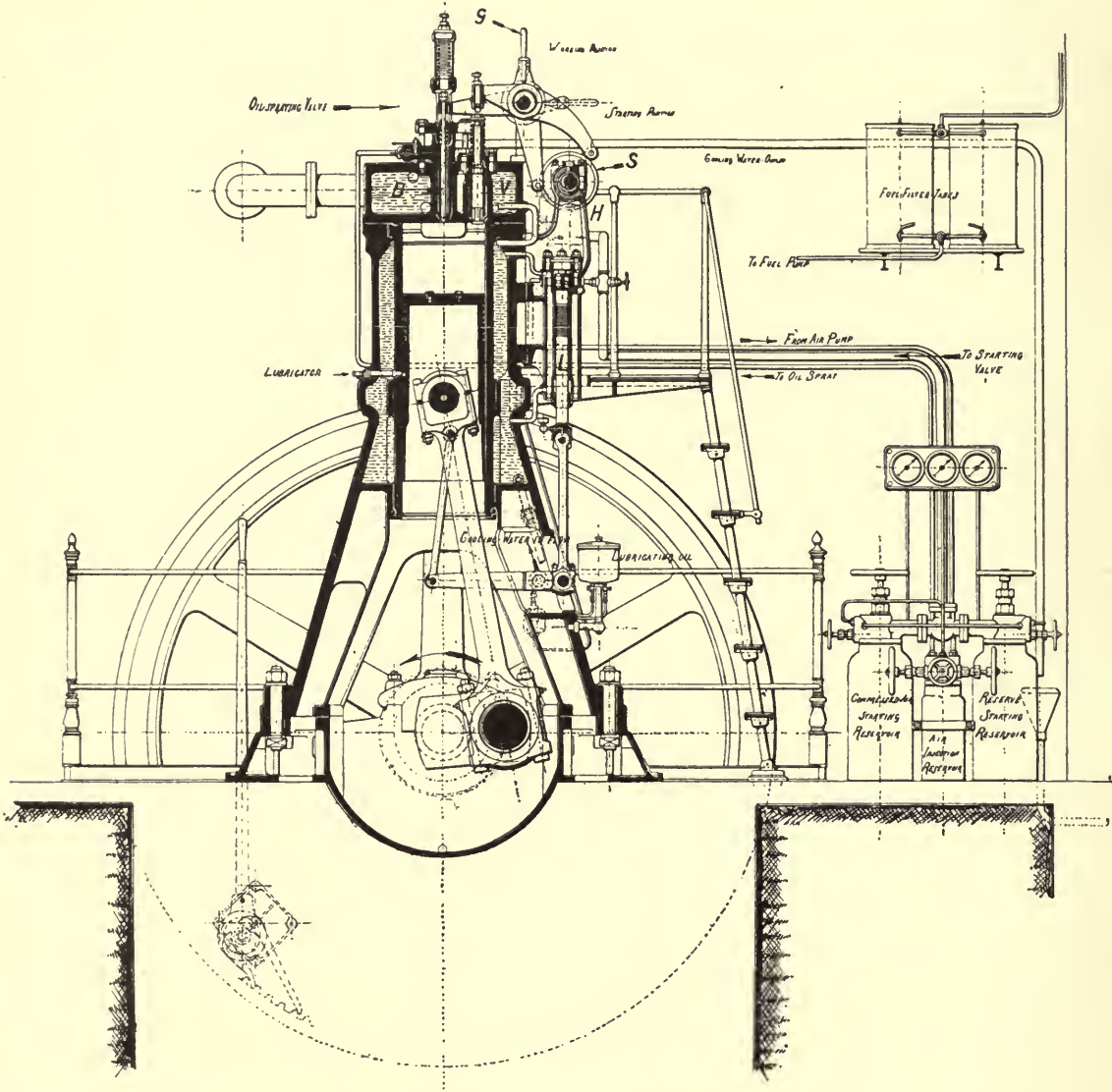
FIG. 32.—Diesel Engine. Transverse Section.

all three are spring closed, the air and exhaust valves being kept closed by pressure inside the cylinder. All valves are opened by the action of the bent rocking levers seen upon the right in the transverse section; the movements of the levers are determined by the cams placed upon the horizontal cam shaft. The cam shaft is driven at half the speed of the crank shaft by means of the bevel gearing and the vertical shaft seen on the right in the longitudinal section.

The governor is of the loaded centrifugal type, and is placed at the top of the vertical shaft ; its action is explained in connection with the oil pump (Fig. 33).

The piston is of the usual open trunk type, directly connected to a connecting rod of the marine type. There are seven piston rings of the Ramsbottom type, six near the top and one much lower, in order that it may pass the lubricating channels.
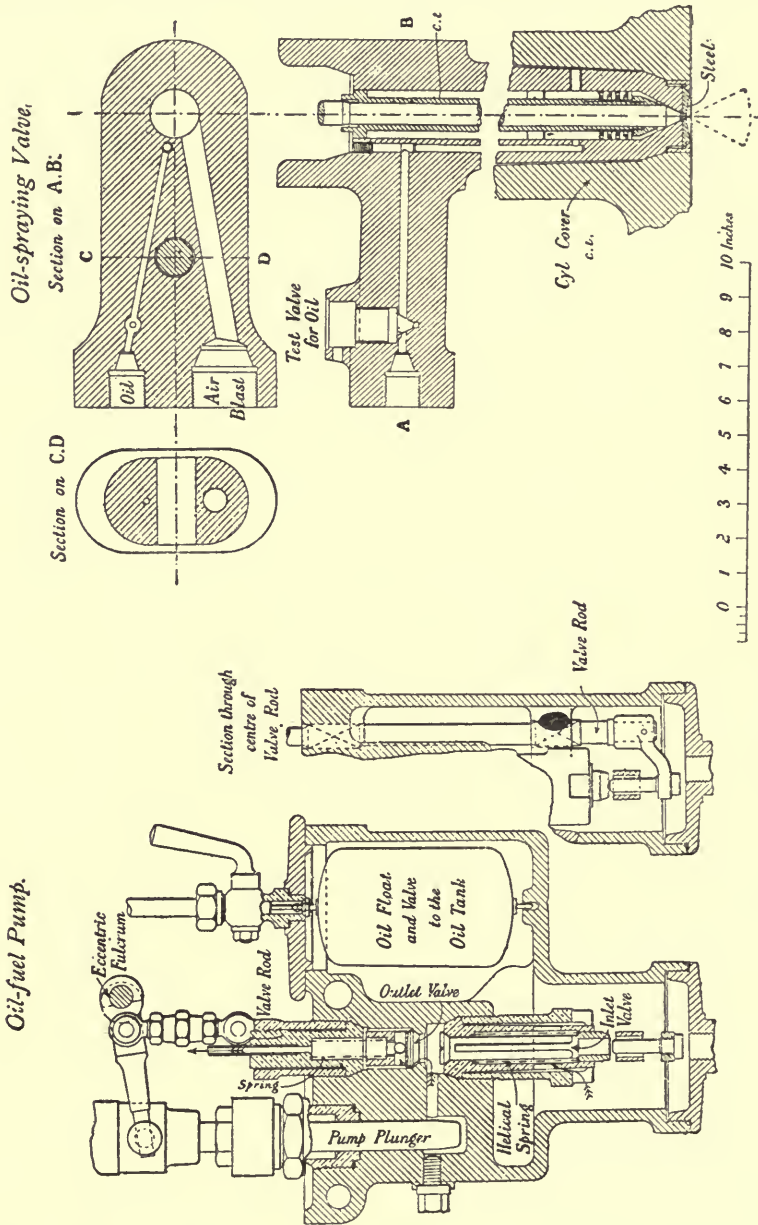

Fig. 33.—Details of 80 Brake Horse-Power Diesel Engine.

The crank shaft is solid, and has three bearings fitted with ring lubricators. The fly-wheel is built in halves, and on the inner edge of the rim is a toothed ring into which work two ratchet pawls, actuated by a rocking lever ; this device is for bringing the engine into the starting position, that is, with the crank just beyond its top dead centre.

On the left of the longitudinal section (Fig. 31) is the petroleum pump P. This pump is connected by a pipe to the petroleum filtering tanks, and by a pipe of small

bore to the oil-spraying valve. The plunger of this pump is driven by a crank pin placed in a disc at the end of the cam shaft, and so has a constant stroke.

On the right of the transverse section (Fig. 32) is the air pump L ; its cylinder is water-jacketed, and the plunger is driven by connecting rod, rocking levers, and connecting links from the small end of the connecting rod. This pump takes its air from the engine cylinder just before the end of the compression stroke, and still further compresses the air in the air-blast reservoir.

The oil-spraying valve is shown in Fig. 33. The horizontal section shows the petroleum and air-blast passages to the central valve, and the vertical section shows the cast-iron body with oil passage and overflow, the central needle valve, and the pulverising device of four metal rings perforated by small holes. The end nose has narrow channels cut in it, through which the pulverised oil passes to the expanding orifice, and is sprayed into the cylinder when the needle valve is raised. It will be seen that the petroleum pump delivers petroleum to the nozzle by the narrow passage, and that the nozzle is in direct communication with the air-blast reservoir, the pressure in which is kept steadily at 150 lbs. higher than the maximum pressure of compression.

The petroleum pump is shown in Fig. 33. The plunger has a constant stroke, being driven from the end of the valve cam shaft. Passing through the head of the plunger is a lever working upon an eccentric fulcrum ; to this lever is attached the valve rod, which opens the inlet valve against the action of a spring. The fulcrum of the rocking lever is eccentric to the shaft upon which it is placed, and this shaft is caused to rotate by the action of the governor, thus altering the stroke of the valve rod and through it the opening of the inlet valve, thus controlling the amount of oil passing to the pump chamber to be forced past the outlet valve to the injecting valve.

TABLE I.—LEADING DIMENSIONS OF 80 BRAKE HORSE-POWER ENGINE.

	Millimetres.	Feet.	Inches.
Diameter of cylinder	400	1	3.75
Stroke of piston	600	1	11.62
Length of piston	905	2	11.65
Length of connecting rod	1,610	5	3.4
Distance between crank bearings	920	2	7.5
Distance between fly-wheel bearings	1,440	4	8.7
Diameter of fly-wheel	3,400	11	1.8
Air pump diameter	60	0	2.36
,, stroke	140	0	5.5
Blast reservoir diameter	204	0	8.03
,, ,, length	900	2	11.42
Starting reservoir diameter	340	1	1.38
,, ,, length	1,785	5	10.27
Petroleum filters diameter	330	1	1
,, ,, length	600	1	11.62
Over all length of engine, including railing	3,900	13	2.6
,, width ,, ,, ,,	3,900	,,	
,, height ,, ,, ,,	3,900	,,	
Depth below floor of engine	1,500	4	11.1
Depth of foundations	2,400	7	10.6
Height required for erection	5,900	19	4

Formerly the air pump drew straight from the atmosphere, but the improved arrangement here described has enabled the pump to be reduced to one-fourteenth of its previous volume, besides introducing the well-known advantages of two-stage compression. This pump is water-jacketed, both round its walls and in its top cover. The cooling water passes first through the pump jackets, then through the cylinder wall jacket, and finally through the cylinder cover. It then flows to a small belt-driven centrifugal pump, which lifts it to an overhead cooling tank, whence, after cooling, it flows by gravity once more through the jackets.

The work done in the small compressor was originally, before the above two-stage arrangement was adopted, about 4 per cent. of that done in the main cylinder. Since the introduction of the two-stage compression its estimated value is now only about $\frac{1}{2}$ per cent. of the whole. The work so done is not lost; only a portion of it is spent on the friction of the pump and valve passages. The rest is redelivered to the main piston during the working stroke.

This pump delivers the air, not direct to the valve box for the oil admission, but into a pair of cylindrical high-pressure air reservoirs. In a 30 horse-power engine one of these is of about $13\frac{1}{2}$ inches internal diameter by $5\frac{1}{2}$ feet long, while the other is about 6 inches internal diameter by $2\frac{1}{2}$ feet long. In the smaller a steady pressure, some 6 to 10 atmospheres above the maximum cylinder pressure, is maintained, and during working this is kept in open connection with the above valve box. The larger vessel serves as an overflow from the smaller one, when the pressure in this latter rises above the loading of a valve inserted between them. To avoid possibility of excess of pressure in the working cylinder at the end of the compression stroke above that desired, there is a similar suitably spring-loaded overflow valve from the top of this cylinder to the larger air-pressure reservoir.

The larger air vessel contains a reserve of compressed air power for starting the engine. This is done by help of the fourth valve in the cover. This valve is kept shut by spring force, as are the other three, and, like them also, is opened by a lever and cam. Its lever, however, is lifted out of reach of the cam tooth during normal working, and is only let down into gear with its cam when the engine has to be started. This is very simply done by throwing over a hand lever, which turns a short spindle carrying the eccentric fulcrum of the operating valve lever.

The starting valve is, in the later designs of the engine, made to serve during ordinary working as the suction valve of the air-compressor pump.

In the normal working of the engine the oil for combustion enters the cylinder by the central plug valve. When this valve opens the oil is blown in by a small puff of air from the reservoir. The quantity so blown in at each working stroke is exactly regulated by the governor and measured out, so to speak, by an oil plunger feed pump. This pump is driven by a small crank pin on the end of the cam shaft. Oil is admitted to the barrel of the pump by a piston valve moved by a lever oscillated by the same shaft. The fulcrum of this lever is an eccentric boss upon a spindle shaft turned to and fro through a small angle by the governor as the engine speed rises or falls. The lever fulcrum is thus raised or lowered, and in consequence the oil admission port area is increased or lessened, and the point of cut-off of this oil admission retarded or hastened in proportion to the load on the engine. The governor used is one of the common type—inverted bell cranks, two balls, and a central spring. This governing of the oil admission, it will be noted, is effected without change in the plunger stroke of the pump.

This pump forces the quantity of oil required for each stroke into the valve box immediately round the nozzle of the valve in the cover of the working cylinder. It does so during the intervals between successive working strokes. The volume of oil so forced in per working stroke is little more than $\frac{1}{200}$ cubic inch per horse-power. In a 30 horse-power engine it is under $\frac{1}{6}$ cubic inch. The cam shaft, several times referred to above, runs at one-half the speed of the crank shaft. It lies horizontally, as seen in Fig. 32, and is driven by bevel gear and a vertical intermediate shaft.

While working under load the external casing keeps quite cool in its lower half—so cool that the hand may be kept against it any length of time—while the top end of this casing may be touched by the hand without scalding. The temperature of the inflow of the cooling water was at 55°, and that of the overflow at 93° Fahr. This was on a rather cold day. A somewhat rough measurement of the external temperature of the iron of the exhaust pipe close to the engine gave between 130° and 140° Fahr.

The exhaust gases are passed through a silencer, and at their discharge just above the roof of the engine house into the open they showed a temperature of only 120° Fahr. These gases are perfectly colourless and invisible when the engine is loaded, and do not in the least degree brown or otherwise discolour a sheet of pure white paper held close over the end of the pipe for three minutes. No smell could be detected in the exhaust, and all the general indications are of absolutely perfect combustion and surprising efficiency in the using up inside the engine of the heat of combustion. When the engine has no load on it light wreaths of visible smoke or vapour come from the exhaust.

Numerous examinations of the inside of the cylinder and of the valve faces and seats have been made after prolonged running. In all cases the piston face and cylinder walls and valve seats have been found clean, without any trace of deposit.

In order to start the Diesel engine the engine is taken exactly as it may have been standing idle for one or several hours, or days or weeks. The pulling of the crank to the top dead point, the pulling over of a small hand lever, and the opening of a small screw-down air valve are all that have to be done. After about four or six revolutions the starting lever is again thrown back, and the engine thereafter looks after itself. In large engines this starting lever and cam are thrown automatically out of gear by the governor as soon as normal speed is reached ; but hand gear is preferable for the smaller sizes, and it is always available in the larger.

The air reservoirs are made of Mannesman steel tube. In use they have to stand from 40 to 60 atmospheres pressure, or from 570 lbs. to 850 lbs. per square inch. The screw-down valves are well ground, and hold this pressure indefinitely without leakage. The practice in erecting a new engine is to pump up these reservoirs in the works, and to send them thus charged to the place of erection. Thus an engine erected at Harrogate had the air reservoirs initially charged and sent over, where they lay for over six weeks without losing pressure before they were used for starting the engine. They may also be initially charged with air by a hand pump, or by help of bottles sent from any neighbouring gas-compressing works, such bottles being now easily procurable in all towns, or by any ordinary chemical admixture for producing carbonic acid or any other gas under pressure. Any gas, whether containing free oxygen or not, serves equally well, as the contents of these reservoirs are not used for combustion.

Mr. H. Ade Clark made careful tests of the 80 and 160 brake horse-power engines, with the following results given as a summary. The 80 horse-power engine of latest type is shown in Plate I.

The oil used was a Texas crude petroleum, a sample of which was tested at the Yorkshire College with the following results :—

Specific gravity 0.922
Gross calorific value .   .   .   .   .   19,300 B.Th.U. per lb.

This oil was completely burned by the engine at all but the lightest load, the exhaust being clear and free from smell of unburnt oil, except when running under very light load, a little smoke being then visible.

TABLE II.—CRUDE PETROLEUM USED IN TEST OF 80 BRAKE
HORSE-POWER DIESEL.

Weight of Vessel.	Weight of Vessel and Oil.	Weight of Oil.	Initial Temperature.	Final Temperature.	Rise of Temperature.	Calorimeter Constant, $\frac{1.75}{w} \times 1850 \times t.$	
Grammes. 48.78	50.48	1.70	° F. 49.0	° F. 59.2	10.2	19,420	19,300
48.70	50.23	1.53	49.5	58.6	9.1	19,260	

TABLE III.—80 BRAKE HORSE-POWER DIESEL ENGINE.

Test at Messrs. Stafford Allen & Sons, London, 16th May 1903.

Summary of Results.				
Load	0	0.5	0.75	Full
Duration in minutes	49	145	78	...
Total revolutions	...	...	...	...
Revolutions per minute	158	157	156	...
Mean effective pressure	25.6	69	91.2	...
Indicated horse-power	23.8	61.9	81.5	...
Effective horse-power	0	38.1	57.7	80
Mechanical efficiency	0	61.6	70.4	...
Total oil in lbs.	6.52	48.22	35.69	...
Oil per hour	7.98	19.91	27.48	...
Oil per indicated horse-power hour	0.374	0.322	0.337	...
Oil per effective horse-power hour	...	0.523	0.479	...
Cooling water per minute lbs.	...	24.1	25.7	...
Temperature of water inlet	...	...	...	...
,, ,, outlet	66° C.	60° C.	64° C.	...
Temperature of room	25° C.	24° C.	25° C.	...
,, oil	21° C.	21° C.	18° C.	...

TABLE IV.—160 BRAKE HORSE-POWER DIESEL ENGINE.

Test of Two-Cylinder Diesel Engine at Messrs. Carels Frères, Ghent, on 7th March 1903.

Summary of Results.					
1. Load	Full	0.53	0.375	0.25	None
2. Duration in minutes	60	60	61	60	30
3. Total revolutions	9,258	9,424	9,639	9,476	4,770
4. Revolutions per minute	154.5	157	158	158	159
5. { Mean effective pressures L	113.4	64.7	51.9	38.2	46.2
{ ,, ,, ,, R	114.5	74.1	60.7	46.2	39.7
6. { Indicated horse-power cylinder 4L	101.0	59.1	46.6	34.4	42.6
{ ,, ,, ,, 5R	103.4	67.7	53.4	40.5	36.7
7. ,, ,, total or mean	204.4	126.8	100.0	74.9	39.64
8. ,, ,, of air pump	3.3	3.25	3.0	2.97	2.98
9. Net indicated horse-power from the oil	201.1	123.6	97.0	71.93	36.66
10. Effective horse-power	164.8	87.2	60.4	35.4	...
11. Mechanical efficiency	80.7	68.8	60.4	49.2	...
12. Total oil in lbs.	67.0	40.58	30.45	25.6	7.6
13. Oil per net indicated horse-power hour	0.333	0.329	0.309	0.356	0.415
14. ,, effective horse-power hour	0.408	0.465	0.505	0.724	...
15. Cooling water per minute lbs.—Inlet {	49.6	43.0	26.25	16.1	...
{	9.5	9.5	9.5	9.5	10.0
16. Temperatures of water, ° C.—Outlet	62.0	52.5	60.5	65.5	67.0
17. Change of temperature	52.5	43.0	51.0	56.0	57.0
18. Temperature of exhaust, ° C.	384.0	239.0	197.0	158.0	...
19. { B.Th.U. per net indicated horse-power minute	108.0	106.0	102.0	114.0	154.5
20. B.Th.U. converted to work	42.4	42.4	42.4	42.4	42.4
21. ,, rejected in cooling water	22.9	26.3	24.3	21.7	...
22. ,, ,, exhaust gases	32.1	28.3	14.4	13.5	...
23. { Thermal efficiency on net indicated horse-power per cent.	39.25	40.0	41.5	37.2	...
24. { Thermal efficiency on effective horse-power per cent.	32.3	28.3	26.1	18.3	...
25. { Exhaust gas analysis—					
{ Carbon dioxide . Vol. per cent.	7.0	4.1	3.1	2.9	...
{ ,, monoxide ,,	...	...	Trace ?	0.1 ?	...
{ Oxygen ,,	11.3	15.0	16.6	17.6	...
{ Nitrogen by difference ,,	81.7	80.9	80.3	80.3	...

Two indicator diagrams of this engine and a comparative diagram given by Mr. H. Ade Clark are shown in Figs. 34 and 35. The four diagrams here shown (Fig. 36) are of the 160 brake horse-power engine.

Diagram at full load.   **Diagram at varied loads.**
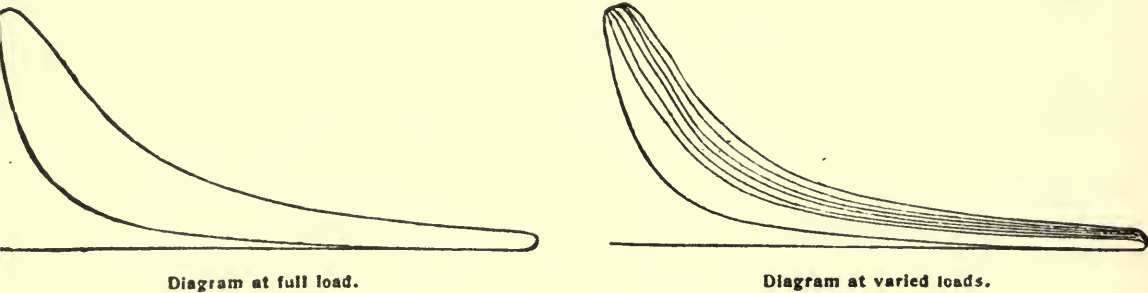
FIG. 34.—Indicator Diagrams, Diesel Engine.

A 2-stroke Diesel engine has been made by Messrs. Scott & Hodgson, Manchester. In this engine, when the piston reaches nine-tenths of its outward working stroke, the exhaust opens, the pressure falls, and an air inlet valve opens into the cylinder from an air reservoir at 4 or 5 lbs. pressure, and thus the exhaust is swept out and the cylinder filled with air. This air is then compressed into the clearance space to a pressure of 600 lbs. per square inch at the end of the in-stroke, the oil fuel is then sprayed into and burned during the first one-third or so of the out-stroke; the out-stroke is continued by expansion to nine-tenths, when the exhaust again opens, and the 2-stroke cycle is repeated.

The air pumps are two in number—one, a large pump, delivers air for a portion of its stroke into the low air pressure receiver, for scavenging and filling the working cylinder; its communication with this reservoir is cut off at about three-quarter stroke, and the remaining air, compressed to 60 lbs., delivered to a small pump which raises its pressure to 750 lbs., to be used for spraying the oil into the working cylinder. An oil pump, the inlet and exhaust valves, and governor are driven by a side shaft; and governing is carried out by regulating the suction valve of the oil pump.

FIG. 35.—Comparison of the Pressures, Powers, and Clearances of Steam, Gas, and Oil Engines.

The indicator cards are drawn to the same scale and for the same total volume of cylinder. Indicated horse-power at 160 revolutions per minute: Diesel engine=105. Gas engine=66. Steam engine, 24×4=96. (Reduced one-third smaller than original diagram.)

The Diesel engine is at present the only one working at such high pressures. The results of trials and tests justify their use, for the economy is beyond doubt. The latest claims made for its economical working are as follows.

The consumption of fuel is less than ½ lb. of crude or other oil per brake horse-power hour, varying from 0.4 lb. in the large sizes to .49 lb. in the smaller sizes.

Apart from the small quantity of oil consumed, there is a great saving in the cost of the oil, as the Diesel engine can be run with unrefined or crude oil, solar oils, etc.,
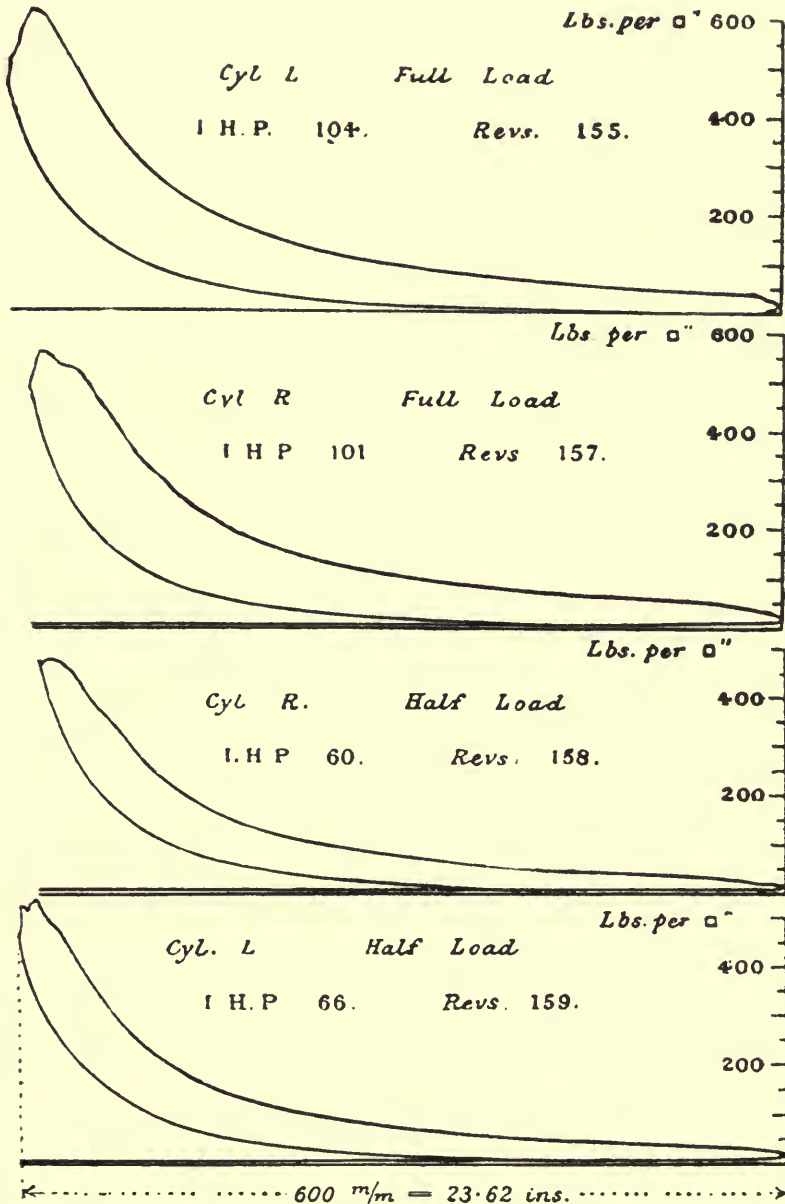
FIG. 36.—Full-size Indicator Diagrams from 160 Brake Horse-Power Diesel Engine.

which, however, must contain no impurities. The Diesel is not, like other engines, dependent upon refined oils, which cost 6½d. per gallon. There is therefore a double saving, both in the quantity and in the quality of the oil used.

The price of the cheapest oil now obtainable is 35s. per ton in bulk at wharf in London and other ports. This is equal to 1¾d. per gallon.

The price of this oil delivered to any part of London will be 40s. per ton, equal to 2d. per gallon.

Of course, the cost of crude oil varies much in different places, due to the railway carriage, which in some cases may be as much or more than the cost of the oil. However, if we accept the cost of oil at £2 per ton and an 80 horse-power engine running sixty hours a week, the fuel cost would not be more than £100 per annum ; so that if the carriage of oil ran the price up to double this it would still compare favourably with an 80 horse-power steam engine of ordinary non-condensing type, which in practice takes about 3 lbs. of coal per horse-power hour, and in few cases coal costs less than 9s. per ton, including carriage ; this gives 7 tons a week, or £3, 3s. for steam fuel against £4 for oil per week, even if the oil cost £4 per ton.   But the savings due to the absence of a boiler and its appendages would even then far more than balance the difference.

Recent tests on a Diesel engine of 70 to 90 brake horse-power give the consumption of oil at varied loads as follows :—

At 70 brake horse-power	.	.	.413 lb. per brake horse-power-hour.	
,, 87.4 ,,	.	.	.418	,, ,,
,, 55.8 ,,	.	.	.432	,, ,,
,, 41.2 ,,	.	.	.473	,, ,,

It will be seen, then, that at last the gradual combustion engine has, after many years, reached a higher stage of perfection than its younger sister the explosion engine.

The pioneer internal combustion engine, working on the gradual combustion principle, was introduced by George B. Brayton, an American, on June 1874.

Brayton, however, made the mistake, followed afterwards by all others till Diesel came on the field, and that was in mixing the fuel and air before they enter the cylinder, and thus requiring a "flame interceptor" to prevent firing back.   In Brayton's engine the air was compressed by a pump and blown through the oil fuel, which entered the cylinder through a flame interceptor ; the air and oil spray were there ignited by an oil flame kept constantly alight, and they combined gradually as they entered and followed the piston.   Many of these engines were made and used, although they had many troubles and required constant overhauling by a skilled man.   The flame ignition was also defective, and as the pressures were low and temperature also low, the oil was not all consumed, and produced soot which chocked the passages.   Its thermal efficiency did not exceed 7 per cent.

The mixing of the fuel and air under pressure outside of the combustion chamber, and relying upon a flame interceptor, has never succeeded, for the reasons already pointed out, and also from the fact that with a mixture of fuel and air low pressures must be used ; for if the mixture is compressed above a limit which is not very high it will explode prematurely.   The correct method for working the gradual combustion engine, it will thus be seen, is that discovered by Diesel, namely, to compress the air and fuel separately, the air being raised to exceedingly high pressures in the working cylinders, and the fuel burned as it is forced in at the beginning of the working stroke.

Whether the Diesel engine has been made for lower pressures and with spark ignition is not published, but there is little doubt that on the lines of the 2-stroke cycle engine just described it could be made to work as low in pressure as any ordinary oil engine, if satisfactory ignition was provided.

In all likelihood there shall be a return to the original gradual combustion type of engine after this successful demonstration of its superiority by Diesel.

GRADUAL COMBUSTION TURBINES

None are at present in the market, but some promising designs exist, and the principles of their construction can be laid down without the essential details for
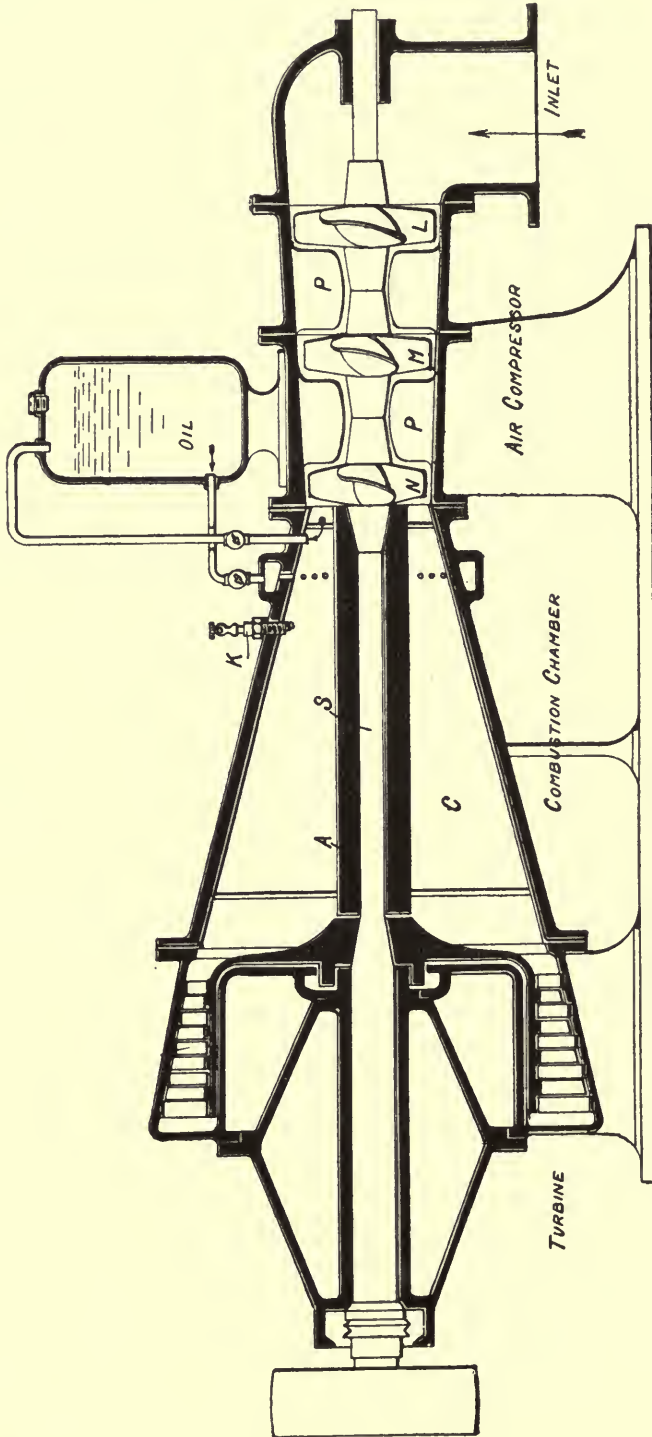
FIG. 37.—Theoretical Diagram of Constant Pressure Gas Turbine.

practical success; these will come sooner or later, probably later, for the difficulties, although not at all great, their solution will cost much money, and the time required will be inversely as the money expended. However, we may profitably briefly lay down the principles and a diagram for future reference to such engines.

1st, then, as to the turbine. The temperature at which the hot gases can be used is limited to that below which steel remains of full mechanical strength, and does not soften by the heat. And it is not desirable to jacket the turbine with water, so that the temperature of the hot gases will be limited to a low red heat. The fuel should therefore be burned in a combustion chamber with a large excess of air to reduce the temperature to a safe limit.

2nd.—The air must be compressed by a rotary screw air compressor, such as Parsons', described in Volume I., running on the same shaft as the turbine wheels, so that no reciprocating motion is necessary nor valves required to pass the hot gases.

3rd.—The fuel sprayed with the compressed air should mix as they enter the combustion chamber, and should burn therein, raising the temperature to the limit of the turbine.

4th.—The products of combustion should pass directly through the turbine.

5th.—In order to reduce the difficulties of great heat and expansion in the turbine a De Laval type or a double-wheel type of turbine in which the gases expand immediately to atmospheric pressure seems at present the best type.

Spark ignition would be necessary to start with, and probably also petrol, in order to get up the temperature required to burn the oil of common petroleum.

Referring to the diagram Fig. 37, the screw air compressor P is mounted on the same shaft S as the turbine wheels T, the shaft extending the whole length and through non-conducting sleeve A in the combustion chamber, which is also lined with fireclay or heat resisters. The oil reservoir is connected to the pressure of the air compressor, and also to an annular space which communicates with the combustion chamber by fine holes for the oil to enter. The entering air from the compressor rushing across these small openings draws the oil with it, mixes, and is lighted up by a spark plug K. After the combustion chamber is heated to ignition point the spark ignition is discontinued.

There is certainly no theoretical and not many practical difficulties in this proposition, and this brief description is given with a diagram to show how a first approximation to working the turbine by internal combustion may be made. Several explosion types will be described under "Explosion Internal Combustion Engines."

It is at present not the case that we do not know how to begin to make a combustion turbine for oil or gas; the difficulty is the great amount of time and expense required to bring the details to perfection,—an operation which can be effected only by actual experiments on a considerable scale of magnitude.

CHAPTER III

EXPLOSION INTERNAL COMBUSTION ENGINES

PURPOSELY the distinction is not made between gas and oil engines in this work. It is sufficient nowadays to treat them as two large classes, "gradual internal combustion engines" and "explosion internal combustion engines." In the latter class the fuel and air—it matters not what the fuel is, gas, oil, spirit petrol, or alcohol—are mixed in the working cylinder, and ignited so that the fuel is burned instantly with a sudden rise and fall of pressure. Properly speaking, they are all gas engines, for all the liquids used are gasified either before or as they enter the cylinder.

The term gas engine is, however, restricted to engines using ready made gas from some separate gas producer, such as the public gas supply, an oil gas producer, water gas, Dowson gas, Mond gas, and suction gas producers.

Oil engines is the term commonly applied to gas engines containing a small gas producer, popularly called a vaporiser, in which heavy oils which do not vaporise or gasify at ordinary temperatures are gasified in the small gas producer on the engine cylinder by heat from a lamp or from the combustion in the engine.

Petrol engines is the term applied to gas engines in which the liquid fuel is easily vaporised or gasified at ordinary temperatures. In a vaporiser called a "carburetter," by merely drawing air through, these fluids evaporate, and the mixture of vapour and air is explosive.

Most of these three classes of gas engines are constructed on the same general plans, and work either upon a 2-stroke or 4-stroke cycle. The difference between the one make and the other make consists principally in modification of valves and valve gears, ignition arrangements, and vaporisers or carburetters. One engine, the large Körting engine, has a 1-stroke cycle, an explosion every stroke, and is built on the lines of a horizontal steam engine, with this exception, the makers follow one pattern for stationary engines, a single acting cylinder with an overhung cylinder head, a water jacket, and a hit or miss governor.

We will not follow any classification further than two divisions already made between gradual and explosive combustion. It is considered better to begin with the simpler and proceed to the more complex engines, examining their modification and differences.

TWO-CYCLE ENGINES

This class of engine has the exhaust ports at the end of the out-stroke, to allow the escape of the spent gases when these ports are uncovered by the piston at the end of the working stroke. Air or an explosive mixture of air and fuel is then admitted, displacing the remains of the burnt gases and filling the cylinder. The in-stroke compresses this charge, and it is fired by spark or hot tube. In another form the air and fuel are drawn

into a pump, and when the piston uncovers the ports at the end of the stroke this charge is forced into the cylinder, clears out the remains of the former charge, and fills the cylinder ready for compression and firing again, thus giving one explosion every two strokes or every revolution. Körting, by doubling the cylinder, performs this cycle at both ends, and thereby obtains a double acting engine, with an explosion every stroke.

In Melhuish's patent engine (Fig. 38), made by Messrs. T. Glover & Co., the charge is drawn in by suction, the exhaust being sucked out when the exhaust ports are uncovered at the end of the stroke.

The simplest engine of all, and one which we have already partly described in the introductory chapter, is perhaps the Bisschop. Fig. 39 is a complete view, and Fig. 9, a section, is shown on page 10, Chapter I.
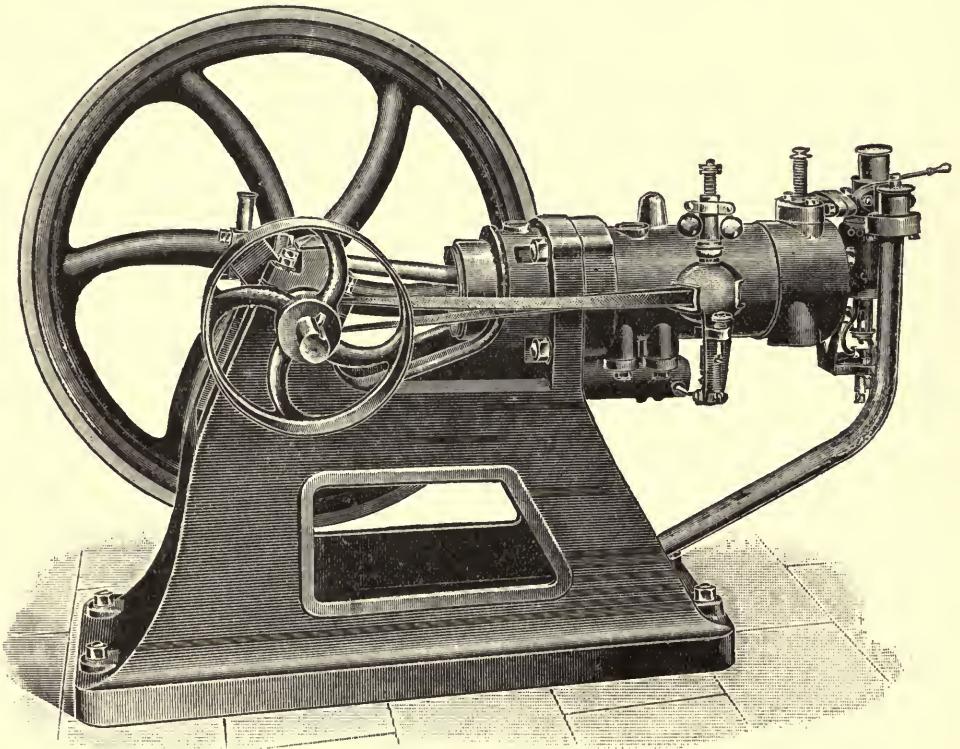
FIG. 38.—Two-Cycle Engine.

It was brought out more than twenty years ago, and introduced by Messrs. Andrew of Stockport, and it is still being made and sold.   The secrets of its success are three. First, it bears in every detail the stamp of high-class engineering design with great simplicity ; secondly, it is well made ; thirdly, it is cheap, and requires little or no attendance. It is only of use for small powers, but is designed with ample materials for long runs.

The piston rod is guided by a piston on its upper end, sliding in a bored guide cylinder having a slot on one side, through which the connecting rod works.   When the crank is at half-stroke the piston rod G and connecting rod C are parallel, as shown in the section, on the up-stroke.   At this point the fuel and air mixture is fired, and the piston pulls direct on the crank, and receives an impulse when it is flying up at full speed.   An exhaust valve worked by an eccentric opens and shuts the exhaust valve

on the down-stroke. To begin the cycle, the piston P rising sucks in gas and air, or petrol and air, through two valves at A until about the middle of the stroke, when it uncovers a little port H with a clack valve. The suction opens this valve and draws in a flame continually burning opposite this ignition port. The flame fires the charge, which expands and drives the piston up at the end of the up-stroke. The exhaust valve is opened, the piston drives out the burnt gases, and the cycle is repeated. There are two ignition flames. The one J which shoots into the port is apt to be blown out, so that another is provided slightly below it to relight it.

The cylinder has gills cast upon it for cooling. These are quite sufficient for the purpose. By attaching a petrol carburetter and adjusting the valves it will work as a petrol engine.

It is not economical of fuel—no small power engine can be, but its general utility and freedom from troubles has carried it through a long period of a useful life.

A rather simple engine of the compression type was patented in 1884 (No. 15,312) by Mr. H. P. Holt. The object of the invention is to dispense with valves in the working of gas engines, and admit, ignite, and exhaust the gases entirely by the movements of the piston. In Fig. 40 the piston *a* is on the end of its in-stroke, in which position the charge is ignited through the ports *b* and *c*; as the piston performs its outward stroke the recess *d* unites the ports *e* and *f* and allows a portion of the charge to escape, a sufficient diminution

FIG. 39.—Bisschop Gas Engine.

in pressure being thereby obtained in the cylinder to cause a new charge to enter when the port *b* reaches the port *g*. On the return stroke the charge is compressed and ignited, when *b* and *c* again coincide. A weighted valve may be added to prevent any escape through the passages *e* and *f* as the recess *d* passes them on the in-stroke. In another arrangement the passage *e* is dispensed with, the piston being formed with a

FIG. 40.—Holt's Engine.

blank end, the passages *b* and *d* being continued backwards and opening into the cylinder at the back end of the piston.
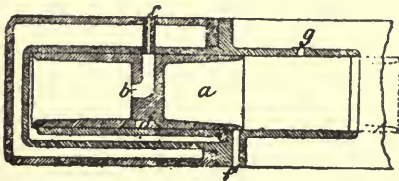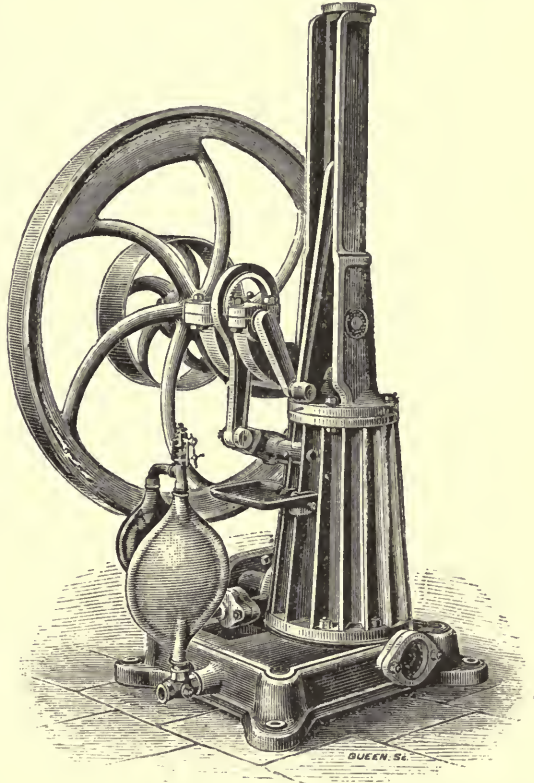
This specification does not clearly provide for the forcing in of the new charge. It provides for its being sucked in by the fall of pressure in the working cylinder.

Later on, in Ridealgh's Patent (Fig. 41), No. 4511 of 1887, the idea of using the crank chamber and the piston in its downward stroke as a pump and receiver of a slightly compressed charge ready to force its way into the cylinder is described.

The air charge is compressed in the chamber E enclosing the crank during the out-stroke of the piston, at the end of which period the exhaust ports T are uncovered and

the charge is admitted to the cylinder through the valve H, and assists in expelling the products of combustion. During the in-stroke the charge is compressed in the cylinder, and another charge of air is drawn into E through the valve F, and a charge of gas into the annular chamber P communicating with E through the valve K ; on the end of the in-stroke the charge is ignited by the hot tube U. The gas is admitted to the passage P^1 from the annular chamber P through ports P^4, P^5 in the piston valve R (Fig. 41), on the spindle of the valve H, and mixes with the air from E in passing through the port P^5. The valve H is raised by a cam on the crank boss ; the gas valve K is opened by the cam N through the rod L, and is controlled by the governor, which removes the catch m from the path of the block m^1 when the speed is excessive.

Then followed J. Day, Patent No. 6416, 1891 (left-hand Fig. 44), who added inlet valves on the casing of the crank.

The gas and air are drawn into the crank chamber on the up-stroke of the piston respectively through the ports H and F and a flap valve, and mixed by the motion of the connecting rod ; on the down-stroke they are compressed, and when the piston uncovers the exhaust port E they pass into the top of the cylinder through a beat valve in the piston or through a passage p as shown. A plate O prevents the charge from mixing with the exhaust, or the admission port may extend to the top of the cylinder for the same purpose. M is the igniting port.

In Chapter I. will be found diagrams giving the cycles in this class of engine which has proved practicable, and recently it has been much used in small boats with petrol for propulsion.

This type of marine engine is also made by Messrs. Fay & Bowen in America, and in this country by the Mitcham Motor Company. Its great simplicity and reliability, when made thoroughly well and with the Palmer patent igniters and vaporiser, make it peculiarly suitable for marine propulsion of small vessels. It is therefore of interest to note a few points in this particular engine.
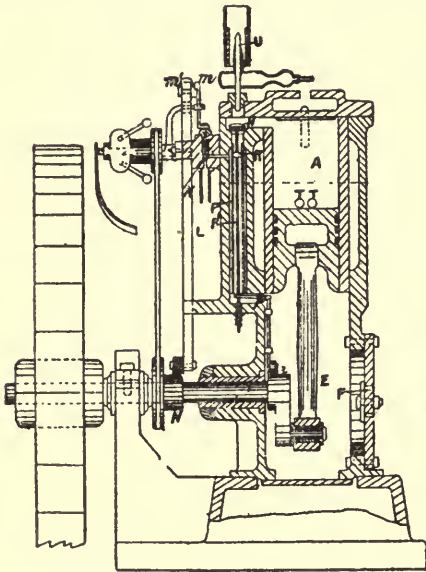
FIG. 41.—Ridealgh's Engine.

Fig. 42 shows three engines combined on one shaft for a screw propeller, with one continuous crank shaft and three separate cylinders, with cranks at 120°, controlled by throttling, regulating all three at once or separately.

For diagrams of the single engine, see Chapter I. page 11.

The ignition is by self-induction spark across a spark gap made by breaking the circuit of a battery with a self-induction spark coil in circuit, a method which might with advantage be more universally employed. The Americans use Edison-Lalande cells sealed up. But there are other cells equally good to choose from. A great deal depends on properly designing the coil to fit the cell, and these points will be fully gone into under "Igniters."

Fig. 43 illustrates the design of the engine frame of a very strong and simple construction, with the cylinder head screw studs in place.

Employing the crank case as a receiver for gases compressed by the outward stroke

of the piston has some drawbacks, and is only applicable to small engines. Large engines should never have closed crank cases.
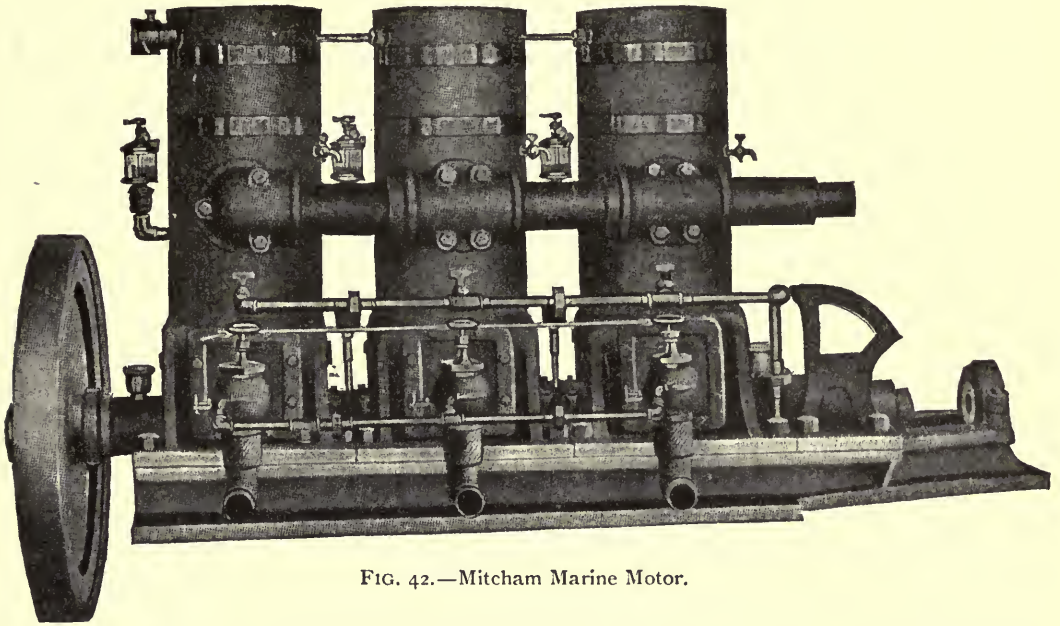
FIG. 42.—Mitcham Marine Motor.

And when the shaft bearing in a closed crank case wears and becomes leaky the gases escape and cause trouble.

For small oil engines or petrol engines the better design is to use the crank case for air only, and to keep the oil connected by a pipe to the crank case, and in a closed tank at a height above the engine. By this means the oil can be injected into the cylinder slightly behind the air, and none of the fuel escapes. This was covered by J. Day's Patent No. 15,514 of 1895, briefly described and shown in Fig. 44 in the right-hand figure.

The air is drawn into the closed crank chamber through the port A, where it is uncovered by the piston and compressed on the out-stroke, at the end of which the piston uncovers the exhaust port C, and the ports H and B supplying compressed air and oil respectively. The oil is contained in a reservoir L in the engine bed, as in Fig. 44, or a separate one, as in Fig. 44, the middle figure ; the oil is expelled by air admitted through a pipe M and non-return valve O from the crank chamber. The oil may be vaporised on a hot plate V in the cylinder. At starting, oil is poured into the cup R and admitted through a valve T into a pipe P, where it is heated by lamp Q.
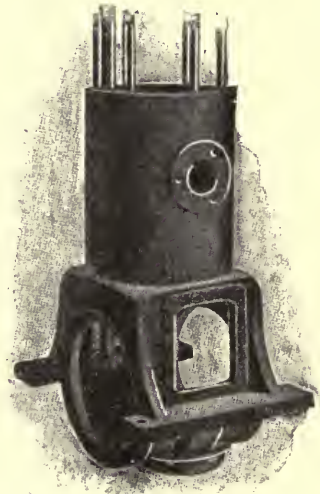
FIG 43.—Frame.

The oil in this engine, if of the heavy high-flash kind, must of course pass through a vaporiser, and if petrol through a carburetter.

One peculiarity of this type of engine is that it will run in whichever direction it may be started. This is in some cases an advantage of some value.

Mr. D. Clerk was the first to apply a separate pump for the gases in an engine with an open crank case in his Patent No. 1089 of 1881.

In one modification there are two single acting cylinders provided with pistons connected in the ordinary way to cranks on one shaft. In one cylinder a mixture of gas or vapour and air is ignited, and power developed, but the other cylinder is employed to effect displacement only, and the two cylinders are hereinafter distinguished as the power cylinder and the displacement cylinder. The air and gas or vapour enter at one end of the power cylinder, and the exhaust takes place by ports so situated as to be passed by the piston when approaching the end of its stroke in its movement from the entering end. The capacity of the displacement cylinder is considerably larger than the product of the area and stroke of the power piston; and when the displacement piston is moving in one direction it draws in air and gas or vapour through a check valve, but the gas or vapour is cut off as soon as the quantity of mixed
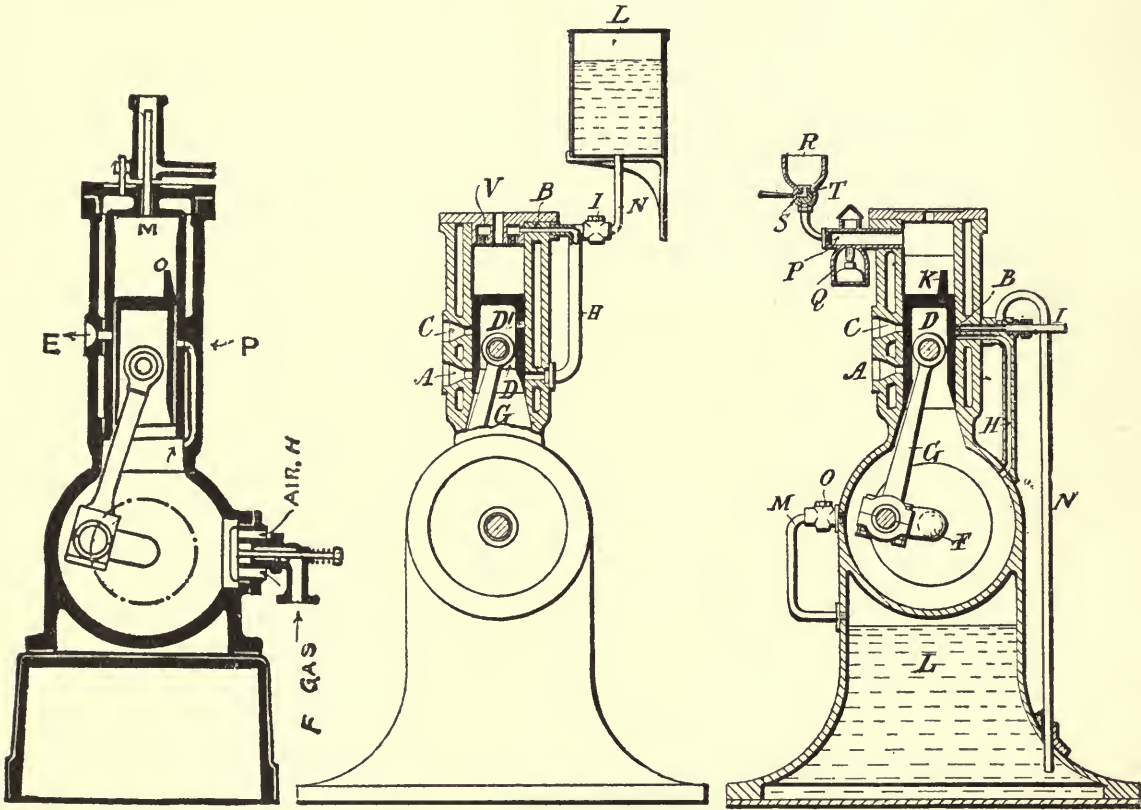
Fig. 44.—Day's Engines.

air and gas or vapour is about equal to the product of the area and stroke of the power piston, and only air is drawn in during the remainder of the stroke of the displacement piston. On the return stroke the displacement piston forces the contents of its cylinder through a check valve into the power cylinder, the unmixed air last drawn in first entering the power cylinder. The cranks of the two cylinders are so placed relatively to each other that whilst the contents of the displacement cylinder are being forced into the power cylinder the exhaust ports of that cylinder are still open, and not only do the burnt or used gases of the previous stroke pass out, but also the unmixed air which enters in advance of the fresh charge. This portion of unmixed air ensures the clearing out of the power cylinder, and prevents any ignited matter from remaining in the cylinder to prematurely ignite the fresh charge. On the return stroke of the power piston, and after it has passed and closed the exhaust ports, it compresses the mixture of air and gas or
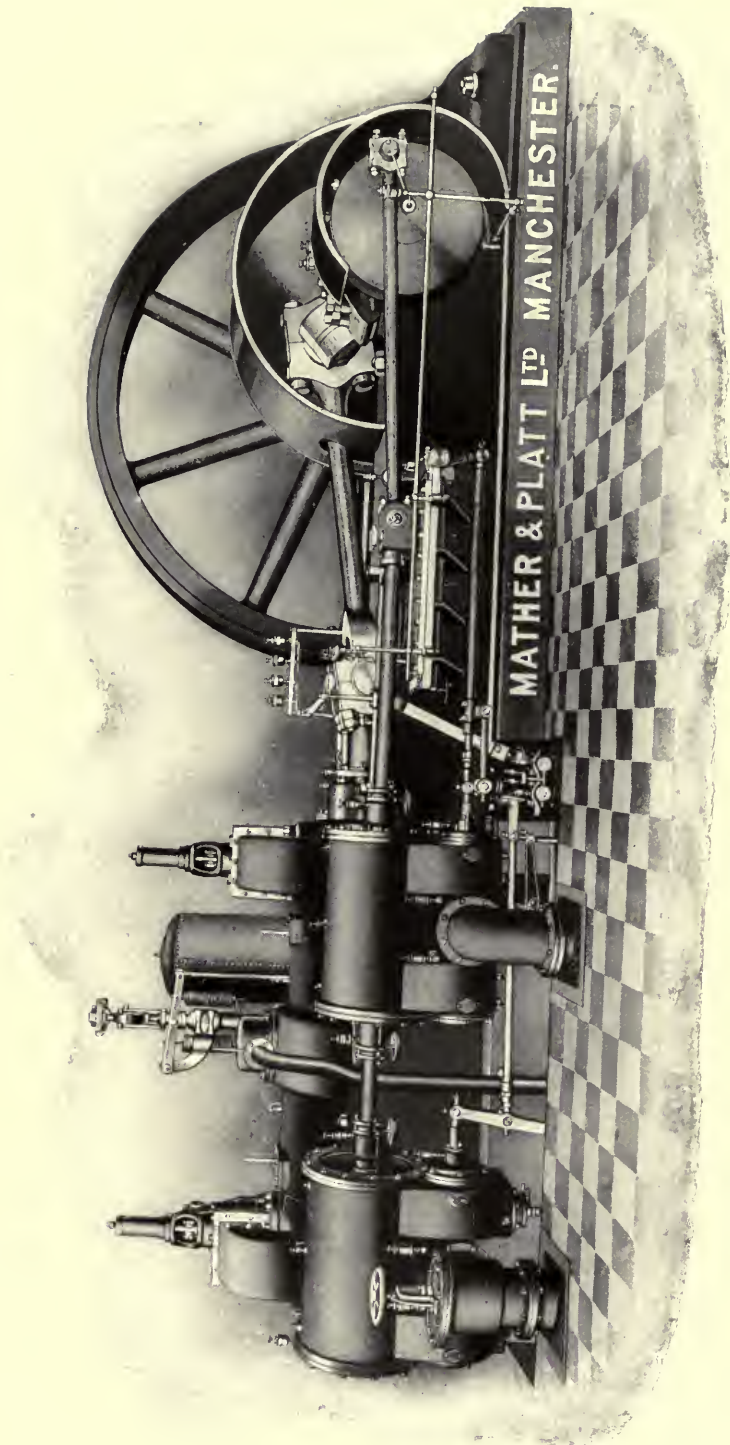
PLATE II.—500 BRAKE HORSE-POWER SINGLE CYLINDER 2-CYCLE KÖRTING GAS ENGINE.

vapour into a clearance space at the end of the cylinder, and the compressed charge is ignited at about the commencement of the succeeding stroke. The ignition is effected by means of a slide worked by an eccentric on the crank shaft, and moving between a port face on the side of the power cylinder and a covering plate, the latter being pressed against the slide by springs. The covering plate is formed with a small open chamber, in which a small ignited gas jet is kept constantly burning, and this chamber has a port past which the slide moves. The slide has a main passage or space formed in it and extending partly along it, and this main passage has a port on each side.

A very small passage having a port on the inner side of the slide communicates through a grating with the main passage, and into this small passage there finds its way some of the combustible mixture from the interior of the power cylinder through a small passage and an elongated port or groove in the cylinder port face. When the slide is in one position the outer port of its main passage is in communication with the port of the chamber in the covering plate, and then the gas entering through the grating becomes ignited, but the ignition is not communicated through the grating nor through the inner port of the slide. The immediately subsequent movement of the slide cuts off the communication of its outer port and brings its inner port into communication with a port leading into the cylinder, and the flame in the main passage of the slide is thereupon communicated to the combustible mixture in the cylinder, all communication with the exterior being completely cut off.

The slide, besides having the passages and ports that have been mentioned, is made with a cavity or port which works in connection with ports and passages through which the combustible gas or vapour passes on its way from the supply pipe to the valve through which it is drawn into the displacement cylinder, the slide causing the gas to be cut off at such period of the indrawing stroke as to render the latter portion of air drawn in unmixed with gas or vapour. The gas or vapour supply passage is also fitted with a valve controlled by a speed governor.

Fig. 45 is a horizontal section, and Fig. 46 a longitudinal vertical section, in which a single acting power cylinder 11 is fixed horizontally in a jacket casing 12, formed at one end of a bed frame 13, which is at its other end provided with bearings for the crank shaft 14. The piston 15 of the power cylinder is in the form of a hollow plunger or ram, but is fitted with a number of metallic packing rings, and no stuffing box is required at the front end of the cylinder. The connecting rod 16 of the power piston is jointed on a double-cheeked crank on the shaft 14 between the bearings ; and outside of the bearings there are at one side of the machine an eccentric 17 for working the valve slide, and a pulley 18 for the belt which transmits the power from the machine ; whilst at the other side the shaft 14 has on it a fly-wheel 19 and a pulley 20, a strap from which last drives the speed governor. The fly-wheel 19 has on it a crank pin 21, on which is jointed the connecting rod 22 for working the piston 23 of the displacement cylinder 24. The displacement cylinder 24 is placed horizontally at one side of the power cylinder jacket 12, being formed in a casting 25, which is bolted to the jacket 12, and which is formed with and carries various parts hereinafter described. At the inner end of the power cylinder 11 there is a conical clearance space 26 formed in the casting 25, as is also a jacket space 27, which communicates with the space in the jacket 12 surrounding the power cylinder 11. Water entering by a pipe 28, and passing off by a pipe 29, is supplied to the jacket spaces 12, 27, to prevent the power cylinder 12 and clearance space 26 from becoming overheated.

The air and gas enter to the power cylinder 11 by an inlet 30 at the outer end of the conical clearance space 26, and the exhaust takes place through ports 31, communicating with a passage 32 formed round the cylinder and leading to the exhaust pipe 33, these exhaust ports 31 being uncovered by the piston 15 as it approaches the outer end of its

stroke. A pipe 34 fitted with a stopcock 35 forms a communication between the exhaust pipe 33 and a part of the cylinder 11 nearer the inner end, and is provided to facilitate the starting of the motor, the opening of the stopcock 35 having the effect of reducing the compression and the force developed at each stroke.

Below the inlet 30 to the power cylinder there is a valve box 36, having in it two check valves 37, 38, whilst the space between them communicates by a pipe 39 with the displacement cylinder 24, and the action of the displacement piston 23 is to draw in air and gas through the lower valve 38, and subsequently force them through the upper valve 37 into the power cylinder 11. With the view of diminishing or preventing the production of noise by the drawing in of the air, a chamber or box 40 is fixed below the lower check valve 38, and the air enters this chamber 40 through a number of holes 41 formed round the bottom of it, and having above them a light rubber disc 42. The opening of the lower check valve 38 admits gas as well as air (unless the gas happens to be shut off), there being in the conical seat of the valve a number of small holes which communicate with an annular passage 43, to which the gas has access by a vertical passage 44.

The displacement cylinder 24 is represented as having a capacity about equal to double the product of the area and stroke of the power piston; and the crank 21 for working the displacement piston 23 is placed a little more than a quarter of a circle in advance of the crank of the power piston 15; these relative proportions and arrangement may, however, be varied in different cases.

This engine had a large sale at one time and did fairly well in competition with the

Fig. 45.—D. Clerk's Engine. Horizontal Section.

Otto engine, but for several reasons it was withdrawn. To those who knew the engine it was felt that it never had a fair commercial chance, that it was not backed up sufficiently, and finally, patent litigation stopped its career.
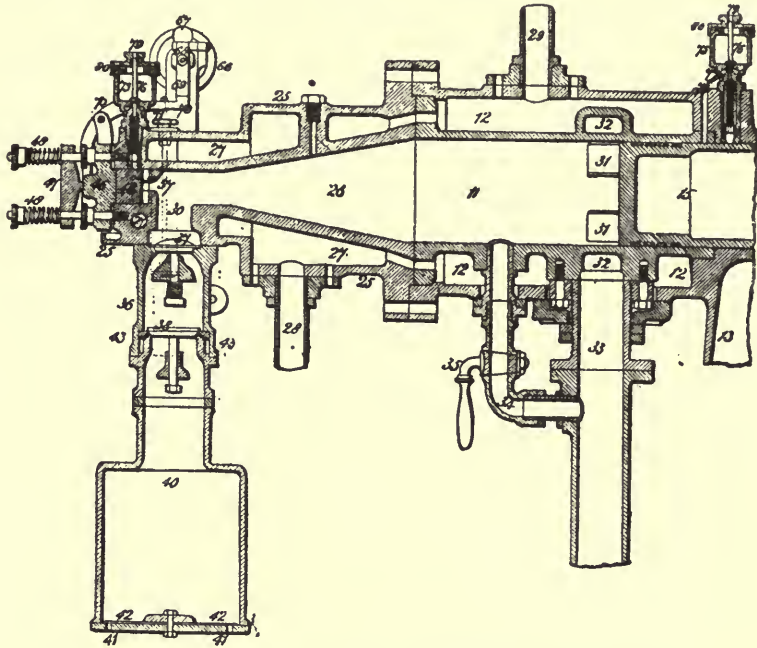
FIG. 46.—D. Clerk's Engine. Longitudinal Vertical Section.

Other 2-cycle engines were introduced, notably by Simon of Nottingham, who was a pioneer in gas engines. This engine had a double piston, a differential trunk.
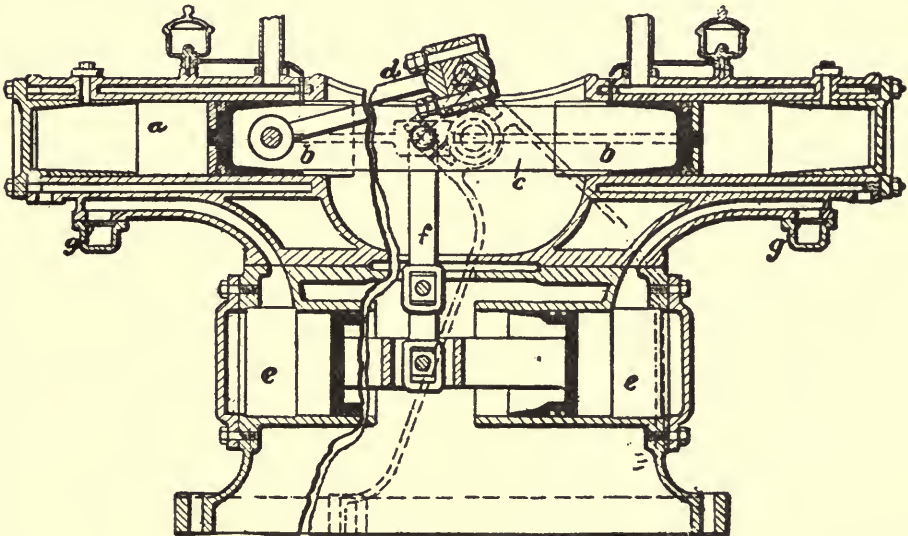
FIG. 47.—Early Stockport Engine.

The large end acted as a pump, the smaller one as a motor piston. It was called the Trent engine. As it is not now in the market, and has no historical or instructive points, it need not be described.

The familiar Stockport engine was invented by Mr. J. E. H. Andrew, many thousands of which are in use. The construction was different, but in effect it had the same action as Clerk's. It had a pump cylinder and a motor cylinder opposite each other, or as they now put it in automobile circles *tête-à-tête*; it is too well known to require description. By duplicating this engine, as in Fig. 47, two impulses are given at each revolution. The cylinders *a* are cast in line facing each other, the plungers *b* being connected together by the arm *c*; their motion is communicated to the crank through the connecting rod *d*. Each cylinder has a separate charging pump *e* beneath it, the plunger of which is actuated by a rocking lever *f* connected at its top end with the arm *c*. Air and gas are admitted to the pump through a slide valve reciprocating at right angles to the ignition slide eccentric rod to which its spindle is connected. On the end of the working or outstroke the piston uncovers an exhaust port; at this time the pump has finished its compression stroke, and the charge enters the cylinder through the gauge *g* and some non-return valves, and is further compressed on the in-stroke. To start the engine, one cylinder and pump are left open to the atmosphere and the fly-wheel turned through one revolution by hand. Another engine may be placed by the side of this with cranks at right angles and the fly-wheel between them to produce four impulses per revolution.

This engine gave good results, but had some drawbacks. But although they seemed serious some years ago, these drawbacks have been overcome, and *tête-à-tête* engines are again coming into use. Messrs. Andrew make their large double cylinder engines on this system now with a girder pattern frame, and with a guide plate in the cylinder to take up the upward thrust of the cylinder, on which the thrust is forward and upwards on the working stroke.

Thus by duplicating parts of their 2-stroke engines Messrs. Andrew made their 1-stroke 1-explosion engine, and still do so for large powers.

Similarly, by duplicating parts of Clerk's 2-stroke engine, Körting produces the large power 1-stroke engines, — of course, adding original improvements. This engine is made by Messrs. Mather & Platt, Manchester, to whom we are indebted for description and illustrations here given.
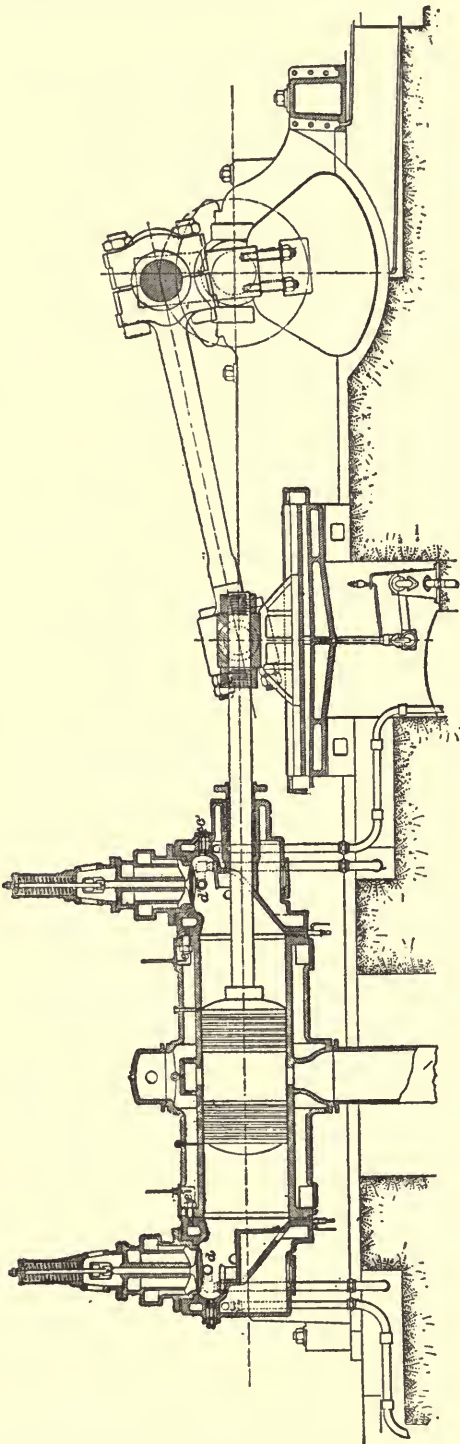
FIG. 48.—Körting Gas Engine. Sectional Elevation.

KÖRTING GAS ENGINE

The Körting engine is of the double acting 2-cycle type, and is therefore built on the same lines as an ordinary double acting steam engine. Each side of the piston receives an impulse every alternate stroke, *i.e.* there are two impulses per revolution, or four times as many as in the single cylinder "Otto" cycie engine. Plate II. is a complete side view, Fig. 48 a side elevation in section, and Fig. 49 a complete plan, and Fig. 50 a sectional plan of this engine.

At the front end the piston rod is carried through a stuffing box fitted with metallic packing, and is connected to an external crosshead in the ordinary way. This arrangement is of great value in an internal combustion engine, where the temperature of ignition is so enormous, as it obviates the difficulties arising from the heating of the internal crosshead pin, which are of frequent occurrence with trunk piston engines.

The outside crosshead, while permitting of free lubrication and cool running of the pin and guides, also does away with undue wear and tear of cylinders and pistons, owing to the resultant of the force of the impulse and the resistance of the crank pin. The piston of our engine is long, affording a good wearing surface, and the front gland, together with the main guide, ensure smooth running inside the cylinder.

Alongside the power cylinder are placed two charging pumps, one for
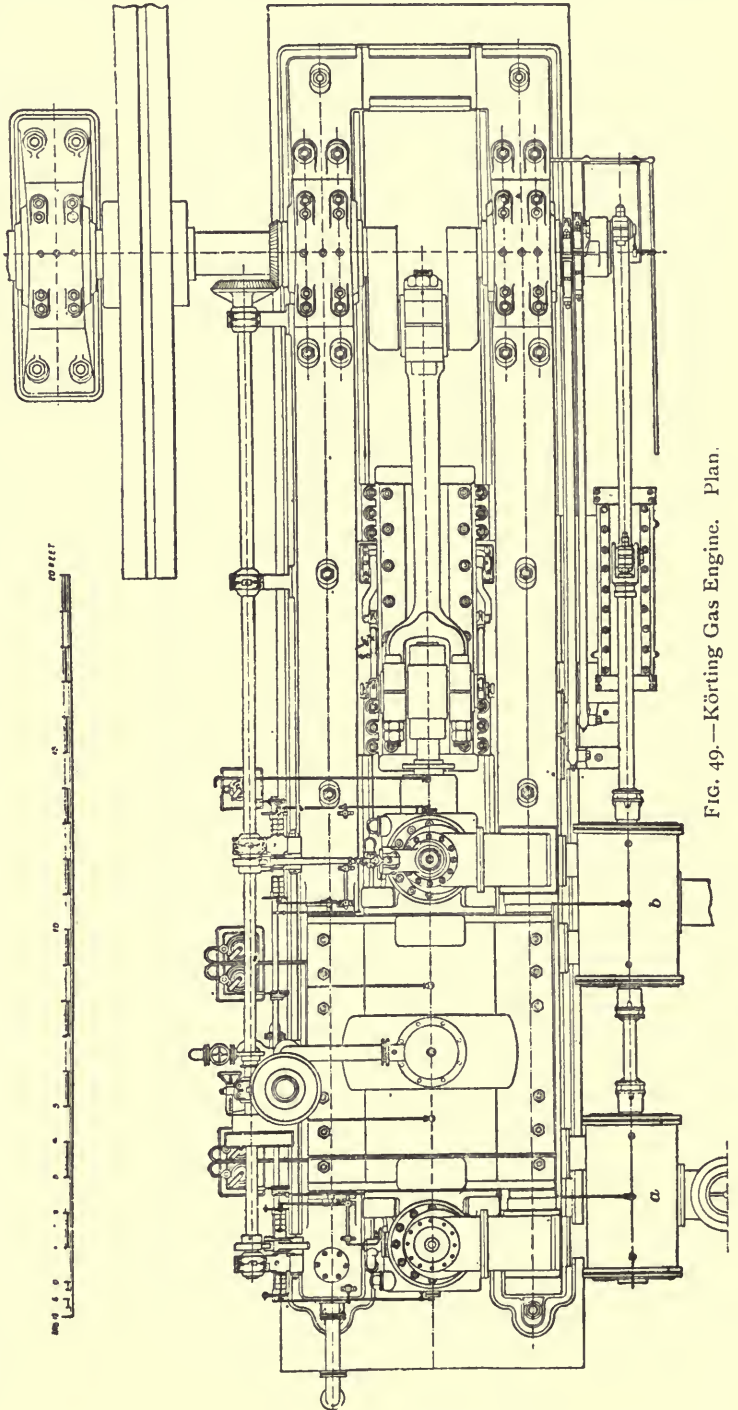
FIG. 49.—Körting Gas Engine. Plan.

air and one for gas ; and it is by the adoption of these independent pumps, which in one stroke supply both the scavenging and explosive charges to the power cylinder, in place of using the power cylinder itself as a pump for this double purpose during two strokes, that the engine acts on the 2-cycle instead of on the 4-cycle system. When the piston P is on the forward dead centre, as shown in the illustration (Fig. 51), the exhaust ports S round the centre of the working cylinder are uncovered, their opening having commenced when the face of the piston was in the position represented by "*d*" on the indicator diagram. At that moment the cylinder pressure, as apparent from the expansion curve, falls to atmosphere, and at the same time the admission valve E is opened by its cam, and a scavenging charge of pure air is sent into the cylinder by the air pump, effectually clearing out the products of combustion. The gas pump, the discharge of which takes place later than that of the air pump, now sends a supply of gas into the cylinder, which discharge, mingling with that of the air pump, forms the combustible mixture necessary for the power stroke. The exhaust ports S are then closed by the return stroke of the power piston P, the mixture is compressed, ignited electrically at two distinct points to ensure complete firing, and the impulse is transmitted to the piston. The same cycle is repeated at each end of the piston alternately, the air pump thoroughly sweeping all burnt products through the exhaust ports S, and thus entirely preventing the preignition of the incoming charge by contact with the hot gases remaining in the

Fig. 50.—Körting Engine. Sectional Plan.

cylinders. This thorough sweeping out of the burnt product by the scavenging charge also prevents the choking of the exhaust ports by carbonised lubricant, or by dust which may pass into the cylinder with the gas. Examination of a cylinder, after months of steady running, has proved beyond doubt that the ports were absolutely clean, and that no undue wear had taken place on the bars between the ports.

A special advantage of the independent pumps is that the air and gas are kept distinct and separate till they reach the admission valve (see Fig. 52), so that there is no accumulation of explosive mixture out of the working cylinder itself, and therefore no back firing can occur.

Regulation is not effected on the "hit and miss" principle, but by altering the quantity of the mixture admitted to the power cylinder : during periods of light load the valve admitting gas to the cylinder is kept closed for a longer period than during heavy load, and *vice versâ* ; so that the charge is proportional to the work done, though the quality of the mixture at the points of ignition is maintained practically constant, thus ensuring full ignition. The advocates of "hit and miss" governing contend that, from the point of view of economy in gas consumption, variation in the quantity of the
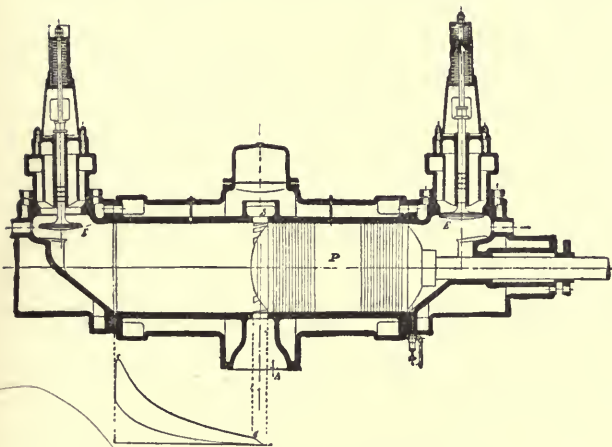
FIG. 51.—Körting Engine. Cylinder Section.
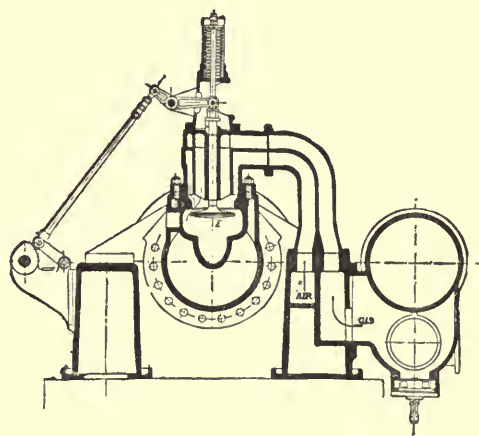
FIG. 52.—Körting Engine. End View Section.

mixture is not conducive to efficiency. Theoretically this is correct, as somewhat less gas is used on light loads by missing an explosion altogether than by igniting a charge at compression below the normal ; but on full loads this economy is not marked, and is more than compensated for by the much steadier running resulting from an impulse at every stroke. This is a most important point to bear in mind ; and as high a degree of cyclic regularity can be obtained without the aid of excessively heavy fly-wheels as can be got with the best design of steam engine.

The mixture is fired, as already stated, at two independent points at each end of the cylinder, and means are provided whereby the time of ignition can be regulated by hand while the engine is running. Weak gases, such as blast furnace gas, require to be ignited earlier than producer gas, and the latter, in like manner, earlier than town's gas. Where the value of the gas is liable to fluctuate, this variable ignition gear is of great service.

Compressed air is used to start the engine, for which purpose a small air compressor, either belt or motor driven with a reservoir for the air, can be supplied with the engine ; the air pressure necessary is about 120 lbs. per square inch. A starting valve, which can be put in and out of gear by a hand clutch while the engine is running, admits compressed air to the power cylinder, and the engine starts at once ; after attaining the normal speed the clutch is thrown over, the compressed air valve shut off, and the engine

begins to draw and ignite its own charge immediately, the main gas valve having been previously opened.

It is interesting to observe the rapidity with which a 1000 brake horse-power gas engine can thus be started, when one contemplates the warming up of cylinders, opening and shutting of drain cocks, and the other operations incidental to the two or even three hours' preparation required for starting a steam engine of the same power. The rapidity with which this gas engine can be started must commend itself to the attention of electric power and lighting station engineers.

The cooling of this engine is carried out very perfectly. In the first place, the power cylinder is completely water-jacketed, including the cylinder heads, metallic packing stuffing box and exhaust port belt. In the second place, circulating water is led to one side of the main crosshead, thence through the piston rod into the piston, back through a pipe inside the rod to the other side of the crosshead, and then away. The interior of the working cylinder is thus kept at a reasonable temperature, which it is quite easy to determine by means of thermometers placed in suitable positions.

The advantages which are claimed for this engine are as follow :—

1. Perfect scavenging with cool, fresh air, whereby preignition by contact with products of combustion is entirely prevented and lubrication much facilitated.

2. Absence of heavy exhaust valves, which are usually a source of weakness and liable to fail in their action owing to the intense heat to which they are subjected by the passage of exhaust gases, and to become fouled by products of combustion.

3. Removal from the power cylinder of up and down strains due to the resultant of impulse and resistance on the crosshead pin, which in this case is entirely outside the cylinder ; ease with which the crosshead pin is kept absolutely cool and easily lubricated, giving a marked advantage over trunk piston engines.

4. By obtaining an impulse each stroke the diameter of the cylinder is just half of what is required for an "Otto" cycle engine of the same power ; the load on the working parts and the weight of the same are therefore small compared with the power given out ; also, since the contents of a cylinder vary as the square of its diameter, but the surface only varies directly with the diameter, it follows that for a given amount of jacket water the cooling results are more satisfactory with the small than with the large cylinder.

5. Great steadiness of running, owing to the fact that in the case of a 1-cycle engine four times as many impulses are transmitted to the crank shaft as are transmitted to the shaft of a single cylinder 4-cycle engine. Lighter fly-wheels can therefore be used, and unnecessary weight and friction are thus avoided, while as steady running and as high a degree of cyclic regularity are attained as with a steam engine.

6. The engine can be started up after standing far more quickly than a steam engine which has been shut down ; lubrication is forced and practically automatic throughout ; the design generally lends itself to hard and continuous running, and should inspection be necessary it can be effected with great ease and in a very short time.

GRIFFIN MARINE OIL ENGINE

Another method for obtaining an impulse every revolution has been put into practice successfully for marine propulsion by the Griffin Engineering Company, Bath. This engine is shown in section (Fig. 53), from which it will be seen that there are two cylinders with two pistons coupled to one connecting rod, by this device, while each cylinder works on a 4-stroke cycle ; the two are so timed that while one is on the suction stroke the other is working, and *vice versâ*.

In early Griffin engines it was the practice to dilute the explosive mixture of gases admitted to the cylinder. When this was omitted the explosion was so sudden that it

produced a dangerous knock, which would be destructive in time. It is most interesting to observe the immediate effect of diluting the charge with inert gases (see diagrams, Fig. 54); in a moment the noisy labouring engine, which threatened injury to itself and
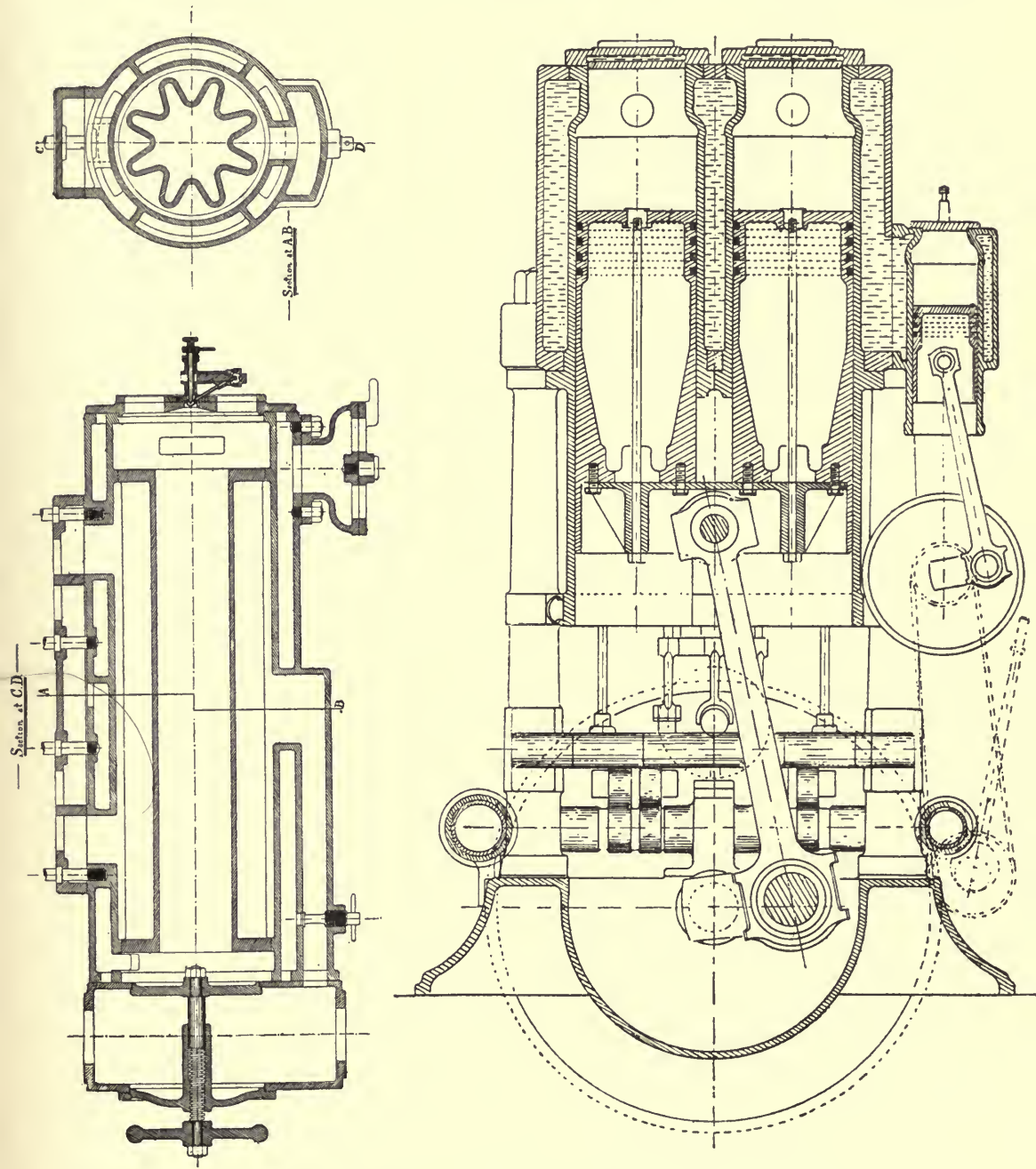

FIG. 53.—Section of Griffin Engine, and enlarged Section of Vaporiser.

to its surroundings, quietens down and runs smoothly without shock or vibration, the explosion having evidently been slowed until it becomes combustion. It is a combustion, however, which leaves no solid products in the cylinder.

Now, however, in the latest engine, the gases are diluted by water in the form of a fine pulverised spray, and thus has a much better effect than inert gases, as it forms steam, compensating by its volume for the reduction of temperature which its formation causes in the exploding mixture.

The engine is fitted with variable speed gear, and the governing is regulated by varying the number of impulses, thus ensuring the greatest possible economy under all conditions of running. Variation of speed between full load and no load does not exceed 3 per cent., consequently in the heaviest sea racing of the engine is entirely prevented.

The special point of novelty is the constitution and formation of the working charge. This consists of certain determined and invariable proportions of oil and water, which are atomised and afterwards heated to a temperature of about 350° Fahr. in a special vaporiser, the intimately mixed vapour thus obtained passing directly into the cylinders, where it is compressed to about 80 lbs. per square inch previous to ignition. During combustion in the cylinders the water vapour is decomposed and burnt in combination with the oil vapour, the added heat of the burning water gas serving to effect the complete combustion of the whole of the heavy hydrocarbons of the oil. Perfect combustion, absolute cleanliness, and great economy is thus obtained.

Ignition is effected by incandescent tubes, this method being both simple and effective ; no single instance of misfire having ever been observed under any conditions
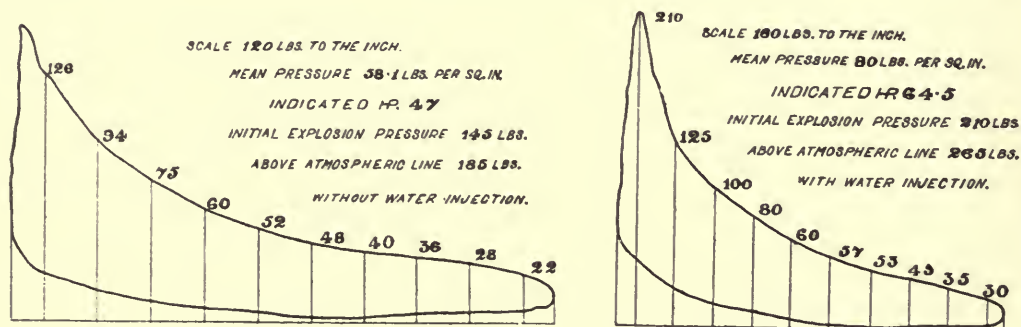
FIG. 54.—Indicator Diagrams of Griffin Oil Engines.

of running. Electrical ignition has been proved to be far too uncertain and troublesome in operation, due to the very damp charge employed.

The starting of the engine is effected by a small auxiliary motor attached to the framing of the main engine, and driving a friction pulley which actuates the fly-wheel of main engine, and is thrown in and out of gear by a hand lever. This auxiliary motor (which is of 6 horse-power) can also be employed for pumping, ventilating, driving deck winch, etc. In one instance, in addition to its primary use for starting, it also drives a rotary pump of new and improved type which discharges the tanks of their cargo of 50 tons of oil in three hours, the pump and pipe arrangement for expeditious loading and unloading being supplied by the barge builders.

The oil and water for supplying the engine are contained in two separate rectangular tanks, each 39 inches by 36 inches by 36 inches deep. These tanks are hermetically sealed, and an air pressure of $7\frac{1}{2}$ lbs. per square inch maintained on the surface of the contents. Being thus isolated, there is no possibility of escape in the roughest sea. This is a matter of the greatest practical moment, and is indeed absolutely essential for safety and success in any sea-going craft.

During a recent five hours' continuous full power trial in the Mersey at Liverpool, in a 3-knot tide, the engine worked perfectly, the manœuvring of the barge under every possible condition being carried out with complete success. The mean speed attained with full load was 7 miles per hour.

During this trial exactly 2 inches depth of oil was consumed from the supply tank, being equivalent to 2808 cubic inches, or roughly 80 pints. The engine during the whole time developed a mean indicated horse-power of 60, the calculated brake horse-power being 48, thus making the consumption .26 of a pint per indicated horse-power, and .35 per brake horse-power per hour. The oil used on trial was American Daylight.

It is interesting to add, that since the above tests were taken the dock authorities of Liverpool wished an oil of 150° flash point to be used with the engine instead of American Daylight, which, in common with ordinary Russian petroleum, has a flash point of about 78° Fahr.

A mixture of Mineral Colza and American White Rose, in the proportion of two parts of the latter to one of the former, has therefore been substituted, which gives the desired flash point, and the engine has been running with same for some time successfully.

In this Griffin engine we get a 2-stroke cycle on one crank with two cylinders in parallel with one connecting rod. In an old form of Crossley engine a similar arrangement was used to get an impulse every revolution from two 4-stroke cylinders, only, it had a connecting rod to each piston separate.

COCKERILL GAS ENGINES

The large Cockerill blast furnace single cylinder gas engines—illustrated connected to a furnace blowing engine in Plate III., and illustrated in line drawings, Fig. 55, a plan and elevation, and Fig. 56, partly in longitudinal section. It is suitable for the largest powers of engines using poor gas from blast furnaces.

It should be stated that Cockerill gas engines have been designed for other purposes than for blast furnace work, such as driving electric generators, etc.; a large number are in use for both blowing engines and dynamo work. For the latter purpose, where a high degree of regularity in running is needed, double acting cylinders are employed. For multi-phase work to run in parallel, two double acting cylinders are placed tandemwise, so that an impulse is obtained every stroke, so as to equalise the turning moment. Such engines can be driven by producer and coke-oven gases as well as blast furnace gas.

Air is taken in through the angular chamber just below the valve seating, whilst the gas is admitted through the opening shown in the right-hand side. The gas thus passes into the centre, and is surrounded by the annular space containing air ; they then both ascend and mix as they pass the valve. The valve is worked by a cam, which is actuated by the eccentrics, indicated by dotted lines, through the trip and levers shown. Below is a dash-pot for regulating the closing of the valve, so as to give it an easy motion. The speed of the engine is controlled by a ball governor mounted on the framing, and which, by regulating the valve, gives a variable cut-off. The Cockerill engines are frequently controlled by an air-cataract governor.

Ignition takes place in the explosion chamber above the inlet valve. Electrical ignition is used, and the spark is produced either by batteries or by a weak current generator, the gear being fitted in duplicate.

The Otto cycle is used, and at the other end of the cylinder is seen the eduction valve, also worked by cam gear from the eccentric shaft, as shown in the illustration. The inlet valve does not need water-cooling, but the exhaust chamber is water-jacketed, and provision is made for circulating water in the valve and spindle, which are hollowed out for the purpose. The guide of the spindle is formed so as to act as a pump for the purpose.

In the single acting engine the valves are worked from a lay shaft, operated by toothed gearing from the crank shaft, the gearing running in oil cases as shown. The gas and air inlet valves and the exhaust valve are shown in perspective in Figs. 57 and 58.

In the Cockerill engine particular attention is paid to keeping the parts at a moderate temperature, a point to the observance of which the success of the engine is largely due. The cylinder is well water-jacketed both on the barrel and at the ends, as
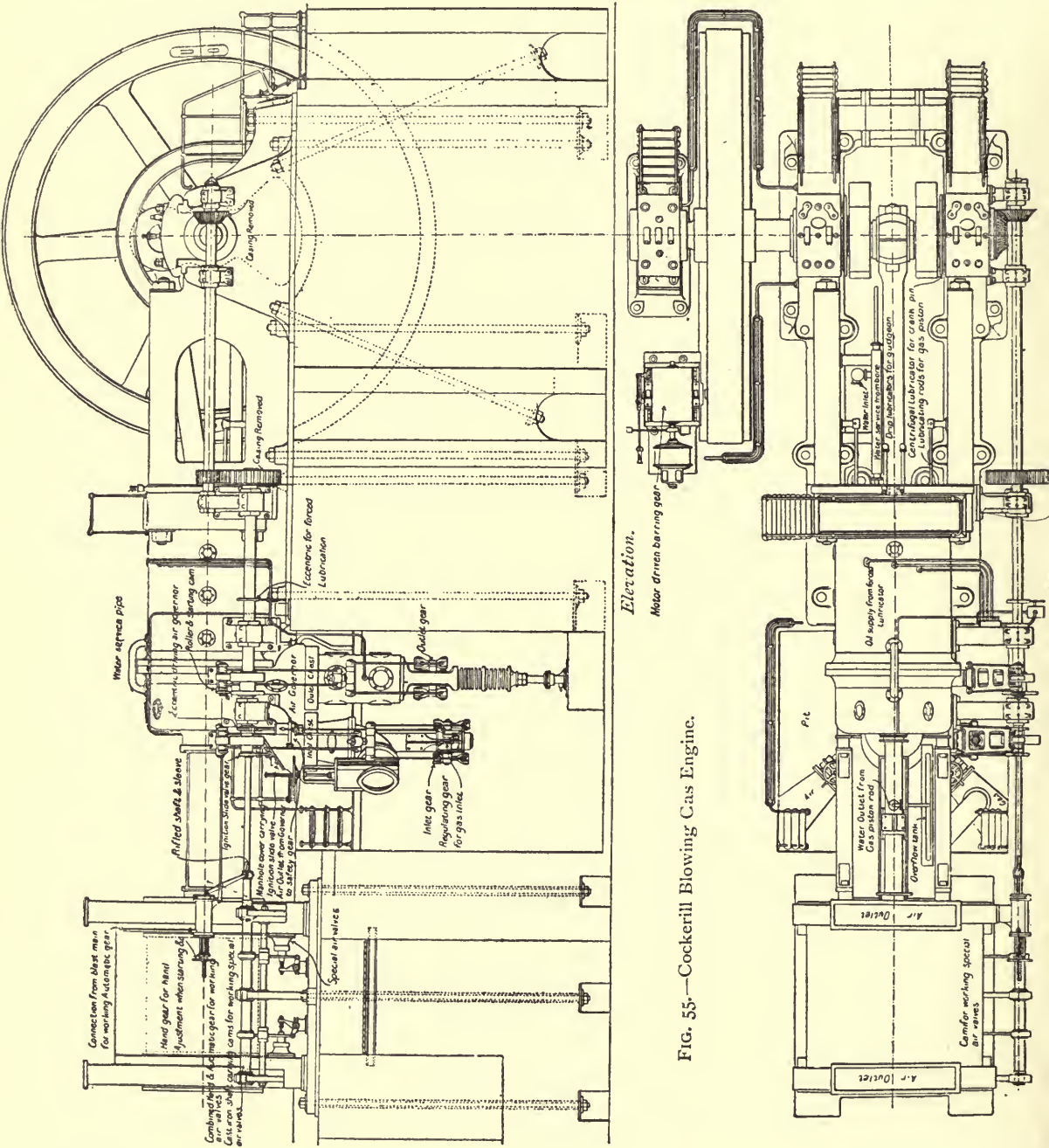
FIG. 55.—Cockerill Blowing Gas Engine.

shown in the sectional view. The water-cooling of the exhaust valve has already been mentioned, and the piston and piston rods are also water-cooled. There is a trombone arrangement (see Fig. 56) actuated by a bracket from near the cross-head, and through this water is forced by means of a pump, not shown. The circulation takes place
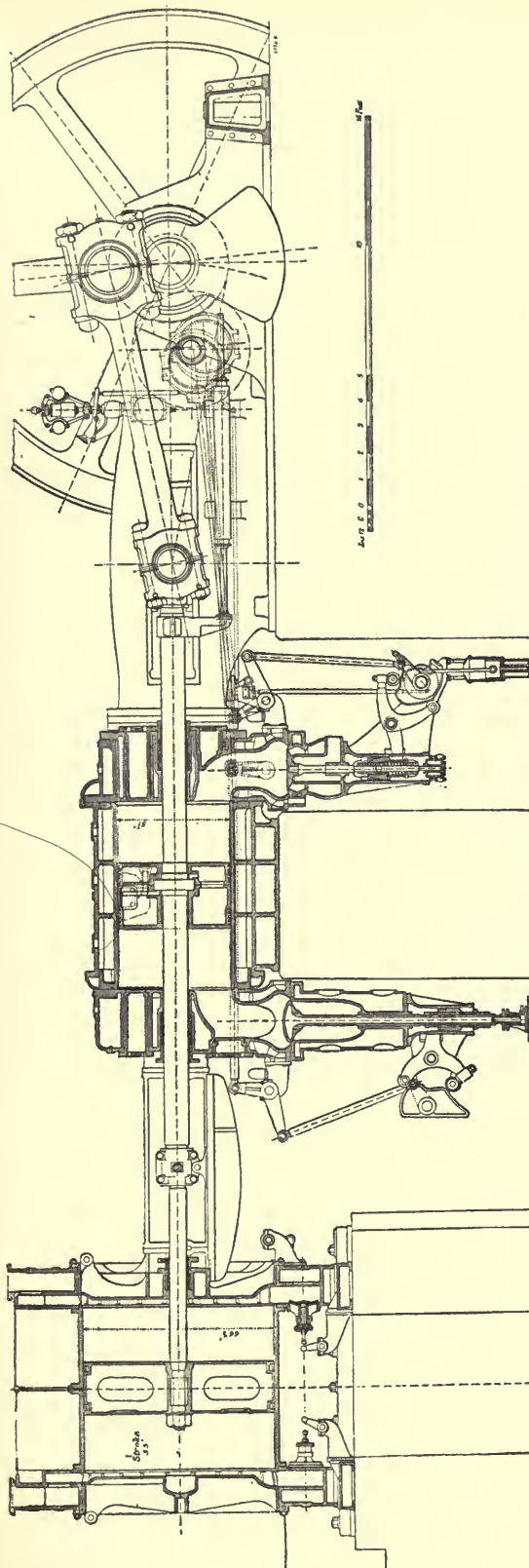
FIG. 56.—Richardsons, Westgarth, & Co.'s Engine.   Sectional Elevation.

FIG. 57.—Blast Furnace Gas Engine Valves.

FIG. 58.—Blast Furnace Engine Valves.

through the piston rod and into the front end of the piston, which is made hollow for the purpose. There are divisions to ensure a proper circulation so as to cool the whole surface, the water escaping through the back crosshead to be collected by a trough receiver. In connection with this system a water governor, not shown, is fitted, and this is so arranged that the engine stops automatically if the water supply fails.

As will be gathered from the illustrations, the framing of these engines is of massive construction, and this, with the heavy fly-wheel, accounts largely for the steady working. Messrs. Richardsons, Westgarth, & Co. have been very successful in producing these castings, and the work on the engine generally is only such as could be produced by well-equipped workshops having the command of exceptional plant and tools. The bearings are in white metal, and the main bearings can be water-cooled, if needed, by means of hollow spaces. This precaution, however, is not often used. Lubrication is by the "ring" system.

In the middle of the year 1903 there were at Richardsons, Westgarth, & Co.'s work in hand nine 750 horse-power Cockerill gas blowing engines, two 250 and two 800 horse-power Cockerill gas engines for dynamo work. A large number are running on the Continent, and one of 3000 brake horse-power is being constructed for the purpose of electric generation at the St. Louis Exhibition, the design having been modified and improved by John Cockerill & Co. of Seraing, who for years have been experimenting in this direction. The company had these engines running successfully for a considerable period before they placed them on the market.

Messrs. Cochrane have found at the Ormesby Works that a blast furnace making 120 tons of iron per day furnishes sufficient gas, if used in a gas engine, to provide at least 4500 horse-power continuously exerted.

Fig. 59.—Air Compressor (Cockerill) for Blast Furnace Gas Engine.

In the blast furnace there is abundance of gas of low quality which can be utilised for power purposes. The quantity has been estimated by Mr. Cecil Cochrane in his valuable paper on the subject by the method as follows.

FURNACE GAS ENGINE COMBUSTION

For purposes of calculation, the amount of gas per ton of pig iron from furnaces using ironstone of constant quality can be taken as varying directly as the amount of coke used. From furnaces smelting Cleveland ironstone the approximate amount of gas produced per ton of pig iron is six times the weight of coke. From monthly results extending over many years this constant can be verified. By measuring the quantity of gas supplied to the Cowper stoves by means of the Pitot tube, many times and under varying conditions, he arrived at the conclusion that with an initial blast temperature of 1600° Fahr. the amount of standard gas required by Cowper stoves alone, in a normal or average condition of cleanliness, is 6720 lbs. per ton of pig iron.

This may be readily converted into cubic feet, since 1000 cubic feet of gas weigh

82 lbs.   This leaves $14112 - 6720 = 7392$ lbs. available for purposes of power.   We have seen, however, that if this stove gas were cleaned and cooled 20 per cent. more would be required, or 8064 lbs. instead of 6720 lbs., leaving $14112 - 8064$, or 6048 lbs. per ton of pig iron available for power.

This waste gas being utilised in blowing by means of large gas engines reduces the expenses considerably and dispenses with the boilers.   The relative efficiency in using the furnace gases to raise steam in a boiler and drive a steam blower, compared with the direct use of the gas in a gas engine blower, is shown to be as follows.

During the test the following figures were observed, which supply all the data required :—

Area of gas main	2.88 square feet.
Water evaporated	12,000 lbs. per hour.
Average gas temperature	595° Fahr.
Barometer	29.92.
Average gas pressure by Pitot tube	25 inches of water.
Mean gas pressure	3 inches of water.
Steam pressure	90 lbs. absolute.
Temperature of feed	175° Fahr.

Then cubic feet of standard gas per hour $= 62.71 \times 60 \times 60 = 225{,}756$ cubic feet.

Thermal units contained in this amount of gas $= 225{,}756 \times 101.72 = 22{,}963{,}900$ British thermal units.

The total heat in 1 lb. of steam evaporated from 175° Fahr. to 90 lbs. absolute pressure $= 1034$ thermal units ; then $12{,}000 \times 1034 = 12{,}408{,}000$ British thermal units put into steam.   Efficiency is therefore

$$\frac{12{,}408{,}000 \text{ thermal units put in steam}}{22{,}963{,}900 \text{ thermal units in gas}} = 54.03 \text{ per cent.}$$

This 54.03 per cent. efficiency of boiler is good when the large amount of inert matter in the shape of nitrogen in the gas is taken into account.

If this steam were used in a 600 horse-power steam engine absorbing 20 lbs. of steam per indicated horse-power per hour, then efficiency of such an engine would be—

$$\frac{600 \times 33{,}000 \times 60}{772} \div 12{,}408{,}000 = 12.46 \text{ per cent.}$$

The combined efficiency of engine and boiler is—

$$\frac{12.46 \times 54.03}{100} = 6.732 \text{ per cent}$$

In the gas engine comparative test the following calculations are given, from which the increased economy is obvious :—

Amount of gas consumed per minute $= 1.08 \times 35.5 = 38.44$ cubic metres, or 2306.4 cubic metres per hour.

The temperature of the gas $= 65°$ Fahr., so that quantity of standard gas $= 38.44 \times \frac{493}{526} = 36.03$ cubic metres per minute, or $36.03 \times 35.3 = 1272.014$ cubic feet per minute.

Calorific value per cubic foot $= 98$ thermal units ; then $1272.014 \times 98 = 124657.4$ thermal units in gas, supplied to engine per minute.

The indicated horse-power of the engine was 742 ; then $\frac{742 \times 33{,}000}{772} = 31{,}704$ thermal units in indicated horse-power.

Efficiency of engine is therefore $\dfrac{31{,}704 \text{ thermal units in I.H.P.}}{124657.4 \text{ thermal units in gas supplied}} = 25.43$ per cent.

The indicated horse-power delivered to blowing cylinder $= 564.3$, and the thermal units in this $= \dfrac{564.3 \times 33,000}{772} = 24,121$.

Combined efficiency of engine and blowing cylinder $= \dfrac{24121}{124657} = 19.32$ per cent.

Mechanical efficiency of machine $= \dfrac{564.3}{742} = 76$ per cent.

The efficiency of steam engine $= 6.732$ per cent. of total heat; the ratio of thermal efficiency of gas engine to steam $= 25.43 : 6.732 = \dfrac{3.7}{1}$. As Mr. Cochrane is dealing with actual conditions that obtain, no allowance has been made for the sensible heat already in the gas supplied to the boiler—that is to say, the comparison is made between a boiler using hot, dirty gas, and a gas engine using cool, clean gas.

GOTHIC OIL ENGINE

All the 2-stroke engines hitherto described have the feed to the working stroke and the burnt gas driven out by pressure produced by a separate pump; or in small
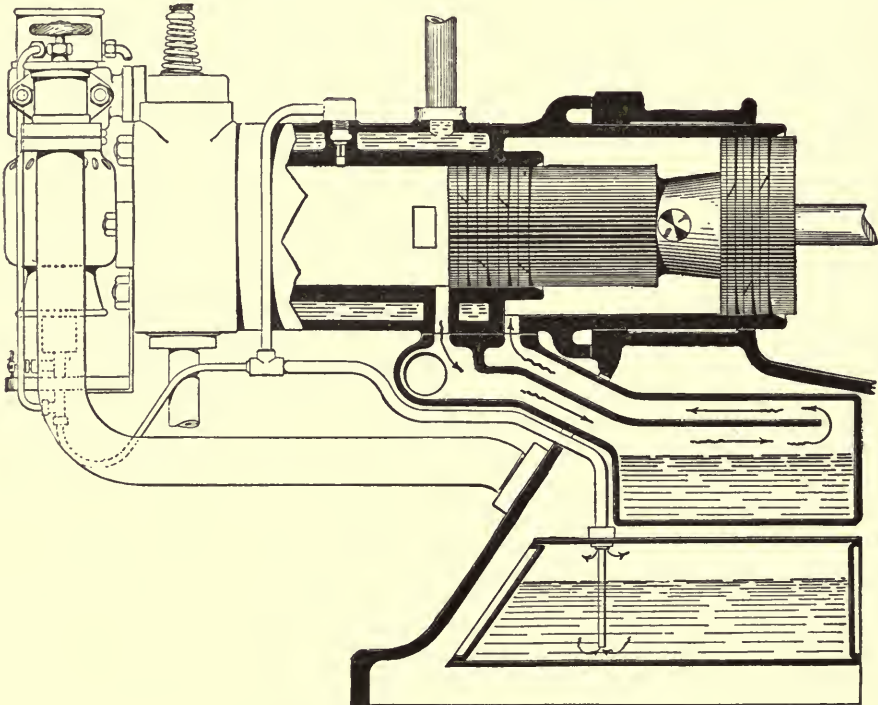
Fig. 60.—Glover's Gothic Engine. Section.

sizes, where complication is fatal to commercial success, by the piston itself acting as a pump, some of the fresh incoming charge is often lost in escaping with the outgoing exhaust.

In the Melhuish engine, made by Messrs. T. Glover & Co., the exhaust is drawn out and the fresh charge drawn in by suction, and there is no necessity for a separate pump or for a closed crank case. Although in the vertical engine the case is shown as closed, that is not necessary except in order to retain the lubricating oil.

From the longitudinal section (Fig. 60) this engine, it will be readily gathered,

works on the principle of exhausting through ports uncovered by the piston at the end of the stroke; but as in this engine the exhaust ports open into a larger cylinder with a piston in which there is a partial vacuum ready to draw out the exhaust, the expansion of the working gases may be carried further, by a longer working stroke than that in engines exhausting by pressure. The exhaust is therefore to begin with cooler, but in order to still further cool it it is, as shown in Fig. 60, caused to pass through a simple condenser on its way to the exhausting chamber between the two pistons. This condenser is simply a water tank with a partition leading the gases over the surface of the cold water. Underneath is the oil tank. This tank is connected under the oil to the lamp for heating the vaporiser, and above the oil to a small outlet check valve, so that when the piston is on the compression stroke inwards the oil tank is maintained under pressure of a few pounds in order to force the oil in to the vaporiser and cylinder.
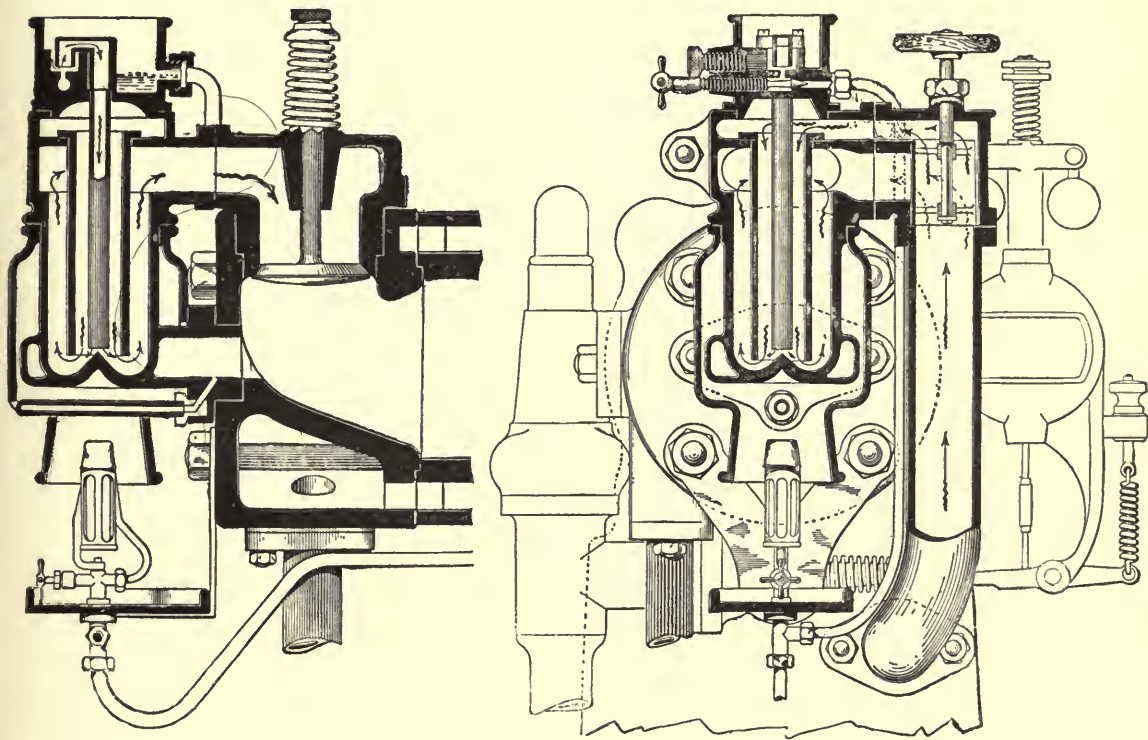
Cylinder End—Sectional Elevation.   Sectional End View.

FIG. 61.—Gothic Engine.

Fig. 61 is a part section through the combustion chamber and vaporiser. There are no valves in the vaporiser nor overflow, the inlet valve being adjusted by spring to admit the correct quantity required at each stroke, and that while the engine is working.

In Fig. 61 is a cross section through vaporiser and air inlet. This air inlet is controlled by the simple air valve by hand wheel, and the oil controlled by simple needle valve, shown at the top. From these two views the construction of the vaporiser and the mixing of the air and oil are clearly seen, also the lamp for heating the vaporiser externally. The oil falls down through the central small tube, and strikes the hot bottom of the vaporiser, as shown in both Figs. 61 and 63. It then, as vapour, passes up the hot sides in the annular space, and mixes with the air drawn up the air pipe before entering the cylinder by the inlet valve, shown in Fig. 61, on the combustion chamber.

The governing arrangement is shown in end view, and on a section of the cylinder is shown an arrangement for belt drive (Fig. 62).

The exhaust under ordinary load is driven out of the large cylinder through a valve shown at the side in Fig. 62, and the governor acts by the hit-and-miss horizontal valve opening when the speed is too high, and reducing the suction.

These are excellent oil engines, from 1 to 20 horse-power. The double piston provides great wearing surface, and the front large head acts as an excellent guide, and prevents the tilting action met with in loose unguided pistons. By coupling a pair *tête-à-tête* we would get a 1-stroke cycle, and with two pair on cranks at right angles an even turning motion for marine propulsion with no dead centre.

Some simplifying modifications have been made in this engine since it came into the market. These can be noticed in the line drawings of the sectional elevation (Fig. 63), and the end sectional view (Fig. 64). The ignition tube is shown immediately under the
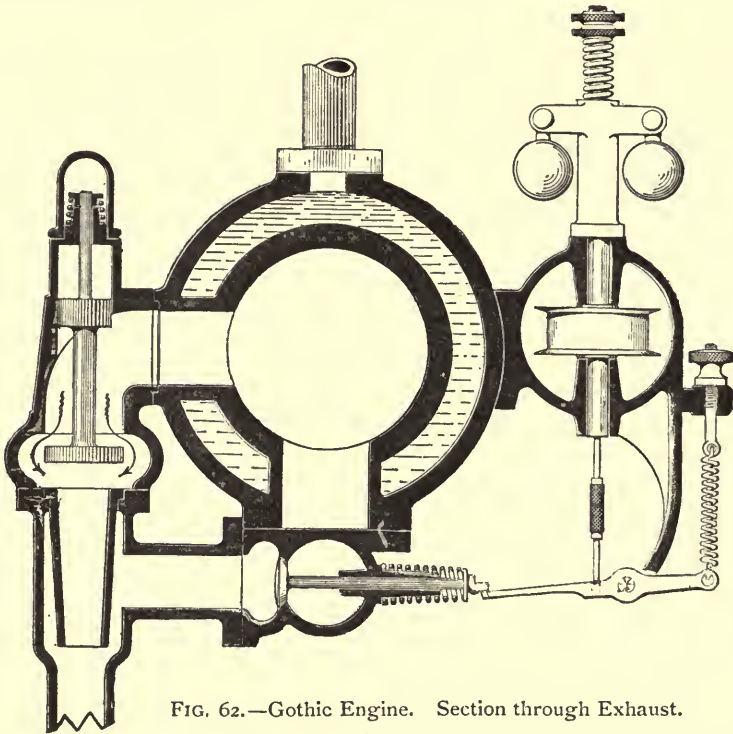
Fig. 62.—Gothic Engine. Section through Exhaust.

evaporating pot, so that the lamp flame keeps both hot. The simplicity of the vaporiser is also marked.

It will burn almost any kind of oil, preferably Russian petroleum with a specific gravity of about .82°, or low or high flash oil between 85° to 150°

Assuming the piston to be at its complete in-stroke and a charge compressed, this is fired by the hot tube in the usual manner. The force of the explosion expels the piston on its outward stroke. When it reaches the port A any pressure remaining passes out through the check valve B, thus reducing the pressure in the cylinder C to that of the atmosphere. The continued outward movement then uncovers the exhaust passage D. It should here be said that during the outward working stroke above described the larger piston creates a partial vacuum in the condenser E. As soon, therefore, as the piston F uncovers the port D, the products of combustion remaining in the working cylinder C are withdrawn into the condenser E and vacuum cylinder G. The new charge thereupon flows into the working cylinder C to take the place of the withdrawn products. On the return stroke the products in the condenser E are displaced through the valve H into the exhaust pipe I. The lower part of the condenser is preferably

covered to a depth of $\frac{1}{2}$ inch with water.   The products of combustion withdrawn from
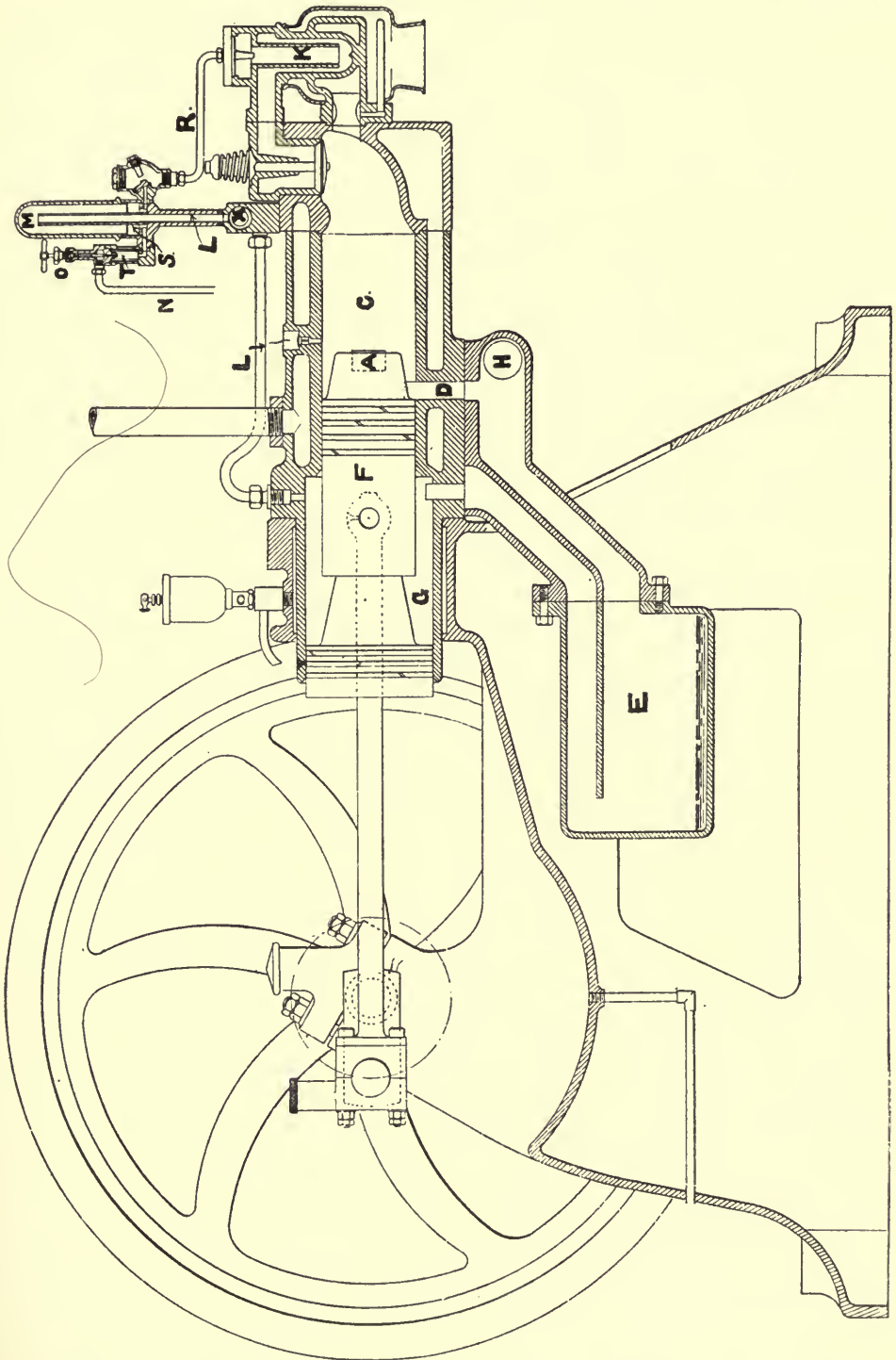
FIG. 63.—Gothic Oil Engine.   Sectional Elevation.

the working cylinder are by this means and by its rapid expansion condensed to such a degree that the portion entering the vacuum cylinder G is comparatively cool.   This is

very important, as by this means the piston (which would otherwise become so hot as to burn off the lubricant, and would, moreover, expand it to such a degree as to seriously lower the mechanical efficiency of the engine) is kept within the temperature limits required for successful working.

The vacuum pump is also used to lift the oil from the container J, and deliver same in definite quantities to the vaporiser K in the following manner:—The partial vacuum obtained on the out-stroke is communicated by means of the pipe L to the vessel M. This vessel is connected by the pipe N and regulating cock O on one side, the lower end of the pipe N terminating in a small non-return valve P. On the other side of the vessel M is a delivery valve Q and pipe R leading into the vaporiser K. Now, at every out-stroke of the piston the partial vacuum lifts a quantity of oil, the amount being determined by the cock O into the small cavity S of the vessel M, the oil being visible as it feeds through the glass T. On the return stroke the pressure exerted by the pump piston drives the oil out through the non-return valve into the vaporiser K. Now here comes into action another important feature of this engine. For instance, it is obvious that, as the hot gases expand and part with their heat to the condenser, the temperature of the surface of the water rises and is given off as water vapour, or say, very wet steam. This then is driven through the pipe L into the vessel M, and is here condensed as water and, mixing, is driven with the oil into the vaporiser K. When it enters the cylinder with a given proportion of air it serves the extremely useful purpose of prolonging
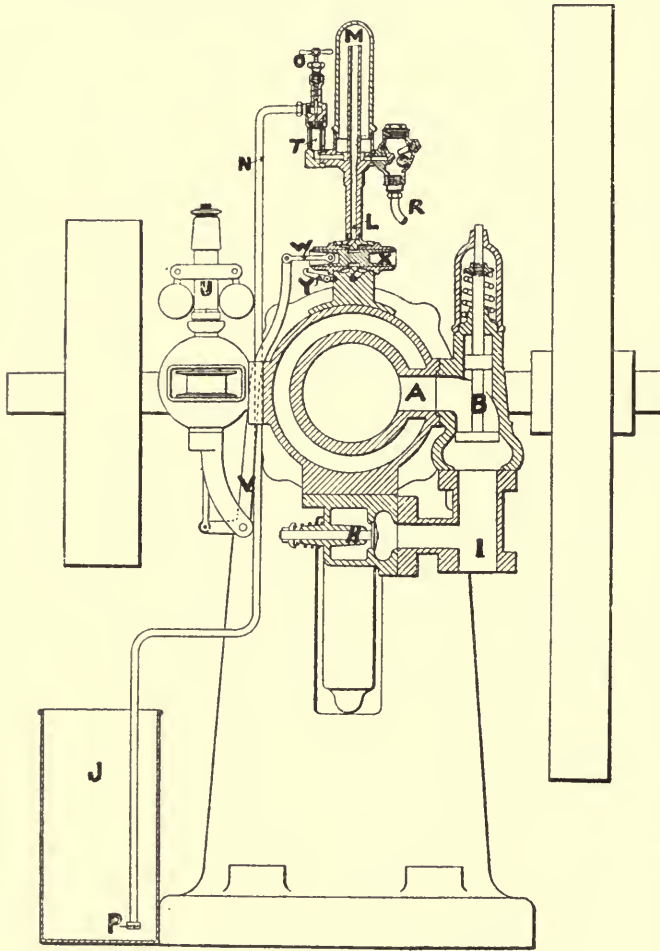
Fig. 64.—Gothic Oil Engine. End Section.

combustion, so that a maximum effect is obtained upon the crank when same is in the best position to transform same into useful work. The evaporation of the water in the condenser E also, of course, assists in keeping the pump cylinder G at a comparatively low temperature. The governing is effected in an extremely simple manner by the centrifugal belt-driven governor U and bell crank lever V, attached by a link W to a plunger X, that by its movement to and from opens and closes communication between the vessel M and pump cylinder C, thereby shutting out the action of the pump and stopping the supply of oil. Should the strap driving the governor break, or should the governor from any cause stop, the plunger in this instance moves out, and by

preventing the flow of oil stops the engine. A stepped catch Y holds the plunger at starting the engine, and when the normal speed is obtained automatically falls and leaves the governor free to act to cut the oil out at too high a speed or at too low a speed.

Considerable space has been devoted to this engine, the features of which the author thinks are important in connection with the 2-stroke engines, more especially with an eye to marine engines, in which there should be no dead points in the revolution and also no separate pumps; with modifications, it seems that it would also meet some of the difficulties met with in furnace gas engines.
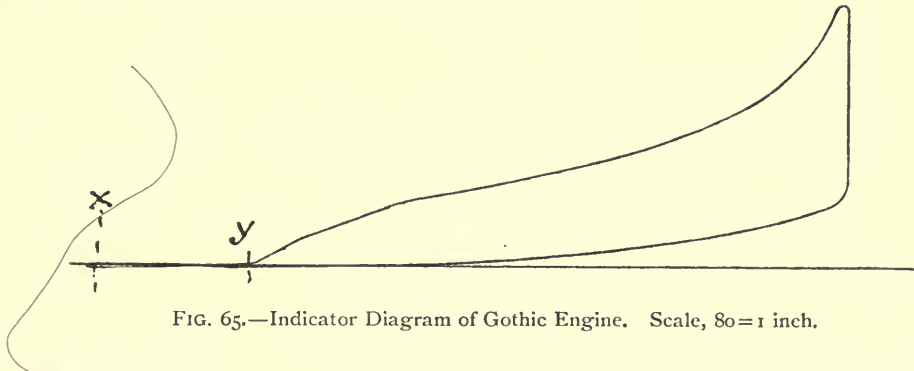
FIG. 65.—Indicator Diagram of Gothic Engine. Scale, 80 = 1 inch.

Fig. 65 is an indicator diagram of this engine. *y* is the point of relief at the check valve, and *x* the end of the stroke.

Another 2-stroke engine for motor cars, by Mr. J. C. Hencke: a petrol oil engine having a 2-stroke cycle and a pump cylinder is shown in Fig. 66. The two cylinders are arranged diagonally in the usual place on the frame. The explosive mixture from the carburetter is drawn into the pump cylinder through a mushroom valve in the head. It is there partly compressed on the next stroke. A pipe connects the two cylinders, and during compression in the pump cylinder the explosive charge is prevented from flowing into the working cylinder by a valve which is kept closed by the back pressure of the previous explosion. The exhaust takes place through the working piston uncovering exhaust ports at the bottom end of the cylinder. This allows the valve to open, and the fresh charge is admitted. This is further compressed in the working cylinder by the return of the piston. The piston of the pump cylinder is actuated from the main crank. It is claimed that this engine is more trustworthy than the ordinary type and needs less adjustment, is more regular in running and is of less weight.
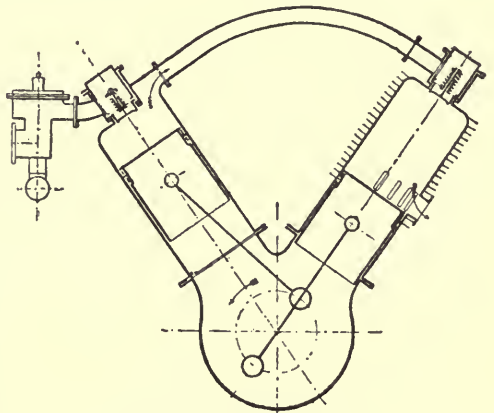
FIG. 66.—Hencke's Engine.

We have now reviewed most of the 2- and 1-stroke engines, the 1-strokers being combinations of 2-strokers, and some of the 2-strokers combinations of 4-strokers.

For a long time the 4-stroke cycle has been a favourite with manufacturers, but there is evidence of a tendency to drop the rigid adherence to it and to come to some more common type of engine. The patents question is played out. Within the past twenty-five years the thousands of patent specifications anticipate almost everything, and at present the chief problem is to design standard engines for special purposes, such as

for traction, road and rail, marine propulsion, and for large powers.   And these develop-
ments do not call for new inventions so much as for good design.

FOUR-STROKE ENGINES—GAS AND OIL

This class all work upon the Beau de Rochas system, commonly known as the
Otto cycle.   It is at present by far the largest class of internal combustion engines so
far as numbers in use are concerned.   It is now intended, by means of a well-drawn
series of illustrations of one good type of engine, to fully describe this cycle of four strokes
in a gas or oil engine.   We will begin with a gas engine, then a petrol engine, and
thirdly a heavy oil vaporiser engine.

For the gas engine the Westinghouse engine has been selected, first, because it is
well designed, and constructed on sound engineering principles.   That, of course, might
be said with truth of many others.   And secondly, because that firm furnish most complete
information as to their manufactures of all kinds.   There are no secrets.   We are deeply
indebted to the many engineers who give information, plans, drawings, and assistance
in collecting materials for works on modern engines, without which the spread of know-
ledge would be impossible.   As far as possible it is desirable to have sectional illustra-
tions to clearly show the special features of any engine, and without these a complete
view of the external engine is of little interest.   Where sections and explanations of
special features claimed by inventors are not furnished freely it is necessary to fall back
upon patent specifications, the contents of which are public property in all countries.
From these we can generally make explanatory sectional views.

Many engineers are only too glad of an opportunity to have their improvements
clearly illustrated and explained, that is, where there are any to explain.   To quote an
authority : " The perusal of a number of gas engine circulars would tend to create in the
mind of the reader an impression that what goes on between the valve on the gas supply
pipe and the belt of the driving pulley is a trade secret which must under no circum-
stances be divulged."

It is too late in the day to assume any secrecy about inventions of any kind.   The
intending purchasers either by himself or through a competent engineering adviser insists
on knowing what are the special features, if there is any specially good invention in the
features of the engine.   To protect these it must be patented, and if it is patented a full
and clear description with drawings must be published freely to all the world.

The progress of gas engines, like all other inventions, goes on by the addition or
subtraction, or both, of special process and parts.   All the fundamental principles of
internal combustion engines are well known, their practical applications all anticipated
by early inventors.   The difference, therefore, between one explosion internal combustion
engine and another consists of different designs and constructions of details, and at the
present, as in the past, these differences are narrowing down, as experience proves, some
of the details in one case inferior and in others superior, so that in course of time the
various makers approach to the manufacture of a standard pattern.

The gas engines already approach uniformity of design, and the oil engine also is
becoming all round of a common pattern.

There is still room for improvements in adapting gas engines, whether worked by
gas, petrol, or oil, to locomotive and marine propulsion, and in perfecting gas driven
turbines.   So far as possible the improvements in these directions will be considered both
as to how far they have been carried and in what direction they may be pursued.

To begin with the Westinghouse 4-stroke internal combustion explosion engine,
shown complete in Fig. 67, and a section through one cylinder is given in Fig. 68.
The cylinders are mounted on an enclosed crank case, the distinguishing feature of this
engine, which forms the base or frame of the engine, and serves as a receptacle for
the oil which lubricates the cranks and upper journals of the connecting rod.   The

engine is single acting, a feature regarded as desirable in a small steam engine, but which is absolutely necessary in a gas engine, for the reason that stuffing boxes and piston rods deteriorate too rapidly when the latter are exposed for half the time to an atmosphere of burning gases.

A simple trunk piston of generous length, carrying a hardened steel wrist pin, which is linked to the crank by the connecting rod, comprises the mechanism for transforming the intermittent pressures on the top of the piston into rotary motion at the shaft. In this respect the engine does not differ from the most elementary steam engine.

The feature about a gas engine which gives an impression that it is a complicated machine is the valve motion. When it is understood just why this gearing is required,
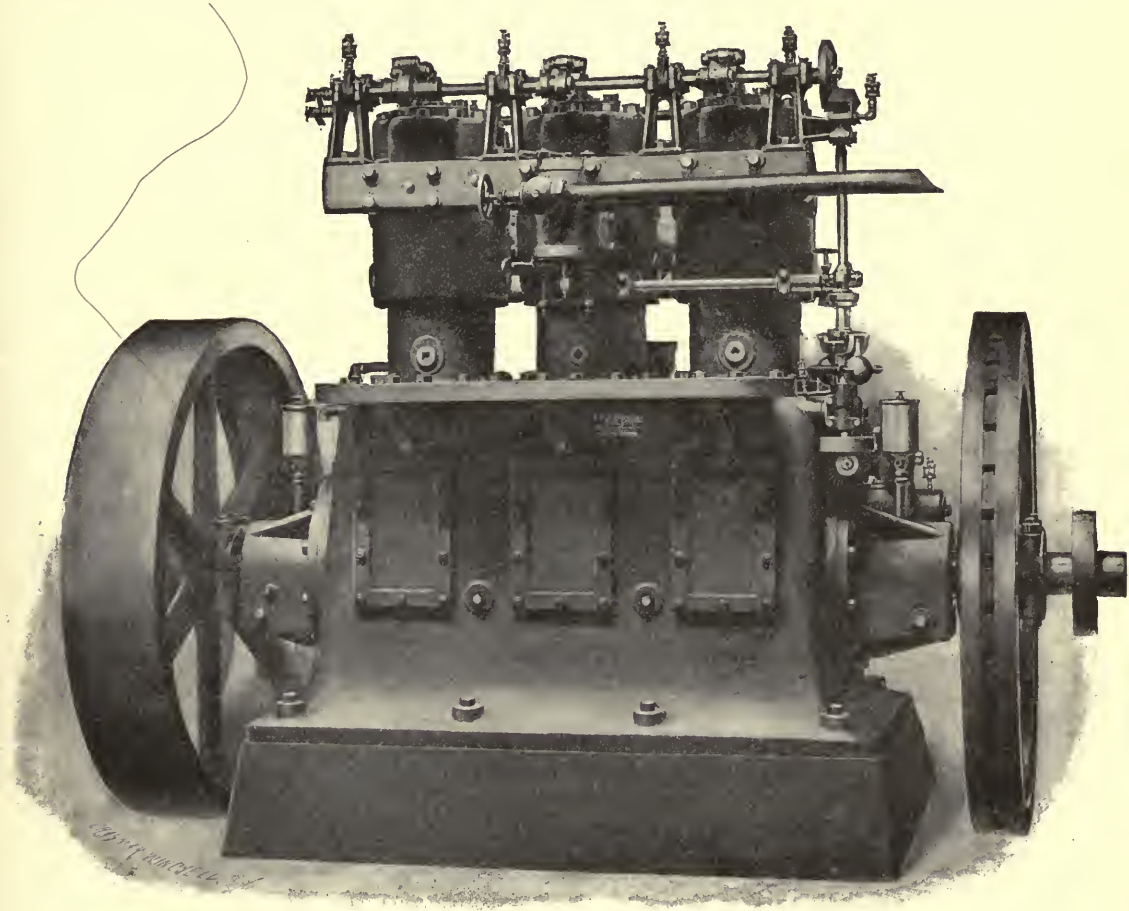
FIG. 67.—Westinghouse 3-Cylinder Gas Engine.

and what purpose it serves, the impression of complication disappears. In order to make the utility of the train of cams, cam shaft, levers, and valve rods and their simple functions clearly understood, it is necessary to consider what takes place in the cylinder. As the gas must burn in the enclosed space between the piston and the cylinder head, it must first be mixed with such an amount of air as will furnish sufficient oxygen for its rapid and complete combustion. If the air supply be too little the gas is not all consumed, and the economy is thereby seriously impaired, and if the air supply be too great the quantity of gas used per stroke is reduced, resulting in lowering the capacity of the engine.

The piston being at the top of its stroke, and moving downward, draws in a cylinder

full of the mixture of gas and air. On the return stroke this charge is compressed into the clearance space between the top of the piston and the cylinder head. The smaller this clearance, and consequently the higher the compression, the more efficient the engine, the reason being that with a measured quantity of gas, such as is contained in a cylinder full of the mixture, the smaller the space in which it is burned the higher will be
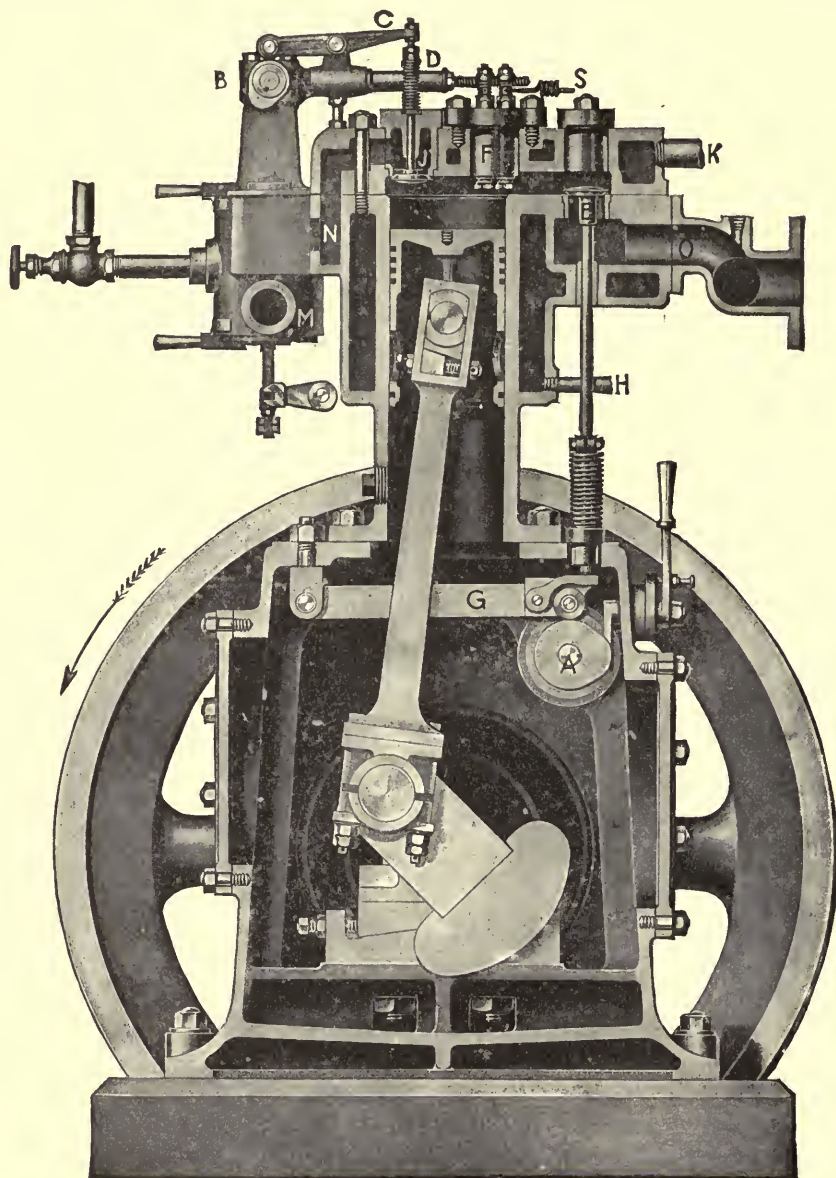
Fig. 68.—Section of Westinghouse Gas Engine.

the pressure generated ; and the smaller the initial volume of the products of combustion under the high pressure, the greater number of times will they be expanded in following up the piston to the end of its working stroke.

A high initial pressure, coupled with a large ratio of expansion, has a more important effect on the economy of a gas engine than of a steam engine, because in the former we do not have to contend with the phenomenon of cylinder condensa-

tion, which in the latter offsets the gain from expansion when carried beyond certain limits.

While there is no theoretical limit to the extent to which compression might be carried with corresponding increased efficiency resulting, there is a practical limit at which we must stop, for the reason that when this is passed the heat generated by compression will cause the mixture of gas and air to ignite spontaneously. This would be fatal to the operation of the engine, as in order to secure good results we must be able to control the ignition and time it accurately, having it occur just as the piston is ready to begin the next succeeding downward stroke.

Premature and spontaneous ignitions cause pounding, reduction of speed and power, and may even cause a complete stoppage.

The piston having reached the top of its compression stroke, the charge is ignited— in the case of the Westinghouse gas engine—by the spark formed by opening an electric circuit in the clearance space. The air and gas being thoroughly mingled in the right proportions, combustion takes place with such rapidity that it may properly be called explosion, and the resulting heat raises the pressure to several hundred lbs. to the square inch. The burnt gases under this high pressure expand, driving the piston downward on its working stroke, and are expelled through the exhaust on the return stroke, which when completed brings all the parts of the engine in position to repeat the same cycle of operations. Most gas engines that have achieved any marked degree of success operate on the plan outlined above, first proposed and patented in France in 1862 by M. Beau de Rochas, although the fruits of the invention, as well as the credit of it, were so promptly and completely appropriated by others that the real inventor has been well-nigh forgotten.

From the general explanation of the cycle of operations occurring in the engine it will be seen that during one revolution it acts as a pump to supply itself with fuel, which it utilises running as a single acting pressure motor during the next succeeding revolution. The valves and the igniters pertaining to each cylinder have therefore to perform their functions *once for every two revolutions* of the crank, instead of once for every revolution, as in the steam engine ; consequently the cams which operate these parts—cams being used in preference to eccentrics by reason of their more prompt action—must be mounted on shafts running only half as fast as the main shaft, and a train of gears is the only positive means by which this reduction of speed can be made, and this is the sole object for its introduction.

Referring, again, to the sectional view (Fig. 68), A is the shaft which carries the exhaust valve cams, and is driven by gears from the main shaft. Each exhaust cam works against a roller carried on the free end of the guide lever G. The exhaust valve E has a long stem projecting downward, and resting on a hardened steel plate on the upper side of the guide lever G. The spring surrounding the stem serves to hold the exhaust valve to its seat, and the stem in contact with the guide lever. From the exhaust cam shaft A a horizontal shaft with bevel gears leads to the opposite side of the engine, engaging with a vertical shaft which in turn drives the upper cam shaft B. Incidentally, the vertical shaft carries the governor. The upper cam shaft carries two cams for each cylinder. One engages against a roller on the end of the horizontal lever C. As the throw side of this cam comes uppermost the opposite end of the lever C depresses the stem of the inlet valve J, opening the latter for the admission of the mixture of gas and air. A spring on the stem of the inlet valve furnishes a means for closing it and keeping the cam and roller always in contact with each other. Immediately adjacent to the inlet valve cam is the igniter cam, which at the proper instant operates a horizontal plunger working through the guide D to break the electric current through the circuit S, at the terminals of the igniter F.

The cylinder heads and the upper end of the cylinder are water-jacketed, for they would soon get red hot without some means of cooling. The cooling water enters

at H and is discharged at K. The illustrations following will illustrate and describe the 4-stroke cycle. The gas and air inlets are separate on the mixing valve chamber
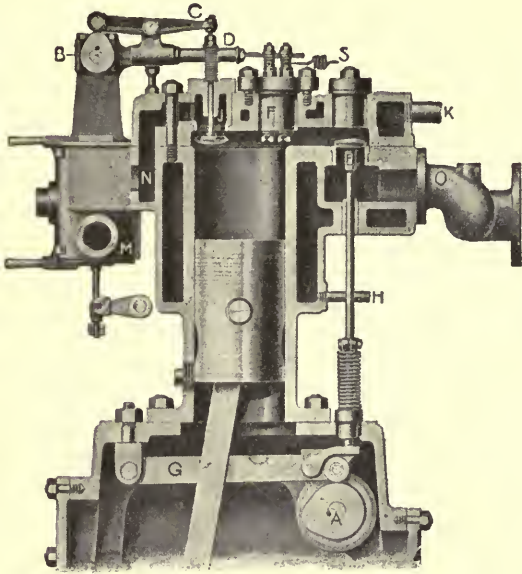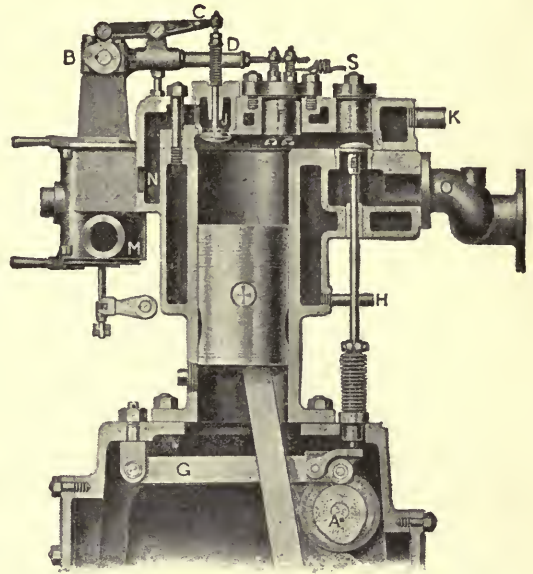

FIG. 69.—Suction.

FIG. 70.—Compression.

M. The mixture is conducted through a distributing chamber to the port N leading to the cylinder head in which the inlet valve is located. The mixing valve is not
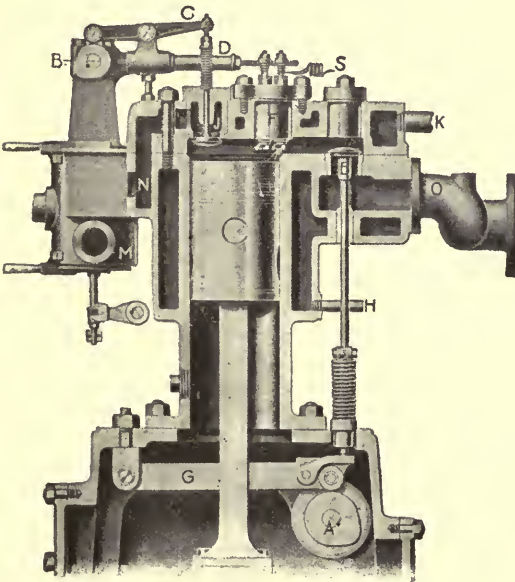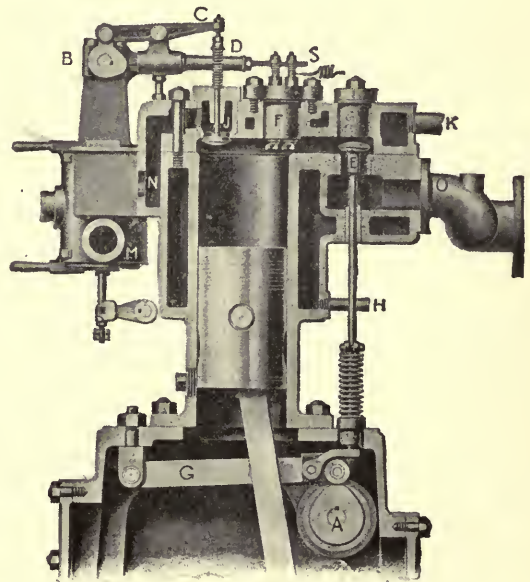

FIG. 71.—Working.

FIG. 72.—Exhaust.

shown in section, but is referred to more at length under the paragraph relating to regulation.

In the suction stroke (Fig. 69) the piston is on its downward stroke, the inlet

valve J is open, and the charge of gas and air is being drawn into the cylinder. The exhaust valve E is closed, and the inlet valve will close just as the piston reaches the limit of its downward stroke.

Then follows the compression in-stroke (Fig. 70). The piston is on its upward stroke, both valves are closed, and the charge of gas and air is being compressed into the clearance space.

Then ignition and working stroke follows, as in Fig. 71. The piston has reached the upward limit of its compression stroke, the crank is just passing its upper centre, and both valves are still closed. Shortly before this the igniter cam has brought the terminals in contact, completing an electric circuit. Just at this instant it releases them, and they fly apart, actuated by a coiled spring located in the guide D, breaking the circuit and forming a spark which ignites the charge. An immediate rise of pressure occurs, and the piston is forced downward by the expansion of the burnt gases, both valves remaining closed until just before the completion of the stroke, when the exhaust valve E opens.

Then follows the fourth stroke, in Fig. 72,—the exhaust. The piston is ascending, forcing out the spent gases through the now open exhaust valve E and the exhaust pipe O. The exhaust valve closes as the piston completes the stroke, bringing everything in readiness to repeat the cycle.

All the 4-stroke engines to be described work upon this cycle. Some may use ready-made gas; some may use volatile oils or spirits, vaporised or gasified; some may use paraffin oil or heavy mineral oil, vaporised, sprayed, or gasified. Different arrangements of valves and valve gear, different igniters, and so on; but all of them work on this cycle.

We may now consider a few details special to this engine.

The main bearings (Fig. 73) are similar in construction to those

Sectional Elevation.   End View Section.

FIG. 73.—Main Bearings.

in the single acting compound steam engines. They are supported in castings which form the ends of the crankcase, and are adjustable from the under side by means of wedges and draw-bolts, as will readily be understood from an inspection of the engraving. As the wear on the main bearings is always downward, this method of adjustment restores the shaft to its original distance from the base of the engine. This is a particularly valuable feature in an engine direct connected to a dynamo, as the allignment of the engine bearings with the dynamo bearings is thereby preserved. Another excellent point is that the clearance between the pistons and the cylinder heads is maintained at a constant volume, so that the degree of compression is unchanged, and the economic performance as affected by the compression is unimpaired.

The igniter is a removable plug fitting in a hole in the cylinder head, and secured by two bolts through a projecting flange carrying the binding post for attaching the wire which conducts the electric current, and also the mechanism for making and breaking the current to produce the igniting spark.

Except in the smaller sizes the igniter has two binding posts and two sets of current breakers, one set only being in use at one time (Fig. 74). In case of accident or failure of the set in use, the other is in reserve and ready for immediate service. The wire

supplying current is connected into the other binding post, and the engine may be run without interruption until it is convenient to shut down long enough to remove the igniter for inspection or repair.

The current for the igniters is furnished by a battery through an induction or sparking coil (Fig. 75). The battery is connected up through a three-point switch, so that the direction of the current through the igniting apparatus may be reversed at
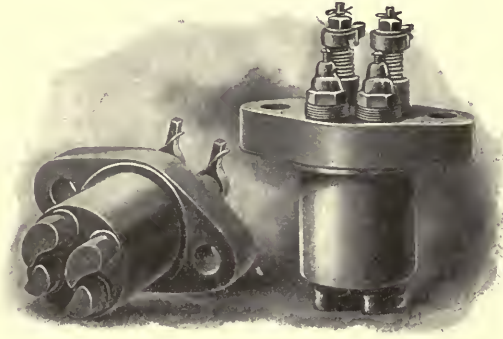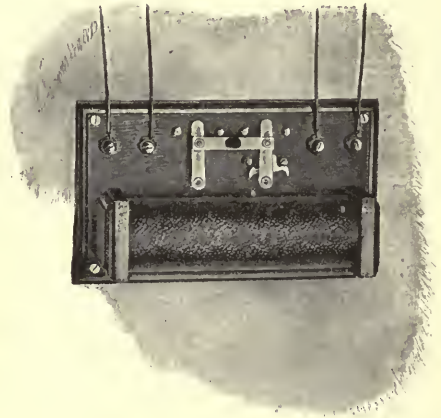

FIG. 74.—Igniter Plug.

FIG. 75.—Sparking Coil.

will. Whenever the terminals on the igniter break the electric circuit the passage of the spark carries off infinitesimal particles of the substance of one terminal and deposits them on the other, the action following the direction of the current. By periodically reversing the direction of the current, whatever substance has been taken away from one terminal and deposited on the other is restored, and consequently the lasting qualities of the igniter are thereby greatly augmented. The battery switch is fitted with a
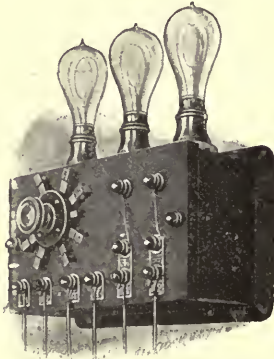
FIG. 76.—Igniter Switch Board.
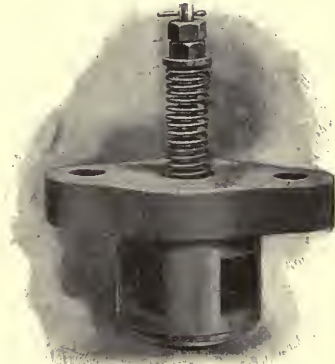
FIG. 77.—Inlet Valve.

locking device, such that when the battery is cut out, as it should be whenever the engine is shut down, it can only be cut in again in the way that will send the current in the reverse direction from what it was on the previous run.

If a direct current lighting or power circuit be conveniently located it may be tapped for supplying the igniters in lieu of a battery, although this is sometimes objected to because the circuit is momentarily grounded every time the igniter terminals make contact. When desired, a miniature dynamo is used exclusively for this service,

in which case, the current being small and nothing else than the igniters being in the circuit, the grounding is entirely unobjectionable.

Where the igniting current is obtained from a dynamo driven by the engine itself, a battery must of course be used to supply the current for a few minutes while the engine is being started, and until it has got up to its normal speed. When dynamo current is used for the igniters it is necessary to have a special sparking apparatus, illustrated in Fig. 76. The battery, igniters, and dynamo are all connected through a box-shaped switchboard, inside of which is located the induction coil. On top of the switchboard are three incandescent lamps in series with the dynamo, which modify the strength of the current, and at the same time give prompt indication of any imperfection in the working of the igniting apparatus. The switch is so arranged that either the battery or the dynamo current may be cut in at will, and so that each time the engine is started up the direction of the igniting current is reversed from what it was on the previous run.

The inlet valve (Fig. 77) is mounted in a plug, which is inserted and secured in the cylinder head in the same manner as the igniter, making it easily and quickly removable for inspection.

A third plug of similar shape, but containing no mechanism, serves to close an opening in the cylinder head immediately over the exhaust valve, through which the latter is readily accessible.

Fig. 78 shows the governor connections on both 2-cylinder and 3-cylinder engines. In the 2-cylinder engine the governor engages directly with the stem of the regulating valve, while in the 3-cylinder engine the governor is placed on one side, and its motion is transmitted to the regulating valve through a rock shaft and levers; other-

Fig. 78.—Governor.

wise the governing mechanism is the same in both types. The gas enters through the pipe and valve shown into what is called the mixing valve chamber. The air supply enters the mixing valve chamber in the 2-cylinder engine through an opening on the opposite side, and in the 3-cylinder engine through one of two openings placed on either side of the gas supply pipe, a little below and at right angles to it. At the top and bottom of the mixing valve chamber are horizontally moving levers with pointers swinging over graduated arcs. The upper lever controls the gas supply and the lower one the air supply. The ratio between the readings on the two scales, with the levers in any fixed position, shows exactly the proportions of air and gas in the mixture supplied to the cylinders. The governor is of the fly-ball type, extremely quick and sensitive in its action. As the balls move in or out, with changes of load, the regulating valve moves up or down, increasing or decreasing the *quantity* of the mixture with the greatest nicety and without altering its *quality*.

An especially valuable feature of the governing apparatus is that it determines accurately the best proportions of air and gas to use. When the engine is running on a steady load, if one mixing valve lever is moved backward and forward while the other remains stationary, the regulating valve stem will be seen to move up or down as the mixture becomes less or more efficient, indicating that a greater
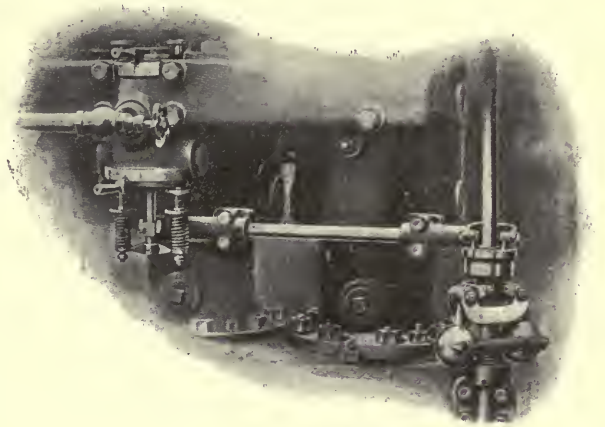
or less quantity is being used. Starting with too little air and gradually increasing it, the regulating valve will move gradually down until the mixture of maximum efficiency is reached, and if the air supply be still further increased the regulating valve will begin to open again. It will thus be seen that the proper quantity of air to be used with any grade of gas becomes a matter of exact measurement, instead of individual judgment.

The starting of a small gas engine is a simple and easy matter. The fly-wheel is given a couple of turns by hand, and when a charge of gas and air has been drawn in, compressed, and exploded the task is accomplished. As the size of the engine increases this process becomes too laborious and eventually impossible, and were no suitable mechanical method provided for setting the engine in motion its practical utility would be confined entirely to the smaller powers.

The reliable and convenient method of starting by compressed air, a method to which, by reason of its multiple cylinder design, the Westinghouse gas engine lends itself especially well (Fig. 79).

FIG. 79.—Starting Valves.

The air supply is furnished by a small compressor (Fig. 81), and is stored in iron tanks thoroughly tested under a pressure of 250 lbs. to the square inch. The storage tanks are of different capacities, to accommodate the several sizes of engines, and in some instances two or more are connected in battery. They are supplied with a pressure gauge and a safety valve to guard against overcharging. Although these tanks are charged to 160 lbs. pressure for starting the engine the first time, the compressor is also arranged for operating by hand in case of need. This emergency, however, is seldom or never encountered. When the plant is once started the compressor is run for a few minutes each day by a belt from any convenient pulley, either on the engine itself or on the line shaft, maintaining the supply in readiness for starting at any time.

On the end of the upper cam shaft on the engine is a screw with a milled head, which, on being given a few turns to the left, renders the admission valve of one cylinder inoperative for the time being. On the back of the crank case is a short lever which, on being moved to the right as far as it will go, throws out the regular exhaust cam and throws in a supplementary cam which keeps the exhaust valve open during *every* up-stroke of the piston, instead of *every other* stroke, as when the engine is in regular operation.

A pipe leads from the air storage tank to the starting valve, which is attached to the end of the crank case, and thence through a check valve into the cylinder in which the valve functions have been altered. This valve is actuated by a cam on the end of the lower cam shaft where it projects through the end of the crank case, and is so timed as to open each time the piston starts on its downward stroke.

It will be readily seen that one cylinder is thus converted into a compressed air motor without disturbing the rest of the engine. The engine being set with the

corresponding crank a little past its upper centre, the air and gas supply properly adjusted, and the stop valve in the air pipe opened, it starts off and continues to run on air pressure until explosion takes place in the other cylinder or cylinders. The air supply is then shut off, the inlet and exhaust valves put back in their normal condition, and the engine is in full operation. The starting valve may be disengaged from its cam when not in use by pulling up on the stem and giving it a quarter turn in either direction.

Three or four revolutions with the air pressure are generally sufficient. The entire operation is strictly automatic, requiring no particular mechanical dexterity on the part of the attendant, and consuming less time than it takes to describe it.

No more forcible demonstration of the sufficiency of the method could be asked for than the daily starting of the 650 horse-power engine illustrated in Plate IV., which is accomplished by the one attendant without any assistance whatsoever.
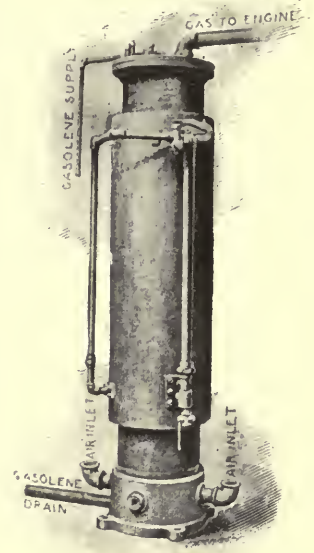
Fig. 80.—Carburetter.
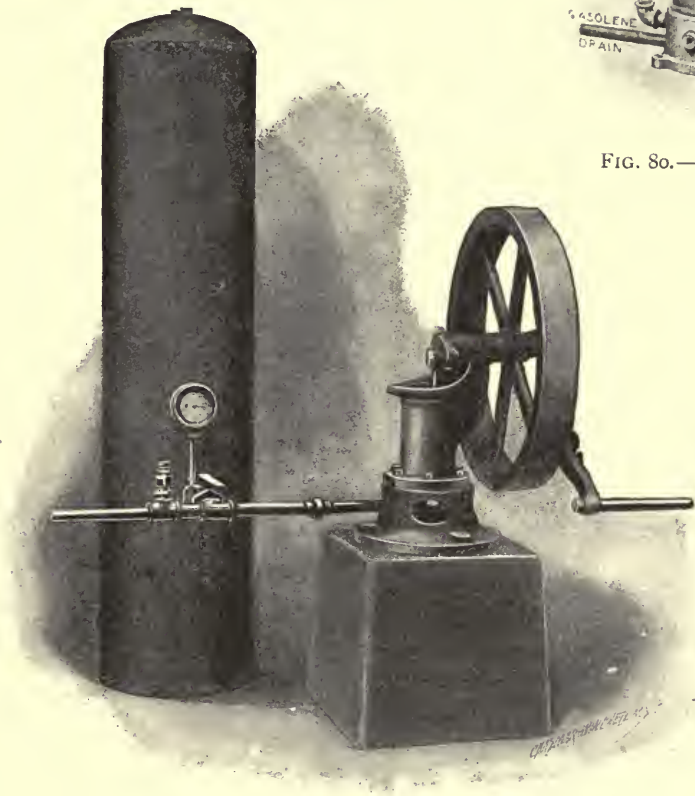
Fig. 81.—Air Reservoir and Pump for Starting.

PETROL ENGINE

Instead of combining a gas engine with a vaporiser, carburetter, or other gas-making device on the engine itself, a separate carburetter (Fig. 80) worked by suction is used, which consists of an upright cylinder of heavy iron pipe closed at both ends, and sur-

rounded by an iron casing forming a water jacket.   The gasolene supply is placed on a lower level, at any desired distance away, and is supplied to the gasifier by a small pump through a $\frac{1}{2}$-inch pipe entering at the top.   On its way down it passes through a spraying device which keeps it in a finely divided state, and such amount as has not been converted into gas is immediately on reaching the bottom drained back to the source of supply.   A gas connection leads from the top of the gasifier to the throttle of the engine, and air inlets are provided at the lower end.   The suction of the engine when running draws air into the gasifier, which passes up through the descending current of gasolene spray, and by the time it reaches the top a gas of excellent quality has been formed.

This is a sort of refrigerating process, and if there were no means of supplying heat to the apparatus the temperature would gradually fall to below the freezing point of water, and the gas would get poorer and poorer in quality until it would cease to be generated at all.   This, however, is taken care of admirably by utilising a portion of the waste heat from the engine.   Part of the warm water from the cylinder jackets is circulated through the jacket surrounding the gasifier, the amount being automatically regulated by a simple thermostat in the latter, so that an absolutely constant temperature is maintained irrespective of the load on the engine and consequent rapidity with which the gas is being generated.

HIGH FLASH OIL ENGINES

The oil engine using heavy oils with a high flash point differs from the gas engine using gases supplied from retorts or producers only in the provision of the vaporiser, and to a small extent in the air admission.   In the Hornsby-Ackroyd engine we have a bottle-shaped vaporiser on the back end of the cylinder, kept at a low red heat by the combustion of the oil inside.   The air is drawn into the cylinder through a separate valve ; at same time oil is sprayed into the vaporiser.   The oil vapour fills the vaporiser and part of the back end of the cylinder.   By the time the piston has arrived at the end of the out-stroke the compression stroke drives the air back into the vaporiser, the oil vapour and air mixing.   The compression of the mixture and the heat of the vaporiser walls fire the mixture on the dead centre of the revolution, that is, at the point of greatest compression.   If the oil used is uniform in flash point, this firing occurs regularly when once the engine is adjusted with the proper clearance to give the pressure necessary for ignition just as the crank reaches the dead centre.   If another oil with a different flash point is substituted, then the clearance space of the piston and cylinder must be readjusted.   If the oil has a lower flash point and no adjustment made for it, then ignition would occur before the end of the compression stroke.   If the oil had a higher flash point and no adjustment made for it, then ignition would not occur

FIG. 82.—Hornsby-Ackroyd.

at all, so that in this method of ignition either a uniform quality of oil must be employed or a ready means of adjusting the pressure at the end of the compression stroke. Diagram Fig. 82 shows the system in an elementary form.   In this case no air is drawn in with the oil into the vaporiser, and there is no valve between the vaporiser and cylinder.

In another system, the Priestman, the air and oil are drawn through a separate vaporiser, kept hot by the exhaust gases, the oil being sprayed into the vaporiser.
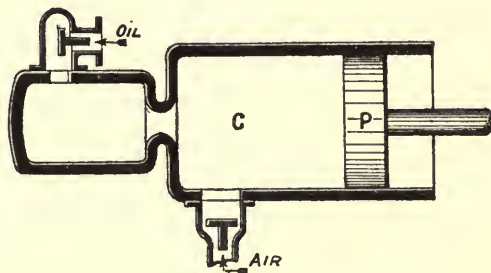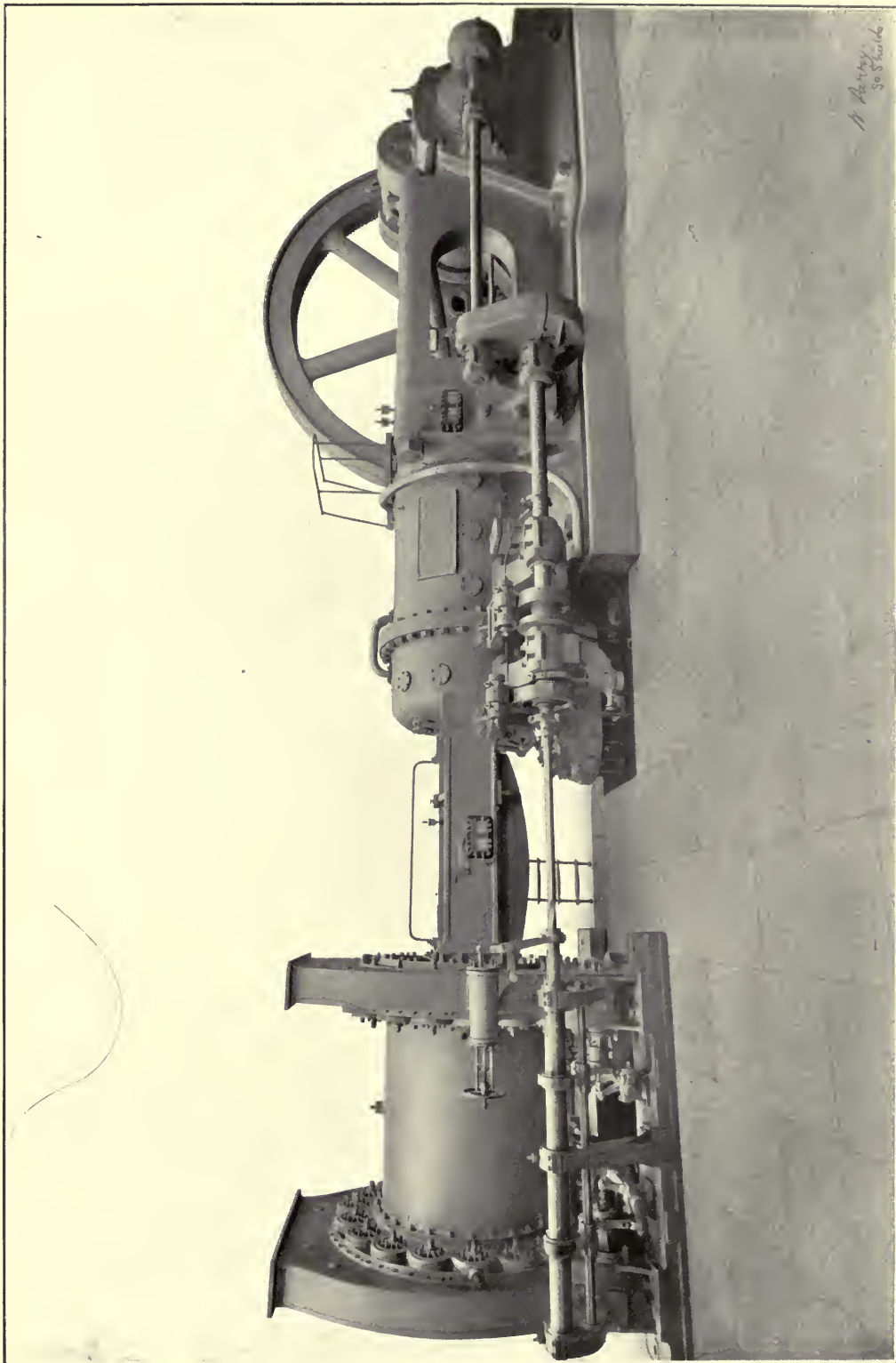
Plate III.—Modern Blast Furnace Gas Engine, working Blowing Cylinder for Blast Supply (Richardson, Westgarth, & Co., Middlesbrough)

The mixed air and vapour pass through a valve into the cylinder, and are fired at the end of the compression stroke by hot tube or electric spark. This is shown in Fig. 83.

In another system (Fig. 84) oil and a small quantity of air, not sufficient to form an explosive mixture, are drawn into the vaporiser, while the balance of air required for combustion is drawn into the cylinder by another valve. There is no valve between the vaporiser and cylinder in this case, and the ignition may be by hot tube or spark.

In a fourth system (Fig. 85) all the air and oil are drawn into the vaporiser, and pass mixed into the cylinder. They are then compressed back into the hot vaporiser, and fired by a hot tube. There is no valve between the vaporiser and cylinder in this case. This system is employed in the Crossley oil engine and others, and seems to be becoming the favourite.

FIG. 83.—Priestman.

These are the four methods or systems for working internal combustion explosion engines with common heavy oils. Why four systems should be used it is difficult to ascertain, unless they are all equally good. Fig. 82, the Hornsby-Ackroyd, seems to meet the whole requirements, and requires no ignition device and no heater after it is once set agoing. It, however, requires adjustment for different oils, and, in cases where frequent stopping and starting were necessary, would require a heating lamp.

The separate vaporiser with a valve between it and the cylinder (Fig. 83) is now dropping out of use.

The drawing in of a portion of the air with the oil and the remainder into the cylinder (Fig. 84) is an unnecessary complication, and does not seem in practice to offer any compensating advantages.
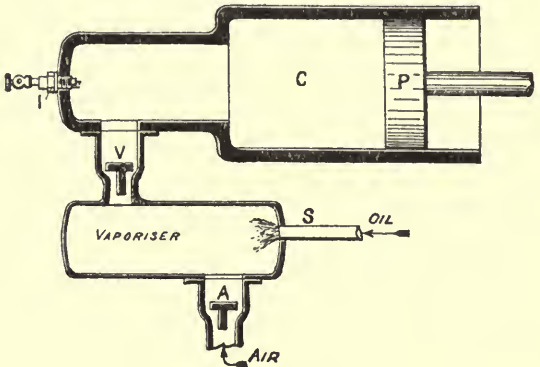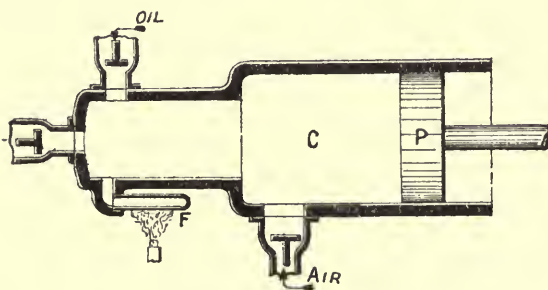
FIG. 84.—Three Valves.
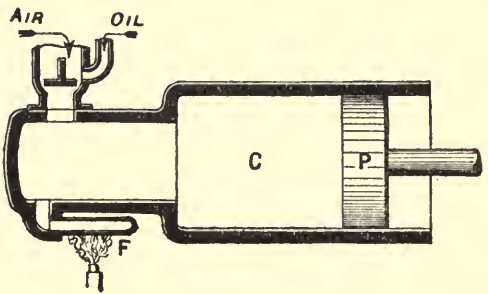
FIG. 85.—Crossley.

The drawing in of some water spray with the oil does seem to offer very considerable advantages, as we have already explained in connection with the Griffin and Glover engines, its effect being twofold, increased power and economy. This was pointed out in *Engineering* in July 1902, in connection with motors using alcohol.

"In theory the consumption of spirits for an equal power is 1.8 times the consumption of petrol; in practice, however, the presence of water in the spirits increases the elasticity and efficiency of the power, and the proportion is only as 1.25 to 1. . . . Spirit motors have more elasticity than petroleum motors, and work more softly; the pressure of the explosion can be increased without disadvantage to the machine, the

expansion curve being very regular. . . . It has been asserted, from results of tests carried out in Germany, that the efficiency of spirit motors is 23 per cent., against 15 per cent. for petroleum and 13 per cent. for steam engines."

In Captain Longridge's paper, read before the " Mechanical Engineers " in 1902, he gives Mr. C. Rainey's conclusions on the point thus, from experiments made:—

1. That while maintaining the petrol supply constant, the addition of water gave increase of power and cooler running.

2. That this effect was maintained until the water reached a quantity equal to the amount of petrol.

3. That a larger quantity of water interfered with the sparking, and caused frequent failures of ignition, which after a short time failed altogether.

Up to the present date no complete explanation of these better results has so far been published. The advantages of water have been described as a contribution of mechanical energy in the form of steam, as a cooling agent obtaining increased charge volume and higher compression, as an absorber of the violence of explosion, etc. During the recent testing with tube ignition of a petrol motor, admitting moisture to the combustion chamber, a sudden advance in ignition was observed, together with an increase of exhaust temperature, leading to burning of the valves. The following may be the possible reason. Assuming the cylinder charge to be pentane (C_5H_{12}), the addition of water or aqueous vapour in contact with the incandescent tube might lead to partial decomposition, carbon combining to carbon monoxide, hydrogen being liberated. In other words, water-gas would be formed. The advance in ignition would be due to the greater inflammability of the gas, and may be illustrated thus. The molecular weight of pentane being 72, 256 of oxygen would be required for its perfect combustion. On the other hand, the molecular weight of the water-gas ($CO + H_4$) being 32, the oxygen needed for complete combustion would be 48. One part by weight of pentane, therefore, would require 3.5 O, and one part of water-gas 1.5 O. This at once shows why the ignition is advanced, the greater inflammability of the water-gas being due to the lesser amount of oxygen wanted for combustion. The increased temperature of exhaust might be accounted for by assuming that the nascent water-gas, burnt with a fierce heat and acting as an extended flame carrier, produced more rapid and complete combustion of the charge. The above is not an isolated case, nor is it confined to one size or type of motor, nor to tube ignition only, the same facts being observed when electric ignition is in use. It has been suggested that earlier ignition is due to the explosion gas entering the water jacket, and, by driving the water from the cylinder walls, increasing the heat of the combustion chamber. But there are a number of arguments against this suggestion, and the phenomena of earlier ignition and hotter exhaust when a little water is present, with increase of power and cooler running when a large and regular supply is added, need another explanation.

Treated mathematically, as a purely thermal problem of profit and loss, it can, no doubt, be shown that, whatever be the physical condition of the water at the beginning of the compression stroke, and whatever be the laws of specific heat, the addition of water to the charge is an entry on the wrong side of the balance-sheet of an explosion motor ; and that the advantage of water injection can lie only in the possibility it gives—of employing much higher compression without risk of premature ignition—of obtaining heavier charges, and of reducing heat loss through the cylinder walls.

Whatever may be the real action of the water, its advantages are beyond all question, and it is being adopted generally.

The fourth system, in which the oil and air are together drawn into the vaporiser and compressed together, requires ignition by tube or spark, and the compression must be limited to prevent premature explosion.

With some heavy oils, such as the Russian oils, even the vaporiser is not required.

Mere spraying of the oil into the air as it enters the cylinder is sufficient.   In Root's specification of 1895, No. 7538, he shows that he had found this out.

He had found by experiment, when oil is sprayed into a working cylinder, that the essential thing is ignition, as the oil has not time to be and is not vaporised, but is fired as oil spray, and that once the ignition is commenced the flame passes almost as rapidly through the particles of oil, as oil spray, as through a completely vaporised and mixed charge of oil.

For Russian refined oils, therefore, simply spraying would suffice.   With American oils it might not be so easy to get satisfactory results without special vaporisers.   These oils are compounded differently, and contain waxy and resinous compounds that in long and continuous running form deposits on the walls and valves.   The conditions for successful use would appear to be uniform delivery of minutely atomised oil in correct proportion, high cylinder temperature, no condensation by contact with cool surfaces, sufficient time for combustion.   For alcohol, similar conditions, with higher compression, appear best suited.

On the whole question of vaporisers it seems that the fourth system would prevail, for it can be used with or without a hot vaporiser, and with either tube or spark ignition. The self-ignition is an advantage, but against that it introduces the necessity for adjusting the engine to different oils.   The engine that can use petrol, heavy oil, crude oil, or any oil without adjustment of any kind, will have the preference in the end.

HIGH FLASH OIL ENGINE VAPORISERS

The Hornsby-Ackroyd is shown in section in Fig. 86.   The oil is forced in a fine jet, as shown at K, into a bottle-shaped vessel S having internal projections C, which become dull red hot.   This acts as a retort, and gasifies the oil.   The mouth of the bottle opens into the cylinder end without a valve.   The gas produced fills the bottle, and on the suction stroke drawing air into the cylinder part of the oil gas also is drawn in.   The oil is injected in measured quantity during the suction stroke only.   The neck and shoulders of the bottle are water jacketed.   It is heated by an oil lamp when the engine is first started, but maintains sufficient heat from the internal combustion to carry on the vaporisation afterwards.

The Crossley vaporiser is shown in Fig. 87.   It consists in the horizontal engine of a cast-iron bend F on the end of the combustion chamber C.   The ignition tube lies along the bottom of the vaporiser, and is heated by the same lamp that heats the vaporiser.   There is a small oil pump, which at every stroke delivers the oil through D for each explosion into a measurer

FIG. 86.—Hornsby Vaporiser.

B.   Any overflow from E finds its way back to the oil tank in the bed of the engine.

In the seating of the inlet valve are a number of fine holes connected to this oil measure, so that when the valve opens the air from A blows across these fine holes, and thus carries the oil in as a fine spray.   The oil is all drawn in before the piston reaches the end of the suction stroke, so that the final inrush is pure air.   This prevents premature ignition.

The Tangye vaporiser is shown in Fig. 88.   The oil flows by gravity from an oil
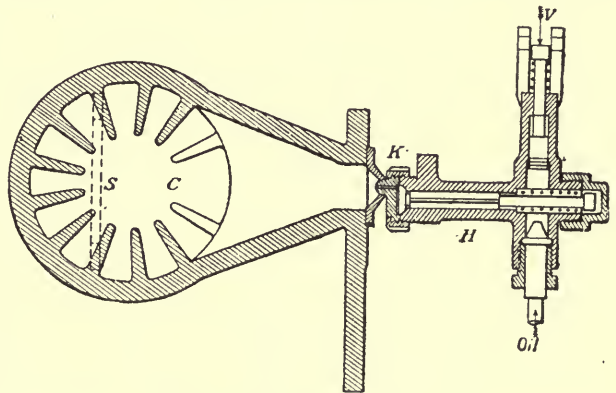
reservoir on the top of the cylinder to a small hole opening in the conical seat of the admission valve, as in Crossley's valve and many others. This is an automatic valve
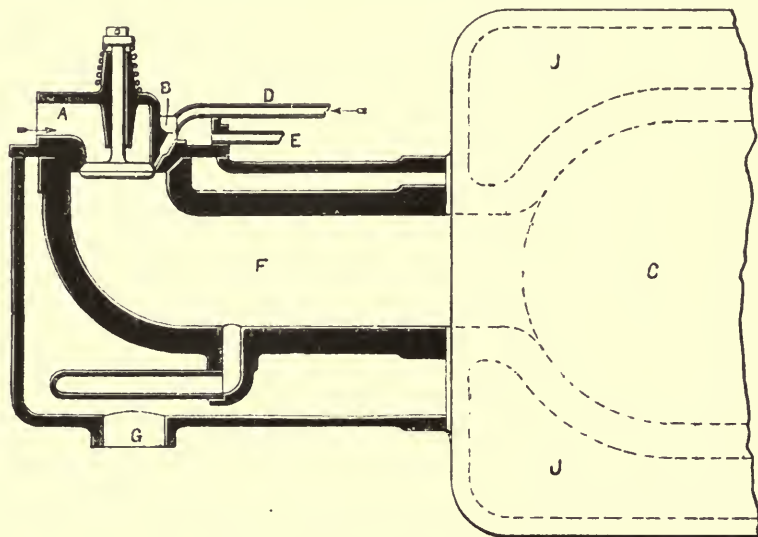

FIG. 87.—Crossley Brothers' Vaporiser.

opening by the suction ; the bottle of the vaporiser V is connected by a side opening to the cylinder C, and on its other side to an igniter tube I. The retort is jacketed, and the jacket has a funnel which can be opened or closed to regulate the heat. The ignition tube also has a funnel which can be closed, and the hot gases from the burner caused to pass through the retort jacket and keep it hot. The oil lamp, after heating the retort of the vaporiser, is shifted so as to heat the ignition tube.

Many variations of these vaporisers are made, but they all act much in the same way. Others will be noticed in describing the engines.
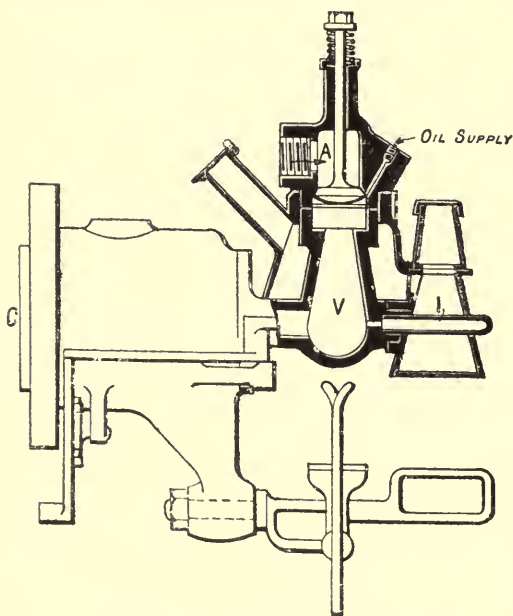
FIG. 88.—Tangye's Vaporiser.

CARBURETTERS

These perform the same functions in the gas engine that the vaporiser does for the heavy high flash oils. The liquids used have a low flash point and are easily vaporised. The liquids are petrol, naphtha, shale spirit, or alcohol.

There are two forms of carburetters, —that most commonly used acts merely by the suction of the piston of the engine, and another in which a measured quantity is drawn in, called the positive feed carburetter ; the former are called aspiration carburetters.

Most aspiration carburetters draw their petrol from a jet communicating with a

constant level chamber or reservoir. The result is inaccurate and faulty petrol supply, since the force of the suction varies with the speed of the engine. Rich charges are thus obtained when the engine is racing, and poor charges when it is slowed down from overload, the reverse of what ought to be. Makers are now recognising this defect, and are introducing devices more or less closely approaching positive measurement in oil engines of high flash point. There is no need to describe these latter, because the type is well known in heavy oil engine work ; for instance, the Crossley, the Weyman and Hitchcock, the Wells Brothers, the Roots, and numbers of other patented devices. As instances of the introduction of positive fuel measurement in petrol motors may be cited the Koch pump, the Gobron-Brillie bucket measurer, the adjustable stop jet in the Mercedes Simplex of the Cannstatt Daimler Company, a similar device in the De Dion voiturette carburetters, etc.

FIG. 89.—Mayback Carburetter.

The carburetter with float feed was patented on 25th August 1893 by W. Mayback, and is shown roughly in his specification.

Referring to Fig. 89, the hydrocarbon is kept at a constant level in the reservoir a by a float valve d, and is sucked through the nozzle c^1 into the current of air which is drawn along the pipe b by the motor piston. When heavy hydrocarbons are used the pipe b is heated by the exhaust gases, which escape by the passage h and valve i. The governor controls a supplementary air valve, which may also be adjusted by hand.

A later form is shown clearer in Fig. 90 in section. On the end of the petrol supply pipe is a needle valve controlled by a float in the vessel A, in which the petrol is maintained at a constant level ; for this purpose a float B, hung on links
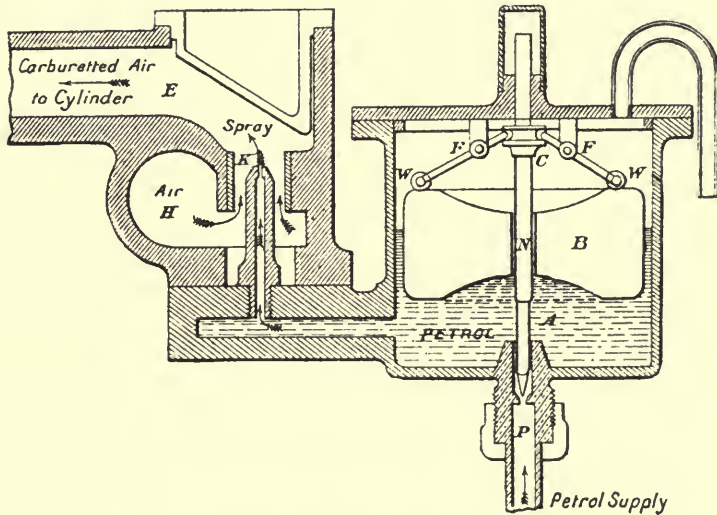
FIG. 90.—Petrol Carburetter.

FF, rises and falls easily. If the float rises it shuts down the needle valve, if the float falls it lifts open the needle valve, so that the oil is kept up pretty nearly to a fixed level. The petrol enters the passage to the cylinder as a spray through the nozzle at K, and joins the current of ingoing air from H. They mix and flow into the cylinder.

Referring to the section of a petrol motor (Fig. 91), the pipe E from the carburetter

(Fig. 90) is attached to the inlet pipe from the inlet valve *a* in the engine.   As this engine is the first petrol one we have illustrated we give an index to parts :—
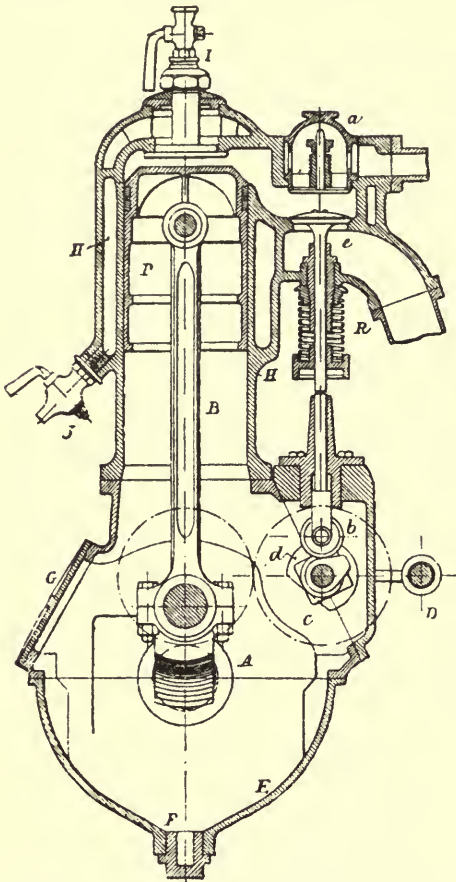
A, Crank shaft.
B, Connecting rod.
C, Cam shaft for exhaust (*b*) and ignition (*d*).
D, Centre for regulating lead and lag in ignition.
E, Crank casing.
F, Drain pipe.
G, Inspection plug.
H, Water jacket.
I, Blow-off cock.
J, Water outlet.
P, Piston.
R, Outlet valve spring.
a, Inlet valve.
e, Outlet valve.

The governing of this motor is done through the carburetter by means of a sliding piston, which throttles the supply of mixture. Fig. 92 shows this carburetter, the following being an index to the parts :—

A, Air inlet.
B, Vapour inlet.
D, Constant level float.
E, Pin valve.
F, Lever controlling the pin valve.
H, Spray port.
I, Outlet of carburetted gas.
T, Controlling rod of adjustable piston.
M, Pin valve spring.

FIG. 91.—De Diétrich Petrol Engine.   Section.

As might have been anticipated, to get the maximum power at any number of
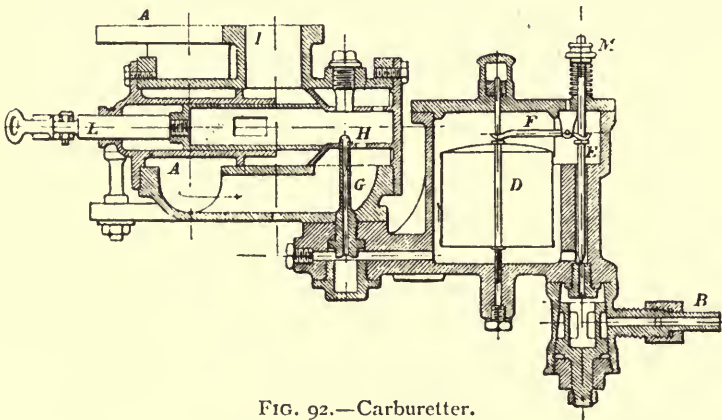
FIG. 92.—Carburetter.

revolutions per minute the jet of the carburetter must be larger for low speeds than for high ones ; and as it is difficult to adjust so small a thing as a hole in the jet,

the carburetter shown here in Fig. 93 has a small air spring valve in the air pipe between the carburetter and the induction valve. This auxiliary valve opens wider and wider as the engine speed increases, closing again as it decreases, thus decreasing or increasing the suction on the jet. At starting, as the jet is a large one, the petrol supply is also large, and the engine starts readily, then as it speeds up the air valve comes into action, and automatically letting in more air reduces the mixture to, and maintains it at, the proper proportions. The idea of an auxiliary air supply for this purpose is not new, and is found in the 8 horse-power De Dion light car, the Darracq light car, the American Holyoke tonneau, etc. In the motors of the Société des Automobiles Crouan, of Paris, the quantity and quality of the gas mixture is so automatically varied according to the speed of the engine that the force of the explosion increases as the speed diminishes ; in other words, the greater force of the piston stroke tends to compensate for the loss in centrifugal power of the fly-wheel.

A number of recent devices on similar lines show that the tendency of the present motor is towards discarding the crude action of the suction jet, pure and simple, in favour of the positive measurers, preferably under control of the engine governor.

The point has been raised whether it is better to carburate the incoming air or to first introduce the air and then carburate it, that is, as in the Diesel engine, add the fuel at the end of the compression stroke. This latter method avoids all possibility of premature explosion, and thus enables higher compression to be used. On the other hand, it is urged that the charge will be imperfectly mixed, and give imperfect and irregular combustion. And it is doubtful whether for petrol and gasoline there is anything in this objection, or whether, if there is anything, it is not more than discounted by the advantage to be gained. It is certain that a number of petrol motors run, and run successfully, by merely injecting the petrol into the cylinder and letting the air and heat do the rest. An instance is the American Weber gasoline motor.
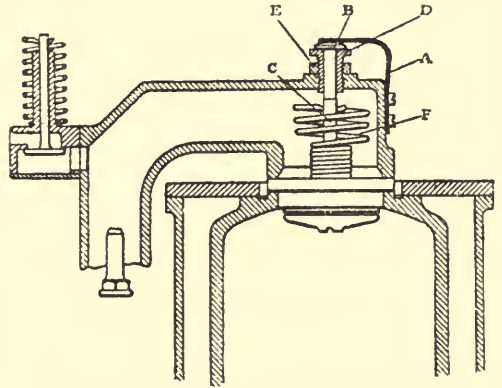

FIG. 93.—Bradley Pidgeon Carburetter.

The petrol is drawn from a tank and supplied direct to the cylinder in a fluid state. No vaporiser is used, nor does the petrol come into contact with air until it reaches the combustion chamber. In the Otto petrol motor, built by the American company of that name, no carburetter is used. The oil is pumped from an air-tight tank to a valve acted on by the governor. This admits a given quantity to the cylinder, when it is immediately pulverised by the incoming air and rendered explosive. No air reaches the petrol on its passage from the tank to the cylinder. In the German Lützky petrol motor of the Maschinen Gesellschaft, Nuremburg, the benzine is conveyed to the cylinder in a liquid state and vaporised per stroke as needed. In fact, in very many German petrol motors care is taken to exclude the air until the oil reaches the cylinder. This is the case even where a separate vaporiser is used. Thus in the oil motor of Dopp Brothers, Berlin, each charge of oil is separately converted into vapour without any air, and highly superheated before it is admitted, in finely divided currents, to the combustion space, where it is mixed with air. This method ensures regularity and completeness of combustion, low oil consumption, and regular working without vibration.

A carburetter with a regulator to control the air supply, either by governor or by hand, is shown in the Mors carburetter in plan and sectional elevation (Fig. 94). The

air inlet can be throttled by turning round the external sliding tube, for which purpose it is fitted with a lever.

The carburetter proper is separate from the float receiver. It is divided by a partition into two spaces, the openings at the bottom of which is provided with a revolving partition. The vapour supplied from the receiver rises in the central tube of the carburetter, from which it is delivered in a jet ; air is supplied through both the bottom openings. The pure-air inlet is on the side opposite to the vapour jet, and the mixture can be regulated at will by the revolving shutters.

Another automatic regulating carburetter is shown in Fig. 95, by Chenard and Walcker. A spring is used for regulation in order to maintain a constant strength of mixture of vapour and air at all speeds.

The air inlet is closed by a flat-seated valve ; the petrol inlet is mechanically closed by a centrally situated conical needle ; the needle is an integral part of the valve and lifts with it, inasmuch as if the air section be doubled by the rising of the valve, the petrol orifice is likewise doubled, and so on. In other words, the relation of the air and petrol orifices to one another always remains the same, in order to ensure the constant carburation, under the influence of the constant vacuum or suction. How, then, is a constant vacuum or suction obtained ? The valve above referred to is always endeavouring to close under the pressure of a spring, the tension of which is practically constant for all gradations of the lift of the valve. In order that the valve may lift off its seat, it is necessary that the suction should equal the tension of the spring. It will consequently be obvious that if the delivery increases, the suction tends to increase, and exceeds the power of the spring ; the valve lifts, consequently, higher to allow greater passage for the discharge, and automatically decreases the suction of vacuum. The same applies—only inversely—if the delivery is reduced.

FIG. 94.—Mors Carburetter.

Thus it will be seen that the suction is practically constant, whereas in most carburetters it varies frequently, whilst in the Chenard and Walcker the utmost variation has been calculated at from 28 to 32 centimetres of water. The obvious advantage of this constant suction or vacuum assures at all times a perfect mixture, for the spray is always produced with the same velocity, the jet always attains the same height (40 centimetres atmospheric pressure), but the diameter of the jet is greater or less, according to the demands made by the motor. The impact of this powerful jet against the perforated disc ensures complete atomising, and contributes to perfect pulverisation, especially at very low speeds of the motor. The valve, consequently, literally follows the movement of the piston. It regulates the carburation for all piston speeds during the same suction stroke ; it commences to lift off its seat at the moment when the piston commences to draw in a charge ; it reaches its maximum lift when the motor attains its maximum piston speed and closes at the end of the stroke, thus reducing down to zero the diameter of the jet of liquid of which the inertia is nullified, since the closing of the petrol is absolute and simultaneous with that of the air.

Fig. 95 represents the carburetter, of which the level is regulated by an ordinary float.

A, Air inlet.
BB, Annular air passage, closed by the valve C.
C, Air valve.
D, Conical needle.
E, Perforated atomising disc.
F, Constant tension spring.
G, Orifice through which the mixture passes into the motor.

FIG. 95. — Chenard and Walcker Carburetters.

Vaporisers and carburetters are the distinguishing features of the heavy high flash oil engine and the light spirit engine, and a great deal depends upon their proper construction. The examples here given are fair specimens of their class. Any engine almost can be converted from one to the other class by changing from vaporiser to carburetter, or by dispensing with both the engine may be worked by gas from an extraneous source. It will be now in order to consider some of these sources of gas for gas engines, and we will take the oil gas generator first. In using the vaporiser to make the oil gas we make the quantity required for every stroke of the engine ; but in using a gas generator apart from the engine we make the gas in large quantities and store it in gasholders for use. This is the method in many cases, but in recent gas plants for making carbon monoxide and water gas from coke and anthracite coal, the plan of making it in the quantity required for each stroke has been successfully employed, thus dispensing with the gasholder.

GAS GENERATORS

Very fine gas can be produced from oils and fat by destructive distillation. Gas for motive power can be made easily from many common organic substances, and hence for pioneer work in colonies the gas engines might be much more in use than they are, they are easier set up, and more portable than a steam plant, in which the boiler is always a difficulty in unskilled hands. Wood, straw, dried grasses, and even dried sea weeds make excellent gas ; peat also makes good power gas. The author many years ago made large quantities of gas of a high illuminating quality and great power by distilling dried sea weeds, commonly known as tangle. Hundreds of tons of this weed are cast up by the sea in autumn and early winter. Gas for power purposes is made from coke or charcoal, and in some cases from common coal, by processes which have become remarkably simple and inexpensive, and in this place it is proposed to describe and consider some of the processes and their application to gas engines.

Oil gas made from *intermediate* oils from Scottish shale, which on a close test flash at 235° Fahr. are very suitable for making gas of high quality. American oils of cheap quality, about three pounds (£3) per ton at the ship side. The oil is usually sprayed or allowed to flow over the hot inside of a cast-iron retort kept at a bright red heat. The oil decomposes, forming a permanent gas, some tar, and sometimes carbon.

The Mansfield oil gas generator is most commonly used. Fig. 96 shows the retort ; R, a cast-iron bottle in a large furnace. The whole is built up of cast-iron segments and lined with fire-brick ; there are regulating dampers G and D, so that the fire can be kept constantly burning to maintain a temperature of about 1800° Fahr. in the retort, a bright red heat which can be seen through the sight hole S. At W is the water seal

on the top of the pipe P, and at L the neck C dips under lead which, when the retort is hot, remains fluid and seals the joint there. The box E contains water, under which the pipe P dips. The tar which collects in this box is cleared out through the door H; the pipe M goes to the gasholder.

The oil trickles down through the inner pipe J, and is vaporised in this pipe before it enters the retort; the vapour then coming into contact with the hot retort splits up into a permanent gas and tar. The gas can be tested at the tap N; it should be nut brown in colour, and a drop of the tar placed on white paper should not mark a greasy circle round the drop. One lb. of oil in this retort makes 15 cubic feet of oil gas. The heating value of this gas is about 860 B.Th.U. per cubic foot, and the cost of the gas is about 5s. per 1000 feet, including fuel for the furnace. And the consumption of oil gas in a gas engine is for moderate powers 10 cubic feet per brake horse-power,—a little over a halfpenny per horse-power-hour.

The gas passes with the tarry and other products through a dip pipe in a water seal, and then through cooling pipes, and in cooling the liquid products are deposited; the gas is passed through a simple cleaning washer and into a gasholder stored for use. Every oil requires special treatment to produce the largest quantity of good gas possible; the quality and quantity depend upon the temperature of the retort, which must be found by experiment best suited for the particular oil or fat, and then maintained constant. The quality of the gas will depend also upon the rate at which the oil is fed in, for if the rate is increased the actual temperature will be decreased. Oil gas is
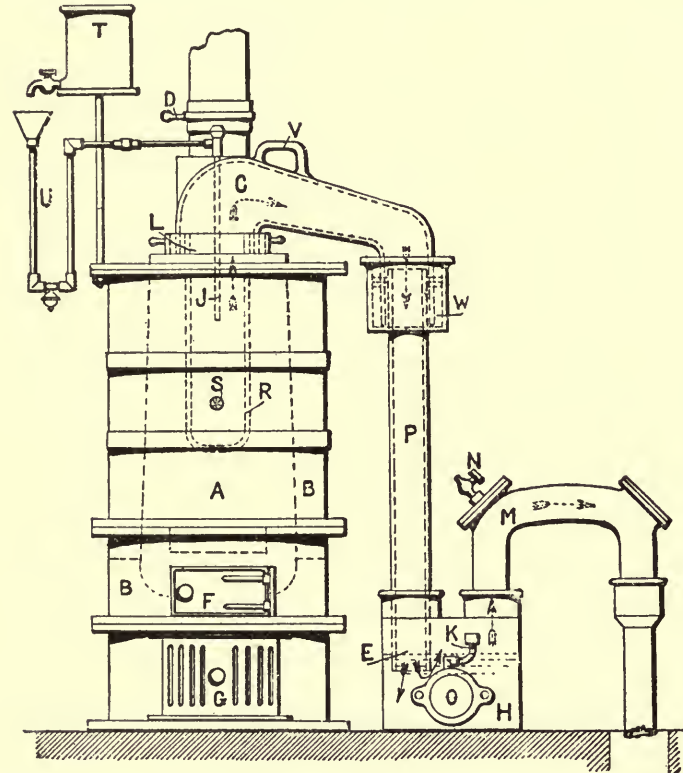
FIG. 96.—Mansfield Oil Gas Generator.

coloured brown, and the tar formed should be free from oil or grease. If the rate of supply of oil is too great, or the temperature too low, the oil is not entirely gasified; some of it will be found in the tar, and the gas will be either white or yellow instead of dark brown. And if, on the other hand, the temperature is too high, carbon in the form of soot is set free, and the colour of the gas becomes very dark. Common paraffin oil distilled at a bright red heat yields about 150 cubic feet of gas of 25 candle-power.

In some cases the oil is first vaporised at a temperature of about 1000° Fahr. in one retort, and this vapour passed into a second hotter retort, in which it is converted into a permanent gas.

The heating value of oil gas made from crude oils, having a flashing point of 240° Fahr. in B.Th.U. per cubic foot, is very high—13.00 units.

This system of Mansfield has had extended applications. It can be used with almost

any animal fats and grease refuse, and cheap vegetable oils, palm oil, cocoanut, and castor oils. There are few places where some kind of material is not available for making gas good enough for gas engines.

KEITH OIL GAS

The gas is made from crude shale or blue paraffin, heavy thick oils of high flash point. Each gallon yields about 100 cubic feet of rich gas of over 50 candle-power.

Fig. 97 shows the complete plant, consisting simply of the retorts of cast iron, inside of which is a narrow gutter. The oil drops into the front end of the gutter, and blows towards the hotter end of the retort, where it is gasified. The gas is led through cooling pipes to a washer, and thence stored in one or more gasholders.

The retorts will produce 2000 cubic feet of gas per hour, with a consumption of coal to heat the retorts of about 6 cwts. The cost of the gas, with oil at 4½d. per gallon and coal at 16s. per ton, is 5s. 9d. per 1000 cubic feet.

A barrel of oil thus goes a long way, and the finest quality of oil mentioned, though so rich in gas, is perfectly safe, the flashing point in the close tester being 272° Fahr., while the permanent firing point is 338° Fahr. Dr. Stevenson Macadam, F.R.S.E., etc., of Edinburgh, reports on this head that "such oil does not evolve any inflammable or explosive vapour during the hottest weather, even when stored in bulk, and there can be no doubt that it will bear transport and exposure in any latitude and climate without the risk of yielding vapour or of taking fire from natural causes."

This oil being the extract of shale coal, all ammonia and sulphur escape from it while being manufactured, so that these impurities, with their attendant bad gases, being removed from the oil to begin with, the gas made from it requires no purification by lime or otherwise.
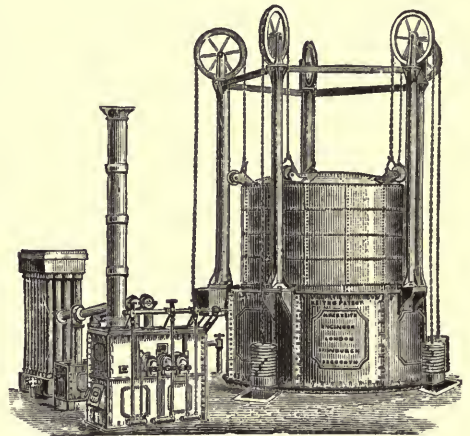
FIG. 97.—Keith Oil Gas Plant.

The illuminating power of the oil gas is shown by the standard photometer to be 54 candle-power, or equal to twice the illuminating standard of Scotch cannel coal gas, and four times that of ordinary London gas. The actual price of the oil gas is about 6s. 6d. per 1000 cubic feet, including oil and coals for heating, etc., which 1000 cubic feet of oil gas is equal, in illuminating power and consumption, to 2000 cubic feet of Scotch cannel coal gas, or 4000 cubic feet of London coal gas. Thus, in comparison, the real price of the oil gas is only 3s. 3d. per 1000 cubic feet, as against Scotch cannel coal gas, and only 1s. 8d., or *at most*, say, 2s. per 1000 cubic feet, as against London coal gas, in the country.

The illuminating power of the gas is so great, and the gas itself so fine in particle, that a number "o" burner, consuming 1 to 1½ cubic feet per hour of oil gas, is equal to, and gives as great illuminating power as, a number "3" or "4" burner of ordinary coal gas consuming, say, 4 cubic feet per hour.

The oil gas itself made by Keith's apparatus is *chemically* made, being distilled by heat like coal gas; it is therefore a permanent and fixed gas, and can be stored in quantity any length of time in a gasholder, or travel any distance through main pipes, etc. This oil gas is thus entirely free from the dangerous condensing and precipitating properties of all vapoury gases, such as the "air gas" and other purely "mechanical mixtures" of a like nature.

The purity and brilliancy of the gas are most marked, and it is so perfectly free from deleterious products under combustion, such as sulphuretted hydrogen, ammonia, etc., that valuable pictures, plants, delicate furniture, and other articles do not suffer from its use in the slightest. The smell of the gas, though decided, is not nearly so offensive as that of ordinary coal gas.

Though by using the smallest size of burners a beautiful flame can be got entirely free from smoke, it has been found that, the gas being so rich, it is advisable to dilute the pure gas with a percentage of air *as it is being burned*, and what has been styled a "meter mixer" has been arranged for this purpose, which carefully measures the proper quantity of air and mixes it thoroughly with the gas, automatically, as the gas passes through it, in the same way as through an ordinary gas meter.

This enables larger or ordinary coal gas burners to be used with advantage, and gives a whiter, larger, and even more brilliant flame (entirely free from smoke) than with the pure gas alone, brilliant though it is, with no more consumption of gas than hitherto, the additional volume being made up of air.

This arrangement also enables the oil gas to be used most economically for driving gas engines and for cooking, etc., as the gas can in this fashion be safely diluted to the required extent, *as it is being used*, to give the necessary explosive or heating power.

Keith's oil gas works, with the meter mixer arrangement mentioned, have been adopted by the Commissioners of Northern Lighthouses for driving their gas engines, etc., and they are also being largely used in South Africa and the Colonies for power and lighting purposes.

The process of making the gas is very simple and safe, which a labourer or unskilled man can easily manage, and the largest sized gasholders in private use can be completely filled and the whole process finished in a few hours at most.

On this oil apparatus Dr. Stevenson Macadam, F.R.S.E., reported, and the following is an abstract therefrom :—

The blue paraffin oil is the product obtained during the refining of the crude paraffin oil, when, after rectification with acid and soda, the paraffin spirit and illuminating oil are distilled off, and the heavier and less volatile oil remaining behind has the solid paraffin taken out of it, leaving the blue paraffin oil. It is therefore a refined oil, practically free from tar bases and acids, and consisting solely of the heavier and less volatile paraffins.

The general properties of the blue paraffin oil are that it has a specific gravity ranging about 870 and 880 (water = 1000), the special sample used in the experiments recorded in this report being 883.5, with a flashing point in the close oil tester of 272° Fahr., and a permanent firing point of 338° Fahr. Such oil does not evolve any inflammable or explosive vapour during the hottest weather, even when stored in bulk, and there can be no doubt that it will bear transport and exposure in any latitude and climate without the risk of yielding vapour or of taking fire from natural causes.

In the employment of blue paraffin oil, in the manufacture of permanent gas, the oil requires only to be run very slowly into an iron retort, previously raised to a bright cherry red heat, when the oil splits up in great part into permanent gas, which can be passed through washers containing water, then through condensers or cooling pipes, and thereafter into the gasholder. As the gas contains no sulphur compounds, or carbonic acid or other impurity, it does not require to pass through purifiers as ordinary coal gas does.

The following table gives a detailed record of the experimental results of one series of trials with the blue paraffin oil :—

Specific gravity of the oil (water = 1000)   .   .   .   883.5
Weight of one gallon of the oil   .   .   .   . $8\frac{1}{5}$ lbs.

Number of gallons of oil in ton of oil .   .   .   253.53 gallons.

Flashing point of oil in close tester   .   .   .   272° Fahr.

Permanent firing point of the oil   .   .   .   338°   ,,

When subjected to the process of destructive distillation in an oil gas work at a bright cherry red heat, one gallon of the blue paraffin oil yields of oil gas 131.86 cubic feet, which, calculated to the ton of oil, yields 33,431 cubic feet.

The oil gas is eminently suited for motive purposes. The quantity of the oil gas required does not exceed 20 cubic feet per horse-power per hour, so that a 4 horse-power Otto gas engine can be worked with 80 cubic feet of gas per hour, and an 8 horse-power, or two 4 horse-power Otto gas engines, can be kept going full speed of 160 revolutions in the minute by a consumption of oil gas not exceeding 160 cubic feet per hour. The engines work smoothly, and require little attention and cleaning.

There are many other oil gas apparatus, differing only in slight alterations of details. They have a field of usefulness under certain conditions. Their chief drawback is the requirement for fuel—wood or coal or peat—to keep the retorts hot. This use of coal is only justified where the gas is required for its high illuminating qualities. For power purposes the gas could nowadays be produced more cheaply and readily from the fuel itself without any oil.

Where oil is cheap and plentiful crude oil may be used to heat the retorts, and that system would be a very successful one in the oil regions. For modern power purposes at this date the "gas producer" from coal, coke, and anthracite has superseded the oil gas plant wherever these fuels are available. Those for power purposes are divided into two classes,—Water Gas and Producer Gas. There are many makes of apparatus for producing these gases, but the principles are the same in all.

WATER GAS

Ruck invented a process for producing water gas. The name of the process explains the composition of this gas. A previous process by White had been introduced. Ruck used a retort containing coke and iron, and heated to a high temperature. Steam forced into the retort was decomposed, its oxygen combining with the heated coke produced carbonic acid ; it combined also with the iron. The hydrogen liberated is given off with carbonic oxide and carbonic acid as some of the carbonic acid formed in the first instance is afterwards converted into carbon monoxide by the excess of carbon present. The gas is therefore a power gas, with little or no illuminating properties. In this process no air is admitted to the producer, and hence no diluting nitrogen is present. It is a pure water gas system. It has been superseded by later methods.

Another early proposal which was tried made what we might term "furnace gas," as it was produced much in the same way as the furnace gases are produced in the blast furnaces. Baggs, the inventor, claimed to be able to produce good heating gas at as low a price as twopence per 1000 feet, and his method consisted in the admission of atmospheric air in limited quantity into furnaces charged with coke and built vertically. The resulting gases were taken off at the top of the furnace, and consisted of the nitrogen of the original air, together with carbonic oxide and a little carbonic acid. By employing sufficiently tall furnaces it was stated that there was no difficulty in producing a gas almost entirely free from carbonic acid. The action which occurs during the manufacture of gas by this means is the conversion of the oxygen of the atmosphere into carbonic acid, which by contact with such a large excess of incandescent coke becomes subsequently converted into carbonic oxide. The entering air contains 20 per cent. by volume of oxygen, and this passes into the form of carbonic acid without change of bulk. This 20 per cent. carbonic acid, in changing to carbonic oxide, would have its volume doubled, so that the final result would be, assuming the decomposition to be complete, that the exit gas would contain 40 per cent. by volume of carbonic oxide, while the

remaining 60 per cent. would consist of nitrogen.   This process is a rough outline of the " producer or furnace gas " producer.

About the same time (1874) another process was introduced which combined the two foregoing processes—that is, both air and steam was forced into the hot glowing coke, and the gas produced was a mixture as follows :—

Carbonic oxide	.	.	.	.	.	.	.	28.6
Hydrogen	.	.	.	.	.	.	.	14.4
Nitrogen	.	.	.	.	.	.	.	53.0
Carbonic acid	.	.	.	.	.	.	.	4.0
								100.0

The apparatus consists of a small iron vessel, which is filled with charcoal and provided with a small aperture on one side near the bottom, and a pipe from the top to carry off the gas.   The charcoal having been ignited, a small jet of steam at moderate pressure is allowed to blow into the small aperture at the bottom of the vessel, and the entering steam draws in with it sufficient air to keep up the combustion of the peat charcoal. The steam becomes decomposed during its passage through the ignited charcoal, yielding hydrogen, carbonic acid, and carbonic oxide.   A further quantity of the last two gases is likewise obtained from the union of the oxygen in the entering air with the carbon of the charcoal, the nitrogen of the air passing forward unchanged.   The various power gas producers are based on one or other of these early processes.

We need not here enter into the construction and operation of the large producer gas plants, such as Monds, Duff, and Masons.   These are more properly classed with boilers of large power for power production on a large scale, a subject to be dealt with in another volume.

The gas producers for isolated small plants designed for operation by one attendant who can look after the whole plant easily properly belongs to this volume.   We have already described one such plant in this volume in Chapter I.

The small plants must occupy very little floor space, and therefore it is an advantage to get rid of gasholders.   This desirable result is obtained by operating the producer by suction from the engine exactly as the petrol carburetter is operated by the suction of air and petrol through a carburetter.   By this simple means the air and steam necessary to form the gaseous mixture are drawn into the " gas producer," and through that form gas enough for each charge.   In Britain we call such a plant a " Suction gas producer," but the French call them " Gasogenes," a very convenient term, and one which sufficiently distinguishes them from the larger gas producers.

Messrs. J. & O. G. Pierson, Engineers, Paris, make a good example, which, taken with that already described, will sufficiently indicate their construction and operation.

In France the cost of paraffin oil is much higher than with us (one of the blessings they suffer under protective tariffs), hence these plants have been cultivated with much more care than over here or in America.   Necessity in this case has verily been the mother of invention, and the result of this necessity for devising " gasogenes " for power gas is that we have in them a cheap and convenient source of power which now rivals the cheap oil, but not in every case.   Ready made fuel in the shape of a barrel of oil is hard to beat at prices from 2½d. to 4½d. a gallon for smaller powers.

The construction of the apparatus can be clearly seen on reference to Figs. 98 and 99.   In these B is the producer, I the condenser or cooler, K the coke scrubber, and N the purifier or drier.

The producer consists of a boiler or water vaporiser A, and a cast-iron cylinder B, which is lined with fire-brick and contains the fuel.   A cast-iron base-piece C is attached to the bottom of A by means of bolts, and can be easily removed.   From its shape it allows ashes and clinkers to be removed.

The cylinder B is closed at the top by a cover plate, in which there is a charging hole E for introducing the coal. The producer will hold sufficient coal to last for a 10 or 12 hours' run. Should this quantity not be enough a special hopper and valve can be attached on the top of the generator, so as to allow coal to be added while the plant is working. The gas from the producer passes along the pipe H into the top of the cooler I. This cooler, as will be seen, consists of an inner tube and an outer shell, and rests upon a dust collector J. A manhole at the bottom of this latter allows of the removal of the dust. The space between the inner tube and the outer shell is filled, through the pipe l, with water, which enters at the bottom and passes out at the top. In this cooler the gas loses its heat, and part of the tarry matter contained in it is condensed, while the greater part of the dust falls to the bottom.

From the cooler the gas passes to the coke scrubber K by the pipe L (Fig. 98), and passes out by the pipe M at the top. Any dust not retained in the collector J is washed
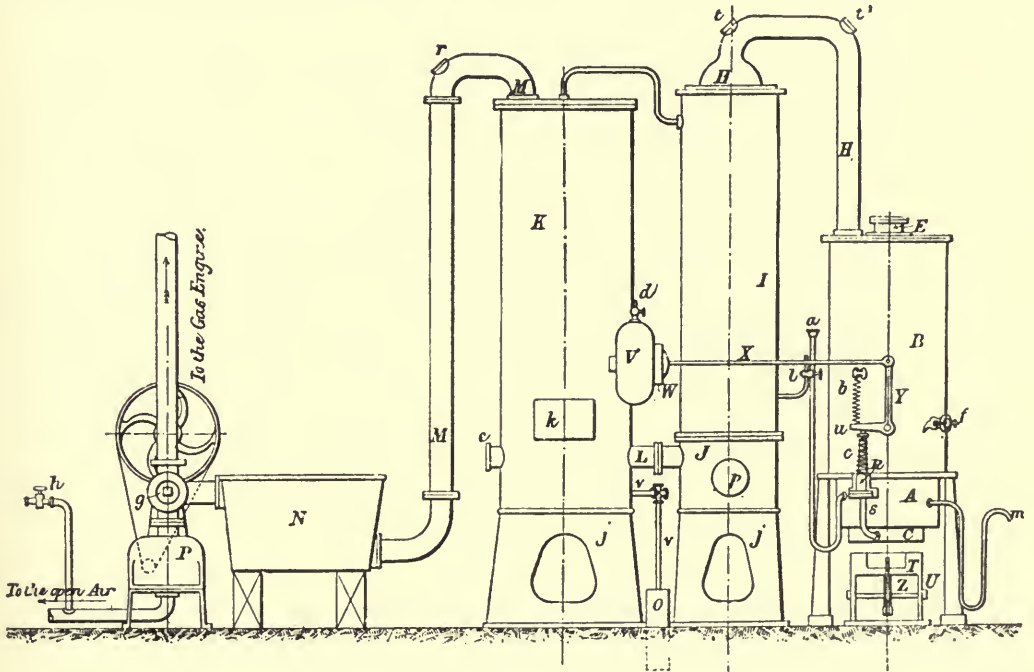
Fig. 98.—Pierson Suction Gas Plant. Elevation.

out in the coke scrubber by means of streams of water flowing down through the coke, as shown in Fig. 98. The water used in the scrubber comes from the cooler I by means of a small pipe at the top, and eventually passes into the syphon-box O through the pipe v, Fig. 98. From the scrubber the dust-free gas flows to the purifier N, where it is dried, and where any impurities that may remain are extracted, and thence passes to the engine. On the pipe which conveys the gas from the purifier a blower P is fitted, and is used to urge the fire when starting, which operation takes only a few minutes. The blower has a 2-way cock g attached to it, which allows the gas to pass either to the engine or to the atmosphere—the latter when the fire is being lighted.

Returning to the vaporiser A, it will be seen that it is fitted with a water supply pipe and funnel a (Fig. 98), and another pipe m, which allows the water to run to fire. If, however, the engine be running light and not requiring much gas, the diaphragm will be only slightly sucked back, and will not cause the vapour valve to open at all, the vacuum in the air vessel V being at once destroyed by air flowing in through the

small cock *d*.   The lift of the vapour valve can be easily adjusted once for all, and the temperature of the fire kept constant.

A serious drawback in some plants of a similar kind is that there is a great difficulty in drawing out the ashes and clinkers while running.   This difficulty only allows the use of the best quality of coal, whereas in the producer under notice any hard coal will
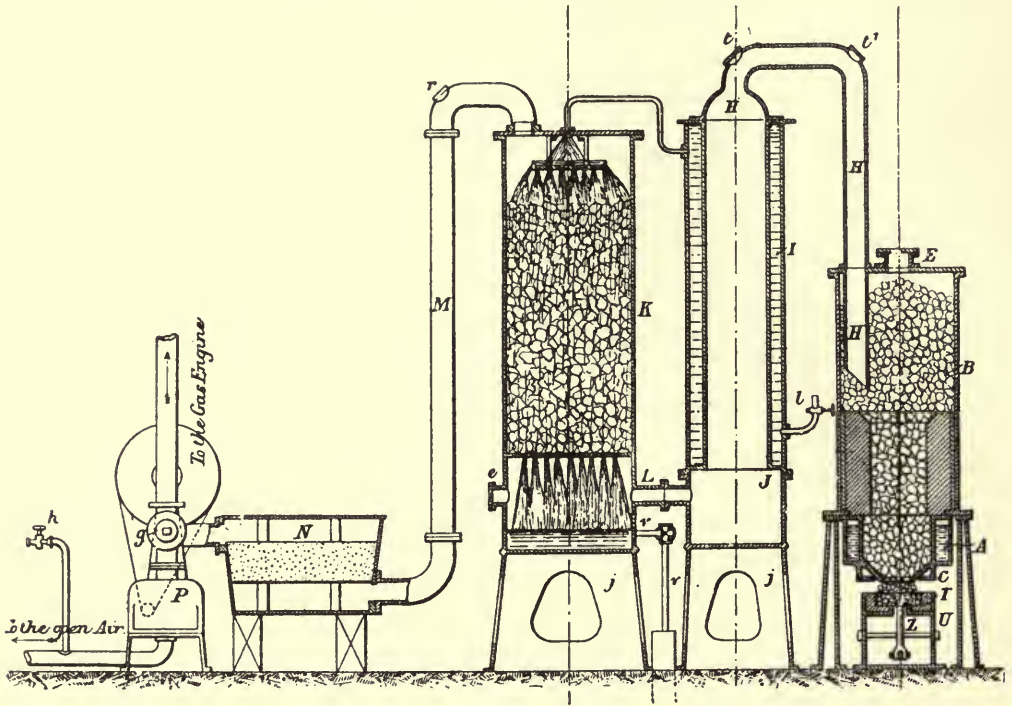
Fig. 99.—Pierson Suction Gas Plant.   Sectional Elevation.

answer, since it is an easy matter to draw out the ashes at any time.   By means of an automatic poker Z the fire can be stirred without disturbing the regular inflow of air and steam.   Fig. 100 is a plan of the plant.

The action of the producer is as follows.   At each suction stroke of the engine a certain amount of air and water vapour is drawn into the fire, and combines with the
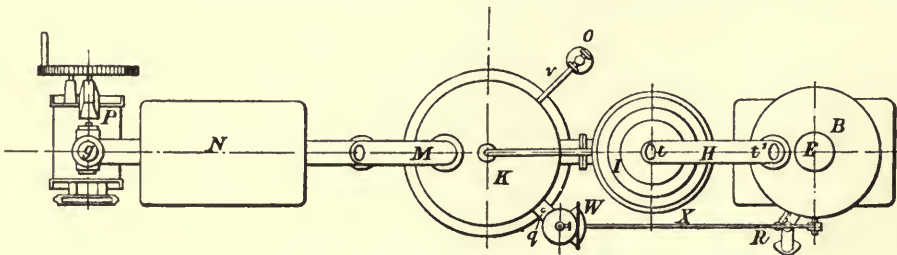
Fig. 100.—Pierson Suction Gas Plant.   Plan.

coal to make a mixture of carbonic monoxide and hydrogen, in association with nitrogen. The gases, after being cleaned, are mixed with the necessary quantity of air in the engine, and are ignited in the ordinary way.

And the claims made for it, which seem to be fully borne out in practice, are—

1. It can be fed with any hard coal (not anthracite) containing up to 10 or 12 per cent. of ash, and as much volatile matter.
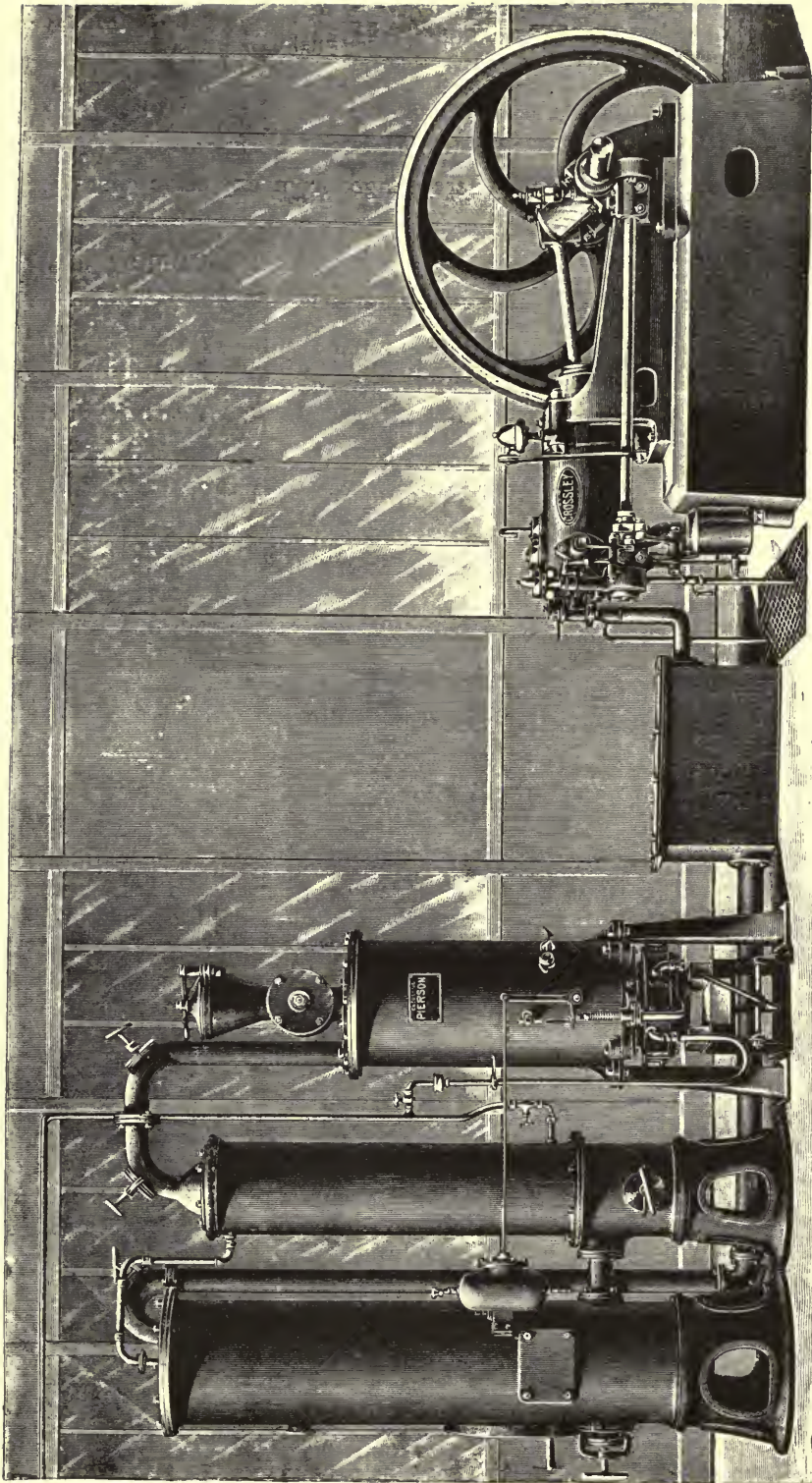
Fig. 101.—J. & G. Pierson's Suction Gas Plant.

2. The engine can be started from cold in less than 10 minutes.

3. Thorough cooling, scrubbing, and cleaning of the gas is secured, which allows the engine to work for weeks without cleaning.

4. Coal is fed in only once every 10 or 12 hours, so that there is no attendance except for stirring the fire, which latter is entirely open.

5. The automatic regulation of vapour admission to the fire is easy, and allows the plant to be run at varying loads without any trouble. This is important, and the makers claim that the plant is the only one of the kind in which this regulation is done, not upon the water but upon the steam. This method has been adopted because it is much easier to regulate upon steam than upon water admission, and especially so when the liquid is only introduced in small quantities.

The full page Fig. 101 illustrates a complete Pierson plant with engine attached.

STOCKPORT GASOGENE

The Stockport gasogene made by Messrs. J. E. H. Andrew & Co. is shown complete in Figs. 102 and 103. It is very simple in action, and a convenient generator of power gas on a small scale from coke or hard coal.

It can be worked either with coke or small anthracite coal. The consumption of coke would be about $1\frac{1}{4}$ lb. per horse-power per hour, and the consumption of anthracite coal about 1 lb. per horse-power per hour. Describing the operation of the plant :—The illustration, Fig. 102, on opposite page shows a sectional elevation of the plant. A is the gas generator, with a small blower or fan A' attached. B is the vaporiser for vaporising a small quantity of water. C is a coke scrubber, and D is a reservoir box for the gas, which is fixed in close proximity to the engine. A fire is lighted on the fire-bars shown, the coal is put into the generator through the hopper H, and the blower is turned by hand until the fuel gets to the proper heat. Whilst the fire is being blown up in the generator the smoke and hot gases travel along the pipes and through an outlet pipe above the tap E, as shown by the arrows on the illustration. During this time the vaporiser B is being heated. When the fuel in the generator is sufficiently incandescent the tap E is shut off. On the engine starting it sucks the gas from the reservoir box D through the outlet F, which is connected to the gas valve of the engine. The suction of the engine causes a certain amount of water to be drawn into the vaporiser B, which is made into steam, and travels through the small pipe G below the fire-bars. This steam with the air is sucked up through the fire-bars by the action of the engine, passes through the incandescent fuel, and then follows the direction shown by the arrows through the coke scrubber C, and into the reservoir box D, and on into the engine. A supply of water for cooling the gas passes into the top of the coke scrubber by the spreader I. The boxes JJ are merely for collecting the dirt from the gas and the surplus water from the scrubber. It will be observed that the gas is only produced as the engine requires it ; if there is no suction there is no gas made. In the smaller types the vaporiser is placed on the top of the generator.

The gas producers working on a larger scale operate some of them on these same principles, but as they are more economical when worked continuously, and the gas stored for intermittent use, they are in fact small gas works.

TANGYES GAS PRODUCER

This producer, shown part in section in Figs. 104 and 105, may be taken as an example of this class of producer, working continuously and storing the gas for use as required.

Speaking from experience, the author, after over thirty years' dealing with steam and other engines, believes that for factory or mill driving the gas plant of this type
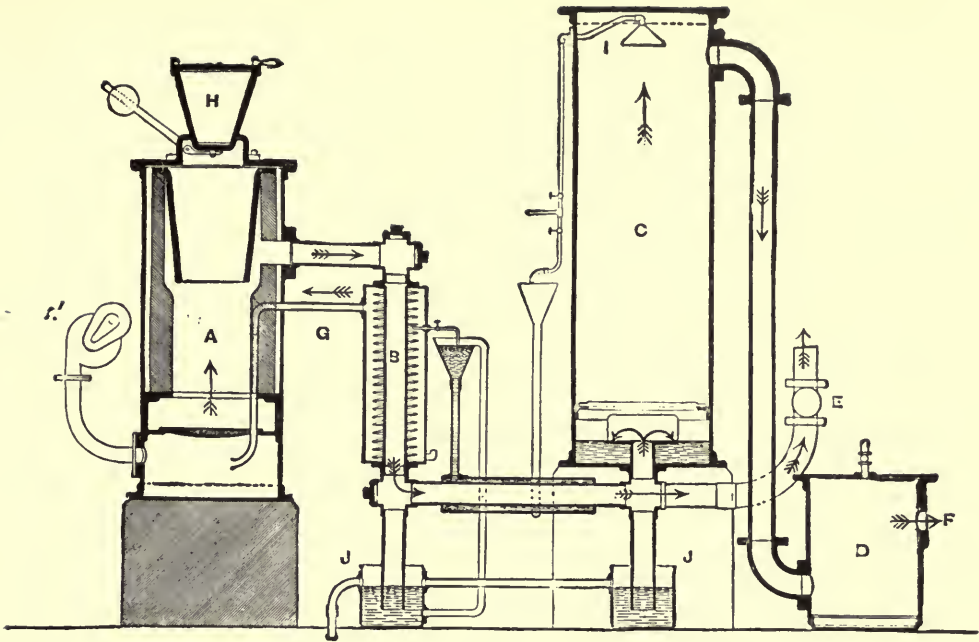
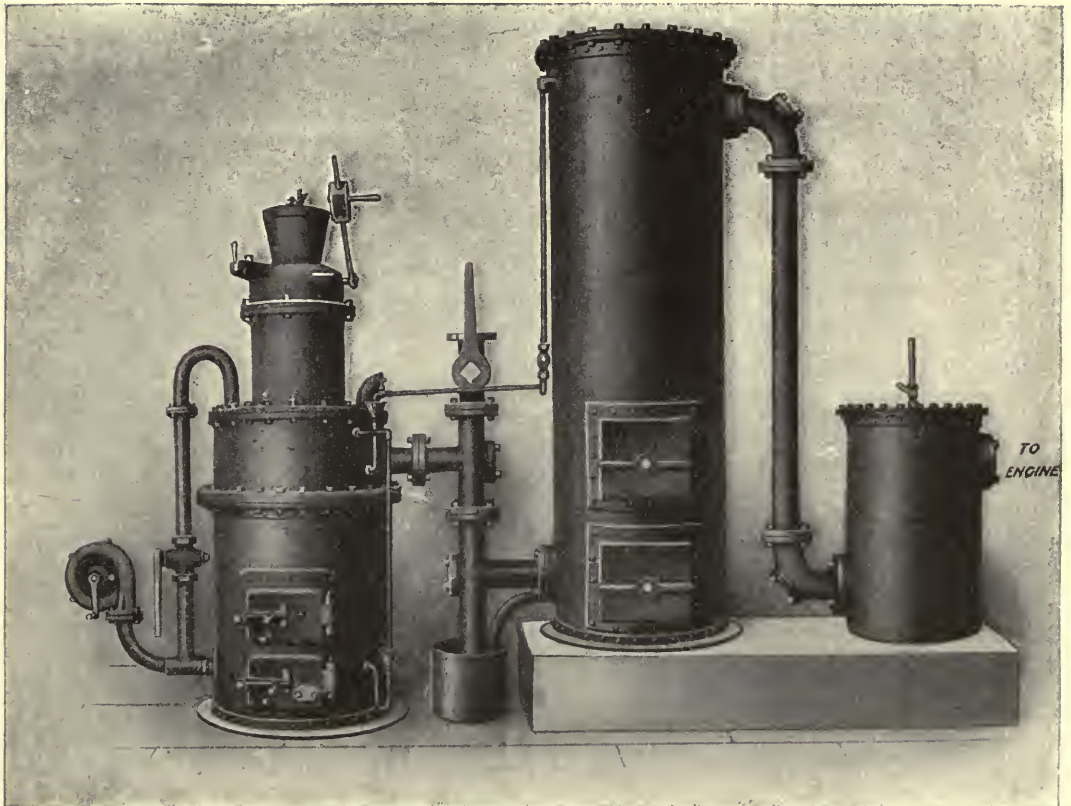FIG. 102.—Section of J. E. H. Andrew & Co.'s Suction Gas Plant.

FIG. 103.—Complete Andrew Gas Plant.

up to about 75 horse-power is by far preferable to steam. And for larger power a gas plant consuming coal slack, as in many of the gas producers now in the market, is still more satisfactory.
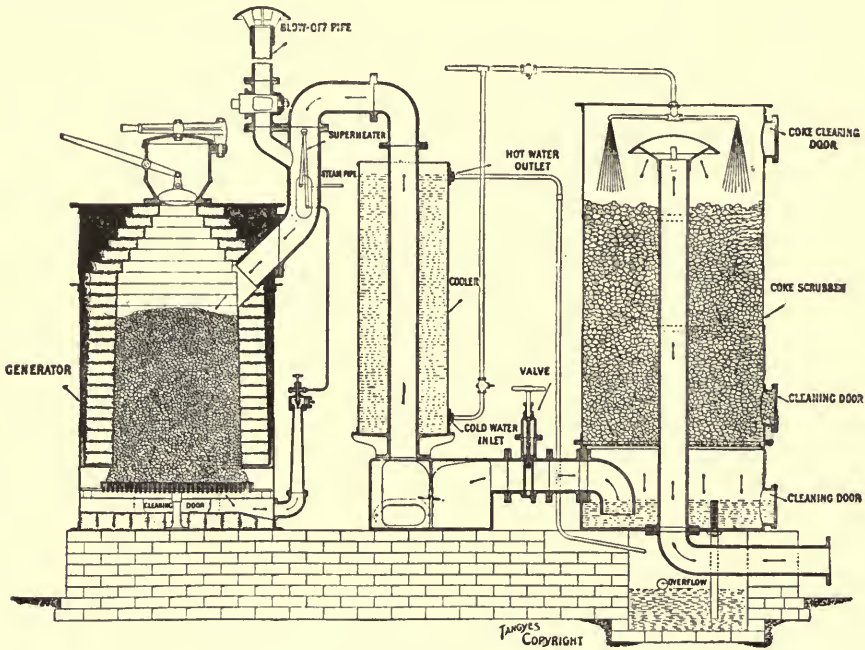

FIG. 104.—Section of Tangyes Gas Producer.

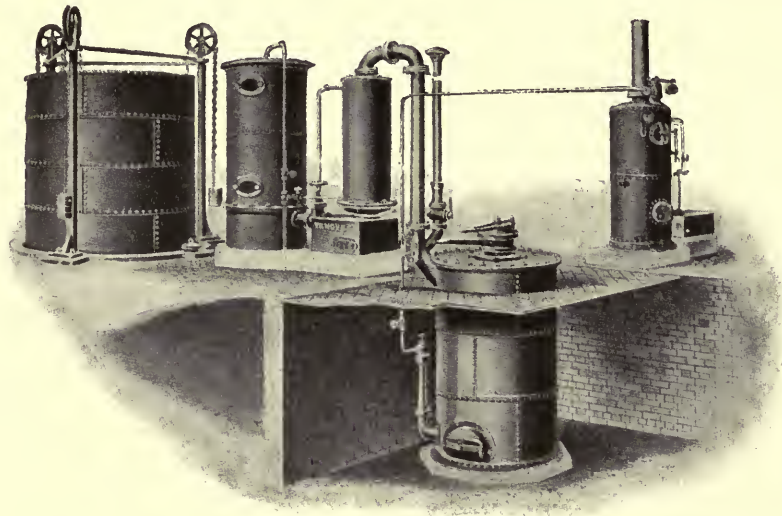A factory or mill fitted out with electric power and light, and in which the energy of the fuel is converted into power by a gas producer, a gas engine, and a dynamo,

FIG. 105.—Tangyes Gas Producer.

represents the most modern combination at this date, and one of high economy. Meanwhile we can only describe this one example of a gas producer, leaving the larger question for future treatment.

The generator consists of a steel casing lined with fire-brick, and steam and air are blown by means of an injector through incandescent coke or anthracite coal. From the figures shown it will be seen that the small steam pipe from the boiler is led into the delivery pipe and immersed in the hot gases, in order to dry and superheat, the steam forming a simple superheater. The delivery pipe is surrounded by a water jacket to cool the gases, and water from this jacket is sprayed down through the scrubber.

The plant will work with anthracite coal or with gas coke, and gives the following economical results :—

With Welsh Anthracite Coal. — At full load, from $\frac{3}{4}$ lb. per indicated horse-power per hour for the larger size gas engines to $1\frac{1}{4}$ lb. per indicated horse-power per hour for the smaller sizes.

With Washed Gas Coke.—At full load, from 1 lb. for the larger to $1\frac{1}{2}$ lb. per indicated horse-power per hour for the smaller size gas engines.

These plants give their best efficiency when worked at full load, but can have the load reduced about 25 per cent. without blowing gas to waste. When required for varying and intermittent loads it is advisable to have two generators of equal or different sizes, depending upon the duty, etc., and by a little care the attendant can work these so as to meet the changing conditions of load without waste of gas.

The steel-cased generator is fitted with a special hopper at the top, through which the fuel is fed. It has a set of fire-bars and is fitted with self-sealing cleaning doors which require no jointing or luting material.

A boiler of vertical type, made of best mild steel plates with all usual steam and furnace fittings, for blowing air and steam into the generator. (This boiler may be dispensed with in places where steam is already in use, and can be supplied to the plant at a suitable pressure.)

A cooler, a dustbox, and a scrubber of ample size to cool and clean the gas before passing into the holder.

A holder made of mild steel closely riveted. The tank for the holder can be of brick and built in the ground, or of mild steel fixed on or above the ground level. The plants are usually supplied with steel tank.

Full instructions for working are supplied, and by carefully following these any intelligent labourer can work the producer.

In factories using this plant the boiler may be made large enough to afford steam for heating the premises in winter time.

CONSTRUCTION OF EXPLOSION ENGINES

It may be as well to consider the more recent types first. Many of the gas engines of 4-stroke cycle are too well known to require notice here ; we need not describe and illustrate all of them. The turbine, being most novel, comes first.

Quite recently a leading automobile authority observed at a lecture that engineers did not know even how to begin to design internal combustion oil or gas turbines. That may be true of automobile engineers, but it is not generally true of all engineers. We have already in Volume I. of this work described two designs which at least show a beginning ; and in Chapter I. of this Volume a further and more highly developed turbine, as originally proposed by the Hon. C. A. Parsons, is shown in a clear diagram, the fundamental design for a constant pressure turbine, which has been worked successfully on an experimental scale.

It now remains to describe a design for an explosion turbine, in which the turbine is driven by a succession of explosions, as in a reciprocating gas engine. In order to explain this engine the three diagrams (Figs. 109, 110, and 111) have been produced, in which are shown the essential parts of this arrangement. It may first, however, be

more useful to refer to early proposals briefly, before describing this later and more complete design.

In addition to the patent of Ferranti, already quoted in Volume I., a patent of 1895, No. 11,955, by L. B. Atkinson, describes a constant pressure turbine, but without showing any details, merely describing the principles of action, and showing in a diagram how they may be applied in practice. Fig. 106 shows this diagram, and the machine is described as follows :—

The improvements consist in utilising the heat developed by the combustion, not for the purpose of raising the pressure of the working fluid to be used in a cylinder, but for the purpose of communicating a velocity to, or increasing the velocity of, the working substance, and then abstracting the motion from the working substance by means of turbine or reaction wheels.

The cycle of operations is as follows :—

The working substances, say, for example, gas and air, are passed into a receiver, or receivers, under some pressure by means of pumps or other contrivances. They are then passed through a regenerator, heated by the exhaust gases of the engine, and are raised in temperature nearly to the temperature of the rejection of the fluid by the engine, then by the combustion of the heated gases the temperature is raised
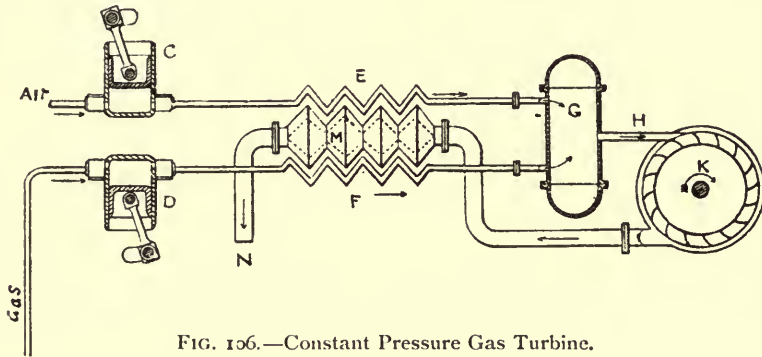
FIG. 106.—Constant Pressure Gas Turbine.

to whatever temperature is required, up to the highest temperature obtainable by the combustion of the particular gases used.

The gases have so far been at constant pressure with increasing volume, and are now allowed to expand by passing out by a jet or jets or aperture, so that the pressure falls to about atmospheric pressure, the temperature at the same time falling, and the gas receiving the energy thus expended in the form of velocity. The working fluid now passes into a turbine engine or reaction wheel, which may be made of any suitable material, and lined with non-conducting substances, to stand the temperature. The working fluid, after having communicated most of its velocity to the turbine wheel, passes through the regenerator before mentioned, heating the incoming fluids, whilst in certain cases, where, for example, steam or water gas is used, the gases may be further cooled by heating water before being finally rejected.

Fig. 106 shows the apparatus in diagram. Thus A is the air inlet to compressing pump C, B is either a gasholder or gas producer, with or without coolers and scrubbers, leading to compressing pump D ; the compressed gases pass through regenerators EF, shown here of the transmission type, but they may be of the storage type with reversing valves as well understood. G is the combustion chamber, which is lined with any suitable non-conducting and heat-resisting material. H is the jet, allowing the expansion of the gases, and allowing them when expanded and moving at a high velocity to impinge on the turbine wheel K. L is the exhaust outlet, the gases passing through

the regenerator M, and exhausting at N either to the atmosphere or through a boiler or heater.

So far this clearly describes the fundamental principles of a central pressure turbine, but leaves everything to be worked out in practice.

Then returning to explosion types, we find a patent of 1894, No. 11,526, by P. Nordenfeldt and another. This is more elaborately worked out, and contains the principles of the explosion gas or oil internal combustion turbine. Fig. 107 represents this proposal, and the following is the description :—

The motor is shown in plan as a parallel flow turbine, in which the wheel a revolves in one direction, while the parts b and c containing the inlet and outlet passages b^1 c^1 respectively are fixed together and revolve in the opposite direction. The motion is communicated to the fly-wheel shaft h^1 through friction wheels f, f^1 carried on arms g radiating from the shaft g^1 and gearing h, and through the sleeve d and gearing i, i^1. The chambers in the wheel a are more or less V-shape, and the wheel is either built up of two perforated discs or is a solid disc in which the chambers are cut, or the blades are inserted and secured by a peripheral ring. When the motor is driven by explosive gases the apparatus shown to the left of Fig. 107 is employed. Assuming that the combustion chamber o contains combustion products under pressure, these escape through the motor until the pressure sinks below atmo-
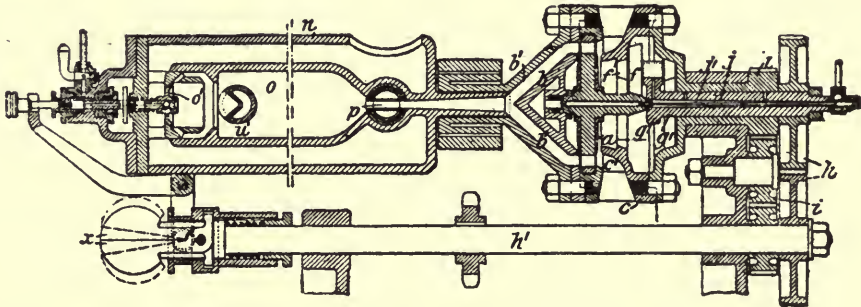
FIG. 107.—Explosion Oil Turbine.

spheric, when, by the momentum of the motor, air is drawn in through the passage n, and passes with gas through the valve o^1, and is ignited by the heated tube p, and closes the valve. When oil is used the stem of the valve o^1 forms a pump plunger, and the oil is vaporised by impinging against a heated tube u. To govern the motor a centrifugal governor x on the shaft h^1 interposes a stop in the path of the valve spindle, and prevents the valve from opening when the speed is too high. The motor may be in the form of a combined reaction and impulse jet wheel, the motor fluid escaping from reflexed jets carried on one revolving part, or fixed and impinging against another part which is thereby made to revolve. This latter part, against which the fluid acts, may be the face or edge of a disc, the interior of a narrow splayed flange on a wheel which may be duplicated, or a hollow cone in which the fluid passes in a helical direction from the larger to the smaller end, where it escapes. In the provisional specification a speed-reversing gearing, for driving vehicles, etc., from the motor, is described, comprising a series of chain wheels of different diameters connected with the driving axle, and which may be put into gear frictionally with a shaft driven in either direction from the motor.

Neither of the foregoing patents disclose any practicable plan of construction. The latter patent (Fig. 107) shows the explosive mixture is fired as it enters the turbine. This is a mistake. The turbine is not the place in which the explosion or combustion should take place. The combustion should be in the combustion chamber, and only the products of combustion allowed to enter the turbine. And further, the suction of the wheels is not to be relied upon to draw in the air charges.

In the designs here given by the author in the three diagrams the essentials for practical work are shown. And in order to show how this turbine might be developed from a well-known gas engine starting device, the Clerk-Lanchester starter is here illustrated (Fig. 108), attached to a gas engine. In this apparatus the vessel C and the engine cylinder at the back end are filled with pure air when the engine is stopping, by opening valve V and allowing air to be sucked in through valve L during the last stroke or two of the piston. When the engine is to be started again a flame is lit at G, and gas supplied to vessel C through pipe O, and to the cylinder through pipe N. The gas and air mix, and when the issuing mixture burns at L with a roaring blue flame, tap K is shut and the mixture fires back into vessel C; and the piston having been adjusted just over the dead centre, the sudden high pressure sets it off. Now, it is not a long step from this device to an explosion turbine, if the engine cylinder is replaced by a turbine, and gas and air in the proper proportions blown in at L; and if, instead of an external flame for ignition, an internal sparking plug is fixed at P we would get a series of explosions, the valve at L automatically closing when the pressure in C exceeded that of the incoming gases.

Referring now to Fig. 109, a side elevation. The turbine to the right is shown in section. It consists of a pressure chamber N of annular shape in the end cover, which communicates with the combustion chamber by an admission pipe shown in the plan (Fig. 111). In practice this pipe is water-jacketed to extinguish any flame which might enter it. Between the pressure chamber in the end cover and the turbine wheels W is a solid partition, in which the diverging conical nozzles of the turbine are drilled at an angle of 30° to the face of the first wheel; two wheels only are shown with one row of guide blades V between; the shaft extends along to a pressure air blower or fan, or screw air pump which is shown direct coupled to the turbine shaft S, but of course may be driven by gearing.
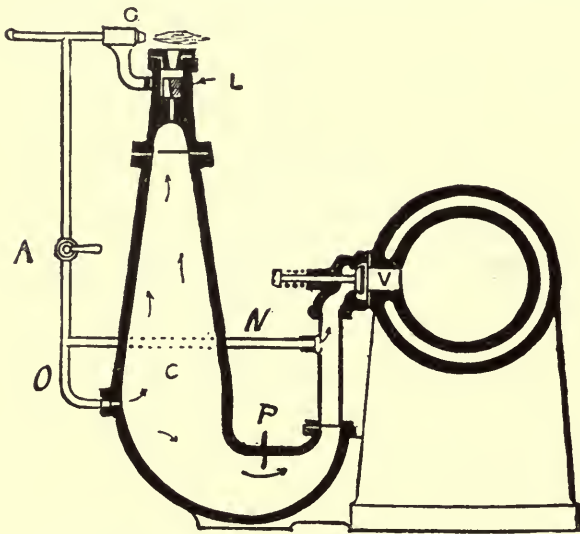
FIG. 108.—Clerk-Lanchester Starter.

The air under pressure and the oil under the same pressure, maintained by a small air pipe C shown in end view (Fig. 110), enter the combustion chamber through the double valve, the air spraying the oil by rushing across the oil orifices in the seat of the valve. The combustion chamber is a steel cylinder of considerable capacity, and fitted inside with refractory baffle plates to mix the air and oil and separate the products of the last explosion from the incoming gases.

To start the machine, the shaft of the pressure blower is spun round by hand or power and the double valve eased up, the sparking plug set aworking. Very soon an explosive mixture fills the combustion chamber and an explosion occurs; the pressure generated closes the valve and propels the turbine, which gathers speed rapidly. With a good fan the air pressure may be as high as 2 lbs. per square inch, quite sufficient to drive out the spent gases and form a fresh charge.

The larger the combustion chamber the less frequent are the explosions, and by a governor cutting off nozzles on the turbine the speed can be regulated.

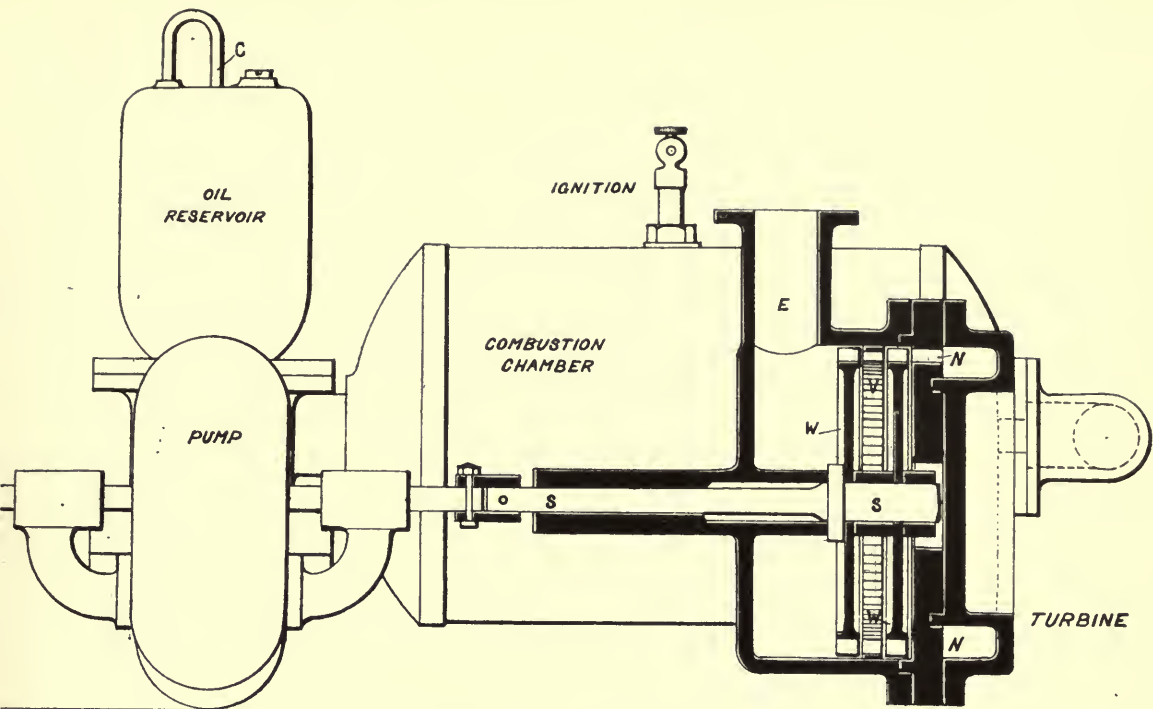Comparing the two systems that are shown on page 41, Chapter II., and this shown

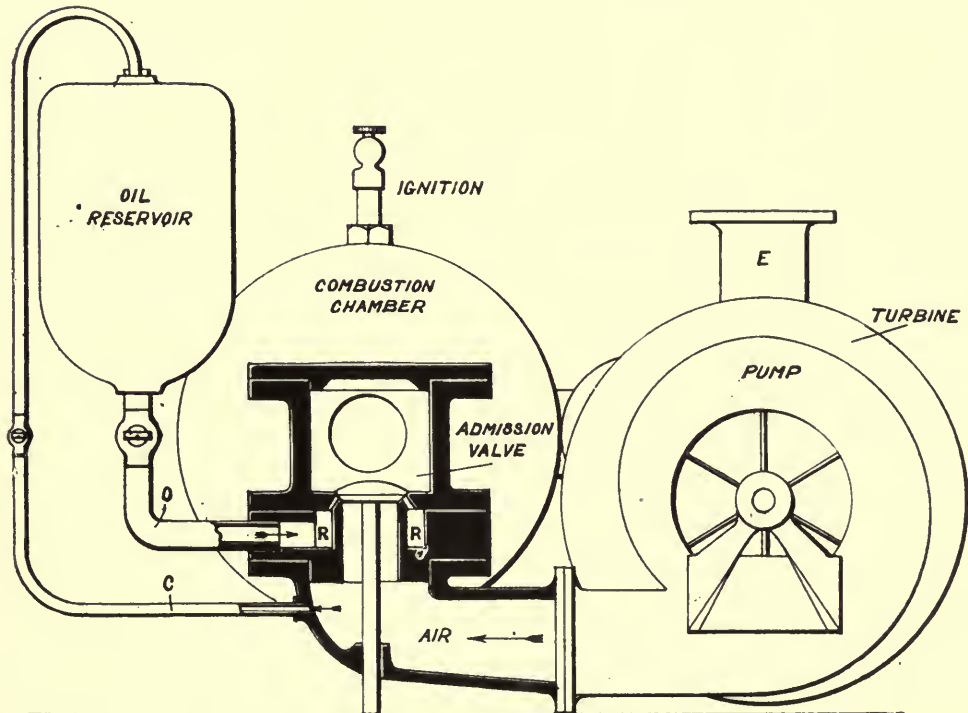FIG. 109.—Explosion Oil Turbine. Side View.

FIG. 110.—End View.

105

here, the first works silently, but unless pretty high air pressure is employed—100 lbs. per square inch or more—the turbine must be one with large blades and wheels of large diameter.
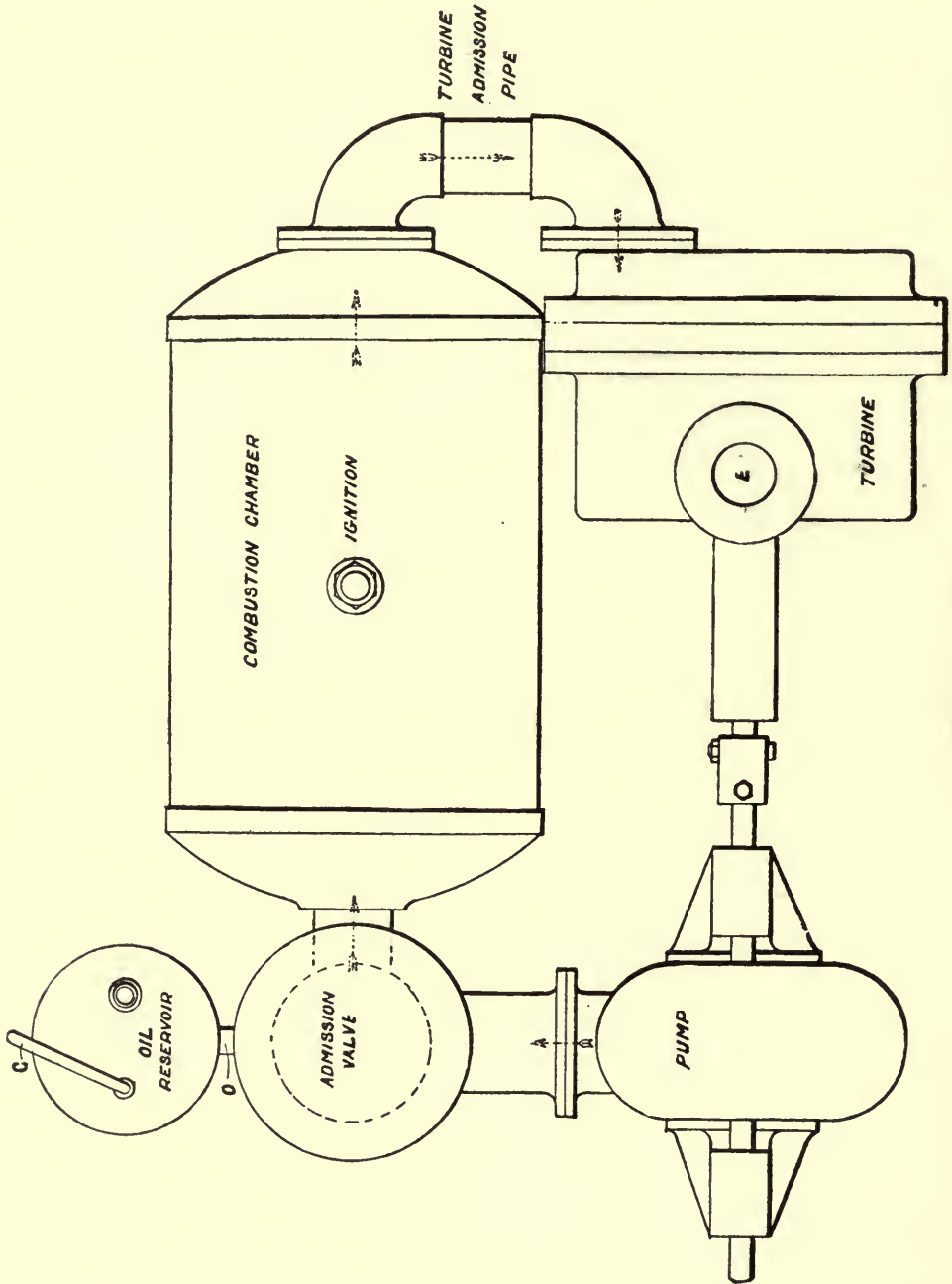

TURBINE ADMISSION PIPE

COMBUSTION CHAMBER

IGNITION

TURBINE

OIL RESERVOIR

ADMISSION VALVE

PUMP

FIG. 111.—Plan.

In the constant pressure turbine with low pressures, such as a fan would give, the wheels would have to be considered as windmills designed to work in a hurricane.

In the explosion turbine the only drawback is the noise of the explosion and the clack of the valve ; these, no doubt, can to some extent be overcome by using a piston valve.

Instead of forcing the air into the combustion chamber, the fan acting as an exhaust fan can be connected to the exhaust pipe of the turbine, in which case a mixture of gas and air can be drawn into the combustion chamber, much as in the ordinary gas engine.

The development of these things requires time, thought, experience, and money to bring to practical issues ; but having found a beginning, the appearance of a turbine in actual service is not far off. Having put on record the designs so far as procurable at this date, future experimenters will now know that so much has been already accomplished. The stage has been reached where the enterprising capitalist is necessary to carry it to the commercial success which undoubtedly awaits the first successful turbine set to industrial work. It will be interesting to observe in the future whether the home or foreign engineers take up the subject first. In the meantime, what we have shown is all that at present is available in the practice of the oil or gas turbine.

WATER PISTON OIL AND GAS ENGINES

Recently a very interesting new internal combustion engine has been introduced in which water is employed in the cylinder in a novel manner to act as a cushion between the explosion and the piston. It has been described in *Engineering* by Mr. Humphrey, to whom, and the patent specification, we are indebted for the description.

It is the invention of M. Vogt, from whose patent the figures are drawn.

Figs. 112 and 113 are sections of the engine, and Fig. 114 a side elevation. The cylinder C carries vertical combustion chambers B_1 B_2 at its ends. The cylinder is completely, and the combustion chambers partly, filled with water, the height of the water in the chambers depending on the position of the piston as it reciprocates. The gas, air, and exhaust valves are situated at G, A, and E respectively, and are all operated in a positive manner by means of eccentrics, rods, and trip-gear as shown. Both the gas and the air are pumped to the cylinder under pressure, the gas pump being driven off the crank shaft by a crank pin set in advance of the main crank, and the air pump being directly attached to the extended piston rod R of the motor cylinder. Intermediate receivers may be used for both gas and air supplies. An ordinary water service under about 10-lb. pressure is utilised to inject a little fresh water at each stroke, as required for cooling purposes, and below each vertical chamber are water valves K, communicating to spring-loaded valves L, which are so operated and adjusted as to retain more water in the chamber when the quantity of the explosive mixture is diminished, and so regulate the clearance as to give a constant compression pressure for all charges.

Starting with the piston in the position shown in Fig. 113, and with a charge of gas and air compressed in the chamber B_2—*i.e.* in the space at the top above the water surface W—the action of the engine is as follows :—Ignition is effected by the electrical igniter I (Fig. 112); explosion takes place, and pressure upon the water surface at W drives down the water column and forces the piston to move towards B, the work being transmitted through a cross-head and connecting rod to the crank shaft in the usual way. Towards the end of the stroke the exhaust valve is opened and the pressure drops to atmosphere. The water level is then below the air inlet valve, and this valve now opens, admitting air under slight pressure and in excess of the total combustion chamber volume, so that all the burnt products are swept out and the cylinder left full of fresh air. If the engine happens to be on full load the exhaust valve closes soon after the in-stroke has commenced, at the same time gas is supplied under sufficient pressure to force it into the cylinder, and then both gas and air are compressed together. The amount of water expelled through the valve K during compression is in this case a maximum, and the final clearance is that necessary to give the desired compression pressure, which pressure is constant (being equal to that at which the spring-loaded

valve lifts), and independent of the quantity of mixture or its temperature. On the other hand, if the engine is on light load, the exhaust valve closes later and the gas valve opens later, the first portion of the in-stroke serving only to expel some of the air previously drawn in. At a given point, determined by the governor, compression
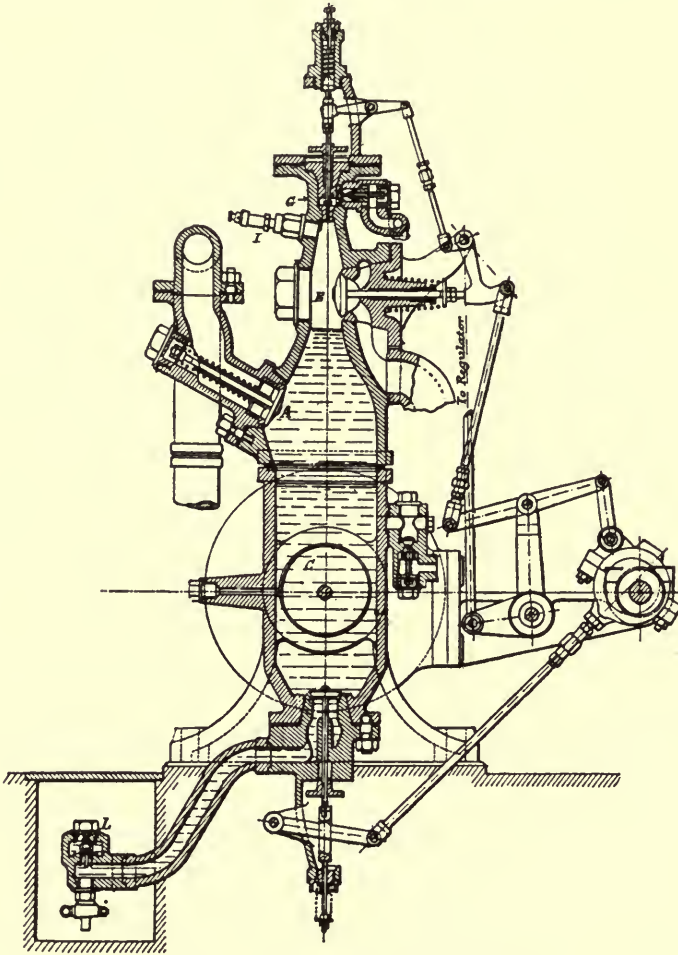

FIG. 112.—End Section Vogt Engine.

begins, and even with a light charge the same compression pressure is reached, but more water is retained in the chamber, so as to reduce the clearance to the proper capacity.

The following gives the cycle of operations :—

     1 = End of working stroke ; air valve opens.
     2 = Air valve closes.
     3 = Exhaust valve closes ; gas valve opens ; compression begins.
     4 = Gas valve closes ; compression of air and gas.
     5 = End of compression ; beginning of combustion.
     6 = Combustion complete.
     7 = End of expansion ; exhaust valve opens.

The experiments were made with an engine of only $3\frac{1}{16}$ inches in diameter of cylinder and $5\frac{15}{16}$ inches stroke ; it is more astonishing that any good results could be
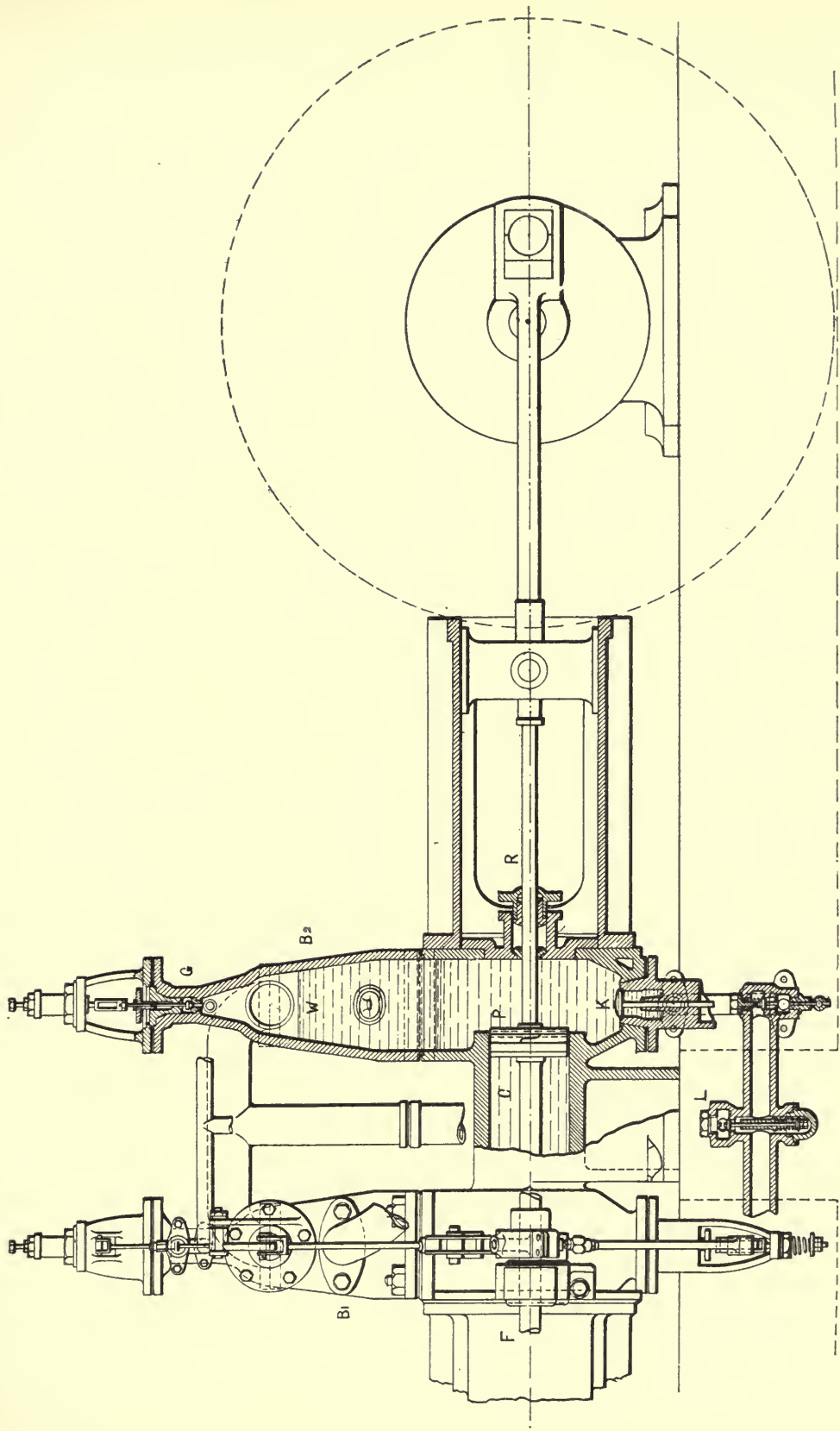
FIG. 113.—Longitudinal Section Vogt Engine.

obtained than that the best results were only reached after careful adjustment and attention.

During expansion the water surface in contact with the gas will be considerably heated to a certain depth, and will certainly be hotter than the temperature of steam at 1.05 atmosphere absolute. Accordingly, there will be a rapid formation of steam at this surface the moment the exhaust pressure has sunk enough, and this steam will rise fairly uniformly and drive out the products of combustion still remaining in the cylinder above the water; thus when the air valve opens to admit the scavenger air there will only be steam at about 100° C. (373° C. absolute) in the expansion chamber. With the instantaneous development of the steam one may assume it to be very wet, and so it will cool the walls of the explosion space. This steam is now driven out by the cold scavenging air; but as this air expands from 1.25 atmosphere down to 1.05 atmosphere absolute a still further cooling will take place. The assumption of 127° C. (300° C. absolute) at commencement of compression, or rather at the commencement of the blowing in of the fuel, will therefore be about correct, and this furnishes us with the
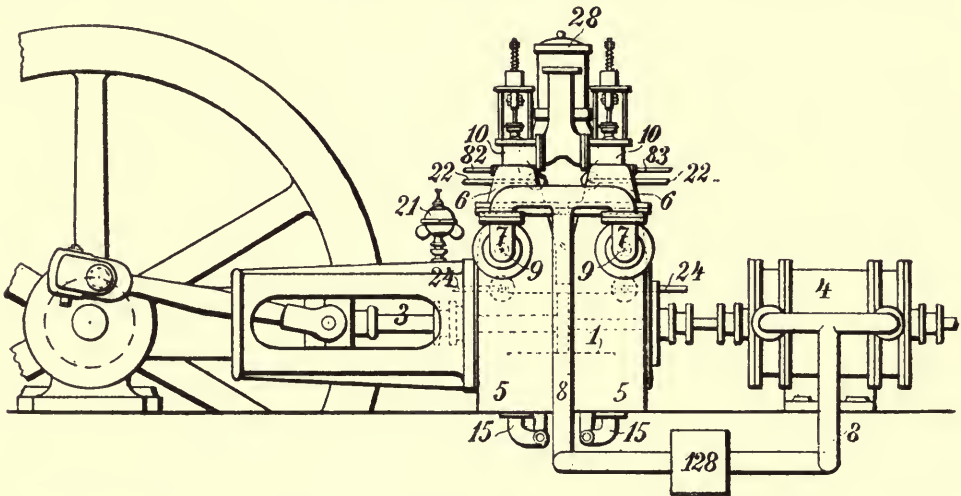
FIG. 114.—Side Elevation Vogt Engine.

starting-point in the temperature curve. It may also be remarked that the 938 cubic centimetres contents of the expansion space will be scavenged with an excess of air, since the 1130 cubic centimetres supplied gives 20.5 per cent. excess.

The blowing in of the fuel also acts as a cooling medium at first, as expansion from 2.1 to 1.05 atmospheres takes place; then the temperature of the mixture rises as compression proceeds. The temperature at the end of the compression is the next point to settle, and all Mr. Vogt's experiments go to prove that at the end of compression the gaseous mixture is saturated with water vapour, and that the temperature is that of saturated steam at the given pressure. In this case it will be about 187° C., or 460° C. absolute. Fig. 114 is a side elevation showing the pump 4.

Such an engine offers many advantages. It at once disposes of the heating difficulties in the cylinder and piston, and with many other obvious advantages should work with furnace gases without the trouble and expense of removing the large quantity of fine dust always associated with blast furnace gases.

A 1000 horse-power engine is to be tried; the result will be of great interest, and may be found in a later volume of this work.

Other inventors have proposed liquid pistons for internal combustion engines, but none have worked out the idea to a practical success like the Vogt engine.

P. F. Macallum, in Patent 13,517 of 1886, proposed to use two liquid pistons for driving vessels at sea by explosion of fuel and air alternately in two cylinders. The specification describes it as follows, and gives an illustration (Fig. 115)—not very clear but sufficient to indicate the ingenious invention :—

Water is ejected from cylinders by the pressure generated by the combustion of gaseous liquid or solid fuel in a finely divided state. A convenient form of apparatus is shown, consisting of a pair of cylinders A A¹ fitted with connections B for the entrance of gas and air necessary for its combustion through valves H and I, and valves F and pipes G, through which the exhaust takes place after each combustion. Each is provided with a nozzle D revoluble by a stem and with valves E E for the entry of water. The gas and air valves may be of any ordinary type, and may be operated by a steam engine, or by a hydraulic engine P connected to the cylinders A A¹ by pipes. The operation is as follows :—Water having been ejected from one of the cylinders, the exhaust valve F is opened to allow the products of combustion to escape, a steam jet or fan assisting if required. Water enters through valves E E, and when it has filled about

FIG. 115.—Water Pistons in Gas Propeller.

two-thirds of the cylinder the air and gas are admitted, so that the charge is compressed ready for combustion, which is effected through a suitable opening. A similar operation takes place in the other cylinder, the two being alternate. Pistons may be used if desired, and they may be connected to a rocking beam, so that the explosion in one assists in forming a vacuum to fill the other. The pipe leading to the nozzle may be curved and slowly rotated to increase the area of water acted on by the jet.

FIG. 116.—Water Pistons.

V. Karavodin in 1895, patent 749, proposes to use liquid pistons in a sort of rotary engine.

It is explained as follows :—In Fig. 116 the liquid, which is preferably oil, is forced out of the chambers A and B alternately, and transmits motion to the piston c of the rotary engine, the passage of liquid being controlled by a rotating slide valve d¹ with two straight ports 7, 8 and two cross ports 5, 6 ; or by a series of flap valves. The motor fluid is admitted and exhausted through valves 1, 2, 3, 4. The faces and seats of the distributing valves may be covered with refractory material. In single acting vertical engines the piston is hollow, is packed with a cup of leather, and works in oil, up through which the motor fluid pipe passes.

This inventor had got hold of a good idea, but altogether missed the main advantages of the water piston by trying to use oil as the fluid and working at high temperature ; besides, the rotary engine part was faulty, and would have caused endless trouble.

The liquid piston engine of Vogt opens up quite a new region of investigation, and will no doubt have a considerable effect on the future of the internal combustion explosion engine.

FIELDING & PLATT GAS ENGINES

We now begin the description of the construction of more ordinary gas engines of the well-known types, but selecting recent improvements.

This engine is illustrated in the full-page Plate Frontispiece, and in Figs. 117, 118, 119, and 120.

It has been designed to develop 150 horse-power, at a speed of 250 revolutions per minute, using producer gas. The four cylinders are each $13\frac{1}{2}$ inches in diameter by 15 inches stroke. The cylinder liners are in two pairs, each pair being contained in one water jacket. This arrangement enables the centres to be kept close together, and tends to simplify the details. From the makers' point of view there is also the advantage that by using the same set of patterns a 2-cylinder engine of half the power can be built. There are in this 4-cylinder engine two impulses at each revolution at all loads. The valves are all of the plain mitre type, the inlet valves being inverted in the top of the cylinders, while the exhaust valves are at the side in boxes, which are cast in one with the cylinder jacket. This valve is of cast iron and is hollow, being provided with a water circulation for cooling purposes. Fig. 117 gives an enlarged section of the cylinder
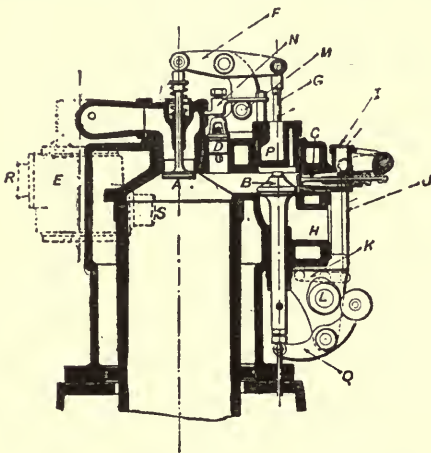
FIG. 117.—Cylinder and Valve. Section.
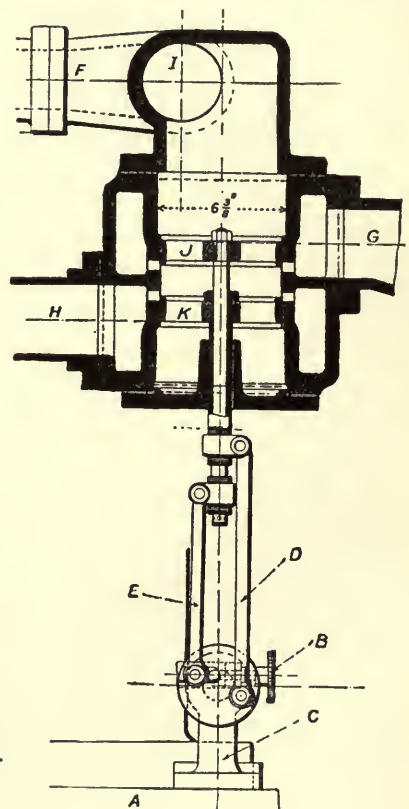
head, and an examination of this will enable the working of all the valves to be appreciated. In this figure A is the inlet valve; B, the exhaust valve; C, the starting valve, which is on one cylinder only; D is the electric ignition gear; E, the throttle valve, which is worthy of special attention, and to which also we shall presently refer in detail; F is the lever working the inlet valve, being itself operated by means of the vertical rod G; H is the exhaust outlet; I, the air pressure inlet for starting purposes: J, the vertical rod for operating the starting valve,

FIG. 118.—Valve Gear.

being worked by the lever K; L is the main cam shaft, and M the ignition cam shaft; N is the cross bar holding the electric ignition gear; O, the breech pipe leading from the throttle valve to the inlet valves; P, the exhaust valve cover; Q, the lever operating the exhaust valve; R, the gas inlet; and S, the air inlet. The main cam shaft will be observed in the engraving. This shaft actuates all the valves, and it is worked by the crank shaft through machined gearing working in an oil-tight box. Starting is brought about by means of direct air pressure, the air being stored in a reservoir at a pressure of from 150 lbs. to 200 lbs. on the square inch, this being obtained by means of a small compressor. The reservoir has a capacity sufficient for several starts. This is a measure of precaution, but failure to start at the first attempt is practically unknown.

Governing is brought about by controlling the gas and air by a special arrangement,
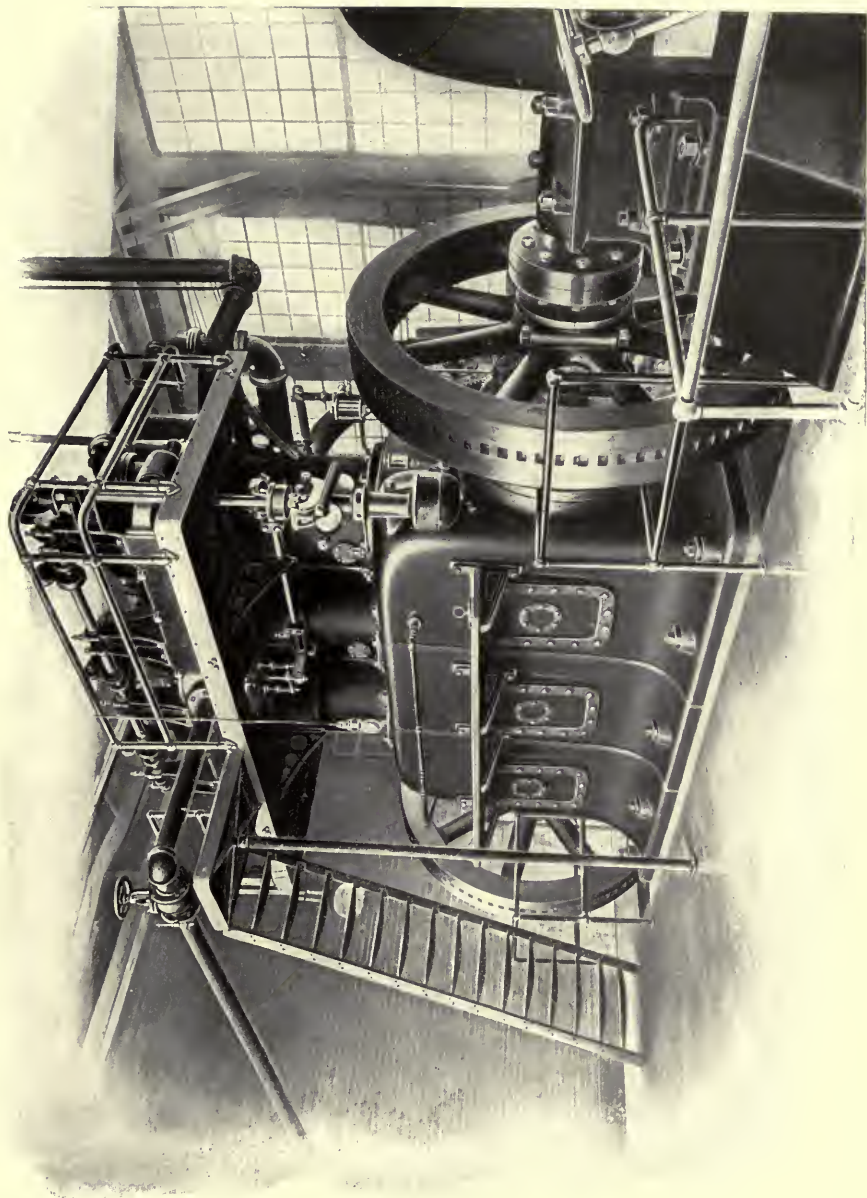
PLATE IV.—650 BRAKE HORSE-POWER WESTINGHOUSE GAS ENGINE.

patented by Mr. Fielding, the designer of the engine which we are now describing. By
this appliance, a section of which we give in Fig. 118, it is claimed that when once the
adjustments are made there is no further need of hand regulation. The proportions of
the gas and air can be regulated when the engine is running at full load without dis-
turbing the regulation and proportions of the mixture for light loads, and *vice versa*. In
Fig. 118, A is the top of the bed ; B is the adjusting thumb screw, by means of which
alterations to speed may be made while the engine is running ; C is the bracket carrying
the governor shaft ; D and E are the air and gas adjusting links respectively ; G is the
gas inlet, and H the air inlet ; I is the breech pipe, from which passages F are taken
to the inlet valves ; while J and K are the gas and air throttling pistons respectively.
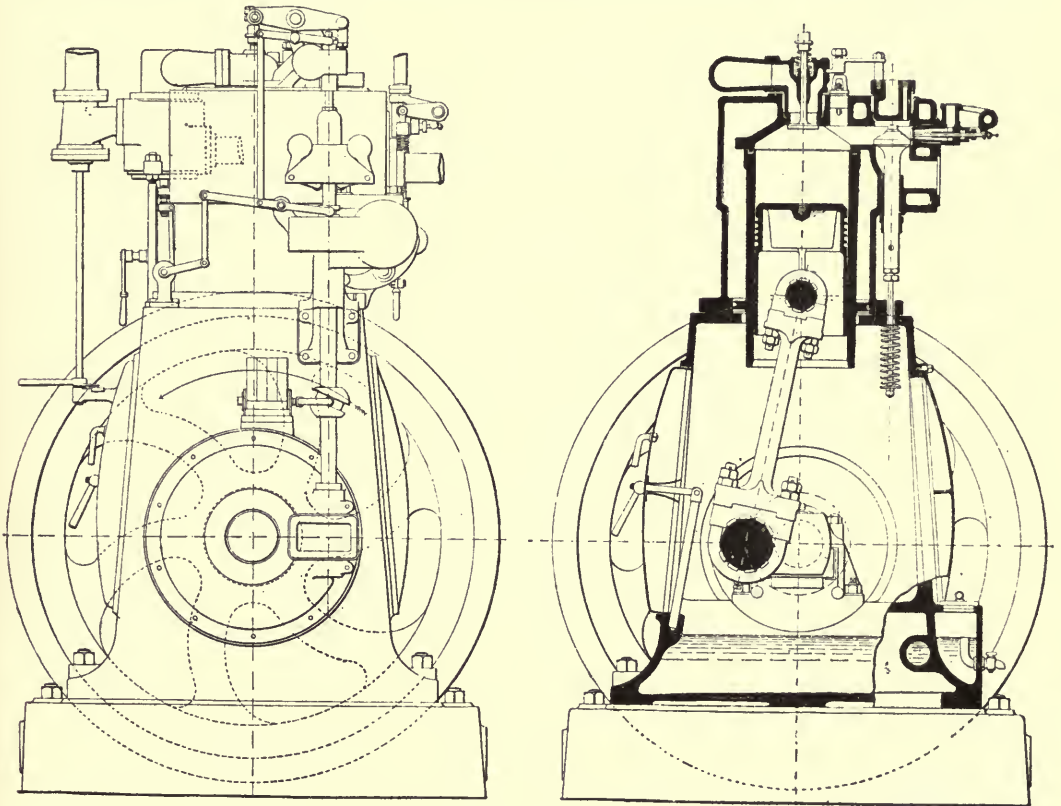
FIG. 119.—Fielding & Platt's Vertical 4-Cylinder Engine. End View and Cross Section.

The working of this portion of the engine is so evident from this drawing that no further
description is needed.

The ignition of the compressed charges is brought about by means of a make-and-
break spark inside the cylinders. This system Mr. John Fielding claims to have been
the first to use, having patented such an arrangement in 1882. A single magneto
machine, which is well shown in the Frontispiece and in sections in Figs. 119 and 120,
provides the necessary sparks. The timing of the sparking is determined by means of
the small cam shaft which will be observed at the top of the cylinders. It is driven from
the vertical governor shaft by a pair of spiral wheels, which can be manipulated to
advance or retard the ignition whilst the engine is running. The governor used is of
the Wilson Hartnell high-speed type. This governor, in addition to timing the spark
automatically, controls the admission of air and gas into the cylinder, and it is said
that the control at all speeds is effective. If full load is suddenly thrown off there

is a variation in speed of about 3 per cent. A fly-wheel, 72 inches in diameter and weighing 50 cwts., is keyed on the shaft between the engine and a dynamo—made by Mather & Platt—which is coupled to it, and the evenness of running is said to be such that there is no perceptible movement of the needle of the voltmeter connected to the terminals of the dynamo.

The engine has been designed with a special view to ensuring ease of access to all parts of it. While being a practically enclosed engine, the large doors on each side enable all the inside parts to be got at. One pair of these doors is arranged on the Sisson system, by which they can be removed in a few seconds by one man. The doors themselves are of light-dished steel, and they fit into bored recesses, a method of fastening which prevents the escape of the oil used for the splash lubrication.
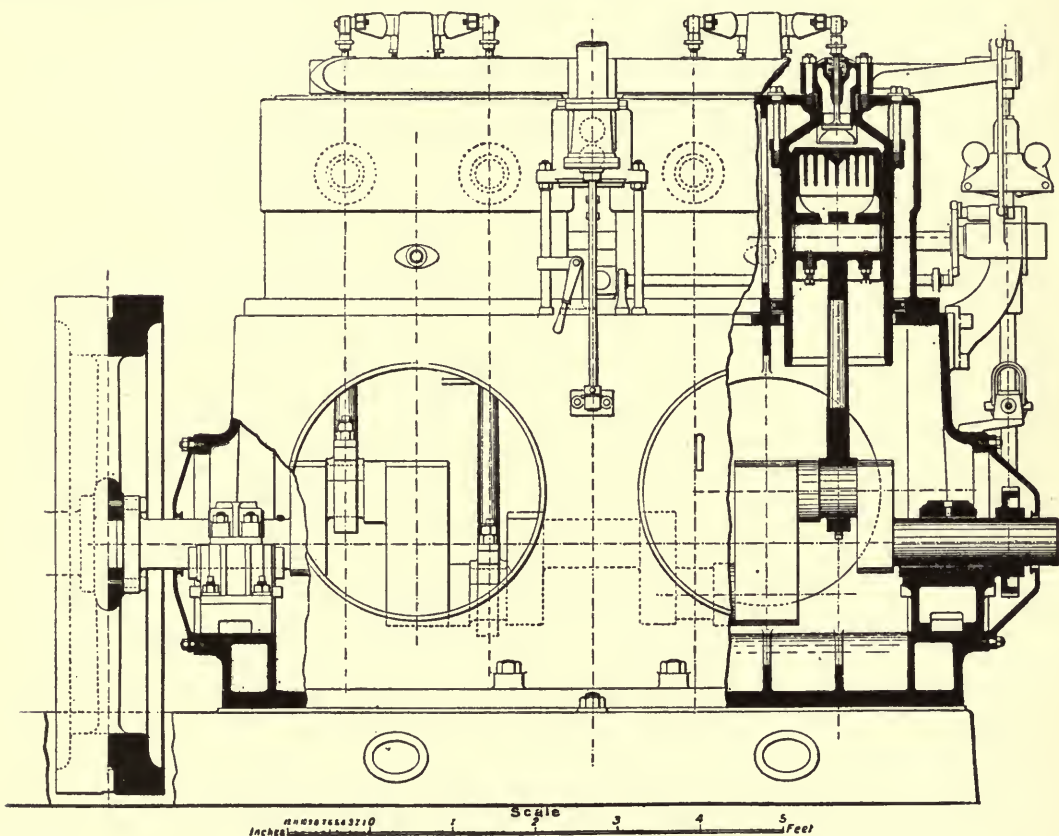
FIG. 120.—Fielding & Platt's Vertical 4-Cylinder Engine. Sectional Elevation.

The crank shaft is 7 inches in diameter in the body and $7\frac{1}{2}$ inches in diameter in the crank pins. There are three bearings, one at each end and one in the middle. They are of phosphor bronze with white metal strips, as are also the connecting rod brasses. These latter are of a design which combines the main features of the old-fashioned strap with the marine cap and bolt type. The lubrication is by splash, and guards are provided to prevent the pistons receiving more than the necessary amount. The ends of the crank chamber are closed by doors, which are independent of the outer bearings, the door or cover nearest the fly-wheel being in halves.

The makers claim for this engine that it is specially adapted to cases where absolute steadiness of running is required ; that it is able to meet sudden demands of power without any appreciable drop ; that no matter what load is on, there is the same

steadiness of turning effort ; and that vibration is reduced to a minimum by reason of the four cylinders.

The working load is 150 brake horse-power. Maximum load, 180 brake horse-power.

Oil engines are eminently suitable for agricultural mining and other operations in remote districts, so that their weight is a matter of considerable importance when transport over long distances requires to be considered. The usual build of engine has very massive framework castings all in a piece, difficult to handle, and too heavy for a long journey across country.

For many reasons it is desirable to have a design of engine easily taken down into small pieces and put together again. A 10 brake horse-power engine is a very useful size, and Fig. 121 of this type of engine is here shown. The whole cylinder head can be separately removed ; the cylinder lifted from the bed-plates. The fly-wheels are in two halves, easily taken off and put on again. The bed-plate consists of rolled steel girders bolted together. After the engines are tested and adjusted all the parts are carefully marked as they stand together, so that they can easily be put up again on arrival at their destination.

The heaviest part of a 10 brake horse-power engine is thus reduced to 4 cwts. The engine, although built in sections, is as strong as the ordinary build of stationary engine,
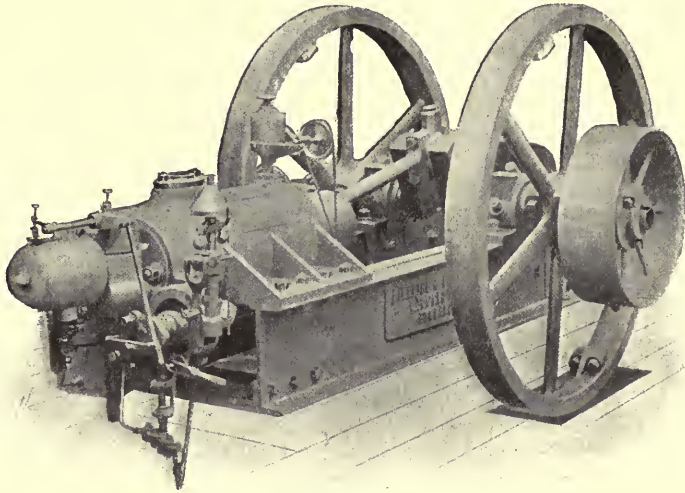
FIG. 121.—Engine for Transport.

only costing something more in price, but the extra cost is in many cases more than saved in freight charges. The base of the engine is broad and the cylinder low down and not overhung, so that the running even on a light foundation should be without vibration.

The engine with opposite cylinders, so long made by Andrew of Stockport, and still made in large sizes, is again attracting other makers. Properly designed and constructed it has many advantages, among which are steady turning movement, balanced motions of cranks and pistons, and great power in small space.

The engine shown in Fig. 122 is a recent design of Fielding & Platt's, and may be understood from the following description.

The Fielding oil engine uses ordinary paraffin oil. The smaller engines are started and operated as follows :—

About ten minutes suffices for the heating of the igniter and vaporiser. This is effected by a small self-acting lamp, which, once started, requires no further attention beyond keeping up the oil supply (this can be done without stoppage). There is no fan or air blast to be worked by hand, so that, having lighted the lamp, the driver can examine and fill up lubricators and see that engine is ready to start. By this time the vaporiser will be hot enough, and on giving the fly-wheel a turn or two the engine is started. A

half compression cam is provided to ease the starting. The engine may be run continu-
ously for long periods, and beyond the replenishing of oil supply it requires no attention.
There is no need to keep it running during meal hours, or when only required at intervals,
as the lamp works exactly the same when engine is standing as when running. This is
a very great convenience, greatly reducing oil consumption and wear and tear.

In the larger engines the starting is by compressed air.

The cylinders, it will be seen, are opposite each other, their connecting rods being
coupled to separate crank pins, the latter being placed at opposite centres, so that the
inertia forces are balanced in a perfectly satisfactory manner. The benefit of this
disposition is shown by the absolute steadiness with which the engine runs, at a speed of
220 revolutions per minute, although not bolted down. The corresponding piston speed
is about 800 feet per minute. The engine has been built specially for electric lighting, and
is fitted with one heavy fly-wheel and an outer bearing to the crank shaft. In this
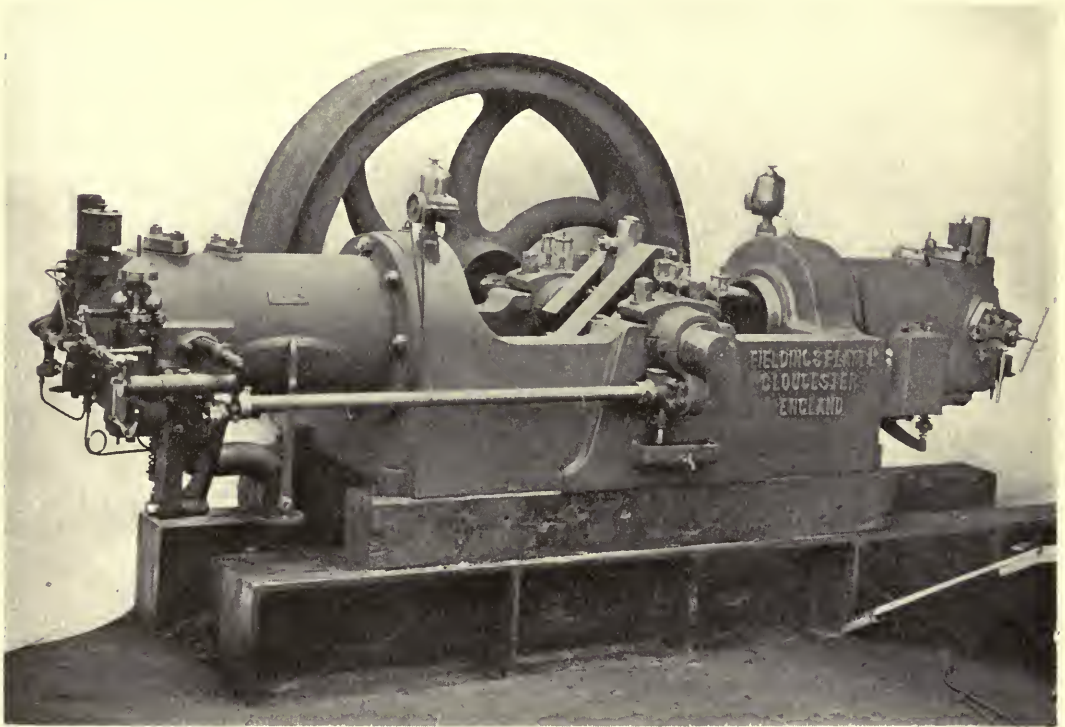
FIG. 122.—Horizontal 2-Cylinder Engine.

particular instance the dynamo is driven by a belt from the fly-wheel, but when required a
direct drive can be arranged for. Each cylinder is fitted with its own valve gear and
governor, duplicate side shafts being employed.

Governing is on the hit-and-miss principle, applied both to the vapour valves and oil
pumps. The latter, of which there are two, draw from a pair of suction vessels, in which
the oil is maintained by a float at a constant level, and deliver against a very slight
pressure into a vaporiser, where the oil vapour is mixed with a small amount of air.

The engine is started in a very easy and reliable manner by direct air pressure
admitted to one cylinder for two or three revolutions, until the other comes into normal
action. The air for starting is pumped by the engine itself into a reservoir. The engine
has been supplied to the order of the General Electric Company, and will supply the motive
power for an electric light installation in the palace of the Emperor of Korea. The total
weight of the engine is 19½ tons.

THE STOCKPORT ENGINES

In the modern form of this engine considerable improvements are apparent. The firm make all the various kinds of engines known in practice for different purposes. We shall only refer to the salient points, and to their special large double engine shown in Fig. 123
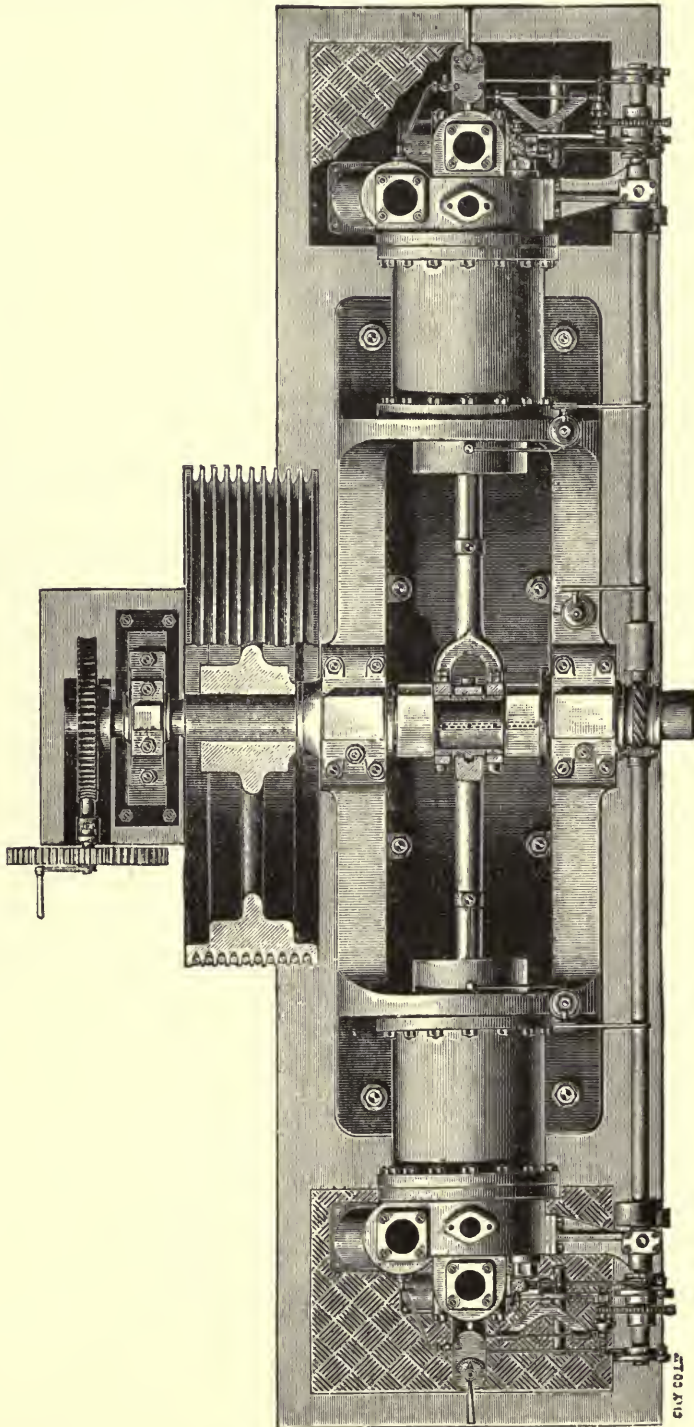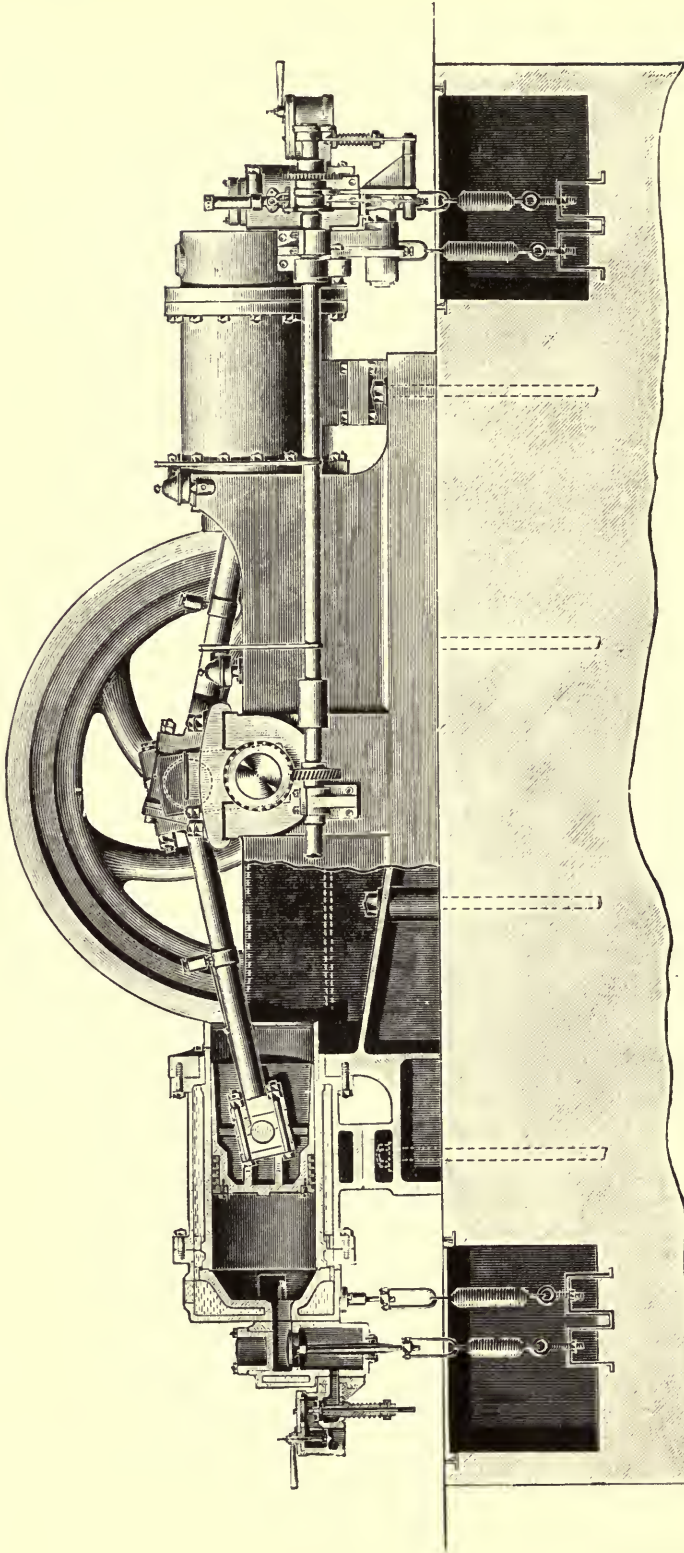
FIG. 123.—Plan of Andrew, Stockport, 2-Cylinder Engine.

FIG. 124.—Part Section. Side View.

in plan, and in perspective in Fig. 125, and in section in Fig. 124, and the single acting engine of large sizes in Plate V. Referring to the general design of Plate V., it will be noticed that the construction is much the same as in a good steam engine design. The cylinder is bolted to a broad base, and not overhung as usually is the case. The piston has a piston rod with a slipper at the front end to which the connecting rod is attached, so that there is true guiding of the piston, and side thrust is taken up by the piston rod slipper. The combustion chamber with all the inlet and exhaust valves and gear forms one whole part operated by one cam shaft. The crank is balanced by weights bolted on. This engine with 20-inch + 30-inch stroke at 160 revolutions with coal gas gives 150 brake horse-power. The flywheels are 6 tons each, on a shaft 9 inches diameter in the bearings.

Fig. 125 shows the 2-cylinder engine with both connecting rods on one crank. Here it may be as well to
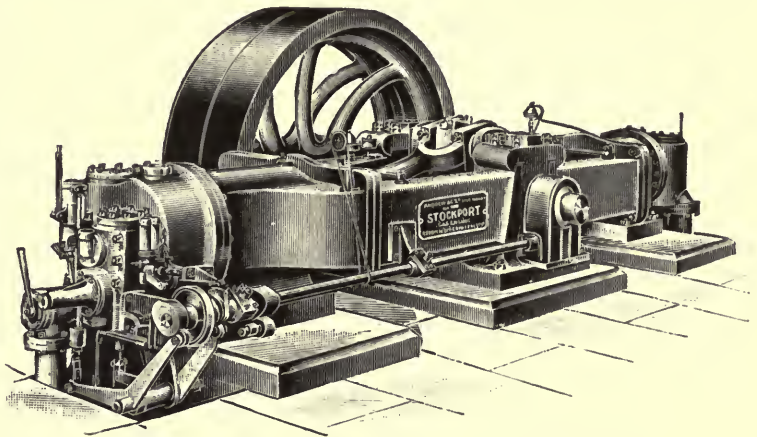
FIG. 125.—J. E. H. Andrew & Co.'s 2-Cylinder Engine.

point out that two cylinders working on the Otto cycle connected to one crank and opposite each other do not give an impulse every revolution. The sequence of events in two revolutions may be shown as follows :—

Stroke.	Left-hand Cylinder.	Piston moves.	Right-hand Cylinder.
1st ⎫ 2nd ⎭	Charge fires	⟶	Charge exhausts
3rd ⎫ 4th ⎭	,, exhausts	⟵	,, suction
	,, suction	⟶	,, compresses
	,, compresses	⟵	,, fires

Then follows the same cycle, showing that two explosions follow each other at the end of one cycle and beginning of next—

Stroke.	Left-hand Cylinder.	Piston moves.	Right-hand Cylinder.
5th	Charge fires	⟶	Charge exhausts

And so on, repeating the above sequence.

In the Fielding and other engines, with the two pistons connected to cranks 180 degrees apart, we get the following sequence of events in two revolutions :—

Stroke.	Left-hand Cylinder.	Piston moves.	Piston moves.	Right-hand Cylinder.
1st ⎫ 2nd ⎭	Charge fires	⟶	⟵	Charge suction
3rd ⎫ 4th ⎭	,, exhausts	⟵	⟶	,, compresses
5th	,, suction	⟶	⟵	,, fires
	,, compresses	⟵	⟶	,, exhausts
	,, fires	⟶	⟵	,, suction

And so on, getting an impulse every revolution. By placing two Fielding engines side by side on one common shaft, with the cranks of the one at right angles to the cranks of the other, we get two impulses every revolution.

This complication, however, is only warranted in the case of marine engines, where no heavy fly-wheels are permissible and no dead points allowed in the revolution.

Referring now to the details of the construction, Fig. 127 is a section of the cylinder end, showing the water jacket and the entrance and exit passage to the combustion chamber, and Fig. 126 shows the side elevation partly in section of the same combustion chamber, showing the air, gas, and exhaust valves in side section; and Fig. 127

shows the manner of operating them by the bent levers from cams on the side shaft ; the exhaust valve is on the left side ; the air valve in the centre with a vertical spindle, and the small gas valve at right angles, operated by the hit-and-miss lever of the governor.   The ignition tube is shown rising vertically from this passage.   The firing and timing arrangement is shown on a larger and clearer scale in Fig. 129.
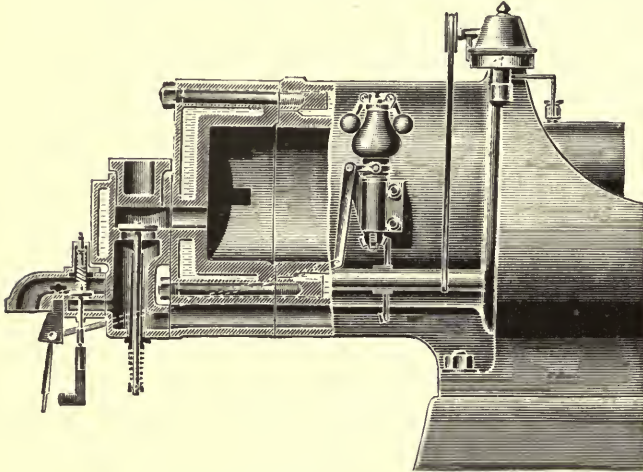
The tube C is the hot firing tube ; F is the timing valve which opens just before the

FIG. 126.—Cylinder Section.
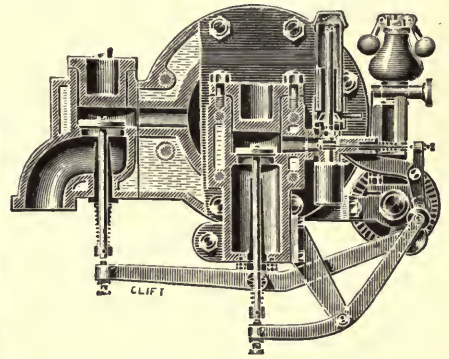
FIG. 127.—End of Cylinder.

end of the compression stroke, and allows the mixed air and gas to be compressed into the hot tube and fired.   Some engines work without timing valves, but a timing valve has the advantage of preventing premature firing of the mixture when high compression

FIG. 129.—Ignition Section.
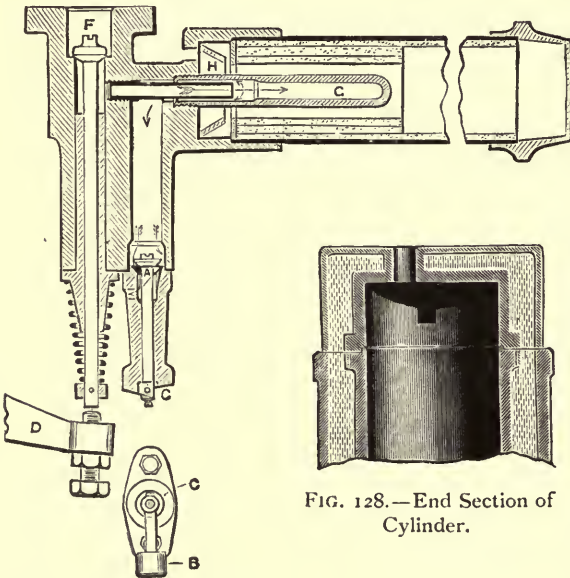
FIG. 128.—End Section of Cylinder.

is practised.   To start the smaller engines the tube is made bright red, and the crank is set at nearly half the out-stroke on the working position or impulse stroke, the timing valve is opened, and the small valve A (Fig. 129) is opened by the starting lever.   When the gas is turned on it flows into the cylinder, and forms an explosive mixture which tends towards the firing tube as shown by the arrows, and escapes by starting valve A so long as it is too weak to explode.   In a few minutes, however, the mixture ignites and fires back into the cylinder, the pressure starting the engine off.   The starting valve is then closed, and the cams set in order, the impetus given by the first explosion carrying on the movement.

They also employ compressed air for starting larger engines, and in order to provide a certain supply of compressed air a very neat arrangement of the old type of Stockport engine, shown in Fig. 130, has been devised.   The left-hand cylinder is the engine cylinder, while the right-hand one is the air compression cylinder.

A 30 horse-power engine on an electric light installation, when tested, gave an indicated horse-power of 34. The brake horse-power, 28.3 ; gas consumption, 18½ cubic
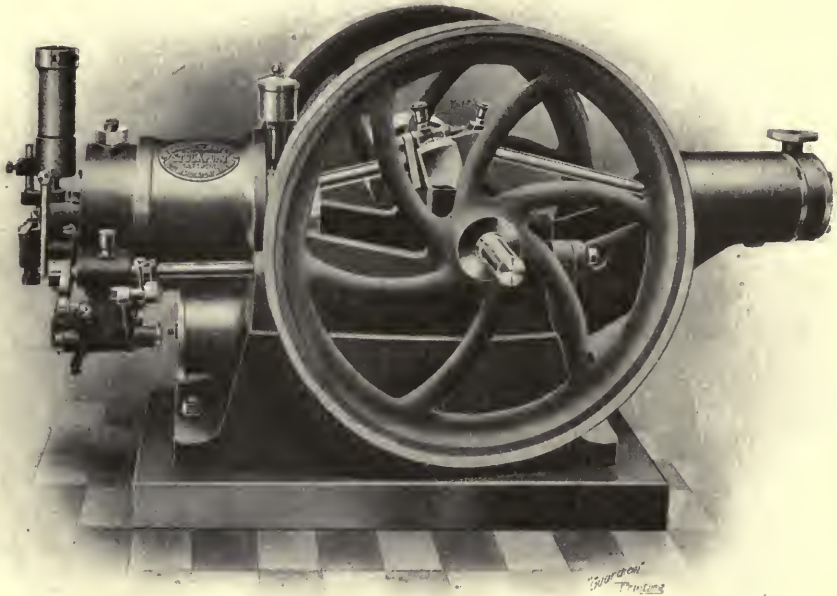

FIG. 130.—Air Compressor.

feet per indicated horse-power, the gas having a thermal value of 550 B.Th.U. per cubic foot.

PRIESTMAN'S ENGINES

This engine was one of the pioneers in the heavy oil engine line.

The Priestman engine is generally similar to a gas engine, with the addition of organs for supplying, spraying, and vaporising the oil.

Fig. 131 shows a general view of the engine, Fig. 132 a section of the cylinder. Z is the working cylinder, H is the piston, K the clearance space into which the air and vapour are compressed before explosion. At Y is the supply tank for oil. To deliver the oil from this tank to the spray maker S, or starting lamp l, an air pressure is maintained in the tank, which is produced initially by a small hand pump M, and afterwards maintained by a pump P, driven by the eccentric. A spring-loaded escape valve on the oil tank keeps the air pressure constant. This pressure can be regulated, and is shown by a gauge on the tank. There is also a glass gauge showing the oil level in the tank. O is the vaporising chamber, provided with a jacket through which the hot exhaust passes. l is the lamp used in heating the vaporiser initially, and this is supplied with oil and air from the oil tank Y. The oil tank has a 6-way cock c arranged very simply. When the handle is upright, the cock is closed ; when turned to the left, air and oil are supplied to the starting-lamp l ; when turned to the right, air and oil are supplied to the spray maker S. The engine cylinder is water-jacketed, the water being circulated either by gravitation from a tank or by a special pump on the engine. At the back of the cylinder are two valves, one being automatic and the other opened

by an eccentric. The upper or automatic valve *s* opens on the suction stroke, admitting the mixed air and vapour from the vaporiser. The lower valve *e* is opened during the exhaust stroke (not during the compression stroke) by an eccentric on a shaft rotating
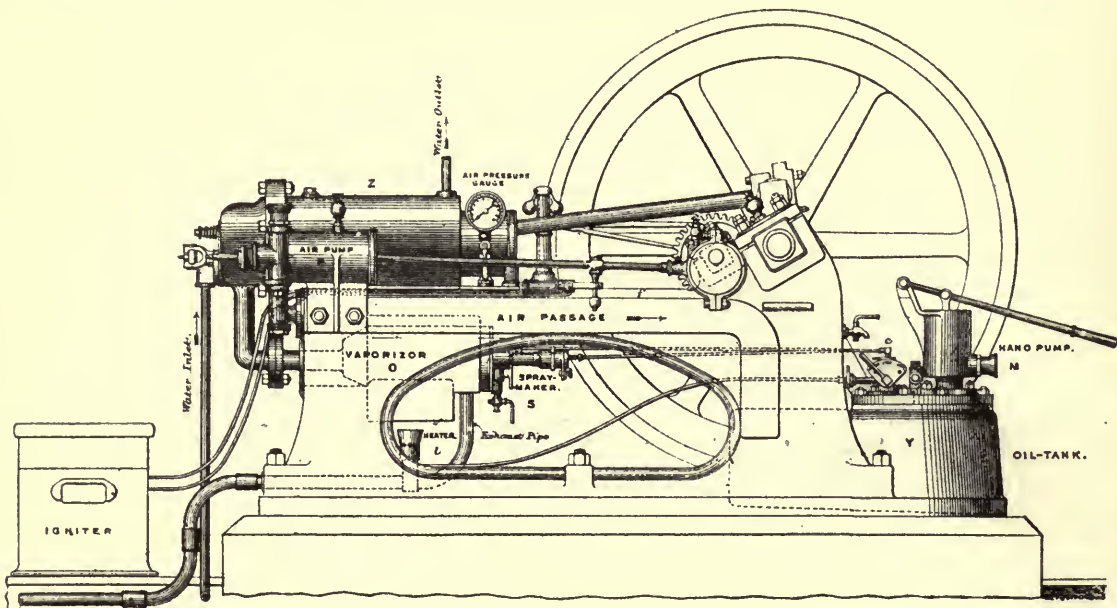

FIG. 131.—Priestman Oil Engine.

half as fast as the crank shaft. Through this valve the exhaust gases pass to the jacket of the vaporiser. At the back of the engine are shown the bichromate battery and the induction-coil used for igniting the charge. The circuit is completed at the proper moment by a contact finger *f* on the eccentric rod, which passes between a pair of springs. A screw plug *i* in the side of the cylinder contains two porcelain bars, through which the electric wires pass. The electrodes in the cylinder are platinum wires.

In starting the engine the oil tank is put under pressure by the hand pump, and the lamp *l* lighted. When the vaporiser is hot enough, which will be in between eight and twenty-five minutes, according to the size of the engine, the
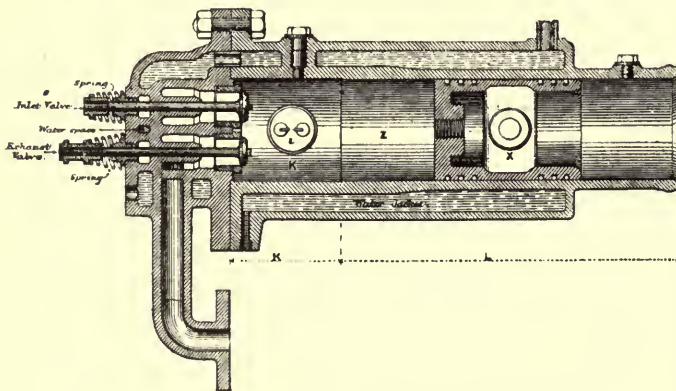
FIG. 132.—Section through Cylinder and Valve Chest.

6-way cock is opened to admit oil and air to the vaporiser. The fly-wheel is then turned, the engine draws in an explosive mixture, compresses it and starts. The cycle of the engine is the ordinary Otto cycle—that is, the explosive mixture is drawn in during a suction stroke and compressed in the return stroke. At the moment of full compression the charge is ignited, and the working stroke is effected by expansion. The next return stroke drives the products of combustion through the exhaust valve.

It is an important practical advantage in the working of the engine that, during the

compression stroke, a small portion of oil condenses on the cylinder surface and lubricates it perfectly. The cylinder requires no other lubrication.

Professor Unwin made elaborate tests on this engine, with the following general results :—

TABLE V.—GENERAL RESULTS OF TRIALS OF PRIESTMAN OIL ENGINE.

|	Trial V. Full Power.	Trial I. Full Power.	Trial IV. Full Power.	Trial II. Half Power.	Trial III. Light.
Oil used	Daylight	Russolene	Russolene	Russolene	Russolene
Counter.					
Mean revolutions per minute .	204.33	207.73	211.32	214.29	187.3
Indicator.					
Mean effective pressure in cylinder in lbs. per square inch . .	53.2	41.38	45.75	25.48	5.51
Brake.					
Mean effective brake loads . lbs.	85.44	73.64	73.64	38.2	0
Brake radius . . . feet	2.3215	2.3215	2.3215	2.3215	...
Power.					
Brake horse-power . . .	7.722	6.765	6.882	3.62	0
Indicated horse-power . . .	9.369	7.408	8.332	4.706	0.889
Mechanical efficiency of engine .	0.824	0.91	0.826	0.769	...
Oil used.					
Oil used per hour . . lbs.	6.5	6.4	6.8	5.0	5.1
Oil used per brake horse-power per hour. . . lbs.	0.842	0.946	0.988	1.381	...
Oil used per indicated horse-power per hour. . . lbs.	0.694	0.864	0.8161	1.063	5.734
Mean air pressure in oil tank,— lbs. per square inch . . .	8.2	8.2	8.5	10.9	9.3
Temperatures.	°	°	°	°	°
Air in engine room . . °F	60.0	58.0	58.0	61.0	60.0
Jacket-water, initial . . .	44.6	41.6	47.2	40.3	40.9
,, final . . .	121.4	128.3	114.6	114.4	104.6
,, rise in temperature	76.8	86.7	67.4	74.1	63.7
Vaporising chamber . . .	287.1	264.5	268.0	254.0	260.5
Exhaust gases	{ above 600.0 }	571.5	531.0	459.0	344.0
Air through throttle valve per second in cubic feet . . .	0.787	0.736	1.065	0.393	0.187
Air through throttle valve per hour in lbs.	216.9	202.9	293.5	108.3	51.5
Lbs. of air per lb. of oil . .	33.4	31.7	43.2	21.7	10.1
Pressures from diagrams.					
Mean explosion pressure,—lbs. per square inch	151.4	134.3	128.5	48.5	9.6
Mean terminal expansion,—lbs. per square inch . . .	35.4	23.7	25.5	15.6	...
Mean vacuum suction stroke,— lbs. per square inch . . .	– 1.0	– 4.0	– 3.3	– 5.7	– 7.0
Mean compression, — lbs. per square inch	35.0	27.6	26.0	14.8	6.0

At the conclusion of the five trials the cylinder cover was removed. The platinum electrodes of the igniter were found to be clean. There was no deposit in the cylinder, the barrel of which was covered with a slight film of condensed oil.

Fuel consumption.—It will be seen that the oil engine worked in Trial I. with 0.946 lb. of Russolene oil per brake horse-power per hour, and in Trial IV. with 0·988 lb. In Trial V., with Daylight oil, it worked with 0.842 lb. of oil per brake horse-power per hour. These are the consumptions during the run. The oil used in starting the engine was an insignificant quantity, being only about 1 lb. of oil in each of the two trials in which it was measured.

THE OTTO GAS AND OIL ENGINES

We have already seen in Fig. 87 the special features of the Otto oil engine—the vaporiser. In other respects the engines for gas and oil are much the same, and we may

FIG. 133.—Section Crossley Gas Engine.

describe them from the following sections. Fig. 133 is a side elevation with the cylinder

End View.   Inlet Section.

FIG. 134.

in section. AB in the base is an air box to silence the suction; the air and gas are drawn in through valve K, compressed and fired by the hot tube L. H is the exhaust

port, shown more completely in Fig. 134. The valve B is conveniently situated under a cover, so that it is easily got at for grinding up purposes. The end view shows the exhaust and inlet valves more particularly, and Fig. 135 is a horizontal section showing the curved form of the combustion chamber, which enables the incoming charge to sweep out the exhaust during a brief period.

The engines are all 4-stroke cycles, and the valves operated by a cam shaft driven by skew gear wheels at half the speed of the engine shaft.

The ignition is usually by means of hot tube. The central ignition tube has been made of iron. Nickel and porcelain iron tubes soon wear out, as they are oxidised by the gases at the bright red heat the tube requires to be kept at. A fireclay or other good heat retainer tube surrounds the firing tube, and also becomes red hot, thus concentrating the heat on the tube inside.

A lever and valve shuts off the communication between the cylinder and hot tube until the moment of ignition arrives, at same time leaving the hot tube open to the atmosphere. During the compression stroke, the mixed fuel and air are compressed, and when the ignition is to take place the lever is so timed to drop the valve, opening the hot tube to the mixed gases which rush into and are fired by the hot tube. The lever then shuts off communication again, and allows the burnt gases in T to escape.
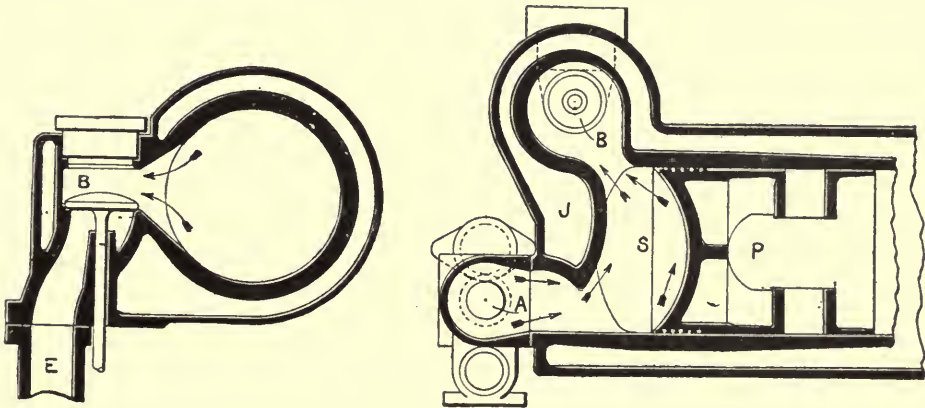
Exhaust Valve.   Suction of Exhaust.

FIG. 135.

The tube T must be fairly long, to allow of the remaining gases to be compressed into the end, and the incoming mixed gases to reach the hot part of the tube.

The scavenging arrangement shown in Fig. 135 operates by virtue of a partial vacuum formed in the exhaust passages. The air admission valve is opened somewhat before the end of the exhaust stroke. And the exhaust valve remaining open, the exhaust pipe is made very long, so that the column of exhaust gases moving at a high velocity, by their inertia move on during the time the piston comes to rest and commences the next stroke, and thus a partial vacuum is produced which draws out the remaining burnt gases before the incoming fresh air.

Crossley Brothers make *tête-à-tête* engines of larger powers for furnace and producer gases and all forms of ordinary gas engines. They have been so familiar for many years that descriptions of them are unnecessary here.

ROBEY SAURER OIL ENGINE

This engine, designed with all the latest improvements and of sound mechanical construction, is fully illustrated by the scale drawings.

Fig. 136 is a longitudinal section, showing at the back end the oil spray, the

vaporiser, the heating lamp, ignition tube, and combustion chamber.   The vapour in
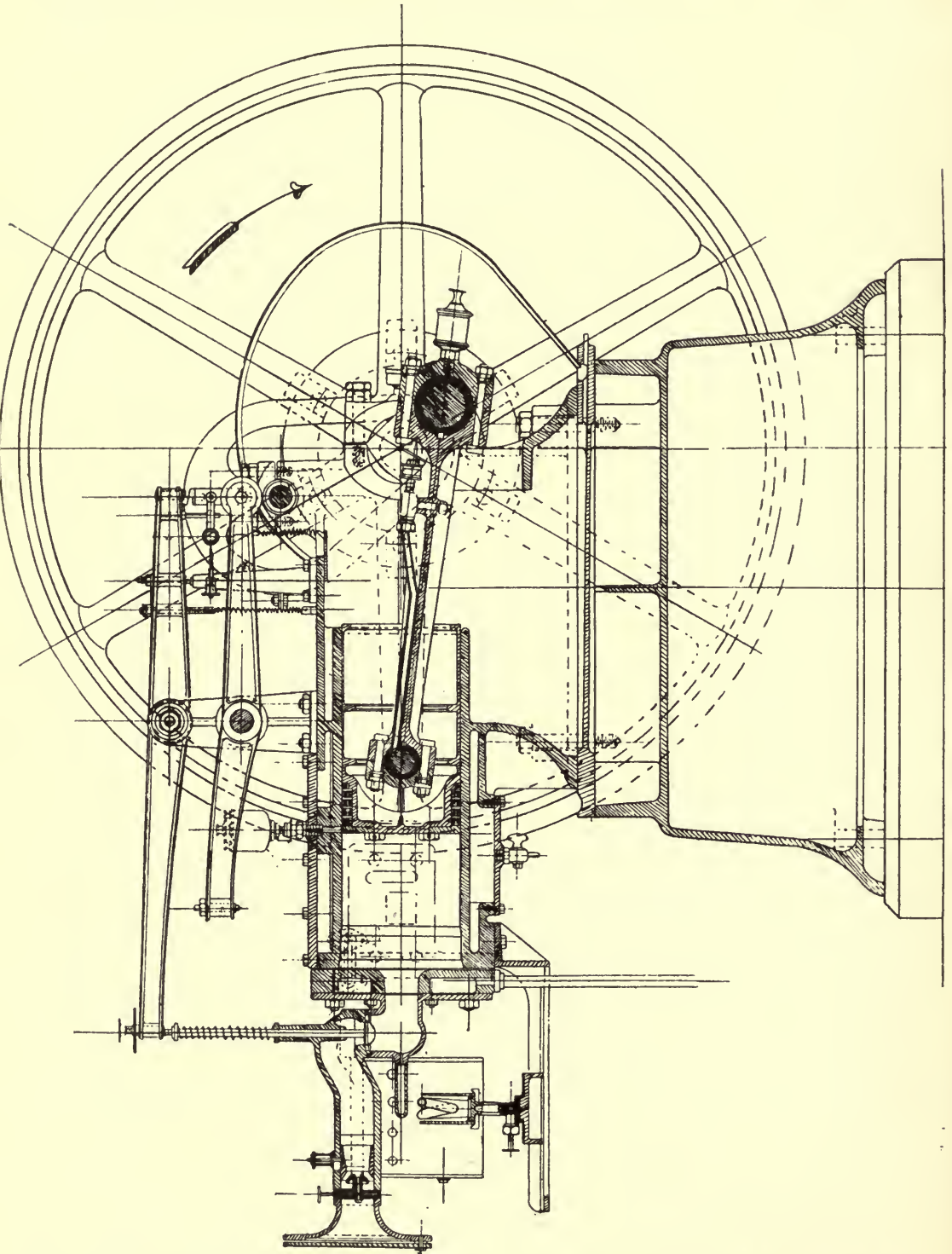
FIG. 136.—Longitudinal Section of Robey Saurer Engine.

this engine passes from the vaporiser to the cylinder by a valve, and the valves are
worked by rocking levers from a cam shaft parallel to and above the crank shaft.

The engine consists of a strong cast-iron base, on which is fixed the casting which forms the cylinder and bearings for crank shaft. The special features of the cylinder are the ease with which the piston can be taken out and replaced, and the arrangement by means of which the water jacket which surrounds the cylinder can be cleaned from all scale. This is an important point, as in some neighbourhoods the cooling water used is so bad that it soon chokes up the water jacket, and in most engines there is great difficulty in clearing this. The piston is an improved construction, whereby the piston rings can be placed in position without straining them over the piston body, and thus in many cases causing distortion and leakage.

The power is transmitted from the piston to the crank by means of a steel connecting rod with specially long bearings. The crank shaft also has very large bearings, which are of great advantage, as the wear is reduced to a minimum. There is no engine on the market with such large bearings.

A special feature of the engine is that the levers for actuating the valves in the engines up to 14 horse-power are all above the engine, and the valves also are all in such a position that they can be inspected at any time with the greatest ease. In the smaller sizes of engine this is an advantage which users will appreciate.

Behind the cylinder is fixed the vaporiser and air valve, through which a regular supply of air is drawn, mixing in its passage with the vapour and forming the working charge. The exhaust valve is at the side of the engine, and the products of combustion are discharged very effectively.

The petroleum is supplied to the vaporiser by means of a special pump, which regulates the quantity according to the load on the engine. The patent vaporiser is of special construction, ensuring complete vaporisation of the oil, thus preventing carbonising and the bad smell arising from incomplete combustion.

A special automatic lamp of extreme simplicity has been designed to keep the vaporiser and the ignition tube hot at the same time. The great advantage of this system is that the engine runs equally well with any proportion of its load up to the maximum. In engines where the heat of explosion is used to keep the vaporiser at the necessary temperature there is sometimes difficulty in running the engine at loads much below the maximum.

The governor is specially sensitive, being worked direct from the main shaft, and adjusting the supply of air and oil through a simple arrangement of levers.

The steadiness of running is so great that the engine can be used with every confidence for driving the electric light without the expense of accumulators.

The great aim in the design of the engine has been to secure the maximum accessibility of all working parts so that they can be periodically cleaned without trouble. This is the chief point in the case of oil engines, and if parts are inaccessible they do not receive the attention which they ought to have if it is desired to have an engine free from vexatious breakdowns.

The engine can be started and full load put on in ten minutes, and once started requires no more attention except to supply the necessary lubricating oil occasionally. The management is so simple that it can be left to any intelligent labourer.

A complete engine with a dynamo coupled to it is shown in Fig. 137. This forms an excellent self-contained electric generating plant for country houses and colonial work. It costs more for a dynamo designed to run at the same speed as the engine, but the compactness and simplicity of the plant compensates for the extra expense; there is also the saving of a belt, and foundations for engine and dynamo separately.

Fig. 138 is a line drawing plan showing the cam shaft and levers, main bearings, and connecting rod end of exceptionally large dimensions.

Fig. 139 is a cross section showing the exhaust valve and the covers of the various openings, through which the cavities and valves may be easily reached for inspection

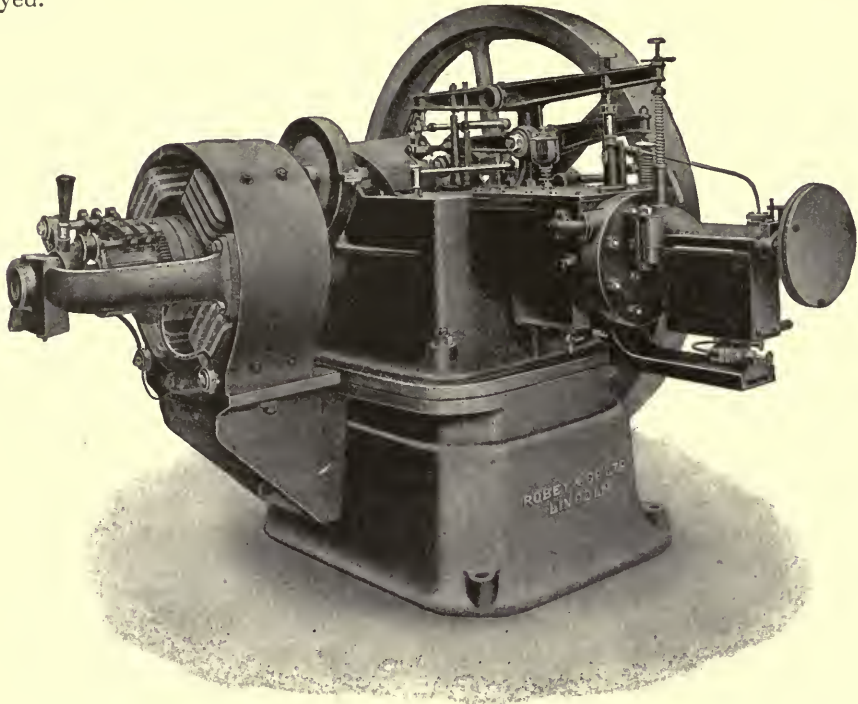and cleaning ; it also shows the gearing for driving the cam shaft, the Otto cycle being employed.

FIG. 137.—Combined Engine and Dynamo.

TABLE VI.—TRIAL WITH A SAURER MOTOR, TYPE M.IV. OF 11.5 HORSE-POWER.

No. of Trial.	No. of Revolutions.	Time of Trial.	Diameter of Brake Wheel.	Speed.	Kind of Petroleum.	Nett Load.	Brake Load in Efficient Horse-Power.	Consumption of Petroleum.		Remarks.
								Total.	Per Horse-Power per Hour.	
	Per Minute.	Hours.	Ft. in.	Ft. in.		Lbs.		Lbs.	Lbs.	
I.	270	3	4 6⅜	64 0	Russoline—Sp. gr., .08.	98.2	11.6	29.1	.8360	
II.	272	1	4 6⅜	64 5½	,,	55.116	6.54	6.9	1.06	Half-load.
III.	269	3	4 6⅜	63 9	,,	97.9	11.5	28.2	.8162	
IV.	270	½	4 6⅜	64 0	,,	55.116	6.5	3.3	1.01	Half-load.
V.	268	3	4 6⅜	63 5½	,,	99.208	11.6	27.9	.8030	
VI.	272	3	4 6⅜	64 5½	,,	55.116	6.54	19.09	.9702	Half-load.
VII.	268	1	4 6⅜	63 5½	,,	97.350	11.39	9.03	.7920	
VIII.	272	2½	4 6⅜	64 5½	,,	55.116	6.54	15.4323	.9416	Half-load.
IX.	270	1	No	load.	,,	...	No load.	2.5	...	
X.	300	1	4 6⅜	71 1	,,	90.389	11.84	10.22	.8624	Higher speed.

The consumption of petroleum by the lamp is not in the calculation; the same amounts for each lamp tube per hour, in round figures 22 lbs., as two tubes burn for ten
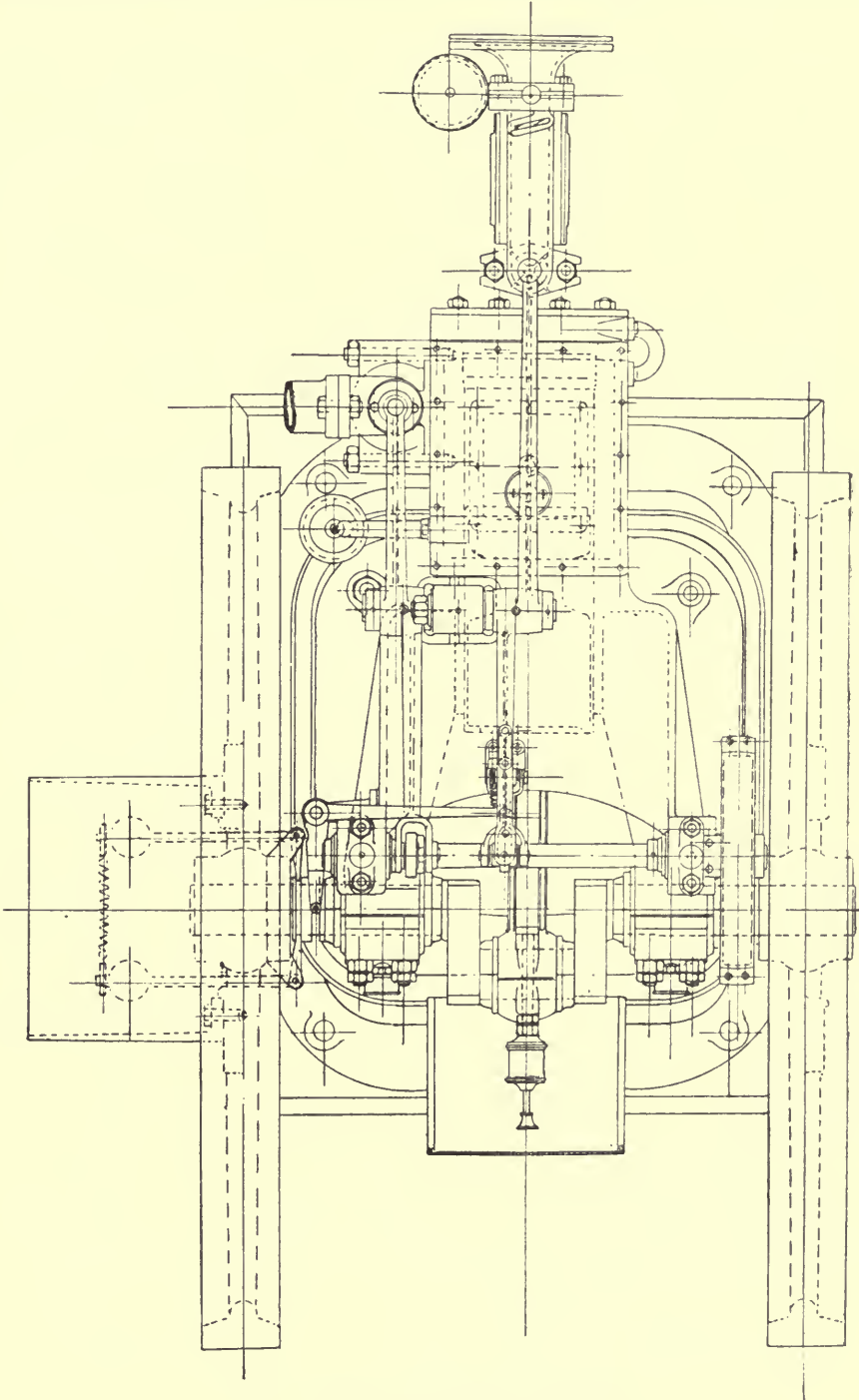
FIG. 138.—Plan of Robey Saurer Engine.

minutes only for heating; and, on the other hand, whilst working only one, the consumption per horse-power per hour is very small.
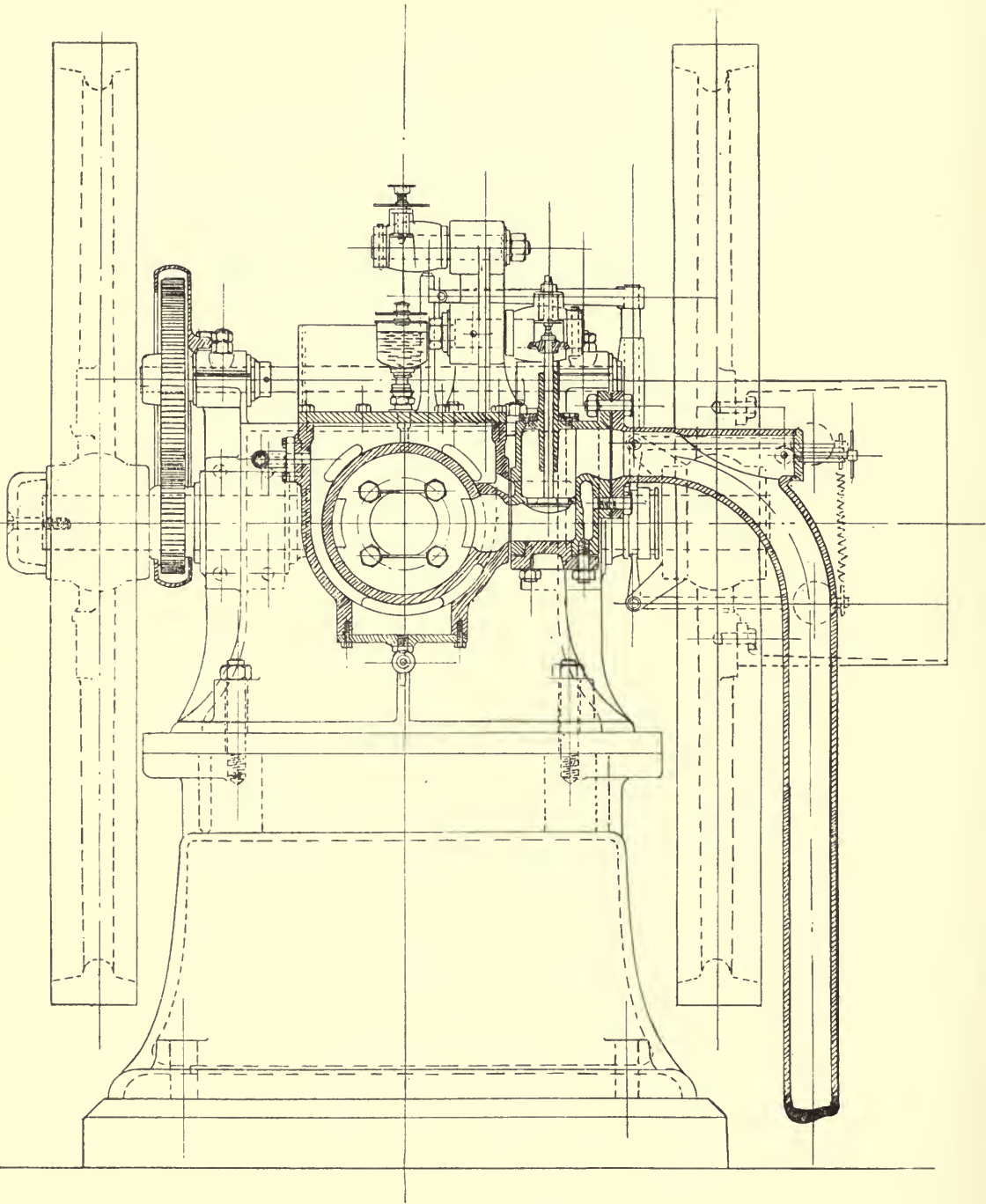
FIG. 139.—End View, Robey Saurer Engine.

BRITANNIA OIL ENGINE (NICHOLSON'S)

This engine works upon the same principles as that introduced by Hornsby-Ackroyd, in which the oil is vaporised and fired by the heat retained in the vaporiser when the charge is driven into it compressed. The following is a description supplied by the makers, with line drawings of the details:—

The centrifugal type is used in preference to the pendulum or inertia governor, but the control is still by hit-and-miss. The entire charge is cut out, so that at all loads a uniform mixture is maintained. The details of construction of the governor have been carefully thought out, and attention has been paid to the reduction or equalisation of friction by proper lubrication, so that it works, as we have satisfied ourselves by repeated tests, with certainty and precision.

An oil pump is dispensed with. On the suction stroke the working piston draws a charge of oil into the vaporiser (Fig. 142). This is, as shown, a flat cast-iron box A, with baffles which cause the oil and its vapour to travel backwards and forwards through passages which are initially heated by a blow lamp. The igniter B is immediately below the vaporiser. It consists of a tube with thin internal ribs, which, having once been raised to a temperature sufficiently high to cause ignition, maintains that temperature without the application of an external flame. This igniter is connected by passages with the vaporiser in such a way that a portion of the rich charge passes through it on its way to the combustion chamber. On the return stroke the compression causes the charge remaining in the igniter to explode and fire the rest of the charge. Referring to the detail drawings (Figs. 140, 141, 142), *a* represents the cylinder, *b* the combustion chamber, and *c* the vaporiser attached to the outside of the combustion
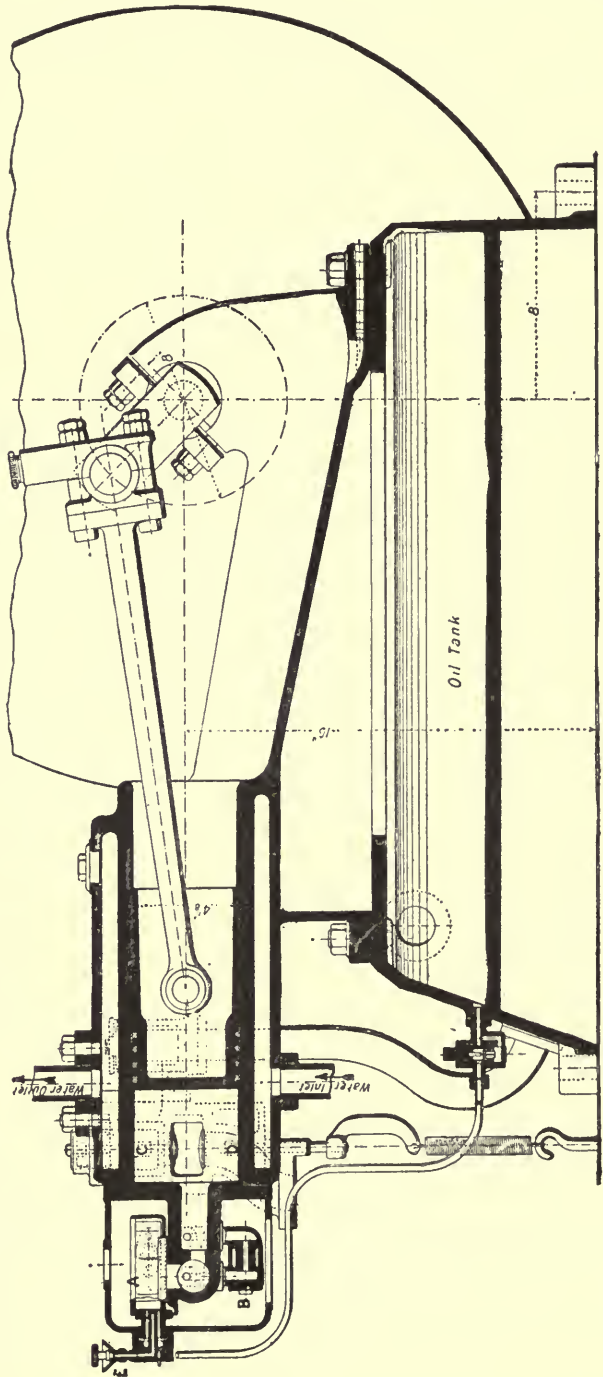
FIG. 140.—Section of Britannia Engine.

chamber b. The internal partial partitions, marked c^1, c^1, cause the oil, which enters through the inlet d, to be drawn by the air entering through the air inlet d^1 in a zigzag path, so as to be presented to an extensive heating area before passing to the combustion chamber. e is an auxiliary chamber, which is in connection with the vaporiser by the passage f; this passage is controlled by the valve g, which normally closes it under the action of the spring piston g; the auxiliary chamber e is also in communication with the combustion chamber b by means of the passage h. A chamber or tube i connects the auxiliary chamber e to the combustion chamber b by small openings j and k respectively. This chamber i contains the igniter, which, in the form shown in the drawing, comprises a tube l having the internal swellings or ribs m, m, which retain the heat and offer a large surface to the vapour coming in contact with them ; n is the main air inlet valve, and o the exhaust valve.

The oil entering the vaporiser c through the inlet d is, during the suction stroke of the piston, drawn by the air entering through the inlet d^1 through the vaporiser, and thence through the valve g into the auxiliary chamber e, where it divides, the major
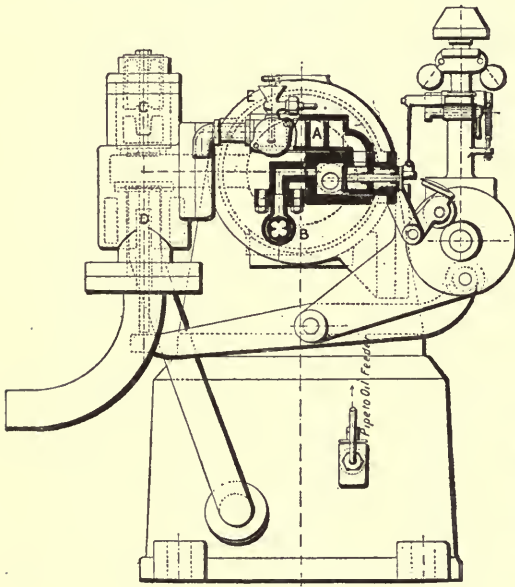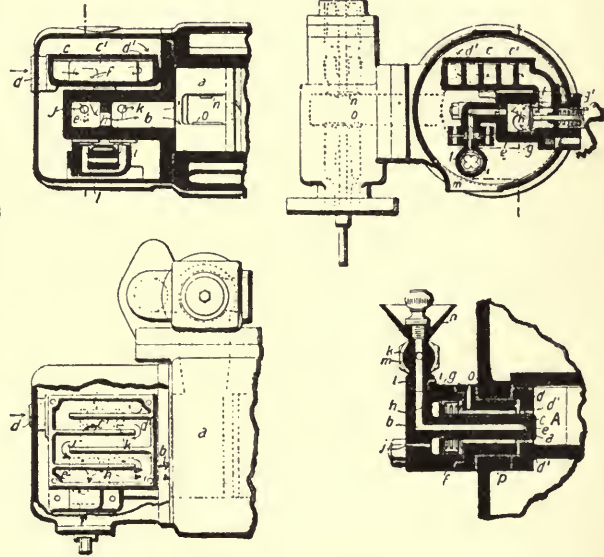
FIG. 141.—End View.   FIG. 142.—Vaporiser.

portion of it being drawn directly to the combustion chamber b, whilst the remainder flows through the tube or chamber i into the combustion chamber b; this latter portion on the following compression stroke of the piston ignites and explodes the charge in the combustion chamber.

To start the engine a blow lamp is placed under the vaporiser and igniter, which it brings to a sufficient temperature in eight to twelve minutes. A little paraffin is then poured into the starting cup E, at the cylinder end, and, the air valve being opened, the engine is pulled round. The charge from the cup is thus drawn into the vaporiser, and after a few revolutions the engine starts up. The starting lamp may then be removed. A section of this cup and starting valve is shown in Fig. 142. A represents the vaporiser, and a the plug, which has a longitudinal passage b, closed by a valve c, formed on a sleeve d, and kept closed by a spring f. The outer face of a on this sleeve is open to the atmosphere by the passage j formed through the flange i. d^1, d^1 are peripheral openings formed at the end of the sleeve cap d for the escape of the oil into the vaporiser. o is a passage through the flange i for placing the space p around the

plug in communication with the atmosphere, so as to permit air to be drawn into the vaporiser around the plug.

The oil or spirit being applied to the plug passage b, and the engine started, air is drawn through the passage o and around the inner end of the plug a, the suction lifting the sleeve valve e from its seat against the action of the spring f; the lifting of the valve e from its seat brings the peripheral holes d^1 in the said sleeve into communication with the plug passage b, whereby the oil or spirit coming through the said openings is immediately picked off and drawn into the engine with the ingoing air. The quantity of oil admitted may be regulated by adjusting the quantity of air entering with the oil, or by a spindle which fits into the passage through the plug, and the front end of which is made conical to fit the inner end of the said passage, which is also made conical and forms a valve seat; by turning this
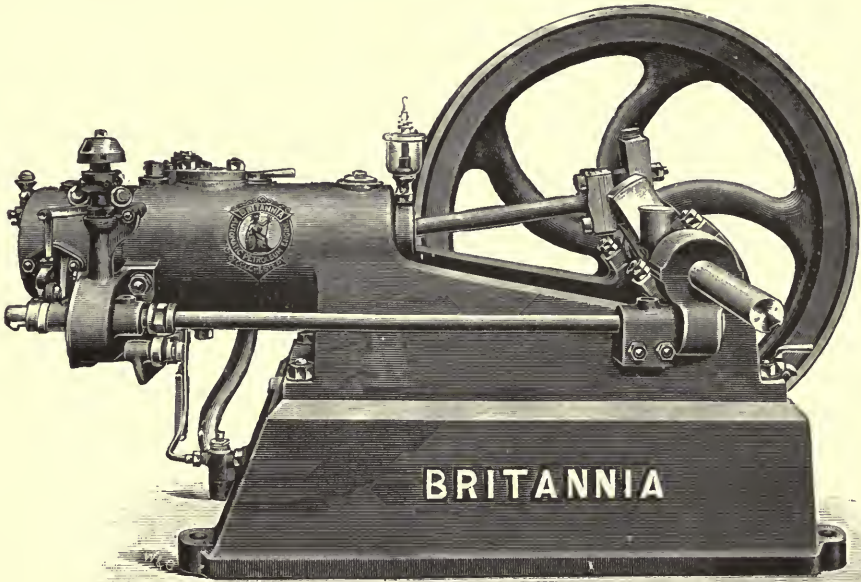
FIG. 143.—Britannia Engine.

spindle, a portion of which is screw-threaded and fits into a nut, the conical portion can be adjusted in position in the conical end of the passage, so as to partially or wholly cut off the oil supply.

The engine is shown complete in Fig. 143.

THE PETTER OIL ENGINE

This is a small engine designed for consuming common oils of paraffin, and works on the principle of ignition by compression and the heat retained in the vaporiser. The vaporiser is first heated by lamp, and after once started the lamp is extinguished. If there is any place where a handy small oil engine is more appreciated than another, it is at a farm. Here there are numerous machines nowadays for carrying out work formerly done by hand or horse. In this engine only two valves are used, and of these the inlet valve acts automatically, so that the exhaust valve alone requires to be operated by mechanism. This reduces the working parts to a minimum. There are no pumps, sprays, vacuum chambers, etc. to get out of order. Renewals and repairs can be made with perfect ease and at trifling cost. The material of which the valves are composed is a special mixture. It does not corrode, and will last for years in regular use.

The general arrangement of the governor is shown in Figs. 144, 145, and a separate view is also given of the following parts.

    A—The oil valve   C—The lower curtain.
    B—The upper curtain.   D—The holder.

The oil valve A has a groove cut along its length, and coming to a sharp point at E near its lower end. The oil valve is controlled by the governor lever F, and works up and down in the oil inlet G, the result being to cut off the oil supply as the speed of the engine increases. When the engine stops this valve rests upon its seat H in the oil inlet, and thus it is impossible for the oil to run to waste if the engine stops when no attendant is near.

The upper curtain B is adjustable to the best working position by means of the screw K. The lower curtain C is raised by the governor lever as the speed of the engine increases, and thus the space for admission of air as well as the oil passage becomes contracted.

D is the holder which carries the lower curtain C and raises the oil valve A. The governor lever is adjustable at M when it is desired to alter the speed of the engine.

To start the engine, raise the governor lever on the hinged trigger N. Turn on the oil for about 5 seconds, then turn it off again and immediately give the fly-wheel a few rapid turns. The engine should at once commence working. Turn on the oil tap again, and as soon as the proper speed is attained the trigger N will fall.

The upper curtain B requires adjusting with minute accuracy. If it is fixed too low the engine will take too much oil and insufficient air, and the exhaust gases will appear smoky. If fixed too high there will be frequent puffs back through the oil inlet. The best plan when the curtain B requires altering is to first raise it to its highest position, and then lower it by slow degrees until the point is reached when no puffing back occurs. This must be done while the engine is running light. When properly adjusted the speed should be quite uniform, the explosions regular, and the exhaust gases perfectly colourless; but to obtain this it is *absolutely essential that the vaporiser be thoroughly hot, and that no excess of oil be allowed to accumulate in the vaporiser.*

There is a small spring inside the oil inlet G at the point O which presses the oil valve down and prevents it from getting stuck on account of grit or any other matter which may be present in the oil.

In adjusting the governor lever at M to alter the speed of the engine, care must

Fig. 144.—Petter Governor for Oil Engine.

be taken to see that the holder D leaves contact with the oil valve A when the engine is at rest, otherwise the oil will not be automatically cut off when the engine stops.

The engines are supplied with a small farmer's outfit complete for about £50, including a chaff cutter and root pulper, and may readily be adapted to churning, cream separators, pumping water, and other labour about a farm.
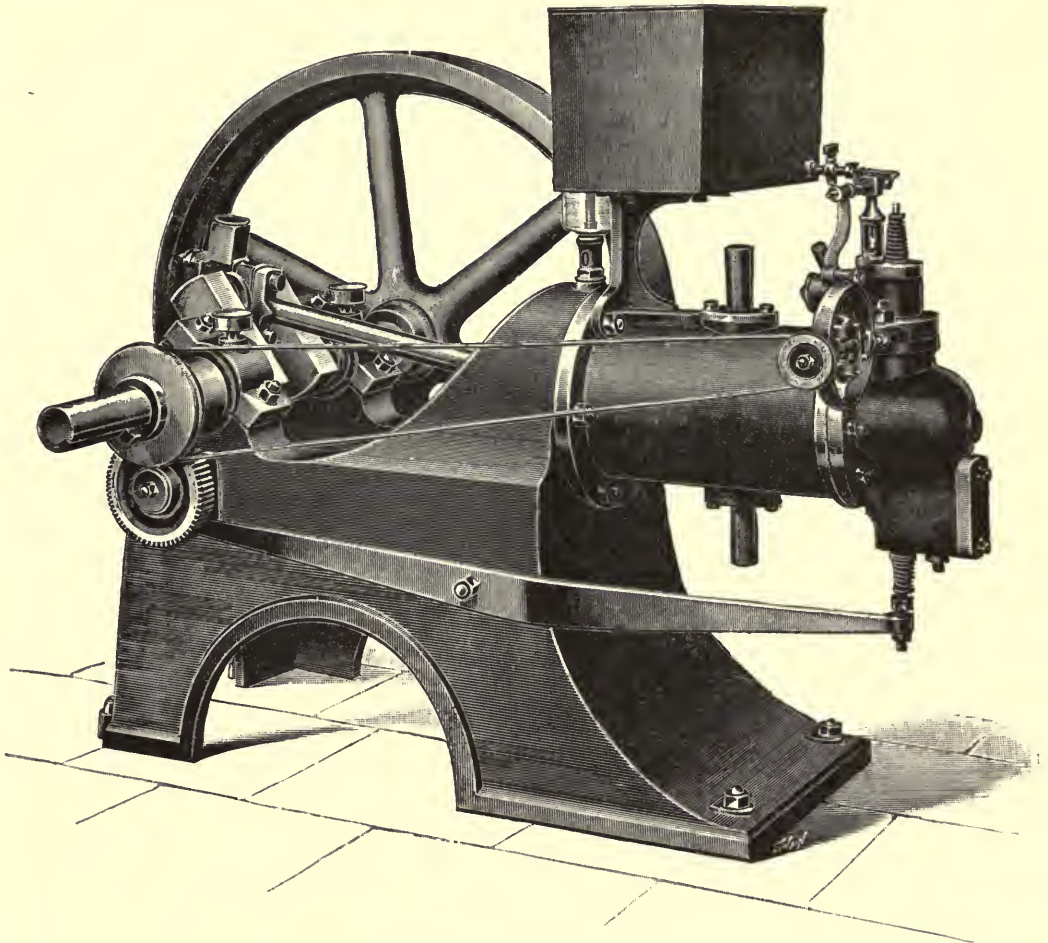

FIG. 145.—Petter Oil Engine.

The governor has been brought to a high pitch of perfection by years of experience and careful experiment; the objects aimed at being (1) regularity of speed under varying loads, and (2) economy of oil consumption.

THORNEYCROFT'S OIL MARINE ENGINES

In Plate VI. is illustrated a marine oil engine by Thorneycroft, complete, with a reversing clutch, screw shaft, and propeller.

The description of one of these engines fitted to a launch for His Majesty the King is here given. With reference to the two sectional views, Figs. 146 and 147, Fig. 146 is a side elevation part in section, showing two of the cranks, pistons, and cylinders. It is a 4-cycle 4-cylinder engine.

The engine is similar to those fitted by the Thorneycroft Steam Waggon Company to their larger motor cars. It will develop 20 brake horse-power when running at the

normal speed of 900 revolutions per minute. There are four cylinders, each 4 inches in

DE DION PLUG

EXHAUST

HALF SECTION THRO CYLINDER & VALVES

HALF END ELEVATION

HALF LONGITUDINAL SECTION

HALF SIDE ELEVATION
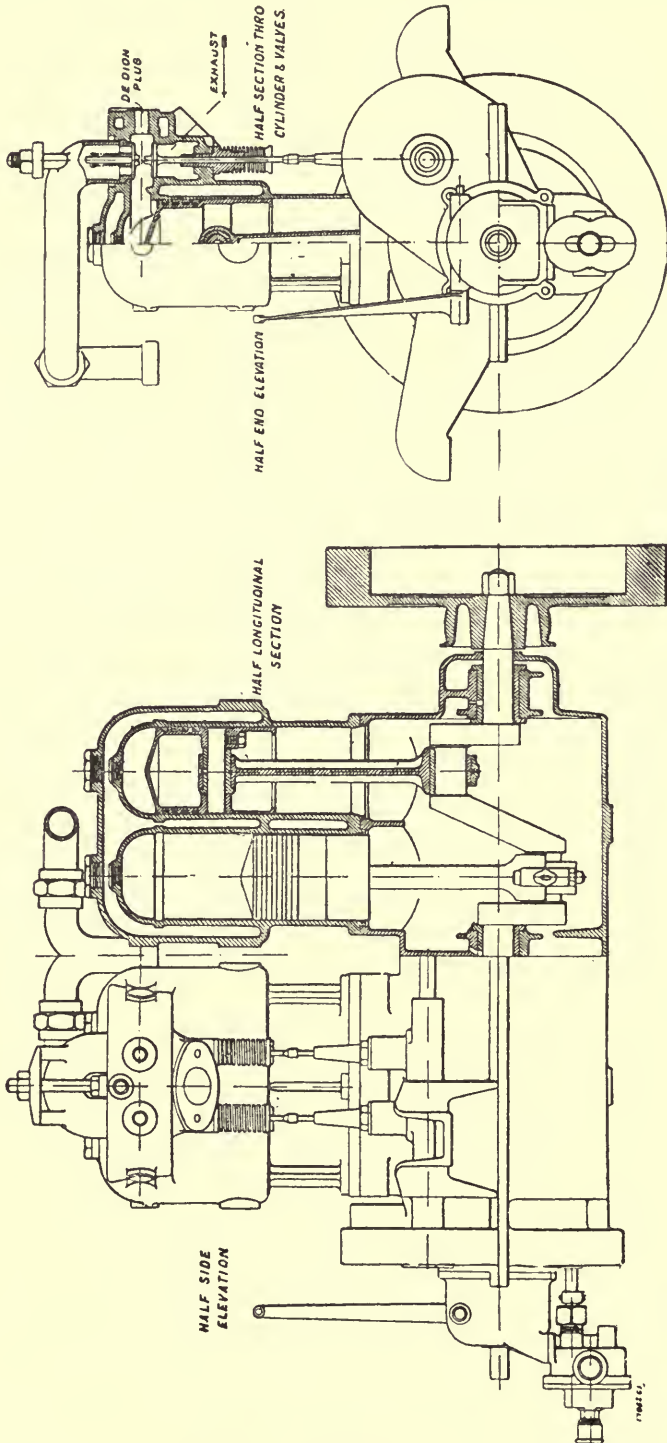
FIGS. 146, 147.—Sectional Views, Thorneycroft Engine.

diameter by 4⅝-inch stroke. They are all bolted to one aluminium bed-plate. The engine bearers are cast in one with the top half of the crank chamber or bed-plate, so that the

bottom half may be removed without disturbing the engine. The keeps to the crank shaft bearings are not formed in the bottom half of the crank chamber in the usual way, but are quite separate, so that on removing the bottom half the crank shaft is left in position.

The half-speed gear for driving the cam which works the valves, and also the governor, is enclosed in aluminium casings, formed in one with the crank chamber.
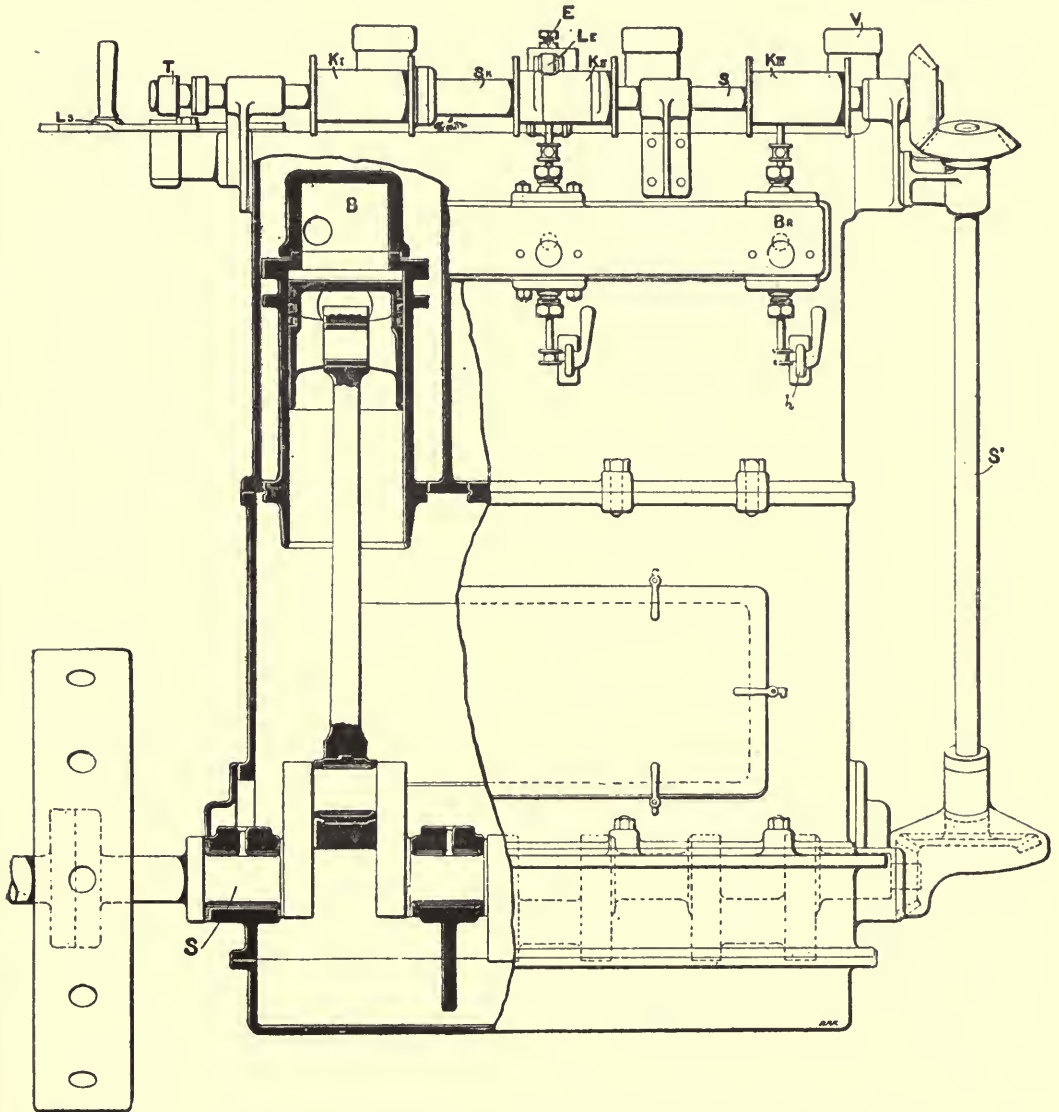
FIG. 148.—Thorneycroft Berthau Engine. Section.

Lubrication is on the splash principle, and the correct amount of oil in the crank chamber is regulated by an overflow pipe.

The cooling water jackets are cast in one with the cylinders, and the water is kept in circulation by what is known as a gear pump, which is driven directly from the crank shaft. This pump consists simply of a pair of spur wheels enclosed in a casing, and is found to be very effective for the purpose. The circulating water is taken from

and discharged overboard by pipes through the skin of the boat, so that an abundant supply of cold water is obtained.

The engine inlet valves are of the automatic type, and governing is effected by throttling the combustible mixture. The handle for starting the engine on first going off is connected to the crank shaft by a chain and ratchet.

It has been found that the heat given off from the exhaust pipes, although they are lagged with asbestos, is unpleasant to those sitting in the stern of the boat. It has therefore been decided to water-jacket the exhaust, and the cooling of the gases which results also makes the exhaust more silent.

The speed of the boat, with the engine running at normal revolutions—that is, about 900 revolutions per minute—is about 10 miles per hour; but the engine may be accelerated up to 1300 revolutions, which will give a speed of about 13 miles per hour. The ignition is on the high-tension principle, current being supplied from two secondary batteries. De Dion pattern sparking plugs are used. External spark pumps are fitted, and, these being always in view, the driver can tell at a glance whether the sparking mechanism is in working order.

It has already been stated that the tank capacity of this boat is 17 gallons, and it has been found by careful experiment that the engine consumes 1 lb. of petrol per brake horse-power-hour. Therefore, when travelling at the rate of 10 miles per hour, the engine developing 20 horse-power, 20 lbs. (approximately $2\frac{1}{2}$ gallons) of petrol will be consumed at the end of 10 miles,—that is to say, the tanks are of sufficient capacity to carry the boat somewhat over sixty miles. It may here be interesting to compare the weight of a steam engine and boiler of equal power with this engine. The weight of the petrol engine complete, with reversing gear, batteries, etc., and petrol sufficient to take the boat sixty miles, is very nearly 5 cwts. A 20 brake horse-power double acting condensing steam engine and boiler complete would weigh about 2 tons, and coal and water sufficient to last for sixty miles would amount to about 1 ton 3 cwts., making a total of 3 tons 3 cwts., or twelve times the weight of the petrol engine and fuel.

FIG. 149.—Thorneycroft Berthau Engine. End View.

The petrol engine also compares favourably with the steam machinery in regard to space. Even if the petrol engine occupies a little more room than a steam engine,

the greater part of the propelling mechanism—the boiler—is left out. The gain in weight and space is therefore considerable, and allows of greater comfort or a much larger number of passengers being carried.

More recently a 3-cylinder engine has been introduced under the Berthau patents. In this engine arrangements are made whereby it can have its motion reversed like a marine engine, and thus the clutch is not required.

It also consumes common paraffin oil. In order to enable the engine to start and reverse it is worked as a compressed air engine for a few strokes at each start. For this purpose a reservoir is kept charged at about 100 lbs. per square inch with burnt gases from the engine for starting and manœuvring. The gases are admitted to the reservoir from the engine cylinder through a relief valve, the pressure being slightly below that of explosion. When the reservoir needs replenishing communication is opened between it and the cylinder for a few revolutions, and on the required pressure being reached the communication is shut off.

The engine, as will be seen from Figs. 148, 149, has three cylinders, so that it has no dead points. The engine works, under normal conditions, on the usual 4-stroke cycle. Oil and air are admitted from the vaporiser V through the mixing valves M_m (Fig. 149). The mixture is drawn in through the admission stroke in the usual way as soon as the pressure in the cylinder falls below that of the atmosphere. Tube ignition is used ; the lamp which keeps the tube hot also serving to heat the vaporiser. The exhaust valve E (Fig. 149) is placed on the top of the explosion box B (Fig. 148), and is opened by the cam lever L_e. This lever is actuated by the main cam K, which also controls the burnt gas valve R and its lever L_r (Fig. 148). The exhaust gases, when not being stored—which, of course, is the normal condition of running—pass through the exhaust pipe P_e and escape under the stern. The main cam K is driven by the cam shaft s, which rotates at half the speed of the crank shaft S, the two being connected by the vertical shaft S_t (Figs. 149) and its bevel wheels. This cam has five different positions, and can be moved along so that the various sections come in contact with the levers L_e or L_r by moving the starting lever L_s. The central position is for stopping, and the two intermediate positions are for the normal working ahead or astern. The extreme positions are for starting in either direction. When the cam K is in its middle position the lever L_e is not acted upon, and the exhaust valve remains inactive, so that the engine stops.

When the cam is in either of the extreme positions the lever L_r is in contact with a section having two prominences, and the lever L_e is in contact with a similar section, so that both these valves are opened once in every revolution of the crank. The motor then works with a 2-stroke cycle, either ahead or astern, according as one end or other of the cam is in contact with the levers. This 2-stroke cycle is, however, only used for a moment at starting, and in conjunction with the burnt gases in the receiver.

Since at starting the motor works with a 2-stroke cycle and has three cranks, it is obvious that there is always one of the three pistons in a position to be acted upon by the burnt gases either ahead or astern, as may be required.

At starting, then, the lever L_s is put hard over, and all the main cams K are moved to their full travel, so that the cylinders are all arranged for a 2-stroke cycle. When the lever is put over the cam K_3 is moved directly by the cam shaft S, but the cams K_1 and K_2 on the sleeve S_k are moved by the spring shaft s^1 and the fork f.

The motion of throwing the cams over to their extreme position opens one of the cylinders to burnt gases, and the engine begins to move. Before it has made more than one revolution the small cam k on the cam shaft, with its lever L_k, throws the trip lever T out of the block b on the spring shaft s^1, and the springs move the cams K_1 and K_2 into the normal 4-stroke cycle position, so that the cylinders 1 and 2 begin to draw oil, compress, and explode in the normal way. The cylinder 3, however, continues to

work with burnt gas, and the 2-stroke cycle until the cylinders 1 and 2 are in proper working order. The lever L_s is then moved over to the normal working position, and the cylinder 3 begins to work with the normal 4-stroke cycle. The whole of this is completed in a very few revolutions.

It will be observed that when the cams K_1 and K_2 are in their central or either of their intermediate positions the springs on the spring shaft are not compressed, as the sleeve S_s has sufficient travel to allow of this; but when they are in their extreme position the springs are compressed, so that as soon as the trip lever T is thrown out the cams K_1 and K_2 fly back, and are prevented going too far by one of the trigger pieces t_1 and t_2.

The speed is varied by moving the lever L_m, which alters the setting of the mixing valve M by means of the shaft S_m with the small levers l attached. These levers shorten the springs and so make the valve open later, as a lower pressure in the cylinder is required to open them, and thus the explosion is somewhat later and the pressure
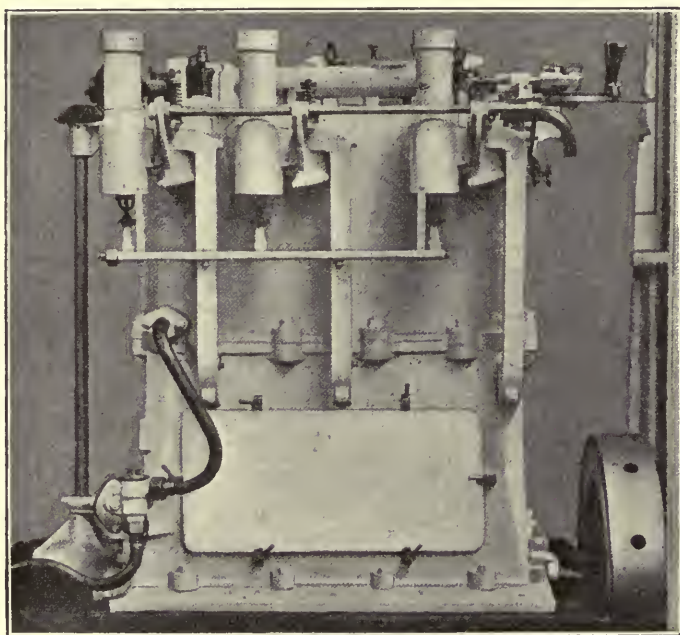
FIG. 150.—Thorneycroft Berthau Engine.

reduced. At the same time the mixture is slightly enriched automatically, so as to ensure a certain ignition and to obtain slower combustion.

The oil is admitted through the valve m, together with a small amount of air which has been heated by passing round the lamp and funnel, and it is then in the form of spray. It then passes through the vaporiser V and is heated, and afterwards goes through the valve M, where it is mixed with more air which is drawn from the crank chamber through the air pipe P_a and then passes into the cylinder.

As will be seen from Fig. 150, the crank chamber and connecting rods are entirely enclosed, in order to prevent smell from leakage of pistons, etc., and to allow thorough lubrication without splashing oil all over the boat.

The cylinder C is bolted to the explosion box B, the latter being cast in one with the water casing W. The circulating water is supplied from the pump P_w, which is worked by an eccentric on the shaft S^1. The water jacket also passes round the valve box B_r, which leads to the burnt gas receiver.

The piston and connecting rods, crank shaft, etc. are of the usual type, and require no explanation. Oil is fed in by gravity from a small feed tank about one foot above the engine, being raised to this feed tank by a hand pump.

The specific gravity of the oil is 0.820, and its flash point about 82° Fahr.

The maximum temperature in the cylinder is probably about 1400° C. The oil used is crude Russian petroleum, which is found to give better results than first class lamp oil.

The consumption of oil is less than 1 lb. per brake horse-power per hour.

The 10 and 30 brake horse-power motors are exactly similar in design to the one above described, with the exception that in the 10 brake horse-power only one lamp is used for all 3 cylinders instead of 3, and the air inlet is taken from outside instead of from the crank chamber. In neither of these two cases has an automatic arrangement been fitted for changing the second and third cylinders from a 2- to a 4-stroke cycle, it being done by hand instead.

The engine is made in the following stock sizes :—

TABLE VII.

B.H.P	Revolutions per Minute.	Weight, including Automatic Starting Reservoir.
10 .	500	11½ cwts.
15	325	25 ,,
30	275	40 ,,

Note.—The weights given—which include reservoirs—are subject to slight modification, as they are somewhat dependent on the convenient disposition of the reservoirs.

The following comparison is made with a steam cutter as supplied to the Royal Navy. It may be of interest :—

TABLE VIII.

	Steam Cutter.	Motor Cutter.
Length	27 feet.	27 feet.
Beam, moulded	6 feet 9 inches.	6 feet 10 inches.
Depth	3 feet 11 inches.	3 feet 9 inches.
Draught	2 feet 6 inches.	2 feet 3 inches.
Displacement	4.29 tons.	3.42 tons.
Speed, in miles	9 miles.	8 miles.
Power	15 I.H.P., or 13 B.H.P.	10 B.H.P.
Fuel	5 cwt. for 12 hours. ·	3 cwts. for 30 hours.
Length of machinery . . .	9 feet.	4 feet 6 inches.
Weight	27 cwts.	13 cwts.
Fuel per hour	0.4 cwt.	0.15 cwt.
Fuel per horse-power-hour . .	3.7 lbs.	1.1 lb.

The results of the Harmsworth Cup trials at Cork, on 16th July 1903, proved that small boats can carry sufficient oil engine power to run over a 9-mile course at the rate of about 20 knots. The largest boat was 40 feet long, and, it is said, carried engines of 75 horse-power. The second boat was 30 feet long, with engines of 50 horse-power. And the third, a Thorneycroft boat, also 30 feet long, with propelling machinery of 20 horse-power.

The speeds were for :—

No. 1 . . . . . . 21.7 knots.
,, 2 . . . . . . 19.5 ,,
,, 3 . . . . . . 17.7 ,,

PRIESTMAN'S MARINE OIL ENGINE

The engine has been considerably employed in marine propulsion. For driving launches and barges a vertical high speed double cylinder engine (Figs. 151 and 152), with one explosion to each revolution, is used up to the present time; the engines constructed for this purpose have been of 2, 5, or 10 horse-power. The 5 horse-power engine has 7-inch cylinders, 7-inch stroke, and works at 250 revolutions per minute. The valve gear is simple: a single eccentric on a counter-shaft, rotating half as fast as the crank shaft, acts on the exhaust valves of both cylinders. The inlet valves act automatically. The air-compressing pump and jacket-water circulating pumps are driven by an eccentric on the same counter shaft as the valve eccentric. There is a spray maker and vaporising chamber similar to that in the land engines. A governor also regulates the supply of air and oil from the oil tank to the spray maker. Ignition is by electric spark. The exhaust pipe
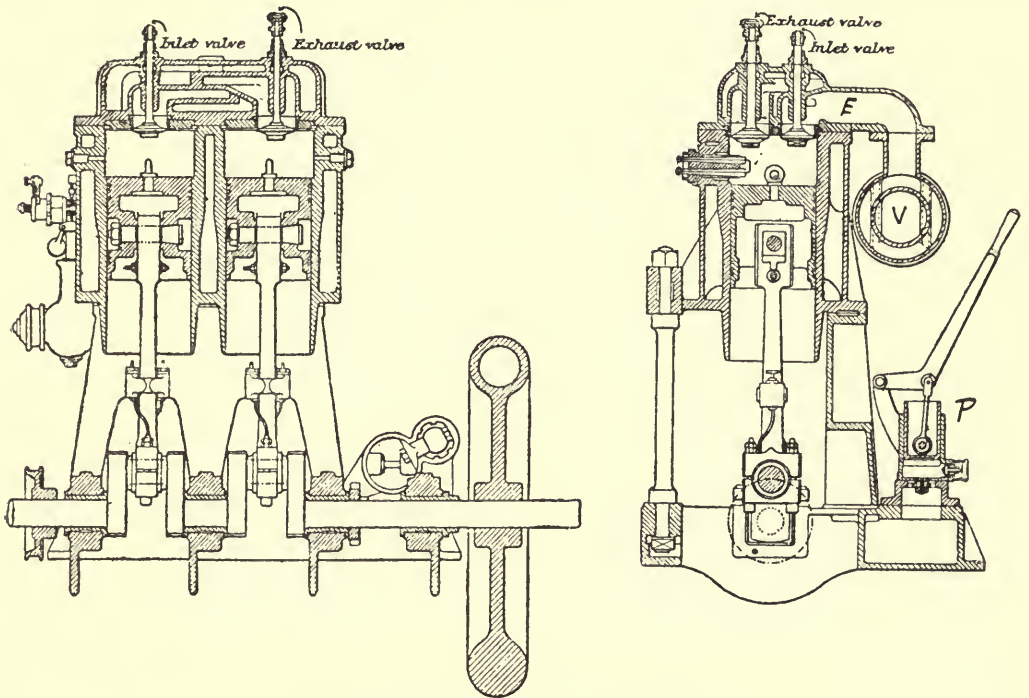
FIG. 151.—Sections, Priestman's Engine.

discharges below the water-line. The oil engine has not yet been constructed to reverse, and to effect this necessary operation in a marine engine Messrs. Priestman have adopted an ingenious form of friction clutch. Going ahead, the propeller and engine are coupled direct, and the clutch is virtually a solid coupling. Going astern, the engine drives the propeller through gearing, and engine and propeller revolve in opposite ways. A single hand wheel operates the clutch, so that the propeller may be driven ahead, astern, or disconnected from the engine altogether. Ordinary lamp oil can be used, and a week's supply can be stored in a tank, from which it can be pumped into the engine oil tank without creating any unpleasantness. Two barges have been built for the Manchester Ship Canal Company, and are each worked by a 10 horse-power oil engine. These barges ply on the Bridgewater Canal, between Manchester and Warrington, a distance of 19 miles. The barges are 70 feet in length and 14 feet beam. The weight of cargo ordinarily carried is twenty tons. From information furnished by Mr. Wiswall, the

engineer of the Bridgewater section of the Manchester Canal, the speed of the barges appears to be about four miles an hour.   The following are details of one of the barges :—

<p align="center">TABLE IX.</p>

Size of Barge.	Weight of Barge Loaded.	Distance from Manchester to Warrington.	Average Time taken.	Consumption of Oil per Hour.	Cost per Mile, Oil at 3⅝d. per Gallon.
	Tons.	Miles.	Hours.	Pints.	Pence.
75 feet long, 5 feet deep, 14 feet 6 inches beam .	42	19	5¼	14	1.75

Fig. 152 is a complete view of the marine-engine referred to.
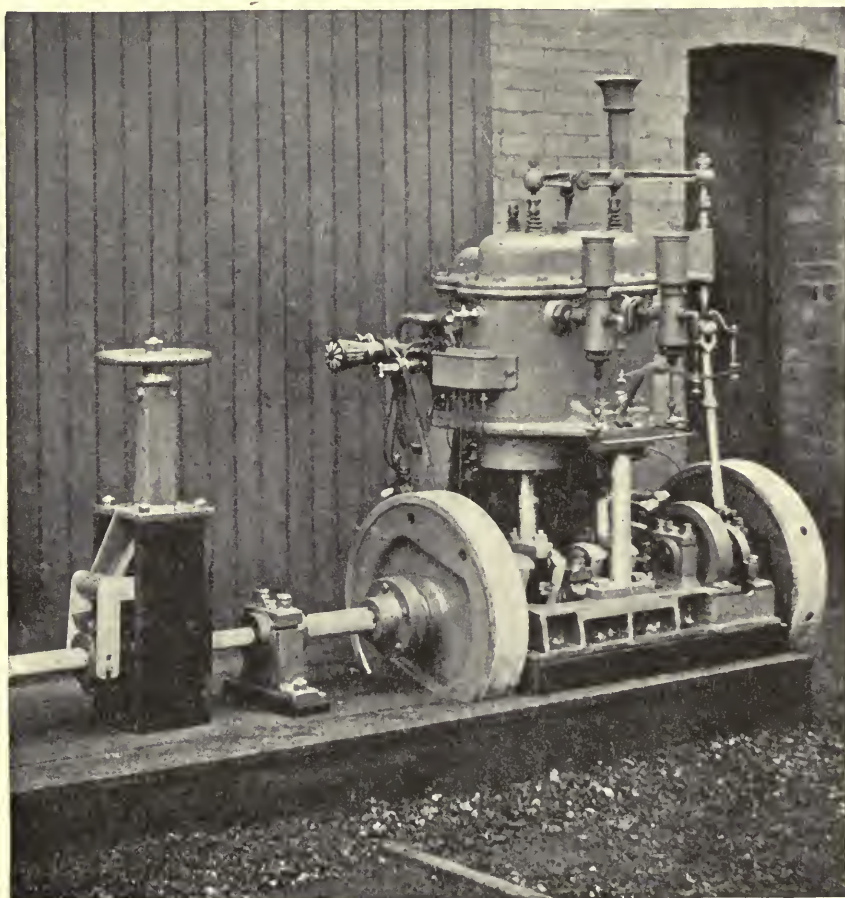
FIG. 152.—Priestman's Marine Oil Engine.

HORIZONTAL MARINE OIL ENGINE

This is a new engine of Diesel type, made by Sautter-Harlé & Co., Paris, described in the *Zeitschrift* as follows, and illustrated in Fig. 153, a longitudinal section and a sectional plan :—

Both pistons work in one cylinder, and at the inner dead point approach as close as possible to the tunnel or passage through which the crank shaft passes, and which penetrates the cylinder at its centre from side to side. Above this passage is the compression space, and in the cover of it the combined valves are situated. They are operated by levers and a cam shaft driven through spur gearing by the crank shaft. To the open end of each cylinder is bolted a casting, which constitutes a guide for a long cross-head secured to the piston rod, from which return connecting rods extend backwards to the crank. The whole engine is carried in a light cast-steel frame, which is freely supported by two brackets, rotation being prevented by the two springs shown in the section. The object of the design is to balance as nearly as possible all moving parts, and at the same time to dispense with the usual bed-plate. It will be seen that the only unbalanced forces are those trying to turn the engine round the crank shaft, and these are counteracted by the springs beneath the cylinders.

Longitudinal Section.

For marine purposes the engine has the following advantages:—It can be placed either vertically, horizontally, or obliquely; that space is economised by placing the crank shaft in the centre; and further, that because the engine is placed across the vessel instead of longitudinally, the hull need be strengthened only locally, whilst the remainder may be made of light construction.

For propulsion by jet propellers it would be a good design with a centrifugal pump coupled up to each end of the shaft.

GRIFFIN DUPLEX MARINE OIL ENGINE

This engine has been referred to already under the heading of "Two-Cycle Engines," and a section of it shown with two indicator diagrams in
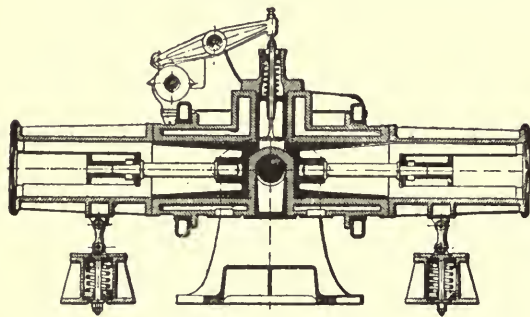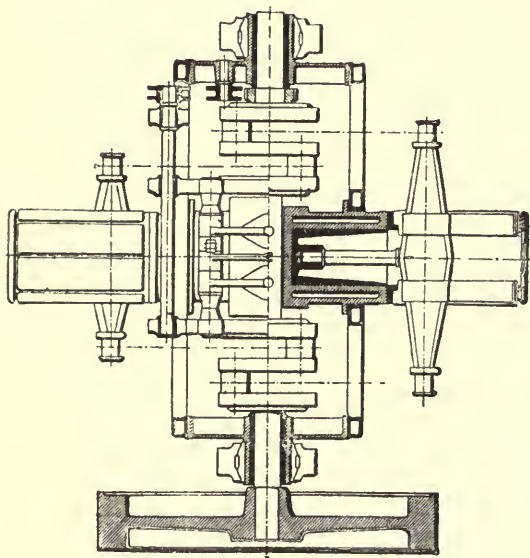
Plan.

FIG. 153.—Sautter-Harlé Engine.

Figs. 53 and 54. We now illustrate this engine complete as fitted into several vessels. There is a small auxiliary starting engine attached to the front of the large engine. This engine is used for starting, which operation is performed through a chain gear and grooved friction wheels, clearly shown in the large print (Fig. 154). The propeller, which the makers call the bi-unial screw propeller, is shown and described further on.

For smaller sizes the method of starting is very simple, and is done by hand in engines up to 20 horse-power. This is accomplished by mounting the fly-wheel loosely on the crank shaft, a friction clutch being provided, by means of which it can be instantly and firmly connected therewith. For starting, the fly-wheel is easily and
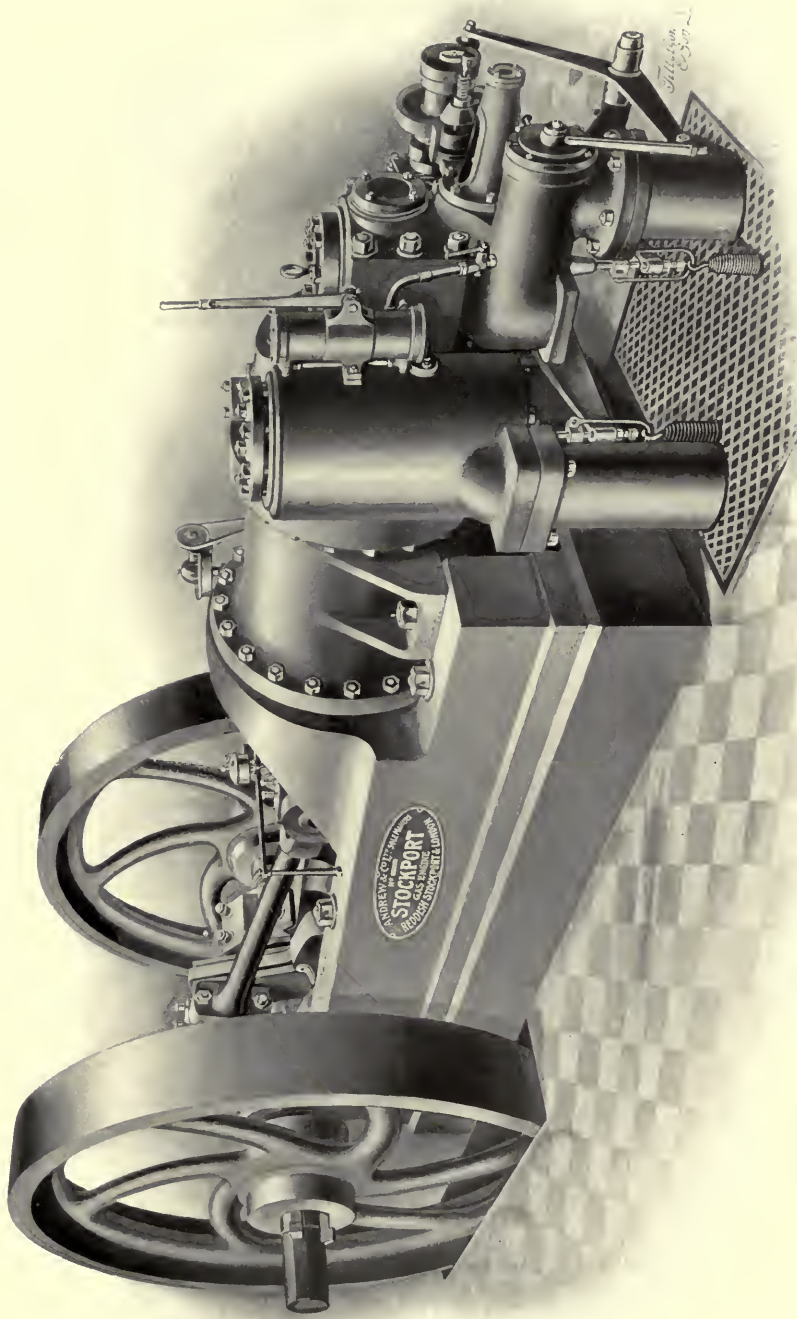
PLATE V.—150 HORSE-POWER STOCKPORT GAS ENGINE, WITH FLAT FRAME AND OUTSIDE SLIDE.

rapidly revolved loosely on the shaft by means of a handle and pitch chain, and while thus revolving it is engaged with the shaft by means of the friction clutch, its stored energy being sufficient to give the engine several rapid turns, thus completing its cycle.
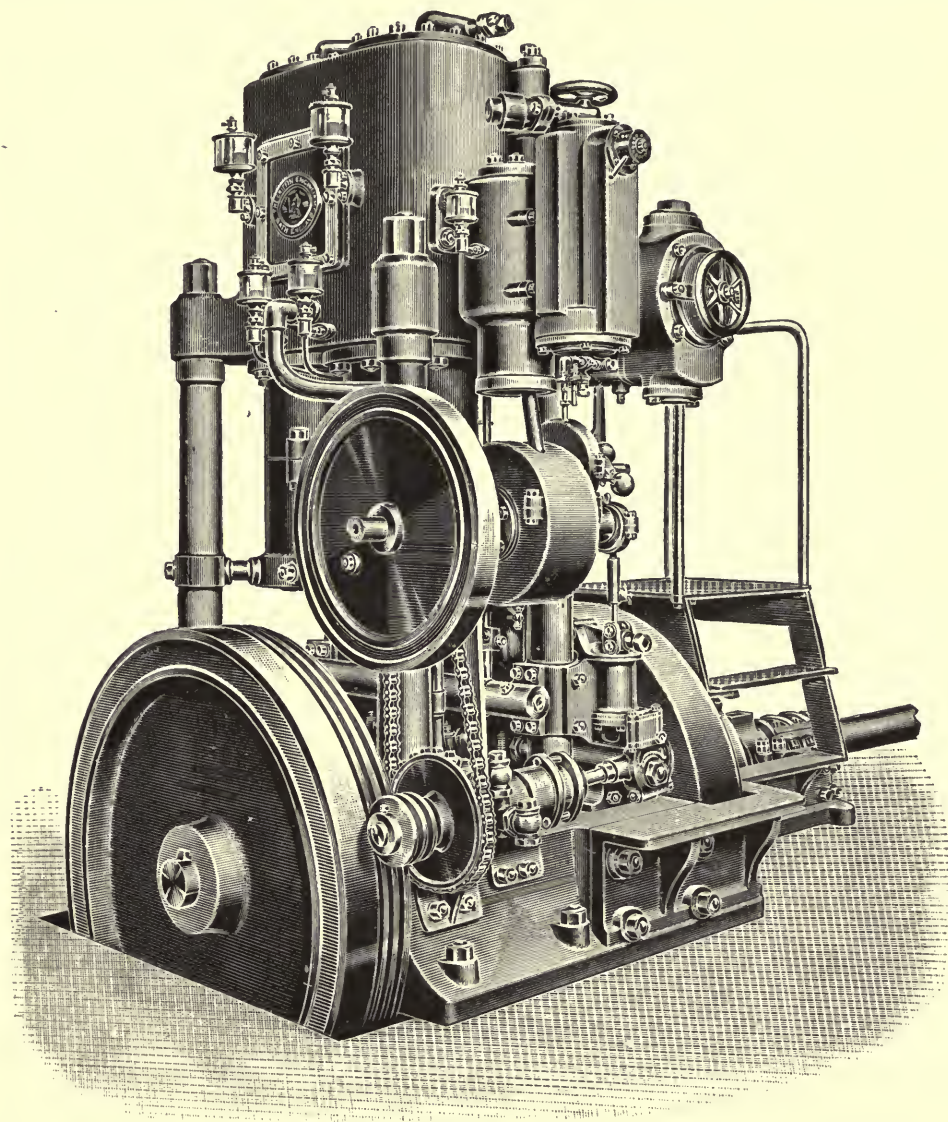

FIG. 154.—Griffin Hydro-Oil Marine Engine, with auxiliary Engine Starter.

It then commences to work automatically without further attention of any kind. One of the most laborious, uncertain, and difficult operations in connection with an oil launch engine is thus rendered easy and absolutely certain.

GOTHIC VERTICAL ENGINE

This engine (Fig. 155) is a vertical modification of the engines already fully described and illustrated on pages 64 to 69, but modified suitable for marine purposes, and having

an enclosed crank casing. For marine purposes the heavy base is not required. Working by suction on the incoming charge, it has the advantage over those small engines working by pressure blowing in the charge in which leakage of the fuel sooner or later occurs at the shaft bearings. It is doubtful if it is good engineering practice to close in the cranks and connecting rods. These are vital parts of an engine, and the connecting rod ends and main bearings are the very parts of any engine which should be constantly under the engineer's eye. And therefore the practice of Griffin, Priestman, and others, in working with open crank cases with easy and free access to the vital parts of the engine, has considerable practical advantages to recommend it.

Notice has now been taken of the engines employed hitherto in smaller craft. Some are specially designed for marine work; others are mere adaptations of motor car engines. These latter are not likely to be very successful. The conditions of road vehicle propulsion and marine vessel propulsion are totally different, and far more absolutely reliable knowledge, gained by experience, exists regarding marine propulsion than about road vehicle propulsion. While there is no doubt a motor car petrol engine will propel a boat of small size, it would be absurd to suppose that fact solved the problems of marine engines.
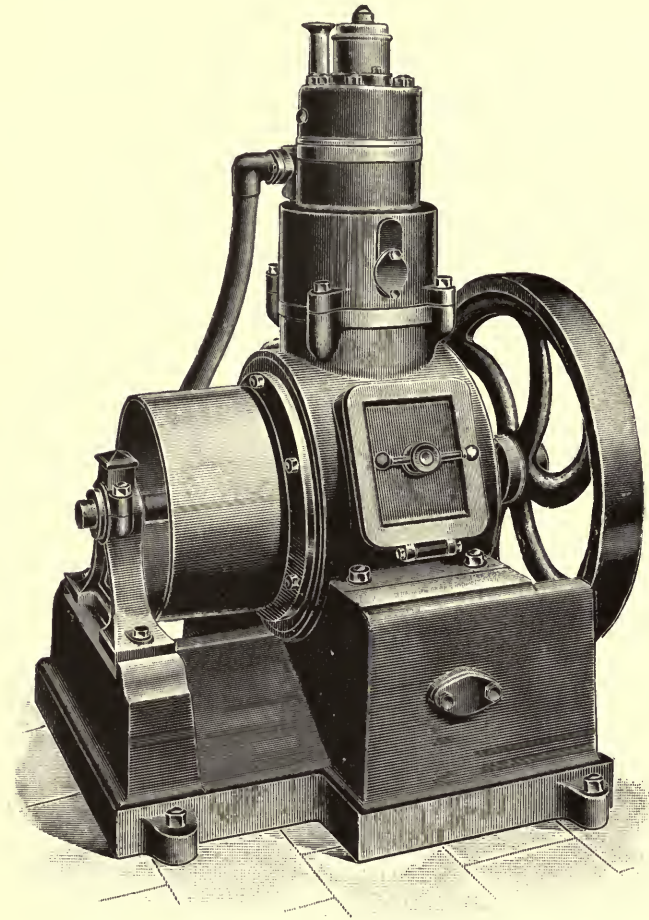
FIG. 155.—Glover's Vertical Engine.

GAS MARINE ENGINES

For marine propulsion on anything but small craft by internal combustion engines an engine somewhat different in design must be eventually evolved,—the turbine, of course, will be the final solution of the problem. But meanwhile the business of marine propulsion must be carried on by the available engines. The Beau De Rochas 4-stroke cycle, although at present the fashionable favourite, has little to recommend it to engineers, and will not hold its own in marine work of any magnitude.

The 2-cycle engine and the double acting two impulses per revolution engine must be adopted for large powers. The reasons why large powers, say on an ordinary steamer of 1000 horse-power, have not come into vogue are many. Chief among them is the inertia of the manufacturers of "Gas Producers" for ship purposes, and also the

irreversible nature of the gas and oil engine, whether it may be a turbine or a reciprocating engine.

The author has for years held the opinion that there is no insuperable difficulty in the way of adapting the gas producer on a large scale on board ship for driving marine gas engines. The steam engine requires 2 lbs. of good coal per horse-power-hour, whereas, as we shall see later on, a gas engine run by producer gas can produce 1 horse-power-hour on 1 lb. of coal usually known as slack coal of cheap quality. The two difficulties which seem to check the abilities of gas producer makers are the water seal whereby the ashes can be constantly removed, and the purification of the gases before they reach the engines. These difficulties are not great. A seal can be made quite as effective as a water seal, and, moreover, it is not necessary that there should be only one or two producers. A number can be used, so that one at a time can be opened for ash cleaning.

Surely, if the stokers on a steam ship can deal with the ashes of twice the quantity of coal, there should be no difficulty with producers. The second difficulty is also much exaggerated. There is plenty of cold water available for condensing out the tar and other liquids from the gas, and these are easily disposed of. The only real difficulty is that no one is ambitious to take the lead or make an experiment. It is, however, a promising field of commercial enterprise, and would go a long way to further develop the marine carrying trade of whichever country adopts it.

A ship with gas producers and engines could go twice the distance on the same coal consumpt that the steamer does. This would certainly give the gas ship a very great commercial advantage. She would be able to take freights at less rates and at the same time make more profits.

If shipowners were aware of the advantages of the gas producer over a steam boiler there is no doubt they would at once make a demand for them ; but before these advantages can be practically demonstrated the producers must be altered in design from that of stationary producers to a design suitable for the altered conditions on board ship. It seems this problem will remain to be solved by some outsiders not connected with gas producers.

The small " gasogenes " working with anthracite coal and an engine which sucks the charge through are now quite suitable for smaller vessels of 200 horse-power or under.

For small craft under 50 horse-power the paraffin oil engine is perhaps best in some places, where cheap oil can be readily obtained, but in many places good anthracite coal can be got, and there is little doubt that in a short time gasogenes capable of dealing with common slack will be perfected for marine gas engines for large and small craft. For trading ships, ocean-going tramps, and long voyages abroad, oil as a fuel is out of the question. The difficulties of storage and of obtaining a supply of sufficient magnitude are too great, not to speak of the cost of oil. Oil supplies are much more restricted than coal ; its transport is more expensive, and any great increase in demand would immediately very greatly enhance the prices.

The next point in marine propulsion by gas engines is the reversibility of the machine. Oil or gas engines can be made to reverse, as we have seen in the case of Thorneycroft's marine engine, by a special arrangement of cams and employing a store of compressed air in order to restart the engine. This method, however, does not provide for controlling the speed of the vessel.

There are five systems whereby a vessel may be propelled and controlled when driven by a non-reversible motor like a gas or oil engine.

1st. By means of a screw propeller, with movable blades operated by a shaft inside of the propeller shaft whereby the blades can be deflected to right or left so as to form a right-hand or left-hand screw for going ahead or astern, and the pitch can be varied to alter the speed. This is a favourite method for small boats up to 5 horse-power or so.

2nd. By a double screw, one right the other left hand, on concentric shafts, either or both of which can be clutched to the engine.

3rd. By a reversing friction clutch on the propeller shaft.

4th. By electrical transmission, the engine driving a dynamo, and the dynamo through an electrical controller driving the screw propeller.

5th. By water jet propellers.

It may be observed that there are no starting difficulties with the steam turbine, nor with an oil engine coupled to a dynamo, for a starting accumulator is a small affair, and quite effective to set the engine in motion.

The first system referred to can be very well shown by Fig. 156, the gear of small vessels built by Messrs. Vosper of Portsmouth, and driven by oil engines using ordinary
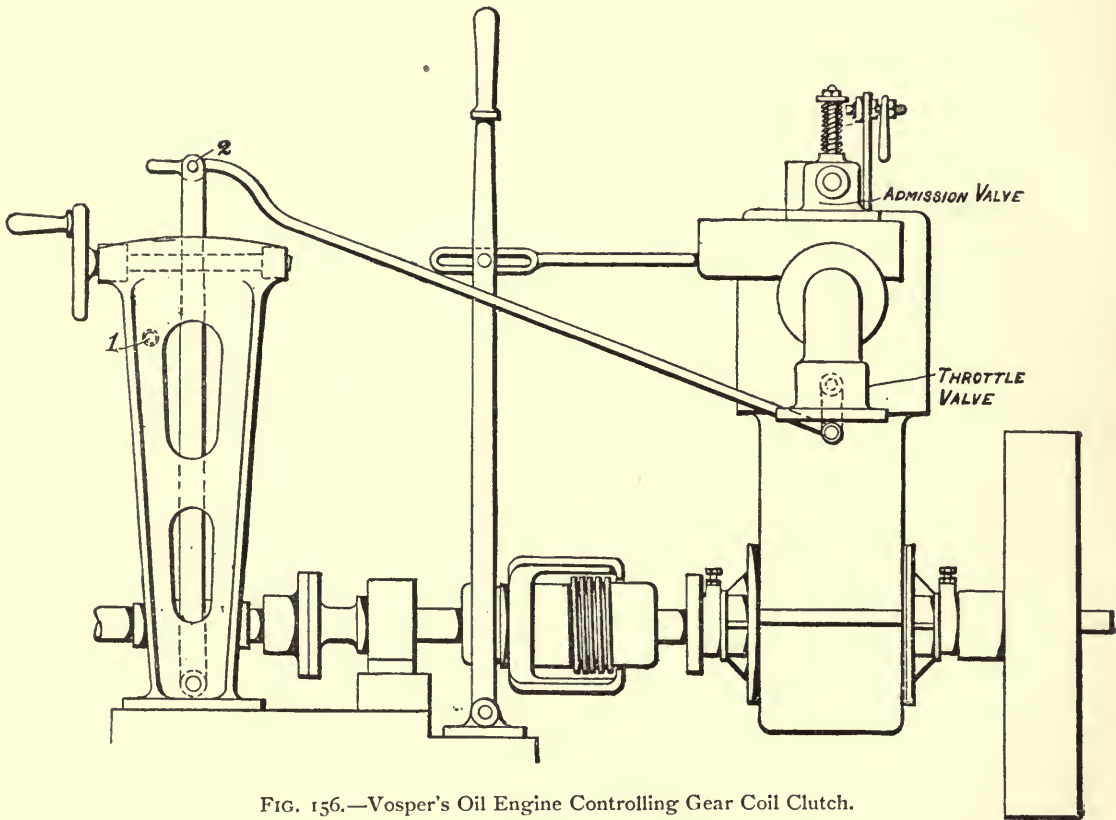
FIG. 156.—Vosper's Oil Engine Controlling Gear Coil Clutch.

paraffin oil. The blades are reversible by the lever and screw worked by a hand wheel as shown. In the mid position of the lever the propeller may run with the blades set to thrust equally fore and aft, the one thrust annulling the other, or a clutch may preferably be used to disconnect the propellers in the stop position. A similar method is also adopted by the Mitcham Motor Company of Cowes (Fig. 157), who make little marine oil engines for launches and small yachts, and by many others. It is perfectly satisfactory for very small powers, with screws up to about 2 feet in diameter.

The second method has been adopted by the " Griffin " oil launch and boat builders (Fig. 158). This arrangement consists of two ordinary screw propellers of right and left-handed pitch respectively, the forward propeller being mounted on the end of a hollow shaft which extends into the interior of the boat. Through this hollow shaft a second shaft passes, and on the end of the latter is mounted the sternmost propeller. Both propellers are thus free to revolve independently of each other. A double friction clutch

attached to the engine shaft, and actuated by a hand lever, is connected with the ends of these shafts in the interior of the boat, the arrangement being such that either of the propellers may be engaged with the engine, or both may be simultaneously disengaged. It will thus be seen that by the simple movement of the hand lever the whole operations of starting, stopping, and reversing the boat are effected without stopping or reversing
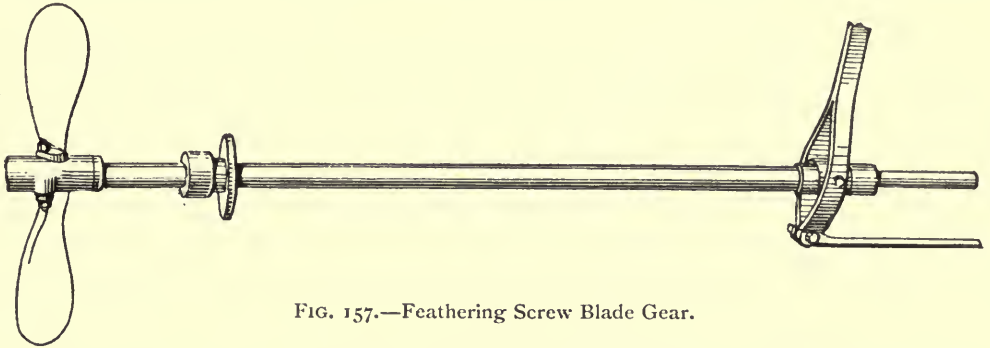
FIG. 157.—Feathering Screw Blade Gear.

either the engine, propeller shaft, propellers, or any part of the driving mechanism ; while, owing to the entire absence of toothed gearing or racks of any kind, its action is absolutely noiseless and free from jerk or shock.

The advantages claimed for this arrangement are many. There is no shock when the propellers are disconnected or put in motion. There are no cogs, racks, or gearing of any kind to get out of order. There is stated to be no obstruction to the movement of the boat when the propellers are out of action, which is said to render the boat so fitted specially suitable for canals. The operations of starting, stopping, reversing, and steering can be controlled by one man seated at the stern. With regard to the claim that there is no obstruction to the movement of the boat when one of the propellers is out of action, experiments have been made, and no difference either in speed or oil consumption could be detected over a measured distance with an idle propeller free to revolve or with the propeller removed.
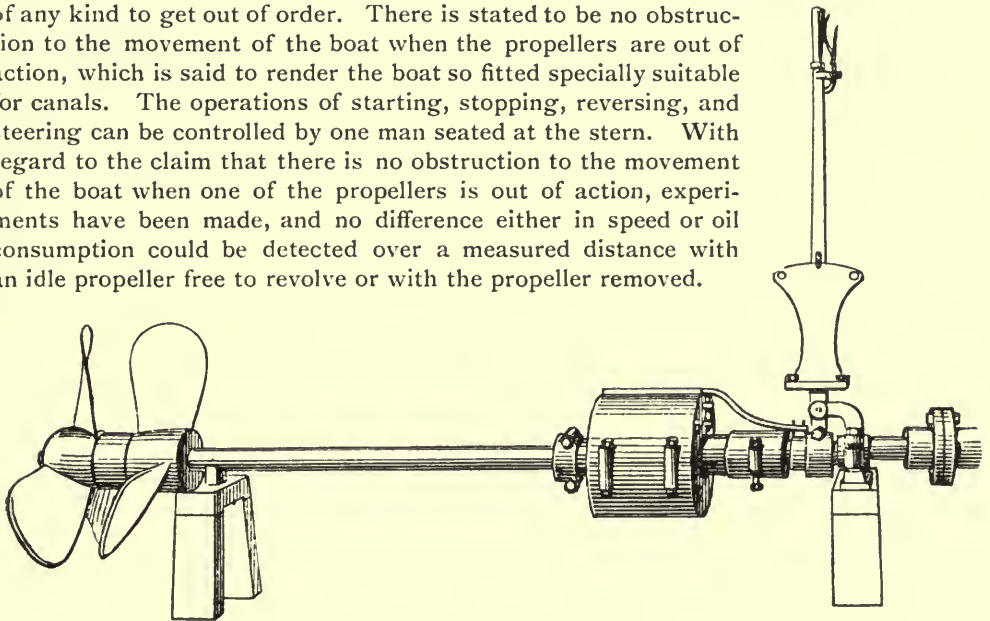
FIG. 158.—Griffin Bi-unial Gear.

The third system—the friction-clutch method. Friction clutches are many in form, but few have been designed for reversing purposes. Thus we find in some instances a clutch used to enable the engine to run free at starting, and a reversible propeller for reversing.

The Hele Shaw clutch has been much used both as an ordinary clutch and as a reversing clutch. It consists of alternately connected sheets of metal pressed into a frustum. Each alternate sheet fits into the other set.

By placing these discs together, as in Figs. 159 and 160, and turning one alternately

to the other, an amount of friction is produced which depends on the acuteness of the angle of the frusta. If a number of these plates are now placed in a box of the type of
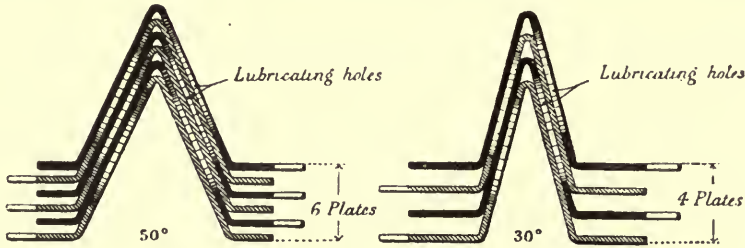
FIG. 159.—Professor Hele Shaw's Clutch Gear.

the "Weston" coupling, so that the plates alternately engage with two sleeves, one connected with the driver and the other with the follower, as in Fig. 161, it will be found : first, there is very considerable gripping power ; second, there is a tendency to part rapidly with heat, owing to the separation of the discs of metal.
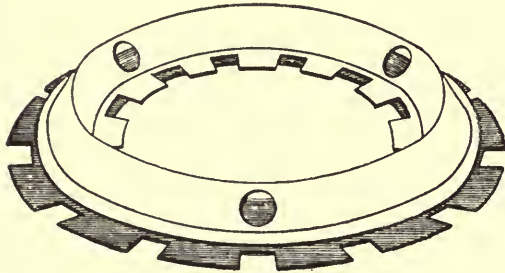
FIG. 160.—Holes in Corrugations, for Circulation of Liquid.

It will be noticed from this illustration (Fig. 159) that the number of plates in a given space depends upon the angle of the corrugation thus : four plates with 30° occupy the same space as six plates with 50°. These four plates, however, give a better grip than the six plates with 50°, and have the great advantage of allowing a freer circulation of liquid, as may be easily seen from the figure. The plates are also much more rigid with the more acute angle.

A standard type of clutch for shafts up to 2 inches diameter is shown in Fig. 161.

The shaft is divided as shown, the outside case being keyed to the left-hand piece of shafting, and driving the set of plates having external driving teeth. The core is keyed to the right-hand shaft driving the plates with internal driving teeth. Pressure is applied to the plates as follows :— The sliding sleeve, containing a coil spring, is fitted with pins which project through the outside case of the clutch ; these pins press against a flat disc, which in turn presses against the plates, causing the clutch to drive.

When the operating lever
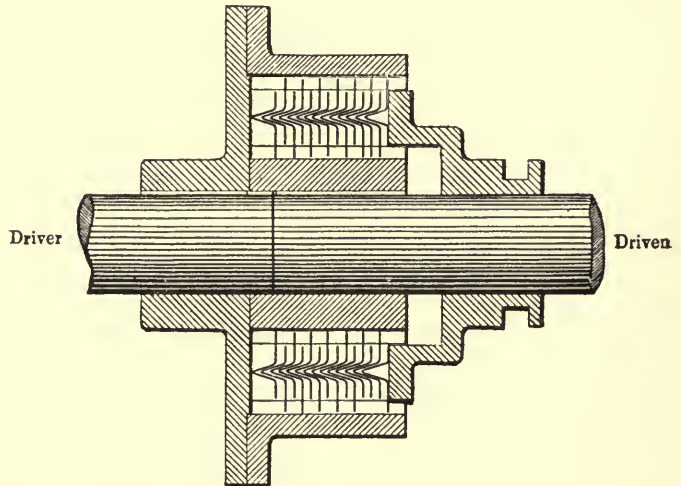
FIG. 161.—Professor Hele Shaw's Clutch.

is worked so as to release the plates the ring encircling the sleeve withdraws the trigger pins from the holes into which they fit ; the spring pressing on the opposite end of the trigger pin causes the trigger to fly up, and the clutch is thereby kept out of operation.

By moving the lever so as to force the ring against the trigger, the pin end falls into the hole opposite to it, and the coil spring is then allowed to transmit its pressure to the plates.

The construction of the single clutch may be readily gathered from the foregoing description given by the inventor. The following is the description given of the reversing clutch, from an advance copy of the inventor's paper read in Leeds, July 1903, before the Institute of Mechanical Engineers :—

The reversing gear shown in Fig. 162 consists of two clutches A and B in a reversing clutch designed for 1000 horse-power. This is the clutch which is of interest in this place, for if it can be relied upon,—and there is every reason to believe it can be,— then it is a valuable addition to the internal combustion engine for marine purposes.

The outer case of the clutch A is keyed to the reversing shaft C, which may be a propeller shaft, the core of A being keyed to the engine shaft D. Inside the rim of the outer case of A teeth are cut in the direction of the shaft, forming an annular wheel H.

To the internal core of clutch B a series of pinions are fixed as shown at J ; these pinions gear with the annular wheel H. They also gear with the wheel K, keyed to the engine shaft, the three together forming an epicyclic train.
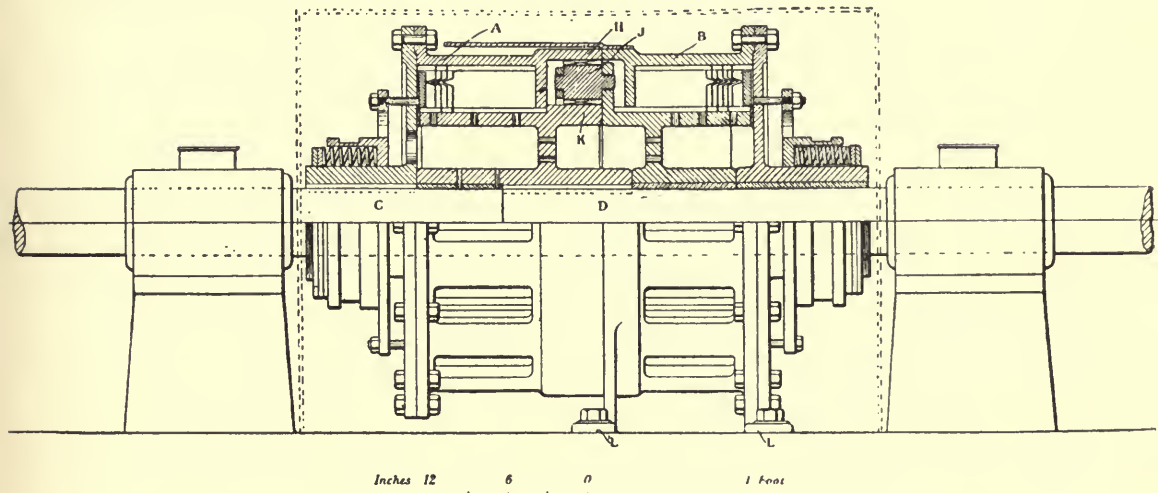
FIG. 162.—Hele Shaw Reversing Clutch. 1000 Horse-Power.

The outer case of B is held stationary, being fixed to the frame of the machine by a bracket L.

The gear operates as follows :—When clutch A is made free, clutch B comes into action. The core of B carrying the pinions J is now fixed to the outside case of clutch B (which is permanently at rest), and, as the core of B is free on the engine shaft, the toothed wheel keyed to this shaft at K transmits motion to the pinions, which, being also in gear with the outside case of A, causes the shaft C, to which A is fixed, to rotate in a reverse direction and at a slower speed than that of the engine.

When both clutches are inoperative the reversing shaft is at rest.

When clutch B is free, at the same time the plates in clutch A are caused to grip ; and as the outside case of A is keyed to the reversing shaft and the core of A to the engine shaft, the two rotate together in the same direction.

The toothed gearing at H, J, and K now rotate as a fixed mass, the teeth themselves not being in operation.

The locking system of operating links and levers renders it impossible for both clutches to grip simultaneously, no matter how suddenly the operating lever M may be moved from one extreme position to the other.

This is a design made for a steam turbine which is also a non-reversible prime mover, and so also is the gas turbine. It was designed for 700 to 800 revolutions per minute, and reversal could be made in 5 seconds.

For reciprocating engines the clutch would be larger, due to the slower speed and the greater torque.

The fourth system, by means of dynamo-electric transmission, is a very perfect system of control both as to speed and direction. We need not enlarge upon it here, for it comes under complete treatment in Volume IV. as generally applied.

The four methods employed in the foregoing contemplate the use of the screw propeller as the instrument of propulsion ; but the screw propeller has some drawbacks which from use and wont have been overlooked. It is so common and so universally accepted as the best instrument for the purpose that no one takes the liberty to question its superiority to all other instruments.

There is always the serious risk of losing the propeller blades, and of the propeller shaft breaking. Both accidents are not infrequent.

The fifth system abandons the screw propeller. We referred to the jet propeller in Volume I. under the heading of jets.
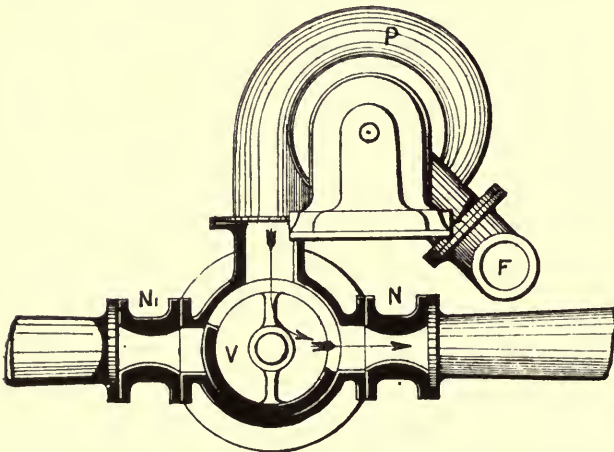
FIG. 163.—Kennedy Marine Water Jet Propeller.

In this system the internal combustion engine drives a centrifugal pump (Fig. 163), which draws water through the bottom of the ship and impresses upon the water a velocity or pressure. The water is conducted aft or forward, and discharged in either of these directions according to whether we wish to drive ahead or astern. Since writing the first volume the author has had some opportunities of investigating the subject practically, and it has been discussed before the Institute of Engineers and Shipbuilders in Scotland at Glasgow.

The whole question of propellers and their properties will come up again. At present we may briefly describe this system in connection with the internal combustion engine, to show its application to boats in general. Consider Fig. 163. P is a centrifugal pump driven by an oil or gas engine in a vessel. Water is drawn in at F, and delivered at the pump pressure into vessel V, fitted with a rotatable valve, whereby the water can be discharged at pleasure through throats N, N_1 fore or aft the vessel. The thrust in this arrangement is equal to the area of the throat N or N_1, multiplied by twice the pressure of the water in V, when the vessel is held fast and not allowed to move ; but when the vessel is allowed to travel in the reverse direction of the jet the thrust is then equal to twice the pressure in V, multiplied by the area of the throat, minus the pressure due to the velocity of the vessel. For instance, if the pressure in V = 10 lbs., and the speed of the ship half the speed of the jet, then the effective thrust would be five times the area of the throat.

As a matter of fact, the thrust is proportional to the additional pressure given to the water by the engine and pump to that given by the movement of the vessel forcing the water into the intake.

If the vessel were towed along at 20 feet per second, and had an arrangement like that shown in Fig. 164, the water would be scooped up by the intake K and produce

a pressure in the pump P, and the water would escape through the throat N and out at the stern. Relatively to the ship, the speed of the water would be 20 feet per second; but relatively to still water outside the ship, the speed of the water would be nothing. If, how-
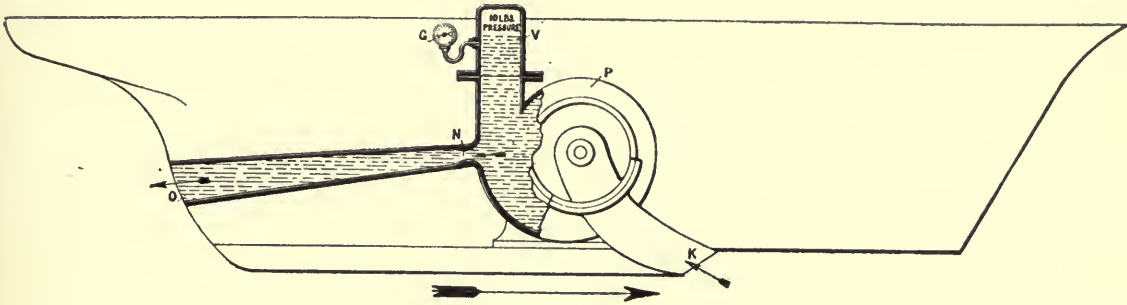

FIG. 164.—Rankin Kennedy Marine Water Jet Propeller.

ever, we drive the pump by an engine, so that we send the water out at 40 feet per second, half of this speed is due to the pump. And therefore the thrust will be equal to the pressure due to 20 feet velocity, or 10 lbs. multiplied by the throat area. The question, however, is not quite so simple as this theoretical calculation makes it. It does not take into account the power and speed of the engine. In the meantime it may be taken that the jet propeller offers considerable advantages, with internal combustion engines for marine propulsion; and a yacht or ship fitted with a jet propeller, driven by a gas engine and gasogene, burning hard Welsh steam coal or anthracite, would be quiet, clean, and vibrationless, no smoke and no smells, and perfectly safe, as the gasogene, having less than atmospheric pressure when at work, has no escape of gas.

THE VOSPER MARINE OIL ENGINE

The new type of Vosper marine engine has been developed from their early Roots' form of motor, in which they had two pairs of cylinders set at right angles to each other. The latest type is shown in line drawings in Figs. 165 and 166, and the following is an index to the parts of a single cylinder engine:—

FIG. 165.—Vosper Engine. Elevation.

A, Oil sight feed.
B, Admission valve.
C, Exhaust valve.
D, Oil feed spindle

E, Projection for turning key.
F, Compression valve.
G, Oil pump suction.
H, Cap for filling reservoir.
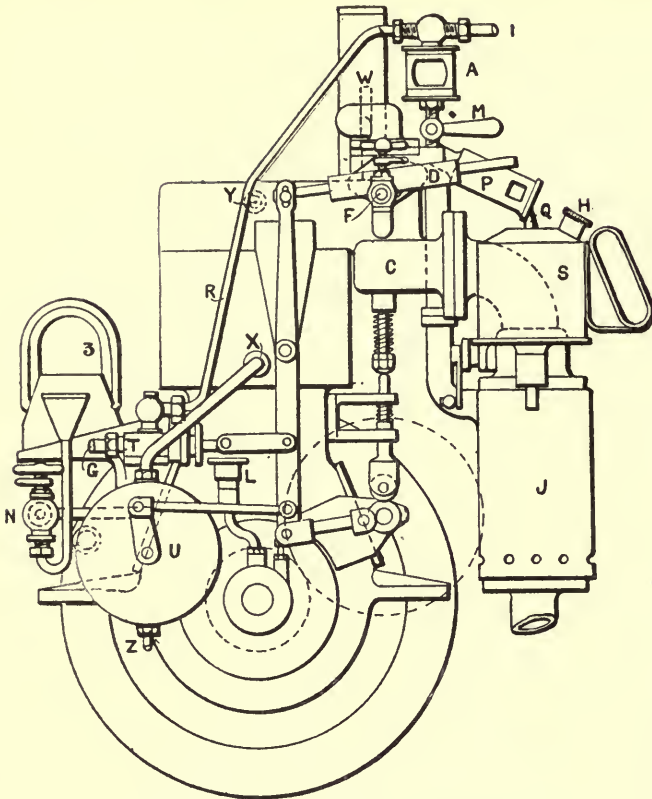
FIG. 166.—Vosper Engine. End View.

I, Overflow from feed.
J, Casing.
K, Auxiliary air valve.
L, Lubricator for bearings.
M, Sight feed oil cock.
N, Cylinder lubricator.
O, Air pump for lamp.
P, Burner.
Q, Burner supply.
R, Sight feed oil supply.
S, Reservoir for lamp.
T, Oil pump.
U, Circulating water pump.
W, Ignition tube.
X, Circulating water inlet.
Y, Circulating water over-
flow.
Z, Circulating water suc-
tion.
2*a*, Electric ignition plug.
3, Magneto.
4, Lever for regulating
sparking moment.

The auxiliary air valve K is closed when starting the engine. C, the exhaust valve, is shut by spring, which must be kept at the tension adjusted.

The oil is pumped up by pump T, and falls into the vaporiser through a sight feed A, the surplus flowing back to the reservoir by pipe I. The ignition tube W is heated at first by lamp P.

When engine has been at work ten minutes, and the brass casing marked heater is quite hot, you can gradually let the lamp pressure off. If engine slows down it shows that it is not quite hot enough, and the lamp must be pumped up, to further heat the tube till it is a bright red hot.

The engine is then started by quickly turning the fly-wheel. The lamp has a separate oil reservoir S, kept under pressure by a small hand pump O. There is also a cold water circulating pump U for the cylinder jacket.

The ignition is by magneto spark. The lever controls the ignition, so that the speed can be regulated. There is also a throttle on the exhaust, by which, when the lever is placed in the centre of the

FIG. 167.—Vosper Single Cylinder Marine Oil Engine.

reversing bracket (Fig. 156), the exhaust is throttled, thus preventing the engine from racing ; but in starting the engine the throttle lever handle must be on the bracket provided for that purpose, marked 1 in Fig. 156, the throttle thus being wide open, and as soon as the engine is properly started the lever handle must be shifted to pin on reversing lever marked 2 in Fig. 156.

Extra speed may be given to the engine, after it has been at work some minutes, by opening the auxiliary air valve K, which is on the pipe leading to the casing of the exhaust tank. A little practice will soon determine how much to open the air valve to get the best results. If engine slows down it must be shut and tried again.

Fig. 167 shows the complete 1-cylinder engine, end view ; and Fig. 168 shows the
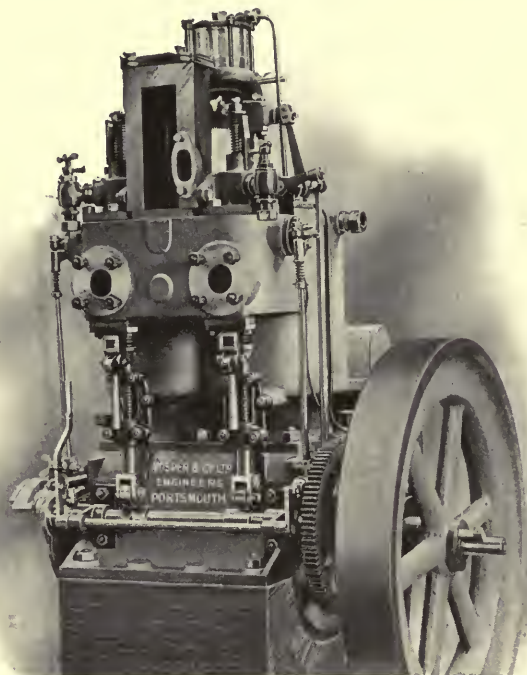
FIG. 168.—Vosper Double Cylinder Marine Oil Engine.

2-cylinder engine, back view. Fig. 156 is a line drawing, showing couplings and the controlling bracket for regulating the direction of motion, also the lever for throwing out and in the clutch.

This motor uses paraffin oil, and has a positive feed for the oil. The piston draws in air and oil through the vaporiser direct into the cylinder. The consumption of paraffin is about one pint per horse-power per hour.

TWO-CYCLE MARINE ENGINE

The design shown in Fig. 173 is a modification of some early inventions, which for simplicity is recommended for marine propulsion. The essential features are a working piston and a pumping piston. This latter exhausts the spent gases at the end of the working stroke, and produces a suction which draws in the new charge. This idea is not new, neither is the plan of passing the exhaust gases through a condenser or cooler on the passage between the working cylinder and pumping cylinder.

Both inventions are shown in O. H. Wildts' Patent No. 6151, 1895, who thus describes it, with a diagram (Fig. 169) :—

A cycle is performed in two strokes. At the end of the out-stroke the exhaust valve h^1 opens, and the products are drawn by the pump q into the condenser t; on the closing of the exhaust valve the admission valve h is opened, and a fresh charge enters the cylinder to fill the vacuum therein, and is compressed during the rest of the in-stroke. The valves are opened by cams g^1, g, and are closed by springs n, n^1. For governing the engine a supplementary cam is turned on the crank shaft, and holds the exhaust valve open longer, and opens the admission valve later when the speed is excessive.
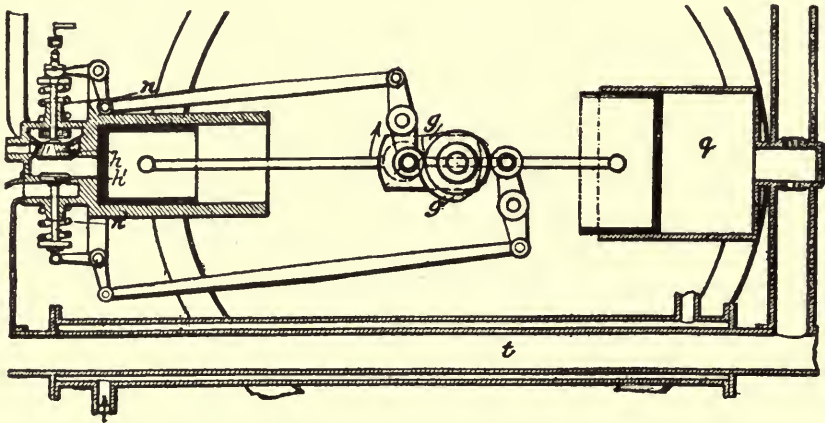
FIG. 169.—Two-Cycle Engine.

Also in the patent of J. Roots, March 1889, No. 6151, described and illustrated as follows (Fig. 170):—

To perform the four operations of suction, compression, expansion, and exhaust in two strokes, the exhaust port R is placed in the position shown, and communicates with a condensing chamber T, at the bottom of which is the automatic exhaust valve S. When the piston opens the port R the pressure in the cylinder sinks to that of the atmosphere, and the further outward motion of the piston, together with the partial
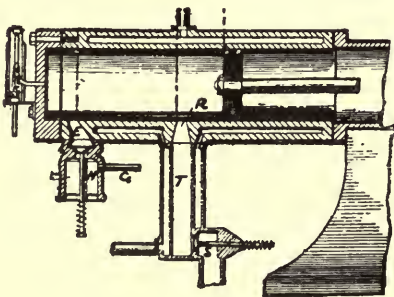
FIG. 170.—Two-Cycle Engine.
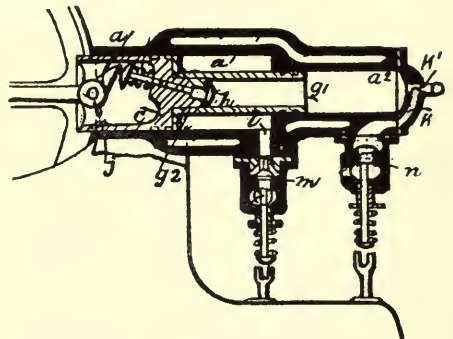
FIG. 171.—Two-Cycle Engine.

vacuum caused by condensation in the chamber T, causes a fresh charge to enter through E; products are again discharged on the first part of the in-stroke, and then, after the port R is covered, the new charge is compressed. The chamber T is cooled by circulating water around it. The bell shown is divided by a partition H, so that the air shall not mix therein with the gas which is supplied by the pipe G.

Also in J. F. Shaw's Specification No. 18,377, 1888, the cylinder is formed of two diameters a^1, a^2 (Fig. 171), in which a common piston c works, and which are periodically put into communication with each other by means of a port g^2 and valve h actuated by

a heel j on the connecting rod. A cycle is completed in one revolution. During the out-stroke the valve h is open, and the pressure resulting from the explosion acts on both faces of the piston. At about half-stroke the exhaust port l is opened and the pressure reduced to that of the atmosphere; the exhaust port is then closed again, and a new charge is drawn in during the remainder of the stroke through the valve n and ports K, K^1, the exhaust being carried before it into the larger part of the cylinder a^1. On the in-stroke the valve h closes, the charge is compressed in a^2, and the exhaust is expelled from a^1 through the port l. The exhaust valve m is a double-faced beat valve between two seats; and both it and the admission valve n are actuated by cams on a counter shaft parallel with the axis of the cylinder.

Also a very good design in Specification 13,572, 1889, by C. F. A. M'Allen, which says, referring to Fig. 172:—

An exhausting pump h is arranged beneath the cylinder, and is driven from the crank shaft through linkwork, as shown. When the piston a^1 has nearly reached the end of its out-stroke the piston h^1, which has just uncovered the port g, moves quickly outward, drawing the products from the cylinder a, and drawing a new charge in behind them through the valve f. The charge is compressed by the latter part of the in-stroke of the piston a^1, and the exhaust is expelled from the pump h through the valve m on the in-stroke of the piston h^1.

In fact, this idea has never been appreciated until the Gothic engine recently intro-duced came into vogue; nevertheless, it is by far superior to the 2-cycle engines working by a compression pump.

In a marine engine of small powers a governor is not necessary; hence this engine is shown in Fig. 173 with only two automatic valves E and V, the exhaust and inlet valves respectively. There are no cams or valve rods or gear wheels, only a contact for electrical ignition on the drawing shaft, and that also is not required if hot tube ignition is adopted.

FIG. 172.—Two-Cycle Engine.

The larger piston P creates a partial vacuum, which, when the end of the working stroke is reached, sucks the exhaust into the condenser C through ports B and D. An opening A opens through a valve to exhaust pipe in order to reduce the pressure to atmospheric before the piston uncovers the port B. The partial vacuum having drawn in the charge through V, it is compressed on the up-stroke, and the gases in the large cylinder compressed out and the exhaust forced through E valve. A circulating water pump circulates cooling water round the cylinder, and in most of the engines the condenser is a surface condenser with tubes, through which this cold water also circu-lates. Thus the exhaust is silent and clean, and the engine works noiselessly.

The crank pin is always under compression, as it is in good high speed steam engines single acting, and with a pair of cylinders as shown in Fig. 173, the engine gets two impulses per revolution. With four cylinders and two pairs of cranks at right angles this engine has no dead points in a revolution.

In order to start and reverse the engine compressed air is used, and it is stored from the engine during the last revolutions before stopping. By closing the gas or oil off, and closing the exhaust pipe valve, the air then drawn in by piston P is forced through valve E in a pipe leading to the reservoir. In another method burnt gases can be used and stored from the cylinder, as in the Berthau engine.

For large powers, if the Vogt engine proves as successful in larger sizes as it has done in the small size, it will be the marine engine to be preferred.

Meanwhile a vertical engine on the Körting system, with two double acting cylinders, working on cranks at right angles to each other, giving four impulses each
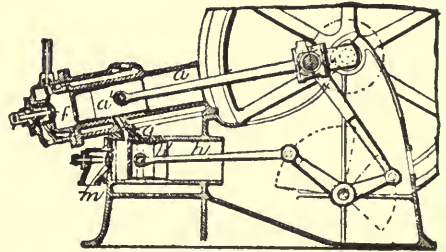
revolution, will be used ; only, instead of pumping in the charge under pressure, the charge is to be drawn in by suction exactly as described for this single acting engine. Producer gas made from cheap coal slack being the fuel used.

In large power units the Beau de Rochas 4-cycle engine is impossible, especially with poor gas. The bulk of air and fuel must be large, and the cylinders, even if four are employed, become large in size compared with the power given out. It is therefore
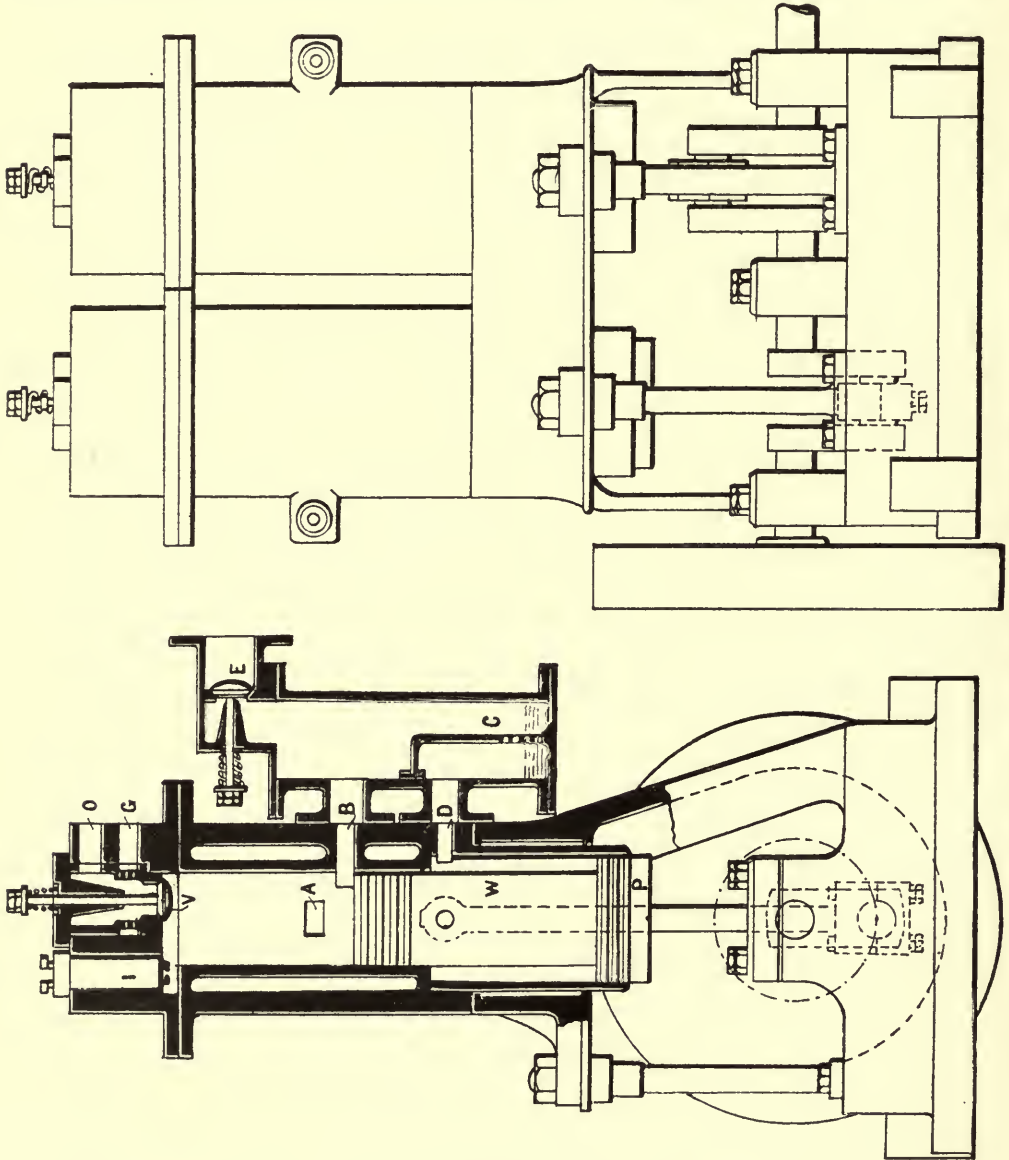

FIG. 173.—Transverse Section and Elevation of a 2-Stroke Marine Suction Gas Engine

necessary to have double acting cylinders, and in large marine engines the author recommends four double acting cylinders working exactly as four double acting steam cylinders, in order to secure great power in small space ; and by dividing the power up between eight impulses per revolution the cylinders may not be very large and are easily kept cool.

A condenser and air pump serves all the cylinders for exhaust. The pump has only to maintain a partial vacuum in the condenser of about 2 or 3 inches of mercury.

Having recently had occasion to make out designs for a marine gas engine of 1000 horse-power for marine propulsion, the sectional views of the same are here given. The engine is designed for power gas, and to work by a suction producer or gasogene. The novel feature is the adoption of a condenser much the same as a steam marine condenser, with an air pump to maintain a partial vacuum in the condenser, and all the cylinders of the engines exhaust into one condenser. There are no pumps, either for pressure or suction, between the condenser and the engine cylinders. The inlet valves of the engine are operated by cams from one shaft, and the exhaust does not pass through any valves, but escapes from ports uncovered by the piston at the end of each stroke directly into the condenser.

LARGE MARINE GAS ENGINE DESIGNS

The Körting type of engine, modified as indicated in the foregoing paragraph so as to dispense with pumps and as many valves as possible, lends itself to good design for marine purposes. The engine room on board of a vessel is preferably open right up to the top deck, in order to allow free access to the engines and ventilation of the hot engine room, and also to save floor space. For these reasons the vertical type of engine is preferred. And in order to reduce the size of the engine to a minimum the cylinders are double acting, and each cylinder gives two impulses every revolution to the crank shaft, and the cylinders and also the piston are cooled by circulating water. No fuel except coal is worth considering, and thus coal produces gas in the gas producer to work the engine. We have found that gas producers work best when the air and steam are blown in by pressure below the fire and sucked out by partial vacuum above the fuel. This prevents leakage of gases and regulates to a large extent the rate of combustion in proportion to the engine work. It is usual with gas producers to blow in the air at pressures from 8 to 16 inches of water column, 12 inches being a fair average. According to my experience for gas engine working, it is better to divide this difference of pressure by providing a 6-inch suction above the fuel and a 6-inch pressure below the fire. In ordinary 4-stroke cycle engines the suction stroke of the piston would provide a partial vacuum sufficient if there were at least four cylinders single acting. In 2-stroke cycles the suction would be produced by a pump drawing out the exhaust and the fresh charge after it; but neither of these methods is satisfactory, the suction is not powerful enough, and results in a weak charge. For large powers it is necessary to provide for a positively powerful suction to promptly withdraw the exhaust and suck in the fresh charge with a powerful draught. This is best accomplished by a rotary exhaust fan or pump driven by an auxiliary engine or a jet ejector, so that the suction is equal at all speeds of the large engine; but in cases where the engine is to run for long periods at constant speed, then the pumps may be driven direct from the engine's shaft. I prefer, however, to run the blower pump and the exhauster pump by a separate engine, and steam for this engine is readily obtained from the waste heat of the gas producer and engine exhaust gases when the engines are working, and from a donkey boiler when in port.

The engine is shown vertical with two double acting cylinders. The condenser or boiler is shown coupled to the engine by a vertical pipe, but in practice this pipe would be converted into a tubular boiler, in which the exhaust gases would raise steam by imparting their heat to the water, and thus would be cooled considerably before reaching the cooler and exhauster.

The piston in these large double acting engines being, as it were, between two fires, must be water cooled. This is done easily by a trombone arrangement through the hollow piston rod. The rod is a tube inside of which is a second concentric tube connected to a sliding water feed tube. Water enters the piston by the concentric inner tube, and leaves by the annular space between the two tubes.

Referring to the illustrations Figs. 174 and 174*a*, the motion parts of the engine are

much the same as those of a standard marine steam engine, and there is no reason why they should be otherwise. To box them up out of sight in a crank case would be absurd, although among the oil and petrol motor car engine makers this proceeding is fashionable, and none dare to be out of fashion in the motor car circles ; yet when we come to marine engines, the conditions are so far different from motor car conditions that open engines must be insisted upon, and other departures from the conventional motor practices must be made when marine propulsion by internal combustion engines is seriously considered for commercial purposes. The present craze for sporting small boats is met by light weight high power motor car engines, grandiloquently called Marine Engines, fitted into boats of small draught, narrow beam, and long length, a build of boat which, on the Clyde, used to be called the "ham-knife" type. This practice may be sport, but it is not marine engineering.

The marine engine is far too important in the question of safety on the sea to be trifled with, and the experience of the steam engine on board ships is not to be lightly thrown aside for the whims of the motor car engineer. Hence in designing internal combustion engines for business purposes the motor car model is useless, and engines modelled more in the shape of steam engine practice are necessarily adopted.

In most large internal combustion engines of 2-stroke operation, reciprocating piston gas and air pumps are used. These have, as already described, been abolished in the present design, as they introduce unnecessary complications in the way of valves, rods, guides, and slides. Only two inlet valves are used, and these are mechanically operated by one cam shaft, the incoming mixture following into the cylinder when the exhaust is withdrawn by the gas exhauster.

Ignition, about which more will be said presently in reference to the whole question
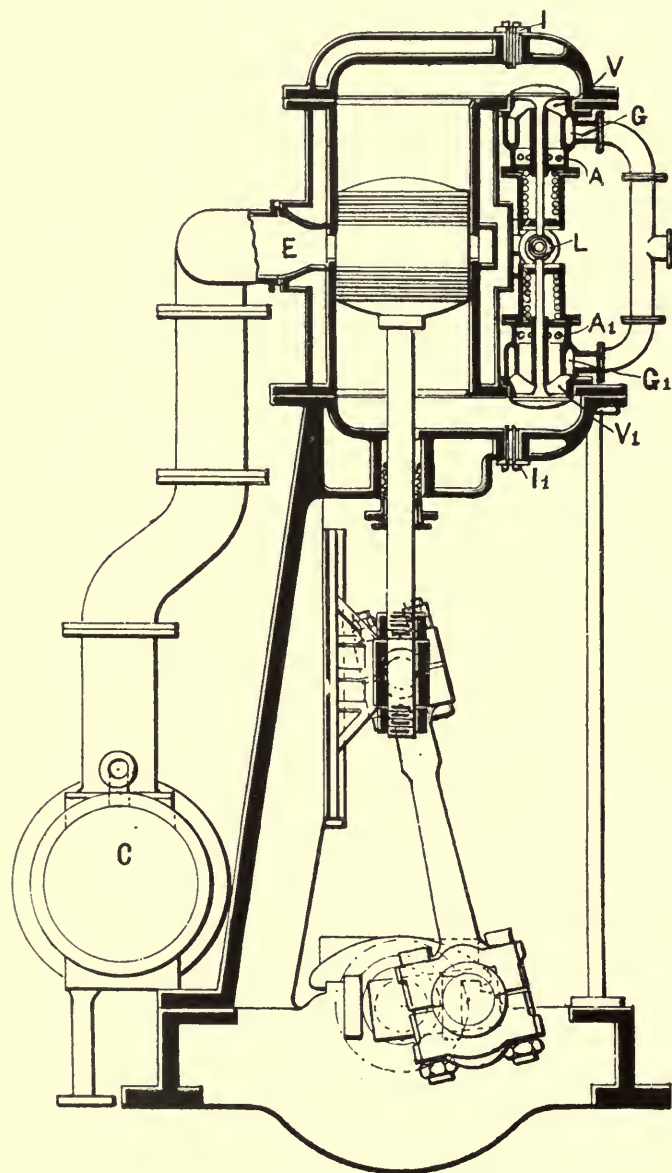
Fig. 174.—Double Acting 2-Stroke Gas Marine Engine. Sectional View.

of igniters, is shown to be by electric spark, but might of course be by hot tube. The cylinders and covers are thoroughly water jacketed, and the piston rod packing gland also well jacketed.

As to starting these large engines, it may be here mentioned that they are to be driven by the only possible fuel for large powers—producer gas ; and in connection with
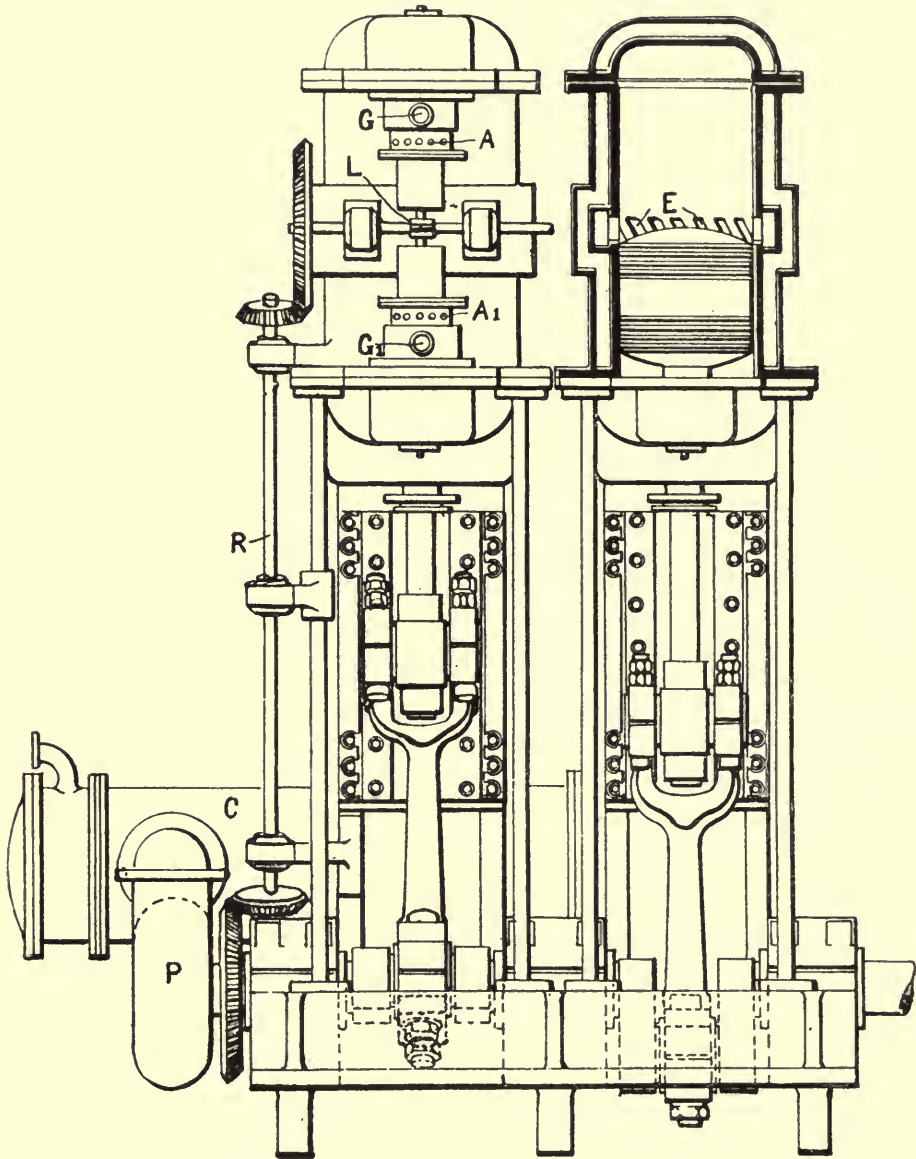

FIG. 174a.—Double Acting 2-Stroke Gas Marine Engine. Front Elevation.

producer gas, a small steam boiler of 100 lbs. pressure is used. This boiler is always in use, and heated by waste heat, but when starting up from all cold it is temporarily fired by coal. When steam is up this boiler runs the gas exhauster for the large engine, and the air blower for the gas producer ; and by a hand valve and pipe connecting it to one of the engine cylinders, the steam can be applied to start the large engines easily.

Of course, like all internal combustion engines, starting is better carried out on no load ; hence if a screw propeller is employed, either friction clutch or electric transmission

of the power must be adopted, especially for reversing purposes. It would be possible to start from rest by means of the steam. When stopping, reversing, and starting have to follow each other quickly and frequently, when berthing a ship, passing through docks or crowded shipping roads ; for these reasons, and also on account of the dangers of propeller shafts breaking and propeller blades being lost, the water jet propeller may be adopted, and then the engines are non-reversing.

The fans of the centrifugal pumps driven by the engines to supply the water jet propeller are made specially heavy, and of a construction very much like the vortex turbine wheel shown in Fig. 175.

This type of radial centrifugal pump fan works at a low speed suitable for the large marine engines without making the wheel of large diameter, the head being proportional to $H = \dfrac{V^2}{g}$ instead of nearly $\dfrac{V^2}{2g}$ when carried tangentially against the direction of rotation, as shown in Fig. 176. Ordinary manœuvring of the ship is then accomplished easily by valves controlling the water jets, while the engine and pumps run constantly on. Marine propellers are not to be treated in this volume, but one reference may be given here to the pump and valves for hydraulic propellers, for internal combustion engine
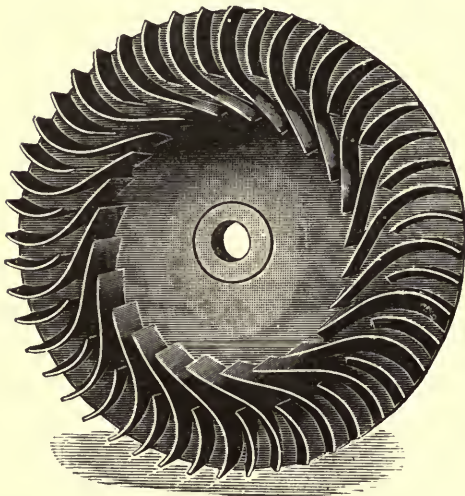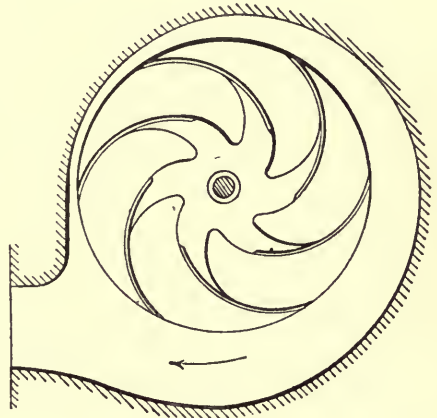

FIG. 175.—Vortex Turbine Wheel.

FIG. 176.—Centrifugal Fan.

driven vessels. It is not to be taken as an example for constructive purposes, but as well illustrating the principles of action. My own theory of the jet propeller is that the velocity or kinetic energy of the water should be, as far as possible, converted into static pressure head, while hitherto velocity only has been the aim principally.

In this example, shown in Fig. 177, the figure from Patent Specification No. 9373, 1892, granted to Mr. G. M. Capell, the *modus operandi* is clear.

In a centrifugal pump the maximum pressure of discharge from the pump casing is found to exist where the wheel approaches most closely to the case. His invention provides for both discharge pipes opening into the interior of the case where the efficiency of discharge is at its maximum.

He combines two openings or mouths with the vortex whirl. These stand one on each side of the turbine outside its case, at any convenient distance therefrom, and more or less opposite to each other. Each mouth is connected with the vortex whirl by a discharge pipe. The most convenient are a tangential one for the one pipe, and a spiral one for the other. When the pipes are led in the respective directions mentioned they both spring from the vortex whirl at the same plane. In other words, the whirl and

pipes meet each other in this plane, which cuts the case where the wheel approaches it most closely, *i.e.* in the plane of maximum efficiency of discharge.   Referring to Fig. 177, g is the tangential discharge pipe; and h, the spiral one, each connecting the vortex whirl with g^1, h^1, the respective openings or mouths already referred to.   These are shown as standing almost diametrically opposite to each other.   The spiral pipe h is shown in the figures as close to the turbine case a, but this is a detail which may be varied, and both pipes are shown as in the same plane as the vortex whirl.
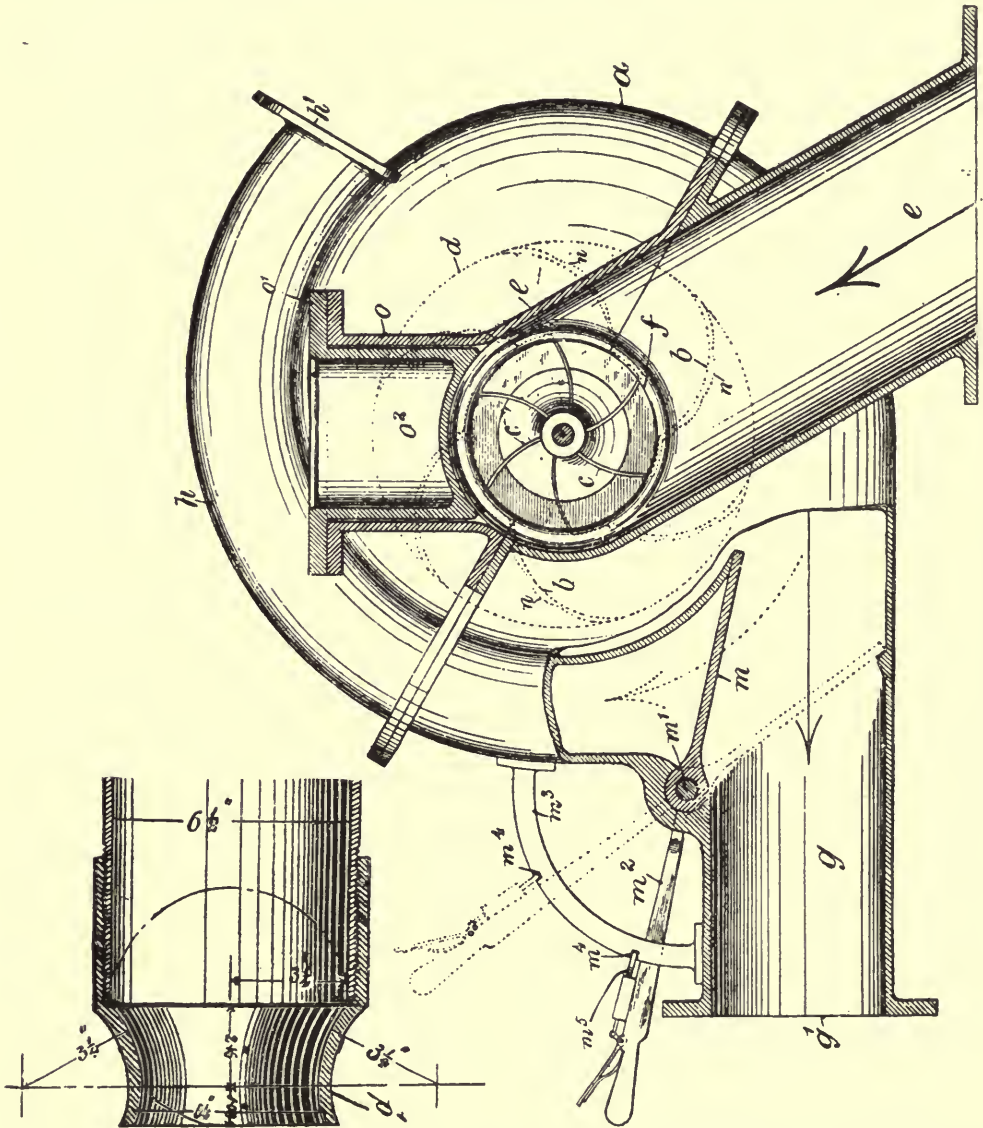
FIG. 177.—Jet Propeller Pump, Valve, and Nozzle.

Capell evidently found that the discharge required throttling through a narrowed throat to obtain back propelling pressure, and describes how to design the throat or nozzle in this same patent specification.

The improved nozzle is shown as connected to the discharge by being screwed on to its end, but any suitable method of connecting pipe and nozzle may be made use of.   Its relative dimensions are as follow :—Taking the diameter of the pipe as a constant and its value $6\frac{1}{2}$, the axis of the *vena contracta* is half the said diameter, *i.e.* $3\frac{1}{4}$, and the diameter

of the outlet 5¼.   The centres of the generating circles which produce the said diameter, as well as the sides of the *vena*, are upon a line which bisects the axis of the latter at a point one-third of the length of the axis from the outlet when the diameter of the latter is to be 5¼ ; but this dimension may be reduced to 4½.   But the dimensions first given are to be regarded as typical, for they give satisfactory results.

This, however, is not altogether correct.   The method of setting out the curve of the throat does not agree with the fact that the areas of the pipe and the throat vary as the square of the diameter ; the pipe in the above example is 33 inches in sectional area, and the outlet is said to be 5¼ or 21 inches area, and may be as small as 16 inches area,—that is, may be in the proportion of 33 to 21, or 33 to 16, *i.e.* the throat is about half the pipe area.   The correct proportions are found by experiments to be described later on.

Referring to Fig. 177, the large pipe *g* discharges through a throat aft, and propels the ship ahead, when the flap value *m* is in the position shown.   And when the valve is moved to the position shown by the dotted lines the water is discharged through another throat forward through pipe *h*, and propels the ship astern ; and when the valve is in mid position, the discharge is both fore and aft, and there is no propulsion.   The water is drawn in through a grating by the suction pipe *e*.

SINGLE ACTING 2-STROKE MARINE ENGINE

This is another engine (Figs. 178 and 179), designed by the author for ship propulsion, and intended for smaller craft—torpedo boats, yachts, packet boats, ferries, and so on. The engines are high speed, and so look small beside the central pump.   They are shown fitted with a vaporiser and tube ignition, and the exhaust is drawn out by a separate gas exhauster driven by a small oil engine, which also drives the electric light dynamo and circulating centrifugal pump.   This engine is started by compressed air or burnt gases.

This is a design for a 20 horse-power set, on a scale of ⅛ actual size, and is intended for a heavy boat for carrying goods.   The engine is shown on a pump, but may be also used with a screw propeller.

The discharge astern or ahead is controlled by a butterfly valve.   For going ahead the discharge is directly aft ; for going astern the discharge is at each side, as it is better to keep the engine well aft and not to run pipes the whole length of the vessel.   High speed is not necessary nor high efficiency when going astern ; hence it matters not that side discharge is inefficient in this case at the sides.

For smaller marine craft it does not matter much what is used either as an engine or as a propeller.   They are not of commercial importance, but have a considerable field of usefulness as pleasure launches and ship boats, and the jet propeller might be of considerable advantage connected with the little enclosed high speed motor car motors generally used in small boats.

For auxiliary power on sailing vessels nothing can equal a gas producer marine engine.   By using this water jet propeller the necessity for a propeller shaft, and tunnel, and screw outside is entirely abolished, and no engineer is required to work the machinery. Any handy man of a sailor can be readily instructed in all the necessary duties.

In a paper by the author, read before the Institute of Engineers and Shipbuilders of Scotland at Glasgow, on the subject of internal combustion engines and marine propellers, the matter was fully considered, and the following quotation from an authority on Marine Engineering, Mr. Matthey, in his discussion of the paper, may be interesting :—" While the security from breakage of shafts and the fact that the jet propelled vessel could sail well would justify a ship owner in very seriously considering whether the jet were not the better system.   And when it came to comparing a steam propelled screw ship with a gas propelled jet ship,—for that was really the question,—the advantage seemed to be entirely on the side of the jet.   The triple expansion steam engine consumed about one

and a half lbs. of coal per horse-power-hour, and the gas engine about three-quarters of a lb. ; so, supposing that with similar ships the jet required more power than the screw for equal speeds in the ratio of three to four, the jet ship would still consume only two-thirds of the coal burned by the other. He presumed Mr. Kennedy contemplated taking the gas producer to sea. No doubt, modifications would have to be made in the producer
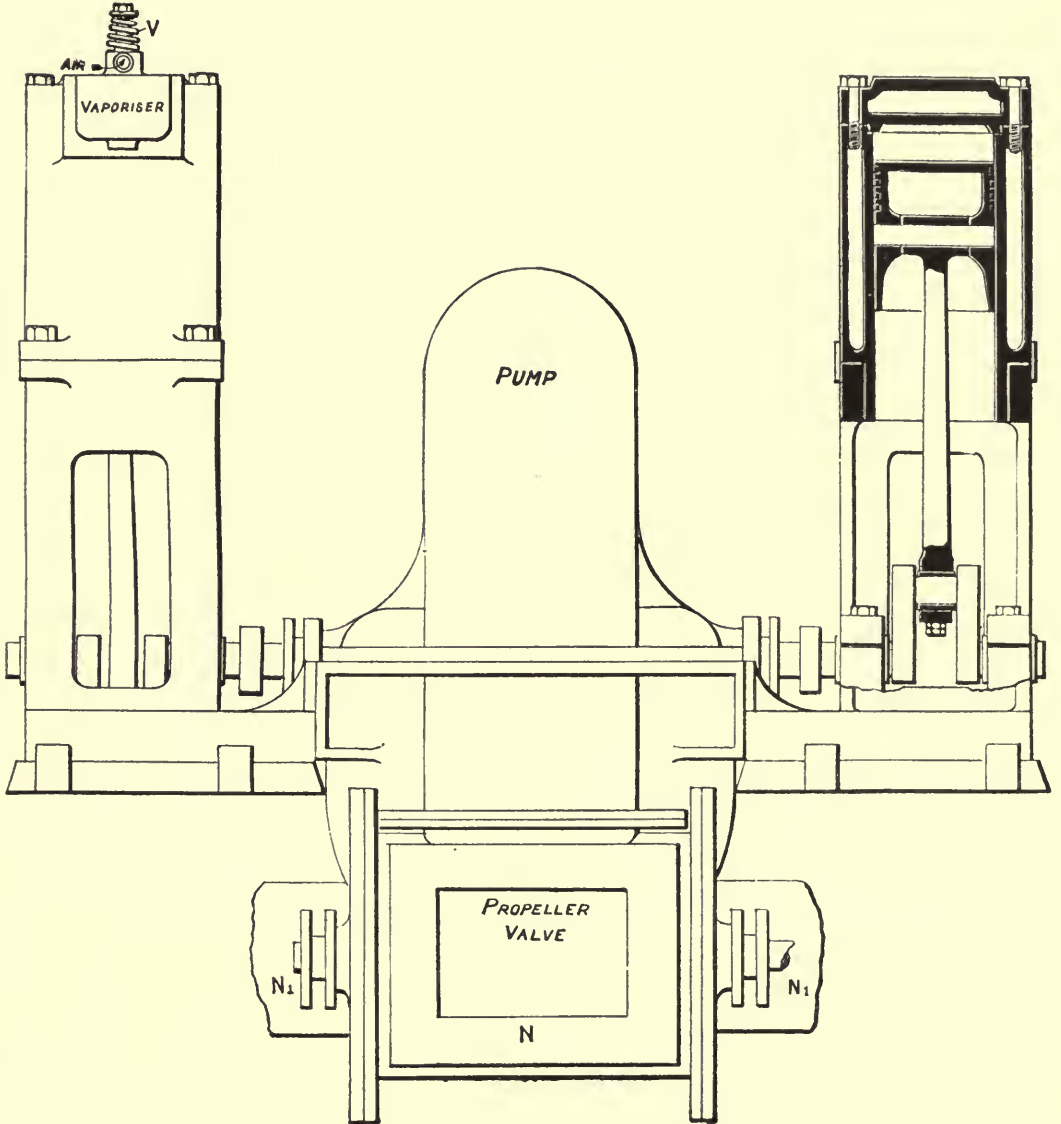

FIG. 178.—Pair of Gas Engines and Centrifugal Pump for Marine Propulsion. Front Elevation.

plant to fit it to the new conditions, but he was quite sure that any difficulties that arose could be overcome."

These are significant remarks, and their accuracy borne out by facts and figures in practice.

The gas producer part of the innovation is a most interesting element. These plants have been hitherto designed for land operations only, but a close study of them from a marine point of view has shown that they are capable of being moulded into

shape to meet the conditions.　No ship as yet has been built for continuous work with a gas producer, but encouraging experiments have been made, and therefore in next chapter we shall briefly examine the gas producer.　We have already described small suction gas plants.

The subject of naval and mercantile "GAS SHIPS," as the gas propelled jet ship has been aptly named to distinguish it from the steam ship, is one of extreme importance,—in
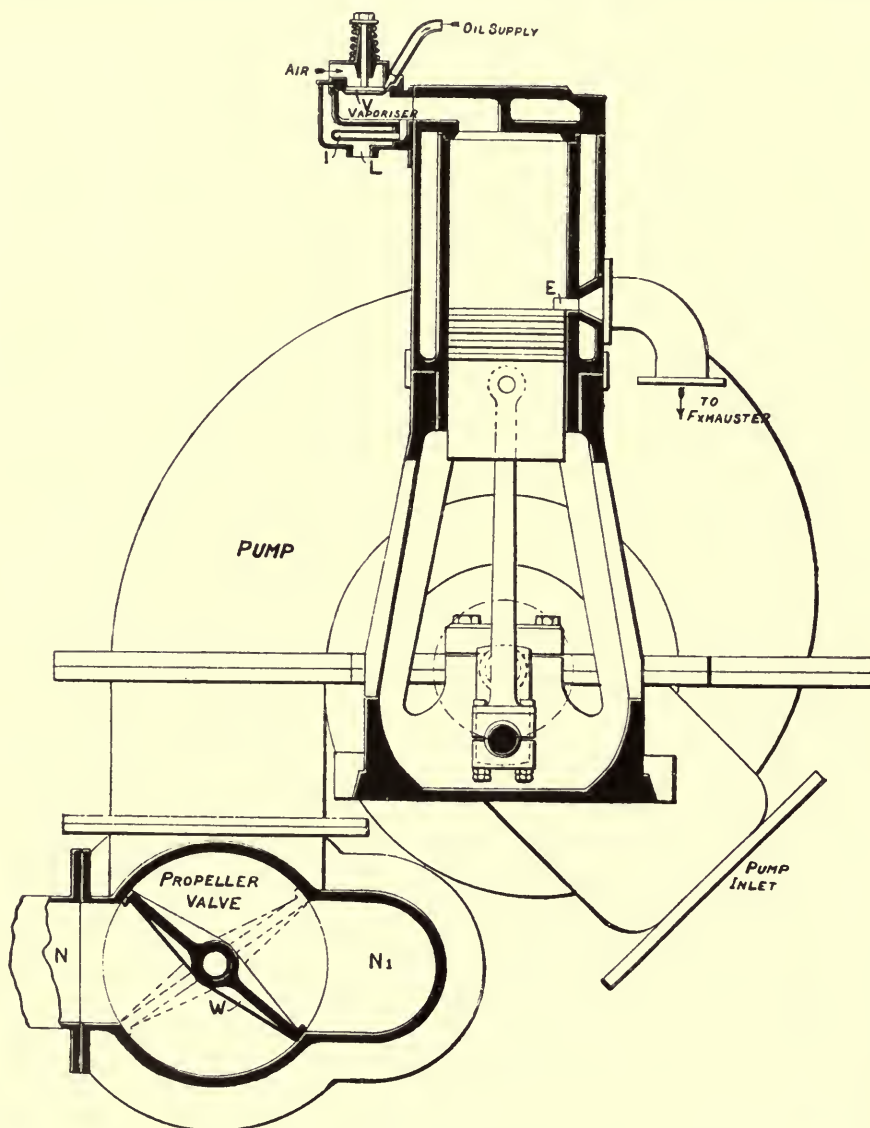

FIG. 179.—Marine Engine and Hydraulic Propeller.　Side Elevation.

fact, of national importance to Great Britain, and in the near future will revolutionise marine propulsion, especially in cargo carrying vessels.

Gas exhausters have been mentioned for these marine engines.　In this connection, perhaps the De Laval combined set, shown in Fig. 180, is the best for steam driven fans. My experience of these engines is that they are absolutely reliable.　They take up small space and require little attention ; and where economy of steam was necessary, would be

preferable.   In a boat driven by oil fuel such a plant would be useful for suction from the engine.   The capacity of the standard sizes are given in the following table:—

TABLE X.—DE LAVAL PATENT TURBINE FANS.

Size of Steam Turbine.	Size of Fan.	No. of Revolutions per Minute.	Delivery of Air per Hour.	Pressure of Delivery in Water Column.	Space occupied.		
					Length.	Width.	Height.
Horse-Power.	No.		Cubic feet.	Inches.	Ft. in.	Ft. in.	Ft. in.
3	3	2700	77,697	5.9	4 11	2 7	3 0
5	3	3000	84,760	7.0	5 6	3 3	3 7
10	5	2400	158,925	8.6	5 6	3 3	4 3

The fan, of course, requires to be made for high temperature gases, but not much above 300° Fahr.

For the water circulation nothing is better than a similar combination (Fig. 181). And the water can be sent through a jet condenser in order to provide a vacuum for the fan and pump engines to exhaust into.   These machines, the fan exhauster and the circulating water pumps, may be driven by gas engines, but as the exhaust gases from the engines and the producer gases from the producers contain a large quantity of waste heat,—for instance, the exhaust gases from the engines can evaporate 2 lbs. of water at 100 lbs. pressure per brake horse-power of engine,—it is as well to utilise this heat for these auxiliary purposes; that being so, steam and steam turbines are naturally chosen, as they are undoubtedly the latest developments of steam engineering.   If a positive gas exhauster is desired, and to be
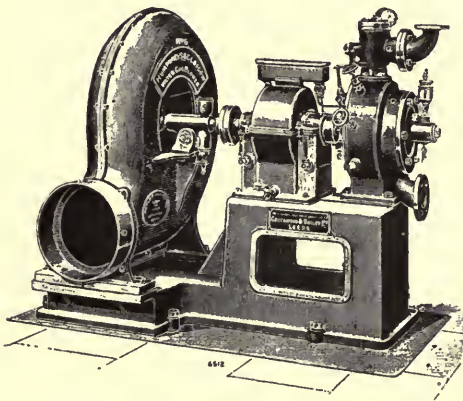

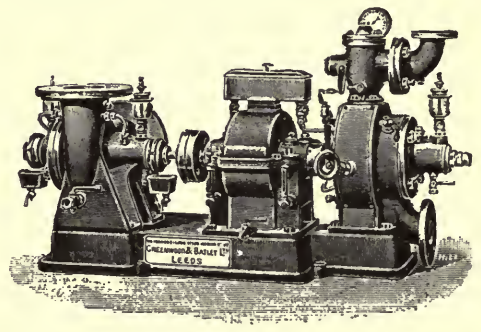FIG. 180.—Turbine Gas Exhauster.

FIG. 181.—Water Circulating Pump and Turbine.

driven on the engine itself, the Crowell exhauster is a good type.   The sliding shutters are tied together by sliding the rods, hence centrifugal forces are nearly balanced, and it works practically gas-tight with little friction.   The cylinder in which the shutters work is not cylindrical in bore, but eccentric to fit the varying radius of the shutters, and the chief point in the invention has been to design a tool to cut the cylinder bore to exactly fit the revolving shutters.   This was accomplished by the inventor, and the result is a superior high pressure blower or low pressure exhauster of air or gases, and one which, having no gear wheels, runs noiseless.

If all the waste heat in the producer gases and exhaust gases is to be utilised,—and it is better that it should be so on board a vessel,—then the blowing of the gas producer should be done, as shown in Fig. 182, by a Körting gas pressure blower by steam jet (Fig. 181a), and applied to a gas producer suitable for marine purposes.

These blowers have been specially constructed for application to gas producers,

and may be applied with great advantage to any furnaces where a blast of from 3 to 12 inches of water is required.

The furnaces can be forced or slackened by giving more or less steam. The fire-bars may be put so close together that all the fuel is effectually burnt on the bars. The fire-bars are preserved, and the stoking and cleaning much reduced. In gas producers
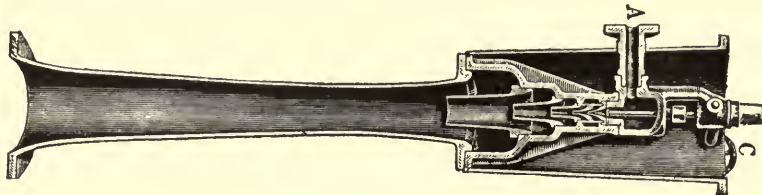

Fig. 181a.—Körting Steam Jet Blower.

with this blower on the under side of the fire and an ejector of the same design on the exhaust pipe, as shown in Fig. 183, the exhauster giving 2 to 3 inches of water column vacuum and the blower 6 to 8 of a pressure, we get all the power required to eject the exhaust and inject the new charges into the engine cylinders.

The same firm make a water-spray gas cleaner, which would no doubt meet the case on board ship; for the gases, after having been so far cooled to about 300° or 350° Fahr. in the boiler, would require further cooling and cleaning, and that may be done by a Körting spray cleaner. This Körting cleaner is shown by Fig. 184, which has proved thoroughly satisfactory, and which not only effectively cleans, but puts the gas under pressure. The principal part of the apparatus is a simplified Körting steam jet gas exhauster E. Water is admitted to the mixing nozzle to prevent
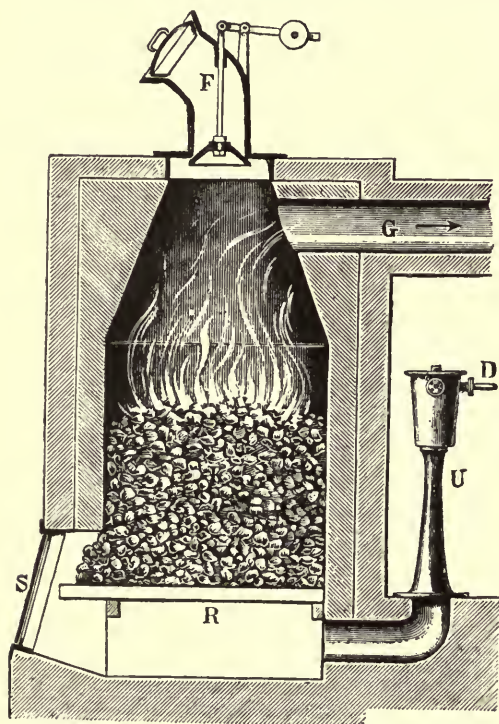

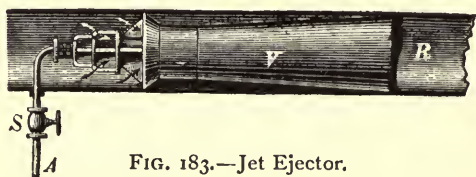
Fig. 182.—Gas Producer and Jet Blower.

Fig. 183.—Jet Ejector.

deposition of dust in the apparatus, and to effect the condensation of the steam. The water and dust particles cling together and separate from the gas. A chamber is provided under the exhauster where the water and dust collect, and from which they are discharged through a trapped drain. For further cleaning the gas passes through a vertical chamber with suitably placed wood baffles over which water is sprayed. To remove finely divided water from the gas a set of baffles is provided above, and these can be cleaned from time to time by running water through them.

With gas which is difficult to clean an additional sawdust purifier may be used, but in most cases this is not necessary.

For regulating the flow of gas through the exhauster a governor R connected to the engine supply pipe controls the steam supply to the exhauster. In marine work

this would be necessary.   Referring to Fig. 184, the gas from the producer enters by pipe G, and is injected into the scrubber; here it has to pass through a fine spray of water produced by Körting's spray nozzle.   The dust and tar and other impurities escape at A through a water seal.

It will be gathered from this that with steam produced by the waste heat and these simple ejectors and injectors the manipulation of the plant becomes very simple.

The marine engine, to sum up, would be either a double acting or single acting open motion vertical inverted cylinder engine, in which the exhaust gases will be drawn out by suction and the fresh charges drawn in by suction, so that it may act on a 2-stroke cycle and with a minimum of valves and moving parts.   The fuel for the engine is to be producer gas, and the fuel for the smaller producer plant anthracite coal, and for large marine plant ordinary bituminous coal slack.

The auxiliary machinery for blowing, exhausting, and pumping to be by steam jets in the larger vessels; and where oil is used as fuel in small vessels, the exhauster is a small turbine fan.

The starting and reversing of the large engines has already been referred to as accomplished by admitting steam by properly worked valves to the gas engine cylinders.   This is the cheapest system in first cost; but a better though somewhat more expensive system is to employ a small auxiliary gas or steam engine, and an engine one-twentieth of the power of the large engine is sufficient.   The large engine will start at a speed not more than one-fifth of full speed.   The small engine may run up to 500 revolutions per minute, while the one-fifth of full speed of the large engine might be only 20 revolutions per minute; hence they can be geared together by a reversing and speed reducing friction clutch, the speeds being 25 to 1.   By these means the large gas engines on board ship can be manœuvred as easily as steam engines of same power with ordinary screw propellers.   When the large engines are standing, and a start is to be made, the small engine is started by steam; but when the ship is going, and is to be manœuvred ahead and astern, the small engine may be started by the clutch on the large engine before stopping to reverse.
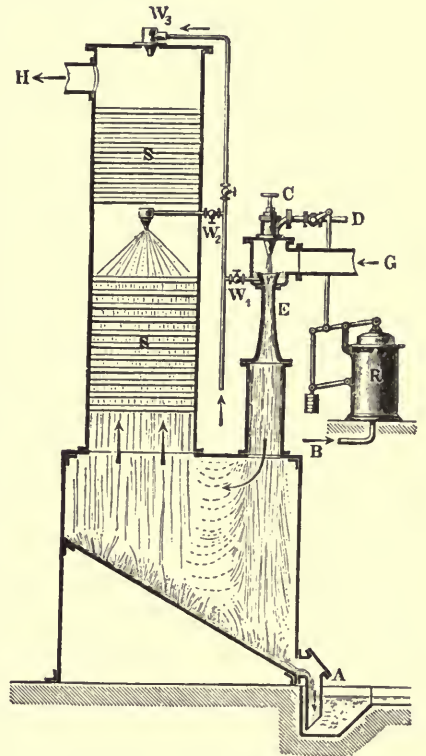

FIG. 184.—Gas Washer and Jet with Governor.

POSSIBLE MARINE GAS PRODUCERS

In order to work large gas engines for marine purposes the Siemens, Wilson, Mond, or Duff-Whitfield gas producers must be modified to meet the case, as already pointed out, and a suitably modified gas producer for the purpose will be fully considered.   Meanwhile it is to be noted just what would be gained by the substitution of gas for steam.

One ton of slack coal produces 150,000 cubic feet of gas of calorific value equal to 140 B.Th.U. (British thermal units).   A unit is the heat required to raise water about ordinary temperature 1° Fahr., and it is now represented conveniently by a symbol $\ominus$, a circle with a diametric line, in order to distinguish it more readily from other units.

In large engines this gas will give 1 horse-power for 60 cubic feet consumed; hence one ton of fuel gasified will give 2500 indicated horse-power per hour.

These results are tor thoroughly cleaned gas of regular quality, such as Mond's gas after it has passed through all the chemical processes for recovering the by-products.

The recovery of by-products on board a ship is, of course, not possible ; hence the plant must be worked without a recovery process, and not quite so cheaply.

The Power Gas Corporation now make plants for driving engines in which there is no recovery processes, and the following table has been compiled by the Corporation, which shows clearly the basis of the calculations of economy.

TABLE XI.—SHOWING COST OF POWER FROM MOND GAS.

STATEMENT OF ANNUAL WORKING COST of a 1000 Horse-Power Plant, working continuously at full load for 365 days of 24 hours :—

	£	s.	d.
Total fuel 4211 tons, including that required to raise steam for the machinery and producers, etc. (evaporation, 6¼ lbs. per lb. of fuel) at 6s. per ton . .	1263	6	0
Labour— Three men (per day of 24 hours) each working 1 shift of 8 hours	246	7	6
Other expenses, including maintenance, repairs, cost of oil, waste, stores, and sundries .	195	12	6
Total working cost per annum	£1705	6	0

STATEMENT OF ANNUAL WORKING COST of a 1000 Horse-Power Plant working intermittently, say 300 days per annum, for 12 hours per day, at an average of two-thirds of the full load :—

	£	s.	d.
Total fuel 1200 tons, including that required to raise steam for the machinery and producer (evaporation 6½ lbs. per lb. of fuel), also for standby losses for 65 days of 24 hours and 300 nights of 12 hours at 6s. per ton	360	0	0
Labour— One man at 5s. per day for 300 days	75	0	0
Other expenses, including maintenance, repairs, cost of oil, waste, stores, and sundries .	118	15	0
Total working cost per annum	£553	15	0

Cost of available gas per 1000 cubic feet . . . . . 0.778 d.
Cost of 1 indicated horse-power per hour 0.0467
Cost of 1 indicated horse-power for one year of 365 days of 24 hours . . . . . 1 14 1¼ (£ s. d.)

If coal be taken at 8s. per ton—
Cost of available gas per 1000 cubic feet 0.9662
Cost of 1 indicated horse-power per hour 0.0582
Cost of 1 indicated horse-power for one year of 365 days of 24 hours 2 2 6¼

Cost of available gas per 1000 cubic feet . . . . 0.8847 d.
Cost of 1 indicated horse-power per hour 0.0533
Cost of 1 indicated horse-power for one year of 300 days of 12 hours . . . . . 0 16 0¼ (£ s. d.)

If coal be taken at 8s. per ton—
Cost of available gas per 1000 cubic feet 1.1184
Cost of 1 indicated horse-power per hour 0.0674
Cost of 1 indicated horse-power for one year of 300 days of 12 hours. 1 0 3

If anthracite coal is used in the suction gasogene the cost of this fuel may be as high as 25s. per ton. The amount consumed in large gasogenes is about 20 ounces per brake horse-power, and the water required for washing and steam about one gallon per indicated horse-power-hour. Although this anthracite coal is a costly fuel, and not so readily obtained anywhere as ordinary coal, yet the saving in cost in wages of stokers, and in maintenance of boilers, pumps, condensers, and other plant, brings out the gas engine, even when using anthracite at 25s. a ton, as cheaper than steam.

Even at 32s. per ton for anthracite coal the cost for fuel is not excessive, as may be seen from a table of tests made by Mr. J. Whitworth, with a Dynamic Gas Company's gasogene.

TABLE XII.—TEST OF DYNAMIC GAS PRODUCER FOR COAL CONSUMPTION.

(Made by J. Whitworth, Engineer.)

Name Size } of Engine, Speed and Description of Brake.	Condition of Producer before and after Test.	Starting up Producer. Time.	Coal Consumption. Best Welsh Anthracite Nuts used.
Crossley Bros.' "Otto." 8½-inch cylinder. 15-inch stroke. 250 revolutions per minute. Brake, 44 inches diameter to centre of rope. Weight of } cast-iron } 101¾ lbs. pan . . } Weight in pan 42 ,. ———— 143¾ ,, Spring bal-} ance showed } 8 ,, $(W-w) = $ 135¾ ,, Explosions counted every 30 minutes. Varied from 106 to 110 out of possible 125. Brake horse-} power . } 11.5 Indicated horse-} power . } 12.5	Producer working the day before shut down at 5 p.m. Producer ½ full of fuel. Ash pit cleaned out before starting test. AFTER TEST. After test contents of ash pit were riddled out through a ¼-inch mesh riddle. Unconsumed } large coal . } 13 lbs. Unconsumed } small coal . } 10 ,, Ash, 4 %. . 3 ,, Fuel in producer left at same level as before the test.	Started to } blow up } producer } 11.0 a.m. with hand } fan . . } Got gas . 11.5 ,, Engine } started . } 11.6 ,, Fan stopped. 11.6 ,, Load on } brake . } 11.7 ,, Engine up to } speed . } 11.11 ,, Put in first } charge of } 11.11 ,, fuel . . } Put in last } charge . } 3.35 p.m. Engine shut } down . } 4.10 ,, Total time of } test . . } 5 hours	Total coal put into } producer . } 74 lbs. Ash, 4 %. . . 3 ,, ———— 71 ,, Unconsumed } large coal. } 13 lbs. Unconsumed } small coal. } 10 ,, — 23 ,, Total coal used . 48 ,, ———— $\frac{48}{5}$=9.6 lbs. coal per hour. $\frac{9.6}{11.5}$=0.835 lbs. per brake horse-power. $\frac{9.6}{12.5}$=0.768 lbs. per indicated horse-power. COST OF RUNNING. Coal, 32/- per ton. ¼ of a penny per brake horse-power-hour. ⅛ of a penny per indicated horse-power. This is for fuel only.

REMARKS.—The producer worked perfectly constant, as seen by the engine's constant speed and very regular explosions. There is no smell or dirt. Requires very little attention,—one man for producer and engine.

Speed was counted and diagrams taken every 30 minutes.

Figs. 185 and 186 illustrate a 75 brake horse-power plant complete. The space occupied by the plant may be gathered from the following table :—

TABLE XIII.—DIMENSIONS OF DYNAMIC GASOGENES.

Size.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Engine Power . .	B.H.P. 5 to 10	B.H.P. 11 to 15	B.H.P. 16 to 20	B.H.P. 21 to 25	B.H.P. 26 to 35	B.H.P. 36 to 45	B.H.P. 46 to 60
Height of Producer .	5 ft.	5 ft. 6 in.	6 ft.	6 ft. 6 in.	7 ft.	7 ft. 6 in.	8 ft.
Height of Scrubber .	5 ft.	5 ft. 6 in.	6 ft.	6 ft. 6 in.	7 ft.	7 ft. 6 in.	8 ft.
Diameter of Producer .	18 in.	20 in.	22 in.	6 ft. 6 in.	26 in.	28 in.	30 in.
Diameter of Scrubber .	15 in.	17 in.	19 in.	21 in.	23 in.	25 in.	27 in.
Floor Space occupied .	4′ 6″ × 2′	5′ × 2′ 6″	5′ 6″ × 2′ 9″	6′ × 3′	6′ 6″ × 3′ 6″	7′ × 3′ 9″	7′ 6″ × 4′

The generator, when the engine is running, needs very little attention, and in most cases the supply of fuel into the producer will only be required about three times a day, and this will only take a few minutes each time, not more than usually occupied in feeding an ordinary slow combustion stove.

The action of the producer is perfectly automatic, as the supply of gas and steam is absolutely under the control of the engine, and needs no attention on the part of the engineer when he has once regulated the air supply at the air valve of the engine. Each stroke of the engine generates the gas required for the work being done at the moment, and also the supply of steam.

If more work is required the engine at once generates a larger supply of steam, and increases the heat in the furnace and regenerator. When less work is done the reverse operation takes place. Not one ounce of fuel is therefore unnecessarily consumed, and there are no by-products whatever. Like all other producer gas contains less hydrocarbons than the ordinary town's gas, which is made for illuminating purposes, and a larger quantity is therefore required to produce the same power. With dynamic gas, therefore, if the engine is to be fully loaded up to its nominal horse-power, a slightly larger engine will be required, but this additional first cost would be far more than paid for within a very short time.
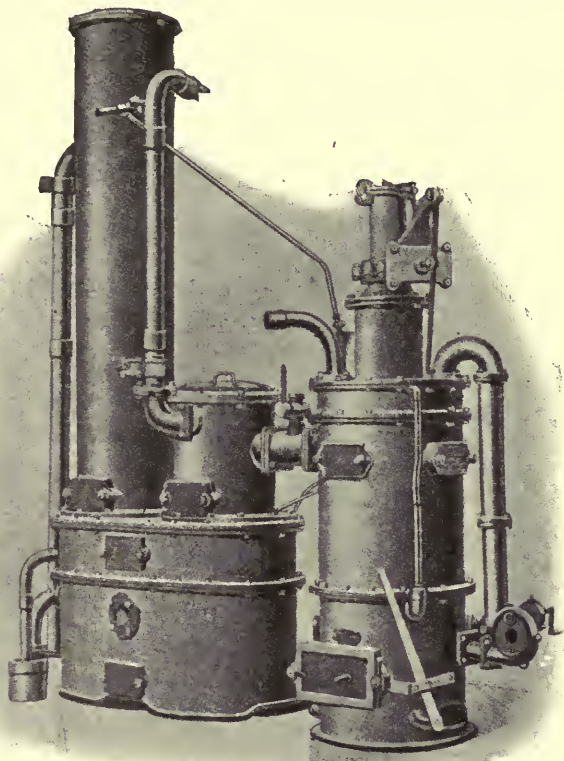
Fig. 185.—Dynamic Gas Producer.

DESCRIPTION OF THE DYNAMIC GASOGENE

A is a cylindrical gas producer of iron, standing upon E, the air chamber and fire-box. B is the boiler, which is divided internally into two chambers,—an upper chamber, which acts the part of a steam generator, and a lower chamber, round or through which the hot gases from the producer pass on their way to the gas washer or scrubber N by means of the connecting pipe SK. D is the door of the air chamber, so that when this door is open the ashes from the producer can be removed. F is a rotary fan, or blower, worked by hand, which is used to blow the fire for a few minutes when first lighted. H is an open tube to lute the water in the boiler B, and Z is a tube through which the water is introduced into the boiler. No explosion is possible, as the end of the tubes H and Z are always open. S is the outlet for the gas into the pipe K after it has passed round the annular belt which forms the lower part of the boiler B. L is a large sluice valve which, when open, communicates with the outside of the building, either by a separate pipe or by connection with the exhaust pipe of the engine, if more convenient, as it is only used for a few minutes after lighting the fire in the producer. C is the hopper through

which the fuel is introduced into the producer. U is the dome-shaped chamber which contains the supply of fuel fed automatically by gravity into the furnace. All joints, both in the hopper and the door of the air chamber D, are air-tight, as the producer is a closed hearth producer, and works by aspiration of air and steam under a slight vacuum. When the engine is started the fire box is, of course, hermetically closed, and never opened until the engine stops, however long this may be. If the fire
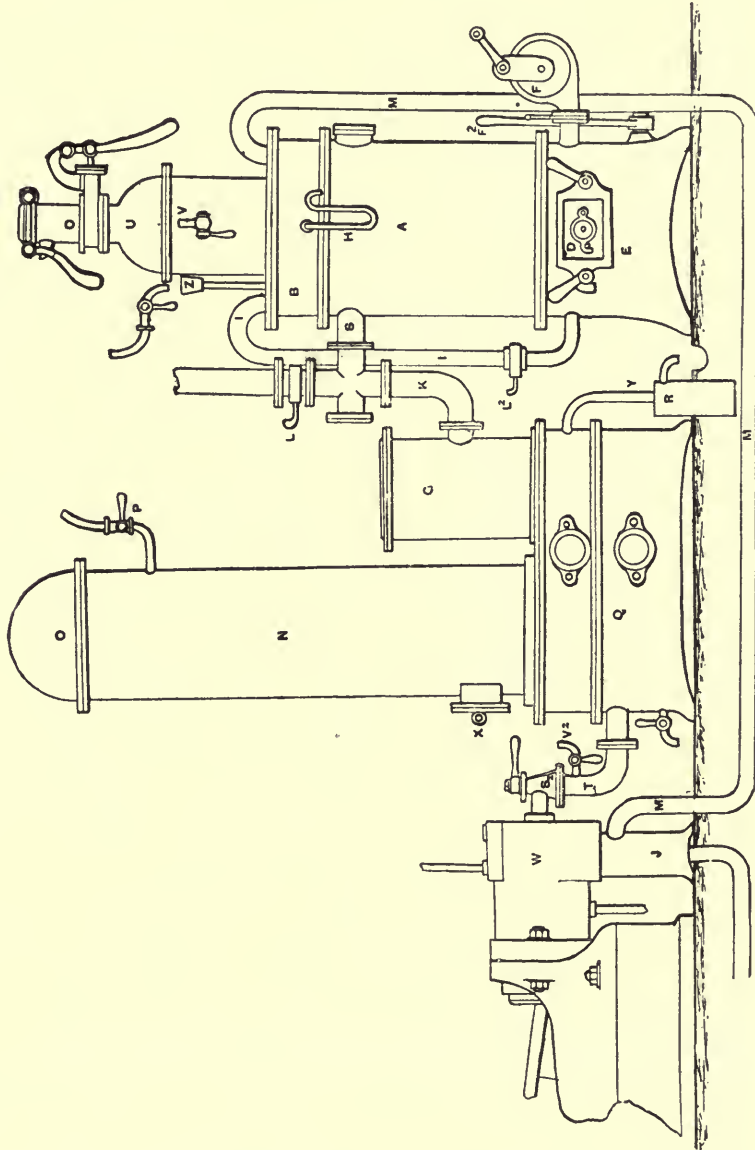

FIG. 186.—Dynamic Gas Producer and Engine. Complete View.

should require any attention the ashes may be made to fall by means of the vertical lever F_2, seen close to the fan, without opening the doors. The pipe K connects the producer A with the gas washer or scrubber N. G is a trap to catch any fine coal dust which may be carried over by the suction of the gas. This scrubber is of cast or wrought iron, cylindrical in form, and standing upon a gas expansion chamber Q. The scrubber is covered by a dome-shaped lid O. The washing water is introduced by the tap P. The pipe Y passing into the open vessel R lutes the bottom of the gas scrubber,

and carries off the water which has been admitted by the tap P. X is a door to remove the packing of the scrubber when it requires cleaning or removal. T is an outlet pipe which conveys the washed and cooled gas by the valve S_2 to the gas engine W. J is a regenerator which heats the air required for combustion by means of the heat generated by the explosion of the gas in the cylinder of the engine, and this heated air is conveyed direct into the steam space of the boiler B by the pipe MMM. The pipe I conveys the mixed hot air and steam into the fire box E.

CROSSLEY BROTHERS' GAS PRODUCER

The producer might with advantage be applied to marine gas engines. The A type, shown in Fig. 187, is intended for slack coal fuel, and for powers of 250 horse-power and upwards. It works on pressure, and is started up by a small hand blower or fan. It has a rotary grate whereby the clinker and ashes are constantly removed; and if clinker or ashes require removal at any time, or the fire require poking, that can be done without stopping the gas supply. There is no boiler required, as the saturator is heated by the hot gases in B.

This gas plant has been designed to meet the want of a cheap producer plant to work with slack coal.

It consists of the following main parts (see Fig. 189):—

(A) *The Producer*—which is a cylindrical firebrick lined chamber, the fuel being introduced by means of two feeding hoppers on the top, to be used alternately at intervals of one hour or more. The air and steam pass upwards through the fuel and become converted into gas, which is taken away by a central collecting bell at the top, which also defines the depth of the active fuel and keeps this always constant. At the bottom of the producer there is a water
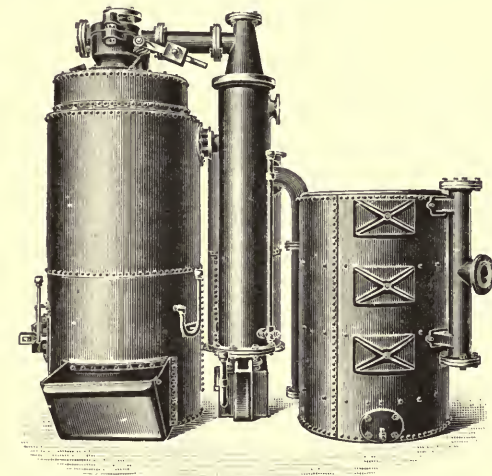
FIG. 187.—Crossley Brothers' Gas Producer.

lute to enable the ashes and clinkers to be withdrawn without interfering with continuous work; also inspection doors and means for rotating the grate, which saves poking. After leaving the producer the hot gas is conducted straight into—

(B) *The Saturator*—which consists of an inner and outer pipe, the annular space between the two being filled with water to a certain height. This is mounted on a hydraulic box. The hot gas passes down through the inner pipe, imparting the bulk of its heat to the water, which becomes very hot at the top and gives off steam. The air supply from the fan is blown round the top part of this saturator, where it mixes with the steam, and the mixture is further superheated as it passes down around the annular space between the outer and inner casings of the producer, and, travelling by a separate pipe, is led underneath the grate. The gas, on the other hand, is further cooled by the almost cold water at the bottom of the saturator, and then bubbles through—

(C) *The Hydraulic Box.*—This acts as a non-return valve, preventing gas passing backwards if the plant should be stopped at any time. It is also arranged with an inclined water trough, which enables any dust or dirt that may accumulate to be cleaned out during continuous working. After leaving this hydraulic box the gas rises up through—

(D) *The Coke Scrubber*—where it meets a small quantity of water trickling down through the coke. The bulk of the tarry matter is here washed out of the gas, and the

latter is further cooled to the temperature of the atmosphere. When the gas is to be used in engines it is then passed through—

(E) *The Sawdust Scrubber.*— This is specially arranged with a very large surface, and by taking out all the last traces of dust and tar makes the gas sufficiently clean, cool, and dry to work satisfactorily in the engines.

The plant for smaller powers consuming anthracite coal is shown in Fig. 188.

For cargo and passenger ships 1000 horse-power is about as small as an average boat worth considering, hence a general view of 1000 horse-power gas generator is well worth considering, and for the purpose the Mason producer has been selected. The general plan and elevation of the plant is shown in Fig. 190 in plan and elevation, according to Duff & Whitfield's patents. In the plan it will be noticed that the various parts are scattered about in a rather straggling group. On board ship this arrangement would not be tolerable; the whole plant would be packed closely into small space.
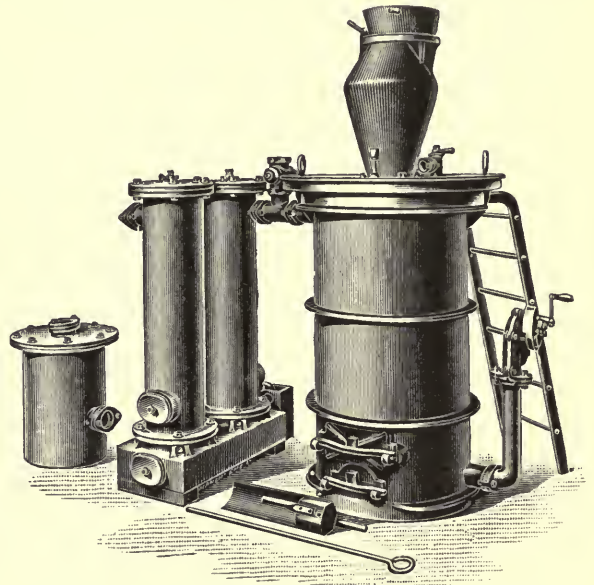
FIG. 188.—Crossley Brothers Gas Producer.
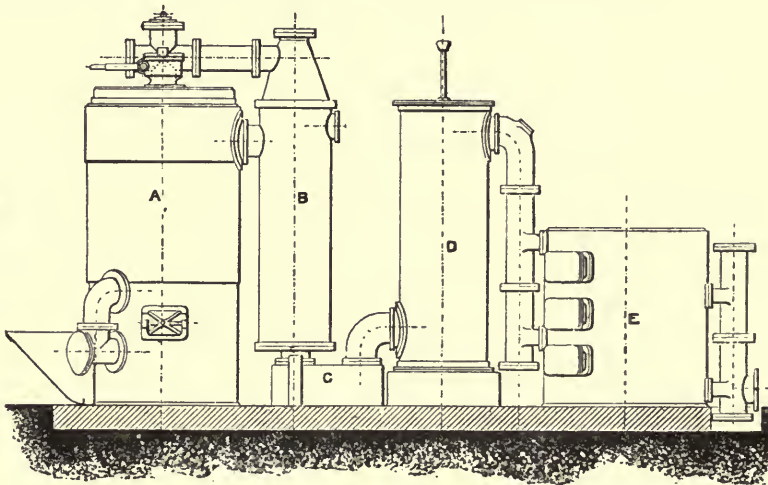
FIG. 189.—Crossley Brothers' Gas Producer.

The following is an index to the Figs. :—

A, Continuous gas generator on the Duff & Whitfield combined patents.
B, Superheater, or gas cooler boiler.
C, Coke scrubber or washer.

DD, Sawdust gas drying boxes.
R, Root's blower.
S, Vertical steam boiler.

Other parts not shown are :—

Gasholder, when required.
Connecting pipes.

Valves.
Hydraulic boxes.

The donkey boiler S can be arranged to be fired by the gas or by the coal, so that when in port the vessel could be worked, if necessary, without the gas plant being run.

This improved gas producer (Fig. 191), which is being made by W. F. Mason Ltd., Longsight, Manchester, embodies some novel and interesting features. The arrangement of inclined grate and water bottom are in accordance with Mr. Duff's well-known patents. The novel features introduced by Mr. Whitfield are the circulating pipes and steam
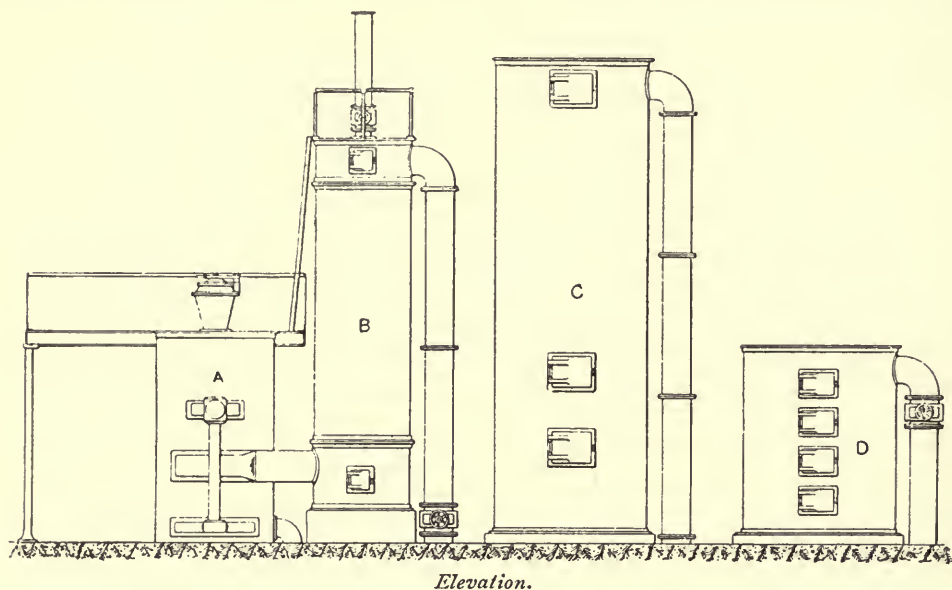
Elevation.
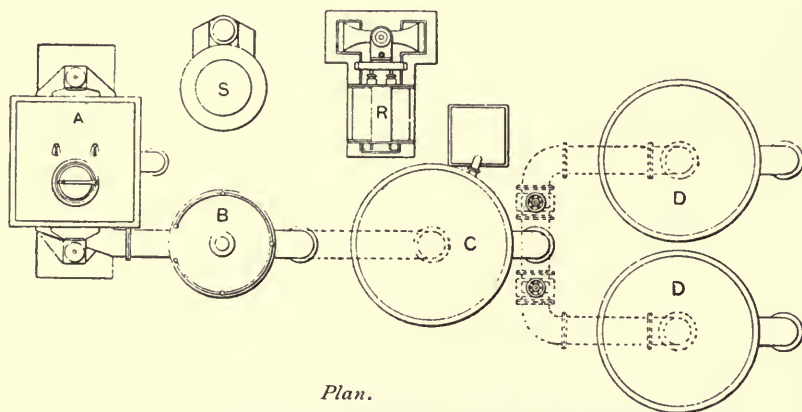
Plan.

Fig. 190.—Mason's Gas Producer Plant. 1000 Horse-Power.

blowers fixed on each side of the producer, as shown in the sketch, and the action of which effects a great improvement in the quality and richness of the gas produced.

In the ordinary producer the air supply is injected by means of a steam jet blower into the space below the inclined grate, and the gases produced by the passage of the air and steam through the fuel, along with the light hydrocarbons distilled from the coal, are drawn off from the top of the producer. Gas produced in this way is large in quantity, but its calorific value is rather low, and it is, moreover, liable to be contaminated with tar vapours, which, if not carefully removed by subsequent washing, are very liable to give trouble by the deposition of the tar on any engine surface with which
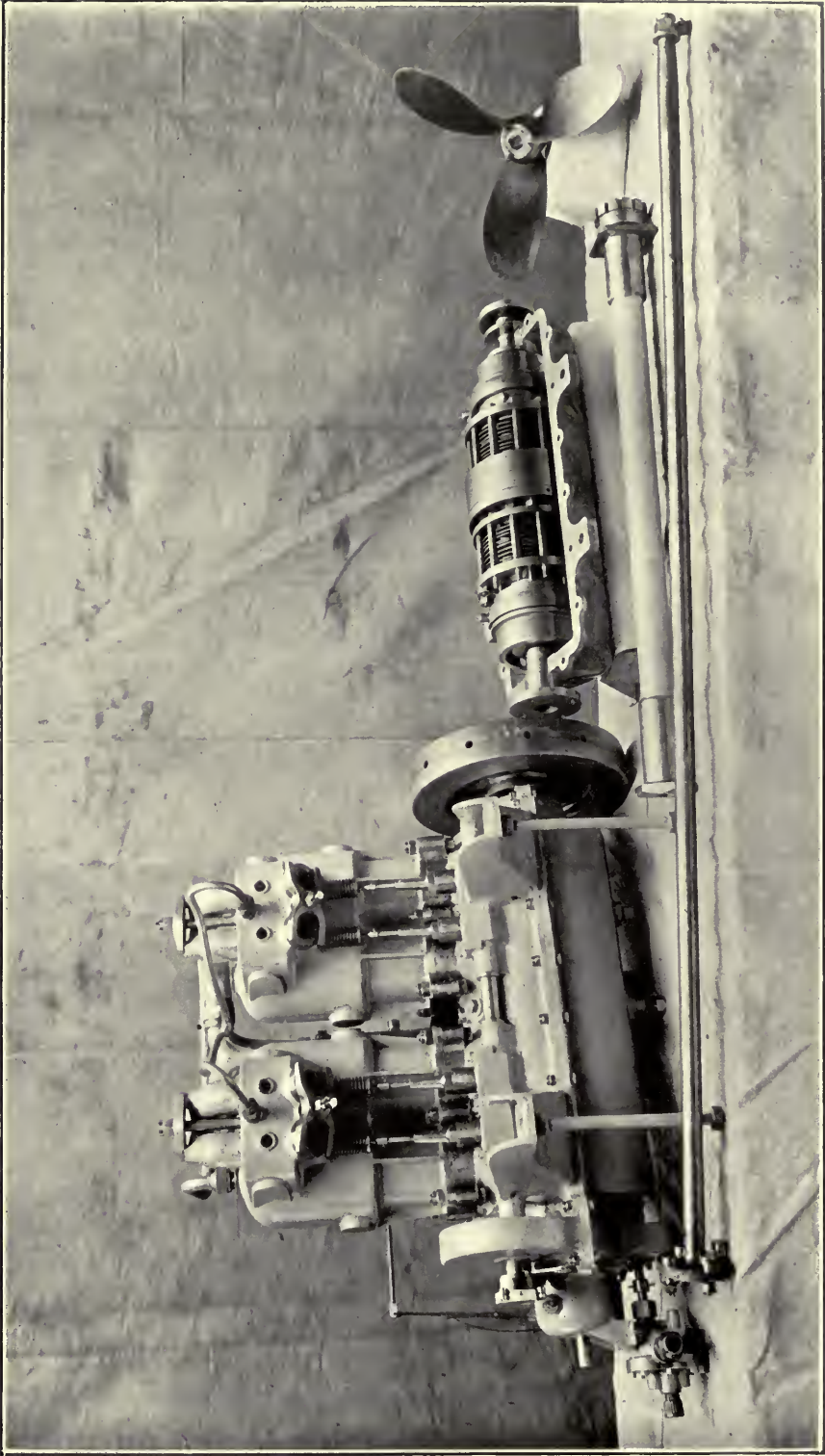
PLATE VI.—MARINE OIL ENGINE, WITH "HELE SHAW" REVERSING FRICTION CLUTCH, SHAFT, AND PROPELLER (SIR J. THORNEYCROFT, LONDON).

it comes in contact, and thus, if used for power purposes, causes trouble by interfering with the proper working of the valves, etc., besides which, of course, such tar deposit represents loss of calorific value.

In the Duff-Whitfield producer here illustrated (Fig. 191) the air supply, delivered under the grate at the bottom of the producer, is supplied by a mechanical blower, and is only slightly saturated with steam, and the characteristic feature of Mr. Whitfield's patent is the method of dealing with the volatile portion of the coal (*i.e.* hydrocarbons or tar vapours), which is converted into gas near the top of the body of fuel in the producer. In ordinary practice these gases, which consist mainly of tar vapour, pass away with the hot producer gas (which mainly consists of carbon monoxide, carbon dioxide, hydrogen and nitrogen). In the Whitfield producer the outlet is not at the top of the producer above the level of the fuel, but at one side, as shown, and below the surface of the bed
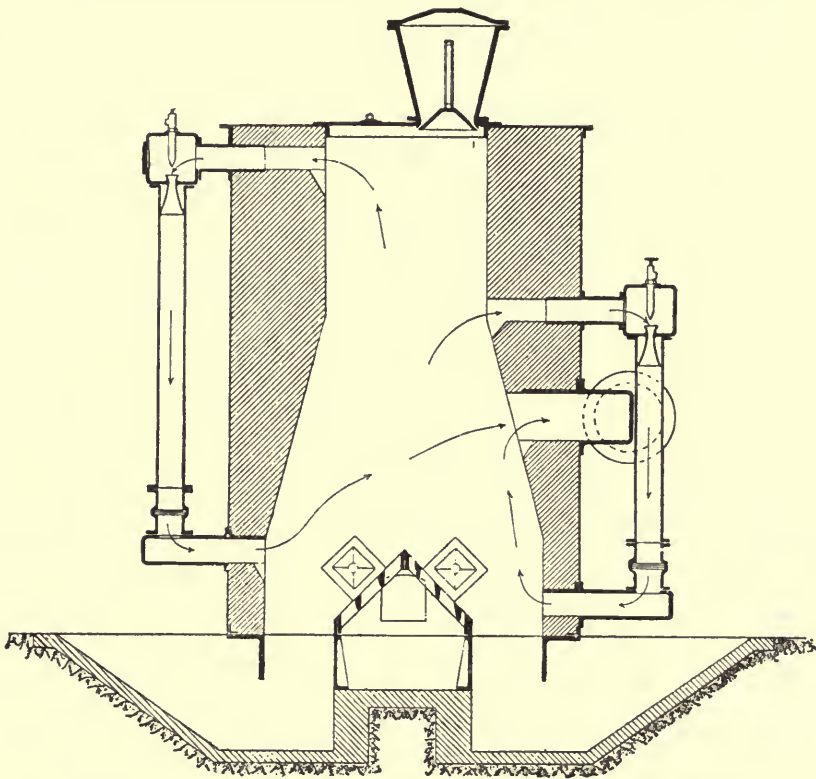
Fig. 191.—Duff-Whitfield Patent Gas Producer.

of fuel. The easily volatilised hydrocarbons, driven off from the upper surface of the fuel, are collected by the steam injecting arrangement shown at the left-hand side in the vertical section, and forced into the incandescent fuel near the bottom of the producer, but above the zone of combustion. Here the steam used in the jet is dissociated, the oxygen therein combining with the carbon of the hydrocarbons to form carbon monoxide, and passing away through the outlet on the right-hand side, where, it will be noted, another similar steam circulating pipe is fixed. Though placed at a slightly lower level, the object of this second circulating arrangement is to supplement the action of the first one, and its function will be readily understood when it is remembered that, while the main bulk of hydrocarbons are evolved at the upper surface of the fuel, large pieces of coal and masses of caked fuel sink some distance before the heat can act upon them and drive off all their volatile products, and it is to catch these and recombine them with

steam, by driving them through the bed of the fire near the bottom of the producer, that the second circulating arrangement is fixed.

It is important to note that no air supply is admitted to these circulating pipes ; their object solely is to draw off the volatile hydrocarbons or tar vapours evolved near the upper layers of fuel, and by combining them with steam convert them into carbonic oxide and hydrogen free from any diluent. Through these pipes there is a continuous circulation going on, the rapidity of which is easily controlled by the steam jets. As the bulk of the light gases are driven off at the upper surface of the fuel the flow is adjusted so as to be most rapid through the left-hand circulating pipe, and the temperature of the producer is kept high enough at the outlet to ensure any carbon dioxide (CO_2) formed above this level being decomposed into CO by drawing it through the circulating pipe at the right-hand side and forcing it with the steam again through the fire. The manufacturers give a pretty fair comparison of the cost of various fuels and different ways of using them.

The annexed tabulated statement of the fuel consumption with the cost of running for an extended period on several of the best known sets of apparatus will prove instructive. It should be borne in mind, however, that this statement does not include anything for interest on capital, stand-by charges, or attendants' wages. Nor is the cost of water taken into consideration.

TABLE XIV.

Type of Engine.	Class of Fuel.	Price per Ton.	Consumption per Horse-Power in Lbs. per Hour.	Cost in Pence per Horse-Power per Hour.	Cost per 100 Horse-Power per Hour.	Cost per Annum per 100 Horse-Power.
Gas engine, with Mason's producer gas	{ Bituminous Coal }	8/–	¾	.03	3d.	£36
High-class compound condensing steam engine . . .	Steam coal	10/–	2	.107	10¾d.	£120
Ordinary non-condensing .	Steam coal	10/–	4	.214	1/9½d.	£240
Oil engine, Otto cycle . .	Petroleum	£6	.88	.56	4/8d.	£591
Gas engine, with ordinary producer gas	Anthracite	24/–	1	.128	1/0¾d.	£146
Gas engine (consumption, 18 feet per horse-power) . .	{ Town's gas (2/– per 1000) }		18 feet	.43	3/7d.	£490

The French engineers have paid much attention to these generators. The Fichet Heurtet plant has been much used in France, and a large power plant has been for some years running the tramway system in Orleans. This producer, which is shown in Fig. 192, has a revolving grate similar to that of the Taylor gas producer, and alongside there is a vertical air-heating chamber which forms the gas down-comer, in the top of which there are inserted some tubes for generating steam for the steam jet blower. Cooler pipes, condenser, washer, drier, purifier, and gasholder are added.

For pleasure and passenger vessels of smaller sizes the anthracite producer would be preferred for its cleanliness and simplicity to the slack coal producer ; the cost would then be just about the same as a steam plant for fuel, but there would be savings in first cost and maintenance.

Petrol and oil fuels are good enough for small launches and small yachts, so that we have plenty of examples of these small craft running about with motor car engines. Evil

smelling and noisy, they can hardly be considered as forerunners of the future type of gas engine propelled vessel. There is always an element of danger with oil or petrol on a boat from explosions or fires. When such accidents as fire or explosion or spilling of fuel by collision or otherwise happen on a motor car the occupants have a chance of escape by tumbling off the car, but on the waters it is not always safe to jump overboard, and the choice would be between burning or drowning. Solid fuel like anthracite or slack coal are always safe, easily handled, stored, and to be procured readily almost anywhere. The advantages of the gas producer boat are so many and obvious that before long shipowners will adopt them, and it would pay in many cases to pull out steam plant from old vessels and refit them with gas plants.
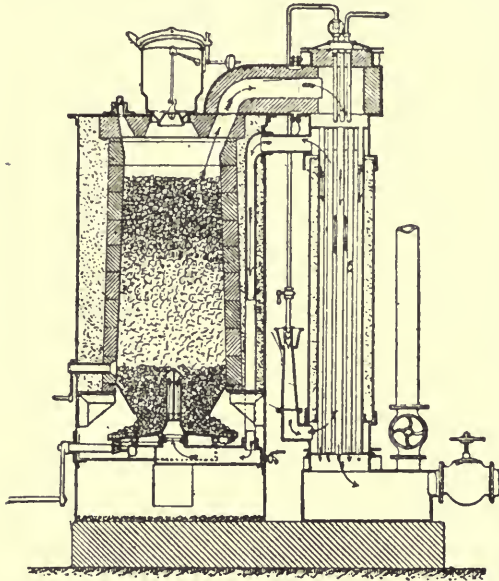
FIG. 192.—Electric Tramway Power Gas Producer.

PROPOSED GAS PRODUCER AND INTERNAL COMBUSTION ENGINE MARINE PLANT

The producer in this plant is shown in the left hand of Fig. 194 ; it is blown up by the steam jet blower described in the last section. The hot gases pass down through a vertical tubular boiler or cooler ; out of the fire box they pass into the scrubber, and from thence to the engine, from which after combustion they are drawn through another boiler of same type, and finally blown out of the funnel by a Körting ejector or chimney ventilator (Fig. 193). It will resist a temperature of 1000° Fahr., and owing to the correct calculation of the nozzles the steam required is very small in quantity. This chimney ventilator adds 2 inches of water column vacuum to the 3 or 4 inches produced by the ejector on the boiler. The gases in passing the boiler will fall considerably in temperature before they

FIG. 193.—Körting Chimney Blower.

reach the first ejector. It is advisable to have two boilers in cases where two double acting 2-stroke engines are used, and also when four 2-stroke single acting engines are used—as in marine work every possible precaution must be taken against any stoppage.

It will be necessary now to explain in detail the working of this plant in a ship. A ship so fitted will very properly be called a JET SHIP. She may be propelled by water jets ; the producer will be blown by steam jet. And the exhaust gases would be withdrawn from the cylinders by steam jets, and if there were enough steam left, as there will undoubtedly be, the water for the scrubbers will be supplied by steam jet water lifters.

Mr. Wilson, of gas producer fame, has designed a special boiler for utilising the waste heat from the exhaust gases, and he puts the matter very fairly thus :—

With a power gas plant a certain amount of steam of any pressure up to 200 lbs.
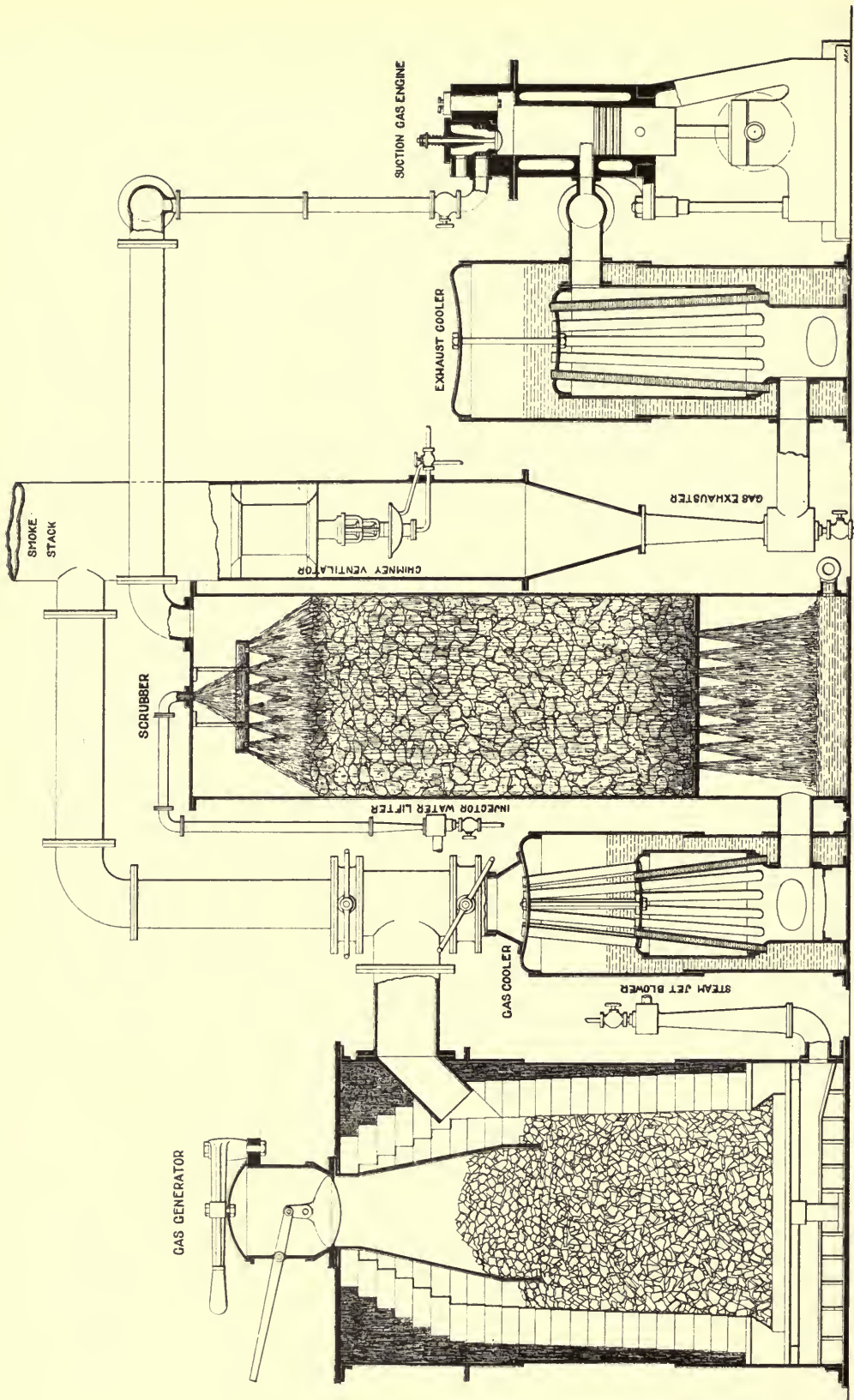
FIG. 194.—Diagram of Marine Gas Producer and Engine Plant.

SUCTION GAS ENGINE

EXHAUST COOLER

GAS EXHAUSTER

SMOKE STACK

CHIMNEY VENTILATOR

SCRUBBER

INJECTOR WATER LIFTER

GAS COOLER

STEAM JET BLOWER

GAS GENERATOR

per square inch may be had as a sort of by-product for practically nothing after the outlay for the necessary special boilers has been incurred.

The explanation of the matter is as follows :—Of all the heat generated in the gas engine, about one-third comes out in the exhaust gas at a very high temperature. By the adoption of a specially designed boiler, placed as near as possible to the cylinder of the gas engine, nearly all this waste heat can be utilised in the generation of steam, and there are a number of Wilson's patent boilers now at work in this way, constructed for steam pressures up to 160 lbs. per square inch, and giving most satisfactory results. The important point is to have the boiler as close up to the engine cylinder as it can possibly be got. Then it is constructed in compartments which, while communicating so as to permit of an equal pressure in each, prevent circulation from one to another, so that they are all at different temperatures. The feed-water comes into the compartment from which the exhaust gases are finally passing, and by this means these gases are so cooled down that they pass away at a lower temperature than that of the steam generated. In addition to this the exhaust boiler, which is of the tubular type, acts as a perfect exhaust silencer.

In large plants such a boiler is very desirable for supplying steam. And for smaller units the boiler shown in the diagram would be handy. It is a modified design of Robey's.

The circulation of the water in this boiler is perfect, and thus the generation of steam is not only facilitated, but encrustation is effectually prevented. The course of the water circulation when the fire is in the boiler is convectional ; at the upper end of the tubes it parts with the steam, returns down the side of the boiler, and, having suddenly to change its course at the bottom, it there parts with any mud it may have in suspension, which mud may be allowed to accumulate in the large space provided for it at the bottom of the boiler, whence it can readily be removed at intervals through the mud-holes.

The circulating tubes being straight, also permit any mud which may be in suspension to fall freely through them when steam is down, so that they are always kept in a perfectly clean condition.

The flue tubes are so disposed that the product of combustion, on its way to the chimney, must strike upon and pass round the water tubes, thus breaking up the flame and abstracting the maximum heat therefrom, instead of allowing it to pass away wastefully up the centre flue in a body, as is the case with other boilers.

Brine collecting in these boilers can be readily blown off from the cold still water at the bottom around the ash pit.

If the starting up of this plant from all cold into full work is now described it will be fully understood in its operation. The boiler marked Gas Cooler is first fired by coal, the smoke passing off through the two valves shown above the Gas Cooler into the funnel ; the producer has a fire also kindled on the hearth, preferably of dry wood, the draught of the funnel drawing in air and carrying off the smoke. When steam rises in the boiler the Steam Jet Blower is turned on the producer, and coal added until a bright hot fire has been made in the producer ; the slack coal is now added, and the producer filled up with it to the proper depth. The engine is prepared for starting. A small steam pipe from the Gas Cooler boiler supplies steam to the Jet Gas Exhauster on boiler marked Exhaust Cooler, and also to the Chimney Ventilator, so that a good vacuum of 5 to 6 inches of water column is produced in flues and fire box of the Exhaust Cooler boiler. One of the engine cylinders is fitted with a steam inlet valve, and this engine is barred round to the proper position for commencing an out-stroke of the piston. Steam at full boiler pressure is admitted, sending the engine off ; a few puffs of steam will enable the speed to rise. Meanwhile the top valve leading to the Smoke Stack is closed, and the gas passes through the bottom valve into the Gas Cooler boiler, from there into the Scrubber, and then to the cylinders of the engine. These cylinders draw in the charge of air and gas from the producer, and the Gas Cooler boiler having had

its ash pit and fire door sealed up, the hot producer gases pass through and on to the Scrubber. The engine will now go on working with the gas, and the hot exhaust drawn through Exhaust Cooler boiler will raise steam in that boiler also. And from Gas Cooler and Exhaust Cooler boilers sufficient high pressure steam is obtained for all purposes, as before described.

It will be observed that the engine is the only moving machine with the centrifugal pump for the water jet propeller.

The hot exhaust in the Exhaust Cooler boiler will evaporate 2 lbs. of water per horse-power-hour, so that with 1000 horse-power engines 2000 lbs. of water would evaporate if necessary in this boiler alone, but in practice half this amount of steam would suffice. The coal required, if of cheap slack, would amount to 1500 lbs. per hour. The cost of the gas per hour for 1000 horse-power would be 5s. 6d. Six men would be required to work it—three shifts of two men each shift. Three engineers and three stokers costing about £10 per week. The weight of steam required to be blown in with the air into the fuel is less than half the weight to that of the fuel consumed.

As to the coal that is suitable for use in the Wilson power-gas plant, Mr. Wilson states, "there is fortunately a wide choice. It is not the fuels that will do well that are the exceptions, but those that will not do. The fuel for choice is any description of free burning rough slack. If it has slight caking qualities it is not detrimental, but if it is of a strongly coking nature it is not suited for any gas producer. It may have a rather heavy percentage of ash and moisture, say 25 to 30 per cent., which under usual circumstances ensures its being cheap, and yet it will work well and make good power gas. The carbon should run 60 to 70 per cent., with 4 to 5 per cent. of hydrogen."

A gas plant of this description is much easier to work than a boiler plant, and requires much less technical skill "and fitters about." The labour of keeping the plant clean is trifling compared to the cleaning of boilers and their flues. There are no high pressures, no liability to leaky and blowing joints, fewer repairs of a small kind, less general depreciation, less liability to get out of order, and no boiler inspector required, nor insurance fees to pay; no trouble about stopping at night and starting again in the morning, more than with boilers.

The gases before entering the water scrubber should be cooled to deposit the tar. In a ship this would be best accomplished by a tubular cooler with cold water circulation. Through the scrubber the gases would flow after leaving the cooler; this cooler would have open flues and wide tubes, so that the gases flow easily, and any deposits of soot and tarry compounds will collect in the ash pit, from which they may be readily cleaned out. This proper cooling of the gases before they touch any water is important; for if the tar is not deposited before reaching the water scrubber it is never entirely separated, for the particles of tar are so fine and thoroughly diffused that they are carried along with the gas as a pure vapour, the water having no effect in depositing them. The tar must be cooled out before touching water.

Hitherto the anthracite coals, Welsh and Scottish, have been looked upon as the best marine fuel for boilers, and in fact the naval engineer uses no other quality, and we ship huge quantities to foreign navies. It occurs in abundance in Wales, but the output is very large, and increasing at an alarming rate, so much so that short-sighted engineers are urging parliamentary action to preserve this coal for our own navy. And all sorts of wild-cat schemes are put forward in order to reduce the consumption of it, without the least effect. As a matter of fact, there is no cause for alarm, and no need for these outcries for preservative action. Welsh coal is steam boiler coal of a very high price, but if the Admiralty and marine engineers generally would wake up they would find the steam boiler inferior to the gas producer in many ways, and that steam coal, *i.e.* Anthracite Welsh coal, is not at all necessary; for the gas producer with common cheap slack would give all the power with that cheap fuel, and that without smoke, and without the costly and dangerous high pressure boilers. The simple solution of the

question of fuel for vessels, naval and mercantile, lies under our noses while we have been groping about for a solution in other hopeless directions.

Good smokeless coal is a necessity for a marine boiler in the navy, but cheap coal is better for a gas producer, for good coal is simply thrown away on a gas producer. This is a feature of Wilson's producer.

In other systems of power-gas plant this important feature is neglected, and many troubles and complications of plant are consequently incurred. The reason of this is, that when water vapour is mixed with the gas in the process of cleaning, every atom of vapour carries a thin film of tar on its surface, and the resulting mixture is most difficult to condense and render suitable for engines.

In the Wilson system the cool and dry gas issuing from the cooling arrangement is passed through a washer, which readily removes the last traces of tar without generating any vapour. A very small water supply is required for the scrubber if the gases are previously cooled in a dry state.

In the Mason producer we have seen that the tarry matter is almost eliminated by passing the hydrocarbons through the incandescent fuel by means of a steam jet.

The cost of 1000 horse-power producer plant, not including the engines, but everything else fitted complete in a ship, would run to about £3000.

Each producer would be of 500 horse-power, and there would be three of them, any two being of sufficient capacity to supply the engines at full power.

The diagram (Fig. 194) shows the plant laid out all in line, but in practice it would be arranged compactly—the producers, boilers, coolers, and scrubbers in one compartment, the engines in another, the coal fed up by a mechanical elevator.

The co-operation of the producer, gas engineer, the shipbuilder, and the marine engineer will very soon perfect the details of this proposed vessel. There are no unknown quantities in the problems connected with it ; all the elements have been pretty well developed in land installations, and the combination of the elements of the plant to render the whole suitable for marine propulsion has been already worked out. The adoption of suction on the exhaust of the engine, thereby abolishing valves and pumps, which are necessary when the charge is forced in and the exhaust forced out, goes a long way towards success. And the utilisation of the waste heat to produce the steam for all the jet blowers and exhausters in the combination results in great economy.

The consideration of the small boats, launches, and tenders run by petrol and oil will be further treated in describing motor car engines.

Sufficient has been shown here that the internal combustion engine with producer gas will be a formidable rival to the steam engine and boiler, and the JET SHIP the ship of the future.

To sum up the present-day position of the internal combustion engine as a marine engine we may divide them into four classes.

1st. The motor car engine run by petrol or kerosene oil. It may perhaps be considered hardly worth while referring to this class, as it is only a temporary affair and belongs to a class of very small boats mostly used for pleasure or pastime. The motor car engine has been developed admirably for road vehicles, in which the engine's failure or success is not a matter of life or death ; in the worst event the passengers can get down and walk, or shove, or a horse or two can be found as a motor power for the time. Whereas the failure of a marine engine is a very serious matter, and in many cases would end in fatal disaster. In motor car conditions light weight and compactness are the first essentials. Whereas small size and weight are of little importance in marine engines, compared with the certainty of running continuously for long periods without stoppage or failure. Everything about a marine engine must have a very high factor of safety, far beyond anything to be seen on the best of motor cars. Every joint and bearing, every slide and guide must be under observation all the time. The enclosing of a marine engine crank chamber should be considered as wilfully courting disaster.

There should be extreme simplicity, and as few valves as possible ; whereas the appearance of the internals of a motor car is a frightful sight of complication. The marine engine room must be in reality and in appearance clear and simple in its arrangements. It is therefore very unlikely that the motor car type of engine will develop as a marine engine, except in the cases mentioned.

2nd. This, then, brings us to the consideration of engines designed for minor marine purposes, and we have just described the Griffin, the Priestman, Vosper, Sautter-Harlé, Thorneycroft, and Glover. These are made and used up to 50 horse-power ; and by 50 horse-power is meant brake horse-power of 33,000 foot-lbs. per minute, not the sporting power of an engine used in a racing boat. The engine should be run by cheap paraffin oil of high flash quality, with a good vaporiser. The engines mentioned can all be fitted to do so. The 4-stroke cycle engine is at present preferred, because it is at present better understood ; and the general tendency is always to go on doing what has been done before. The engine, however, is simpler and more powerful on a 2-stroke cycle, and if properly designed, to work by suction on the exhaust, instead of pressure, it seems to the author, on the whole question, to be the superior type. Built open in design, with large bearings, massive pins and rods, ample inlet valves operated mechanically, it meets the case on the score of reliability and safety. In these smaller powers below 50 horse-power a cooling chamber is necessary between the suction cylinder and the exit valve of the exhaust. This is shown in Fig. 173.

3rd. Beyond 50 horse-power and up to 250 or 300 horse-power the engine should still be 2-stroke single acting ; but oil fuel is too troublesome and expensive for these larger powers, for the smaller craft oil fuel would cost about one halfpenny per horse-power-hour. For the moderate powers up to 300, the suction gas producer plant, with anthracite coal as fuel, must be used ; the cost would then be about $\frac{1}{6}$ to $\frac{1}{8}$ of a penny per horse-power-hour for fuel. This fuel is safer and much easier handled and stored than large quantities of oil. According to the author's design, the gas producer should be worked, while the engine is at work, by a slight pressure produced by a steam jet blower, combined with the suction of a gas exhauster on the exhaust of the engine. And the exhaust of the engine is to be drawn through a tubular boiler, so that it raises enough steam to work the jet blower and gas exhauster ; no pumps or valves are in the exhaust passages, and the engine alone has moving parts. The water for cooling the cylinders is circulated by a pump, and feeds into the boiler after passing the cylinder jacket. In this design the boiler can be fired by coal, when it is desired to start up all cold. And the engine is started by steam from this boiler, the steam being afterwards a by-product of the waste heat engine. This type of engine is shown in diagram (Fig. 194).

4th. For the largest powers the bituminous slack coal gas producer is the only generator possible, and the engines may be double acting, although the single acting for cylinder 2-stroke engines may be found best, at least up to 1000 horse-power. In these large plants the steam generated by the waste heat does all the auxiliary work in the power plant. The plant is shown in Fig. 194, and fully described in last section.

Considerable attention is now being paid to this development, and hence considerable space has been devoted to it. Not much has been done practically on any commercial scale. The author's idea is to direct attention to what may be considered safe and practicable lines of procedure, and the illustrations given are selected more with a view of the discussion of the subject generally than as actual designs. The large high pressure steam boiler as a means for capturing some of the heat of fuel, and turning it into engine to produce work, must go before power gas producers, not so much because of any difficulty about the boiler itself, but because of the low efficiency of steam as a vehicle for power carriage and delivery.

In all the foregoing sections the internal combustion engines in their latest and most modern forms are described and illustrated. We have still to examine a few of that large class of engines which have been before the engineering world for a long

time as gas and oil engines. Their details and performances are of interest. It may be as well first to collect together a description of the various ignition systems in use, and proposed for use on gas and oil engines.

IGNITION

The method of ignition of the gaseous charge in an internal combustion engine is of vital importance, and is still in an evolutionary stage. The electrical ignition of mixed gases was invented long before gas or oil engines were invented, both on the high electric pressure, and low electric pressure systems, commonly known in motor car jargon as high-tension and low-tension systems. There are three systems of electric ignition. 1st. That produced by a high electric pressure causing a spark to leap across a gap in the circuit, generally between the end of a wire and another wire about $\frac{1}{32}$ of an inch apart. The high electric pressure is generally produced by an induction coil from a low pressure voltaic battery or accumulator, or other source of electric current. It may, however, be produced also by a static influence machine, such as are commonly in use for gas lighting.

2nd. That produced by breaking the circuit, carrying a current from a primary battery or accumulator, in which there is included considerable electromagnetic inertia (self-induction). The spark, so called, in this case is not a true spark, but an arc of low pressure burning across the opening break in the circuit. It is a more powerful igniter than the spark, being, in fact, a high temperature flame of burning metal.

3rd. That produced by breaking the circuit of an induced current in a coil of wire moving in a magnetic field of force commonly called " Magneto Ignition," presumably because a permanent magnet affords the necessary magnetic field of force for the coil to move in.

When a coil of wire has a magnetic flux quickly thrust into it, or quickly withdrawn from it an electric pressure is set up, producing a current through a complete electric circuit. This current starts feebly, rises to a maximum, and falls to zero, usually in one wave of current. And if the circuit is broken at the moment when the wave of current is at its maximum strength, an arc is formed of burning metal, bridging the opening gap at the break. There is no difference between this arc and the arc produced by the primary battery or accumulator with a self-induction in circuit.

Some magneto igniters have an armature driven continuously from the engine, so that they merely take the place of the primary battery or accumulator with a self-induction in circuit.

All these methods were known to the ancients, and pretty well reduced to practice by them. The modern forms will be shown herein.

Some dealers sell primary batteries for charging accumulators, to be used either for the systems No. 1 or No. 2. It must be pointed out, that to charge an accumulator from primary voltaic batteries is a very wasteful and expensive proceeding. In the first place, the cost of electricity produced by the best primary voltaic battery is about 3s. per unit; an amount which can be got from a public supply for a price varying from 2d. to 6d. And in the second place, the primary battery doing such work would have a very short life; 50 per cent. per month on its first cost would barely cover repairs and renewals. And thirdly, if the primary battery can charge the accumulator it might as well be used for the ignition itself instead of the accumulator, and so save the expense of the accumulator and trouble of charging.

There is much to be said for and against the several systems; all of them have drawbacks and advantages. The author, after thirty years' electrical engineering experience and close study of the subject, thinks the high electric pressure spark produced by an induction coil is best; and the primary current for the coil may be furnished by primary cells, accumulator cells, or magneto-induction machine.

The primary cells seem to be the simplest source of current, but those who adopt them must be prepared to treat them properly, and not to expect too much of them. The best primary cells are dry cells of good make. Many dry cells are made only to be sold, and many people accordingly have a poor opinion of them. A good dry cell can be made and supplied at a price which is not prohibitive of its use until completely discharged and then scrapped. A dry cell has a certain life, and then is of no further value.

As to accumulators, unless careful arrangements are made for recharging, and, what is more important, *never over-discharging*, they are a continual source of trouble. Many people go on using accumulator cells in preference to primary cells because they fondly believe they have the same old cell, all the time, after it has been renewed and coopered up repeatedly, whereas they have only the box of the first battery delivered.

In cases where the accumulator can be regularly charged and never over-discharged, and renewed when actually worn out, it is a good carrier of electrical energy for the induction coil or self-induction coil; but in 75 per cent. of the cases wherein gas or oil engines are used these conditions are not possible, and the accumulator is a failure. Primary cells have the advantage, in that when used up they are actually useless, and may at once be thrown away and fresh ones substituted.

Whether primary cells or accumulator cells are adopted, the user must attend to them carefully; in the first instance to renew them as they die out, and in the second to provide careful and efficient recharging, and after a while replacing the plates entirely.

The magneto-electric supply is not fraught with so much concern about renewals and replenishings, but it has points to be well considered. In the first place, the starting up question has to be considered. A continuously driven magneto machine would produce plenty of electromotive force while the engine is at full speed, but requires to be of large size to

FIG. 195.—Magneto Igniter.

provide enough force on the slow speed when starting up. And the magneto machine, worked by a cam or wiper by oscillating an armature also requires magnets of great weight, for the motion is slow. The quicker the motion which produces the electric pressure the smaller the machine may be; but in any case it must be designed to spark freely when starting up, unless tube ignition is provided for starting purposes, as it sometimes is in oil engines; for the vaporiser has to be heated up by a lamp, and this lamp may also heat an ignition tube until the engine is fairly started. The lamp may then be extinguished, and ignition carried on by electric spark or arc. This is done in the Vosper engines and in others

Vosper magneto-ignition arrangement may be taken as an example of the oscillatory magneto generator, and is shown in Fig. 195. It has been proved by actual experience to be thoroughly reliable in its action; is extremely simple, and will last for years without requiring more attention than would be bestowed on any ordinary piece of mechanism. The spark is obtained from a magneto-electric machine of special construction, the armature and magnet of which are fixed. The electric current is produced
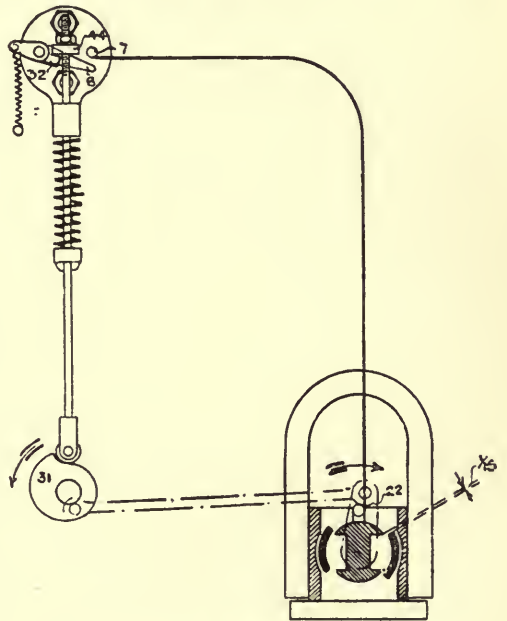
by a reciprocating movement imparted to a soft iron envelope surrounding the armature, between it and the magnets, and by means of patent gear of various designs.   The contact breaker within the combustion chamber of the cylinder is so arranged that the circuit can be broken and the spark obtained at any part of the stroke, but always when the tension of the current is at its greatest, thus invariably producing a most powerful spark.

Amongst its advantages are the following. No fear of ignition failing through rain, sea clogging, or dampness.   The means of timing the ignition, and thereby altering the speed of the motor when running. Saving of oil for lamp, and less heat.
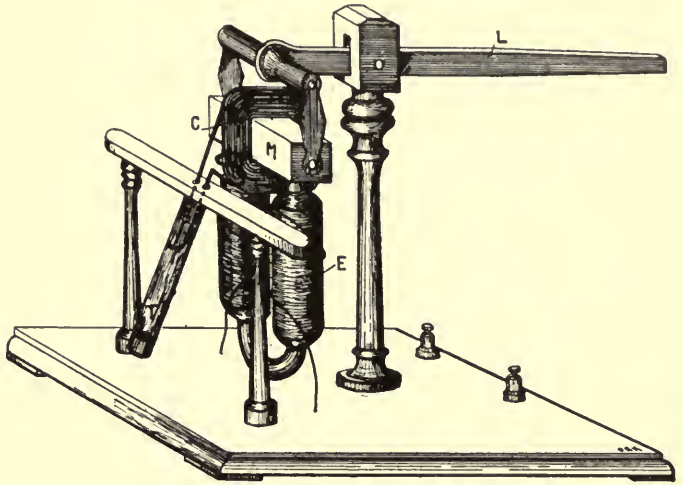
FIG. 196.—Original Magneto Igniter.

We have already shown in the Westinghouse engine the internal arrangement for breaking the circuit of the current to produce the arc in the cylinder.

Electric ignition by magneto-induction was introduced over fifty years ago in an old apparatus worth describing. It was shown at several exhibitions, and called the "thunder pump." It consisted of an electro-magnet E in Fig. 196, the keeper of which carried a long coil of wire, and it is thus described in *Noad's Electricity*. To the ends of the coil C two thick copper wires are to be soldered, in order to form a complete metallic circuit when the lifter M is in contact with the poles of the magnet E.   The magnet is mounted poles upward on a wooden stand, having a pillar with an arm or lever L passing through a mortice in the top of it, for the purpose of removing by a sudden jerk the lifter from the poles of the magnet.

In front of the magnet a glass tube is fixed, having its top closed by a cap of boxwood, through which the copper wires soldered to the extremities of the coil pass as near air-tight as possible into the glass tube ; the end of one wire, being flattened, is bent at right angles and well amalgamated. The other, which is straight, can be brought down or removed from it by means of the lever.   The whole arrangement will be readily understood by an inspection of Fig. 196.

FIG. 197.—Oscillating Magneto Igniter.

The mixed gases are introduced into the tube T by means of a bent or flexible tube.   On giving the lever L a smart blow with the palm of the hand the iron lifter M is suddenly removed from the poles of the magnet E, a current of electricity is induced in the coil, contact between the wires in the tube T is broken, a spark appears, and the gases are immediately exploded.

A good steel magnet answers equally as well as the electromagnet.   In this early machine we have the whole of the features of magneto-induction ignition of mixed gases.

Another magneto-induction apparatus is shown in Fig. 197.   This machine has been considerably used for ringing bells.   A modification of it has been made for ignition purposes.   A coil of fine wire C wound upon a coil of thin strip soft iron is carried in a German silver clamp A, fixed to the end of a stiff steel spring S.   Normally, the coil hangs between the poles of the steel magnet, and one end of the coil is connected through the spring to T_1, and the other end through a flexible spiral E to T.   When the coil is pushed aside and let go it produces a series of oscillations which induce alternating electric pressures, which will cause an arc if the circuit is broken.   The magnet may be about 7 inches long and 1 inch wide between the poles, and made of the best magneto steel. The coil of wire may be of Varley type, size of wire No. 28 S.W.G., about 3 ounces in weight of wire.   A wiper or cam on the engine shaft moves the coil aside, and at the proper moment lets it go, and immediately after breaks the circuit just as the coil swings through the magnet, and the electromotive force is at a maximum.
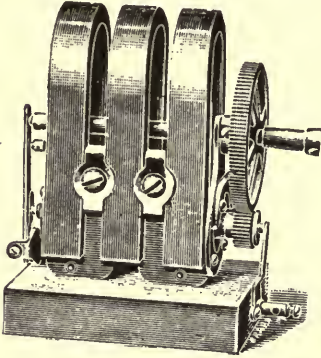
FIG. 198.—Continuous Working Magneto.

There are many possible designs for machines on these principles.   This latter design, acting on the trigger principle, gives an equally powerful arc in the cylinder, however slow the engine may be going, for the velocity of the swing of the coil is always the same when let go.

By constructing this apparatus with a heavy magnet and a coil of very fine wire, No. 40 S.W.G., a spark can be produced in an ordinary sparking plug without breaking the circuit mechanically.

The common low pressure magneto is shown in Fig. 198.   This gives a good arc when the circuit is broken, as the self-induction of the armature core and magnet poles is high.

This high-pressure sparking magneto system is preferable to the low-pressure arcing system, the abolition of a rod and a moving make and break in the cylinder, with all the mechanism for working it, is a great advantage.   The only point requiring careful attention in the high pressure sparking system is the insulation of the conducting wires and the sparking plugs, and these points are easily attended to.

The next system is one which has been much used, namely, the induction coil system,

FIG. 199.—Coil Battery and Switches.

with a trembling spring contact breaker.   A battery of primary or storage cells is required to work it, preferably an accumulator.

Fig. 199 shows an ignition set of Castle coils as exhibited and sold by the United Motors Industries Limited, designed for working a 4-cylinder engine fitted with one trembler only and four Morse keys, to enable the driver of the car to cut out any cylinder by simply pressing the button or buttons.   As will be seen, the coil is also fitted with covered terminals, the case being handsomely French-polished.   Only having one
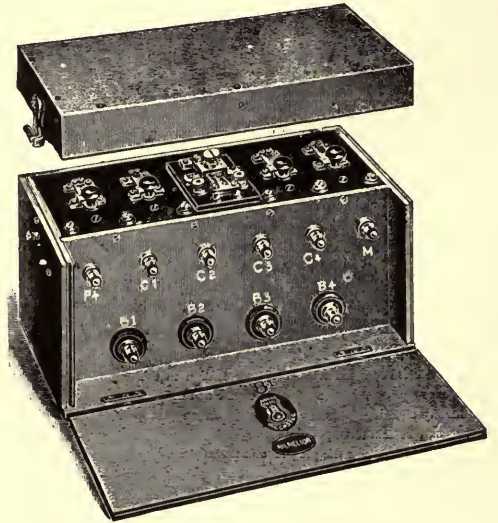
trembler gets over the very serious difficulty that has always occurred to get the four tremblers exactly to the same time, and thus get true running of the four cylinders. Having one trembler to do the work of four, obviously the business of the adjustment is reduced to a minimum.

Fig. 200 represents the Castle accumulators also supplied by that firm ; these were the accumulators much used in the Gordon-Bennett Motor Car Competition. A very convenient and well got up charging apparatus for taking a charge from an electric lighting circuit is shown, made by Messrs. Everett & Edgecumbe, contains an ammeter to show the current, and a lamp as a resistance, with terminals and flexible wires, with a plug for insertion in the lampholder, to which it is attached for charging.
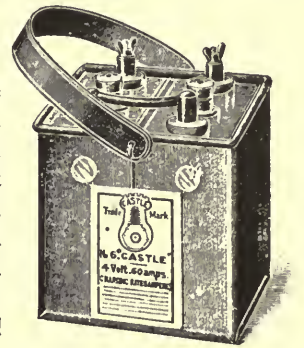
FIG. 200.—Ignition Accumulator.

The next method is that employing a self-induction coil and battery, with a mechanical make and break in the cylinder. We have described the Westinghouse apparatus for this system. Properly designed it is a very good method in some circumstances. A good battery is necessary, and an induction coil designed to suit the battery. Among primary batteries the author prefers the sack cells, a set of four being illustrated in Fig. 201, by the G. E. Co., of Manchester. Small cells are a nuisance ; large cells are cheaper in the end, and can always be depended on. The induction coil, which is merely a bobbin of insulated wire about 3 inches long, with a $\frac{7}{8}$-inch fine iron wire core. This iron wire core should be made about 6 or 7 inches long, so as to project beyond each end, and spread out to form a "hedgehog" transformer. The coil should have seven layers of insulated wires, well waterproofed by paraffin, wax, or shellac. About half a pound of No. 26 S.W.G. wire will be required for four cells in series.
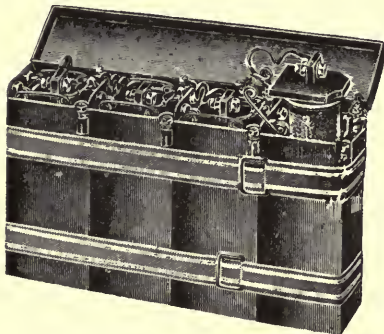
FIG. 201.—Primary Sack Cells.

The sparking plug may be illustrated by one as supplied by the G. E. Co., of Manchester (Fig. 202).

This plug has been designed to give absolute protection from leakage in wet weather. As will be seen by the illustration, it is fitted with an insulating cap of ambroin, which has great mechanical strength and affords valuable protection to the porcelain insulator ; in addition to this it is fire and waterproof. The high-tension wire is fixed by means of the set screw in the back of insulator, and the rubber insulation
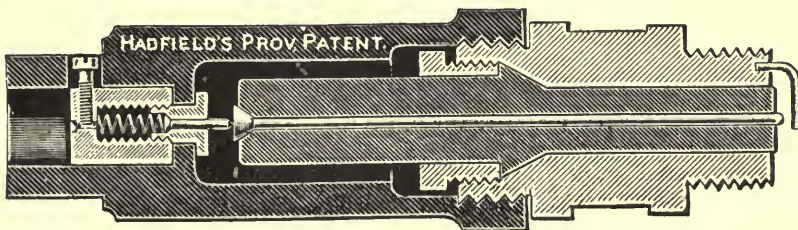
FIG. 202.—Protected Sparking Plug.

of the wire is held in position by a hard cement. The insulating cap can be removed without interfering with the electrical connections.

It has been found to make a great improvement in sparking ignition to provide a second spark gap outside of the cylinder ; it renders ignition much more certain. The reason for this is that, even if the internal spark gap becomes coated with carbon or

soot, which would allow electric current to leak across and so prevent the pressure from rising high enough to leap across as a spark, the second clean external gap prevents any leakage, and the pressure rises high enough to jump the first gap.   The rush of current will be too great to be carried over by the soot in the second gap, and a spark will also jump there, and even if the soot should carry any current it is likely to be heated and burnt.

Electric ignition can be used to fire weaker mixtures with certainty, and has always been in favour from the beginning of the internal combustion engine's history.

Ignition by flame through valves has now become obsolete.   The only other practic-
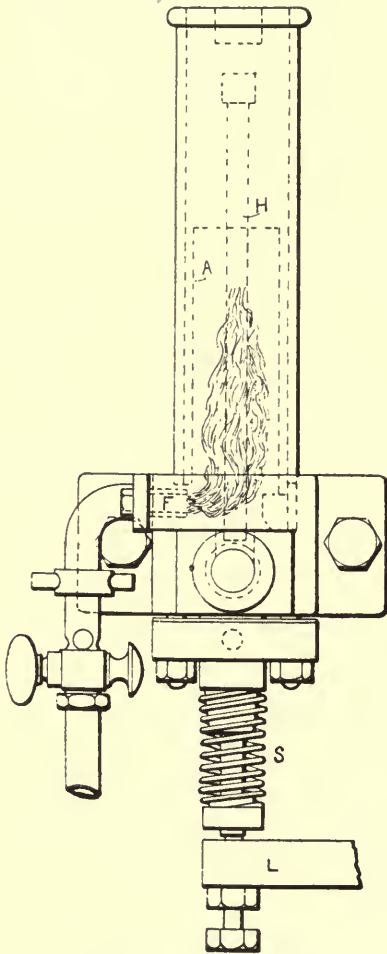
FIG. 203.—Tube Igniter.
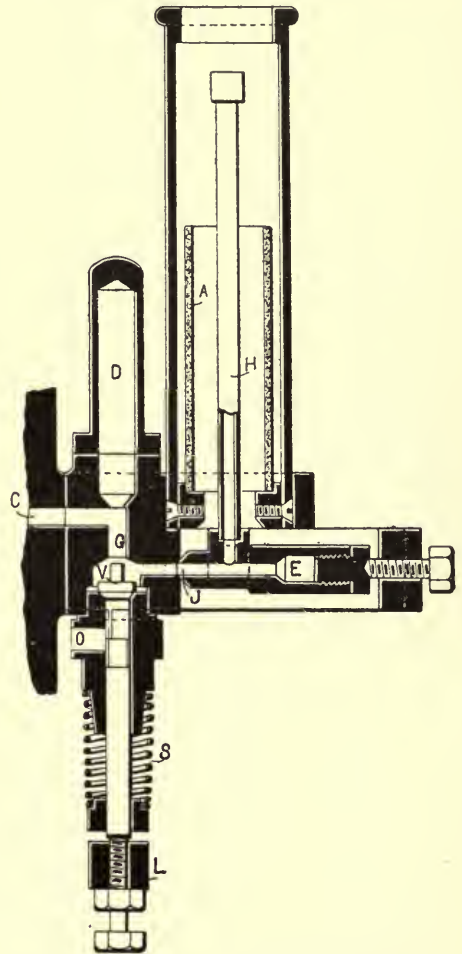
FIG. 204.—Section of Tube Igniter, showing Timing Valve.

able igniter is the hot tube, a system also very early invented, and used in an early engine.   A tube of iron, porcelain, or platinum is kept at a bright red heat by a Bunsen flame, and by means of a small valve called a timing valve.   At the right moment this valve is opened by a cam, and the gases entering it by compression are fired.   The construction can be gathered from a description of the Otto hot tube igniter.   The hot tube is a piece of iron pipe H in Figs. 203, 204, and ⅜ diameter, closed at the upper end, heated by the Bunsen flame F, and surrounded by a clay or asbestos mantle A, inside of a cast-iron chimney.   C is the passage to the cylinder ; the timing valve is shown at V, worked by lever L.   During the compression stroke valve V is lifted, the small end

closes G, and opens the tube H to atmosphere, and any gases in it escape. When the moment for ignition arrives, the cam drops valve V and opens the tube to the cylinder ; part of the compressed charge now flows into the hot tube, is ignited, and fires the charge in the cylinder. The chambers E D receive the burnt gases from the passages.

The iron tube becomes burnt, and requires frequent renewal about every three days.

Porcelain lasts for months, but are liable to crack.

Platinum has been used, but it is too expensive, costing somewhere about £2, 10s. per ounce.

Finally, we have self-ignition in the Hornsby-Ackroyd and Diesel engines. In the first the ignition takes place by high compression of the charge into a hot combustion chamber at a dull red heat.

In the Diesel engine the fuel ignites by being forced into air compressed up to a red heat.

There are also catalytic igniters, which fire gases by bringing them into intimate contact in the porous structure of spongy metals, such as platinum, but they have not yet been successful.

STARTING OF INTERNAL COMBUSTION ENGINES

In describing the internal combustion marine engines it has been assumed that the waste heat from the gas producers and exhaust of the engines will be utilised for steam generation to work the injectors, exhausters, and blowers. And that one of the steam generators can be fired by coal when starting up all cold. There is no difficulty in that case, in starting the marine engine by steam pressure. This proposal was made by Hartley in his patent specification of 1893, and it is shown in Fig. 205 how he proposes to carry it into practice, and the directions given for its use are as follow :—

Steam is admitted to the cylinder to start the engine through a valve V, which may be operated either by hand by lever H or from the counter-shaft ; the admission valve cam is thrown

FIG. 205.—Steam Starting.

out of gear, and in 4-stroke cycle engines the exhaust valve is opened by a special cam at every back stroke ; the steam is used in one cylinder while gas is used in the other. If the engine is operated by producer gas the steam from the boiler supplying the producer may be used for starting. In the provisional specification it states that compressed air may be used instead of steam.

There is another method of using steam-starting gear where producer gas is employed, and that is by means of a small steam engine on the same crank shaft on the
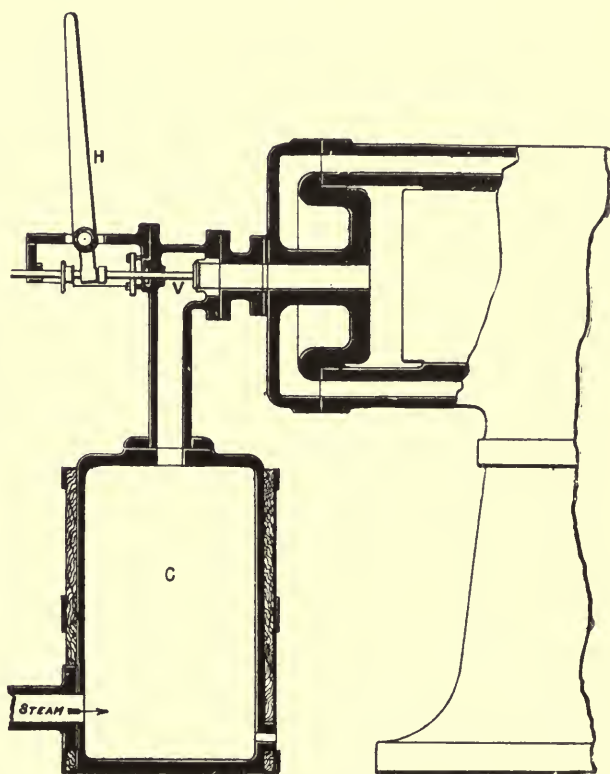
gas engine. Driving through a friction clutch or disengaging gearing, by this means, large engines can be quickly stopped, reversed, and started. The steam starter is very good on either system where steam is available from the waste heat.

The next method, one very early invented by Mr. H. P. Holt and F. W. Crossley, and now used by several recent engines, employs compressed burnt gases from the exhaust of the engine, and the advantage is that the compressed gases are obtained simply without a compression pump. It has some drawback in requiring a valve for the passage of the hot burnt gases. Valves for this purpose are sometimes difficult to keep tight. The Specification No. 3537, 1884, describes it as follows :—

A reservoir *a* is connected by a pipe *b* to the cylinder, and at every explosion a portion of gas is driven past the loaded valve *d* into it. To start the engine the valve *d* is raised by the lever *e*, which allows the compressed gases to come back behind the piston ; the hand wheel *f* is added to screw the valve down firmly on its seat when
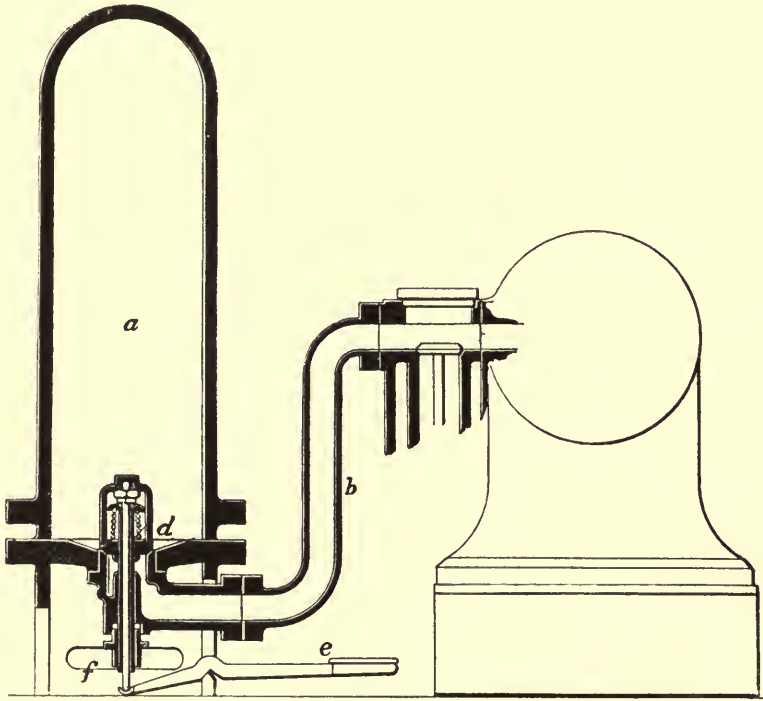
FIG. 206.—Burnt Gases Starter.

required. The valves and their spindles are so arranged at the bottom of the reservoir that the condensed liquid therefrom seals them, and effectually prevents any escape of the gases. Fig. 206 illustrates the device.

Compressed air is the favourite medium for starting, and it is furnished either by hand pumps or separate small pumping engine, as we have already seen in connection with the Westinghouse and Andrew, Stockport, engines.

In some cases, as in the Fielding & Platt and Hornsby-Ackroyd, and others, the air is pumped up during the last revolutions of the engine when stopping, after the gas or oil has been shut off.

The Hornsby-Ackroyd arrangement is shown in Fig. 207. C is a screw-down charging valve operated by lever, shown on a large scale. In the left position the right-hand valve is held open, while the left-hand valve, being freed by the screw, acts as a non-return valve, and the engine pumps air into the receiver.

When the reservoir is charged the lever is put in the mid position and the valve

screwed down.   To start the engine, the valve is opened, and the lever thrown over to the left position, lifting the non-return valve and admitting the compressed air.   A few strokes sets the engine in motion, and then the oil is turned on when ignition begins.   An auxiliary compressing hand pump is shown. This is used in any case where a charge of compressed air has not been provided, or has by any accident been lost.

A very well-designed and convenient compressed air plant, made by the Campbell Gas Engine Company of Halifax, is shown in Fig. 208 — useful not only for starting gas engines or oil engines of large sizes, but also for working small compressed air machine tools. It consists of a small engine with a working cylinder and an air pump side by side.   The reservoir is of very ample dimensions, so that a large reserve of air is always on hand.
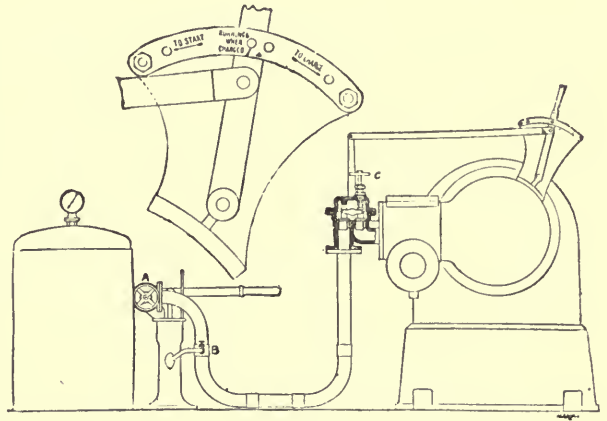
FIG. 207.—Compressed Air Starter.
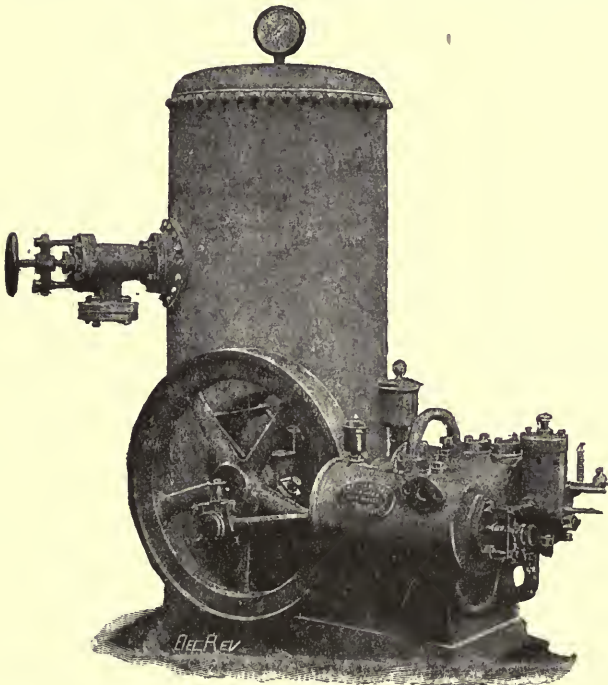
FIG. 208.—Campbell & Co.'s Starting Engine.

FIG. 209.—Pennington's Spring Starter.

Somewhat akin to this storage of power for starting is a device by E. J. Pennington, who stores the power for restarting in a coiled spring instead of air.   It is shown in Fig. 209, and described as follows :—

Before the engine stops, a drum A containing a spring G, or attached to a weight, is pressed against the rim of the fly-wheel E, the spring is thereby wound up, and retained by a pawl J.   To start the motor the lever C is turned in brackets D through half

a revolution, when the pawl is removed, and the spring in unwinding turns the fly-wheel.

It is necessary to turn the spring the other way about in order to make it drive the wheel in the correct direction when unwinding.

The next method is that already shown in Fig. 108, page 104, as the Clerk-Lanchester starter, in which a charge of gas and air fills the cylinder, with the piston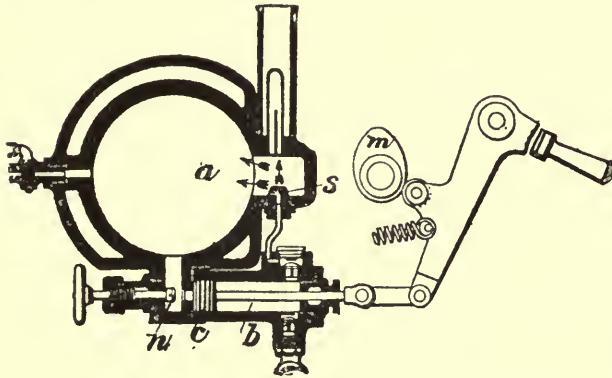 in the best position for starting up. When the mixture is of proper proportions it is fired, and the resulting pressure starts the engine in motion. It is not a method of much value, and is now seldom used ; it is uncertain in action, and, if it misses fire, requires the barring of the engine.

FIG. 210.—Clerk's Starter.

In another method now in considerable use, but not likely to be long continued in face of the compressed burnt gases or compressed air systems, is that in which a mixture of explosive gases is stored, and these fill the combustion chamber and are exploded to start the engine. The following description of D. Clerk's system will illustrate it, from Specification No. 18,788, 1891 (Fig. 210) :—

In the arrangement shown a hand pump b forces gas into a charge of air drawn into the motor cylinder before stopping, and by igniting as it enters through the nozzle s raises the pressure in the cylinder and forces the piston outwards, the pressure at the same time acting on the back of the piston c and assisting in the expulsion of gas from the cylinder b. In the next out-stroke in Otto cycle engines air is drawn into the cylinder a and slightly compressed on the in-stroke, the gas pump being worked by a cam m until the engine is properly started. The cylinder b is closed to the main cylinder a by a valve n. For petroleum engines, oil is forced by the pump c and vaporised in the pipe between the pump and nozzle s. In another form a reservoir is connected to the cylinder, and both are charged with mixture by a pump remote from the cylinder. The charge
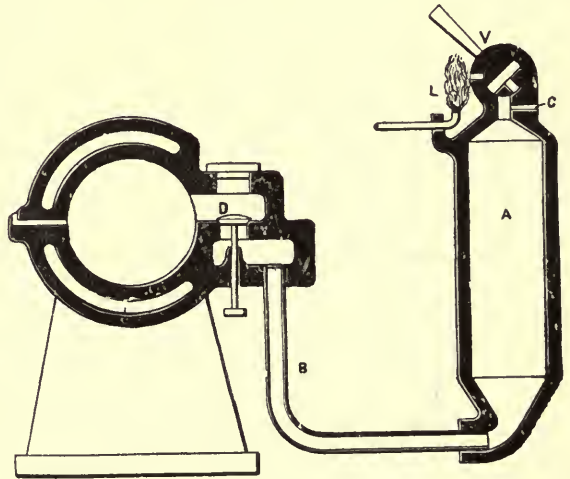

FIG. 211.—Explosion Starter.

in the reservoir is then ignited at the pump end, and the flame either passes the check valve into the cylinder or causes the pressure in the latter to rise high enough for the mixture to be ignited by the ordinary heated tube. The reservoir may be in the form of a coiled tube, a double tube, or a cylinder with conical ends, and the flame may be drawn into the charging pump by its piston overrunning a port in its side. The reservoir may be charged without the aid of a pump, the gas entering it and the cylinder at the ordinary town pressure and expelling the air at an igniting port at the end of the reservoir remote from the cylinder. When the mixture becomes suffi-

ciently explosive the gas supply is cut off and the flame flashes back into the reservoir, the rise of pressure causing a valve in the igniting port to close. Any method of igniting may be employed.

Another form of it is shown in Fig. 211. Here the explosive mixture is pumped into the strong reservoir during the last few strokes of the engine when stopping, the ignition being cut off so that the gases are compressed into the receiver instead of firing.

Another compressed explosive mixture method is shown in Fig. 212, from Pinkney's Specification No. 3203, 1892.

In this device a small hand pump B is fixed to the engine and charges the cylinder with explosive mixture. The crank is placed in the most advantageous position for starting, and the charge is admitted through a hand valve to the igniting tube. An
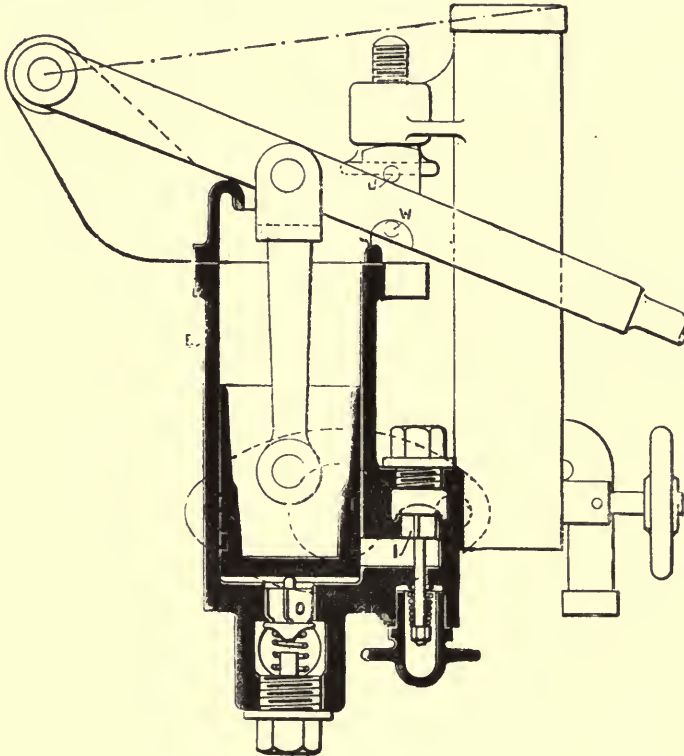
FIG. 212.—Tangye Starting Pump.

adjustable relief valve O indicates when the requisite pressure for starting is reached, at which point the pump piston is depressed to cover the discharge port and hold open the relief valve. It is secured by pins U, W; any leakage past the valve I will thereby escape. In small engines the crank is held in its starting position by a spring hook, which is disengaged by the pressure of the explosion, and falls out of the path of the crank shaft.

Small engines are usually started by hand turning of the engine shaft without much trouble, the engine running loose or free until the starting is accomplished.

In describing the Griffin engine the simple device of a fly-wheel which can be clamped or clutched or run loose on the shaft was described. The fly-wheel is spun round, and when it has acquired moment enough is clutched fast; it then gives the engine a few turns sufficient to start it.

When a gas engine is employed for electric lighting with accumulators it is

convenient and easy to start up the engine by means of the accumulator driving the dynamo as a motor. Nothing special is required except a starting regulating switch to control the current at the start. The regulating resistance must carry the full current for which the dynamo is built, and have sufficient total resistance to give this current on the first step. And as the speed increases and the current falls in strength, as shown by the ammeter, the regulator is shifted up until at full speed the resistance is all out. And the electric pressure of the dynamo overpowers the cells and feeds current in to them. The dynamo may feed lamps and cells at same time, or by switches the circuits can be separated so that it feeds into either lamps or accumulators as desired. See Fig. 213 for connections and switches.

By one or other of these means the engines are started, usually under no load.

The steam and compressed air starters, however, can start under considerable load, and that in some cases is a considerable advantage.
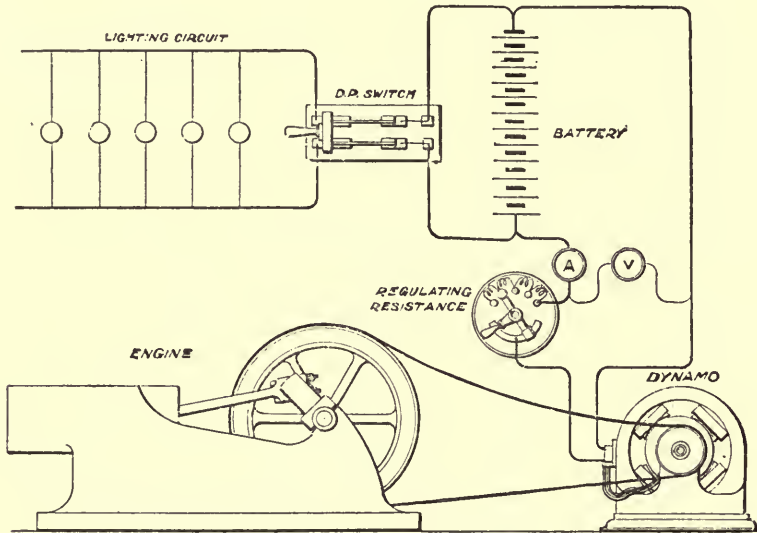
FIG. 213.—Electrical Starting-on Accumulators.

VARIOUS TYPES OF ENGINES

Dunn's suction gas engine is shown in diagram (Fig. 214).

In order to clear the combustion products from the cylinder and prevent the new charge mixing with them in engines working on a 2-stroke compression cycle, a shield J is formed in the cylinder which projects beyond the exhaust valves B, C, and a suction apparatus E is employed for withdrawing the exhaust. Towards the end of the out-stroke the port C opens to the atmosphere, and allows some exhaust to escape ; and for a portion of the in-stroke this port is closed and the valves A and B opened, allowing the suction device to draw the remaining products out of the cylinder and to draw in a new charge at the same time. For the rest of the stroke all the valves are closed and the charge is compressed.

This method entails the use of exhaust valves, and no valves on an engine will for long withstand a temperature of 1200° to 1400° Fahr., the exhaust gas temperatures. In the author's engines these valves are dispensed with, and the gases cooled before they enter the exhauster, which is also of a class with no moving parts, being an ejector of the steam jet class.

The Hornsby-Ackroyd engine, using common kerosene or paraffin oil and self-ignition by compression of the mixture of oil vapour and air in a hot combustion

chamber, holds a high position among oil motors. It is constructed to work on the Beau de Rochas cycle, very similar in appearance to a gas engine. The vaporiser is a special feature of this engine, and distinguishes it from all other types by not requiring either a hot tube, electric spark, or slide valve with flame for the purpose of ignition. The vaporiser is a bottle-shaped chamber or extension of the cylinder, being connected with the cylinder only through a neck or contracted passage. It is partially water-jacketed, and heated by a lamp when first starting the engine; afterwards it maintains itself at a temperature high enough to cause the ignition of the oil vapour and air. The oil is pumped, from a tank formed in the base of the engine, by a small plunger pump into the hot vaporiser during the air suction or charging stroke. The oil is then vaporised by the hot walls of the vaporiser, and mixing with the products of the combustion remaining from the previous explosion. The air is not drawn into the vaporiser but directly into the cylinder, and on the compression stroke is forced into the vaporiser through the neck end; it there mixes with the vapour contained in it. At first the mixture does not contain sufficient oxygen for combustion, but at the end of the compression stroke the mixture attains the proper explosion proportions, and is ignited by the hot walls of the vaporiser. Another important feature claimed for the Hornsby-Ackroyd oil engine is that it will work satisfactorily with heavier oils than other engines. It will even work with some oils weighing up to $9\frac{1}{4}$ lbs. per gallon, if the engine be suitably adjusted for the purpose; but the oils recommended as being the most powerful and giving the most economical results are refined Russian or American pet-

FIG. 214.—Two-Stroke Suction Engine.

roleum, having a specific gravity of from .79 to .825 and a flashing point of from 74° to 830° Fahr. (Abel's close test), or, following these oils, any well-known brand of Scotch oils having a specific gravity of about .81 and a flash point of 225° Fahr. (Abel's close test), also the heavy crude petroleum oil or Astatki oil, if properly adjusted.

The oil pump is connected to and actuated by an air lever, and forces the oil immediately prior to its entry into the vaporiser through a valve box attached to the vaporiser, in which box are two spring valves—one horizontal, the other vertical. The oil enters the valve box by way of the horizontal valve, which is opened by the pressure of the pump, and then flows through the spraying jet into the vaporiser. The regulation of the engine is effected by a "Porter" governor opening the vertical or overflow valve when the speed is too high, and causing the oil pump to return the oil to the tank. A regulation handle is also provided, by means of which the vertical valve may be opened or shut and the supply of oil intercepted, this being the method of stopping the engine. If it is known that a light load is to be dealt with, more steady running is secured by altering the stroke of the oil pump, for which due
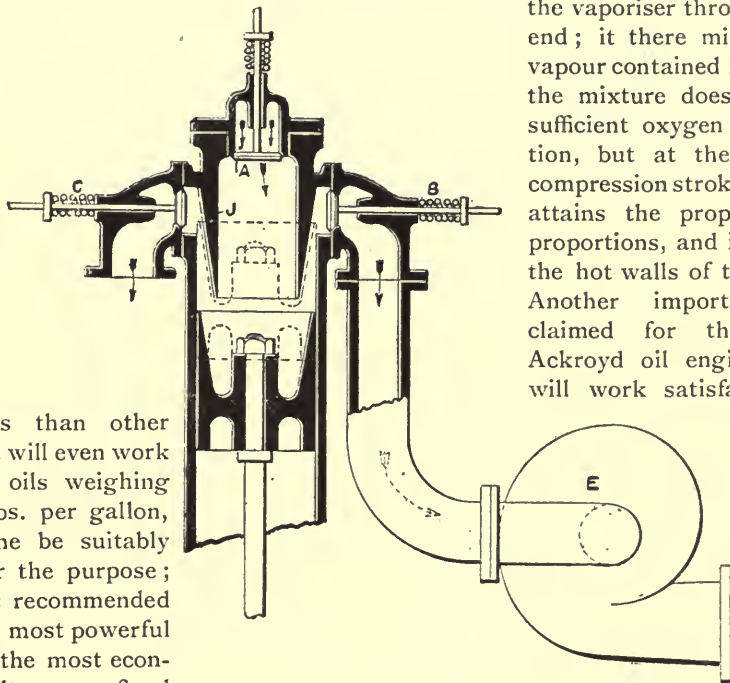
provision is made.   The air and exhaust valves are worked in the same manner as in
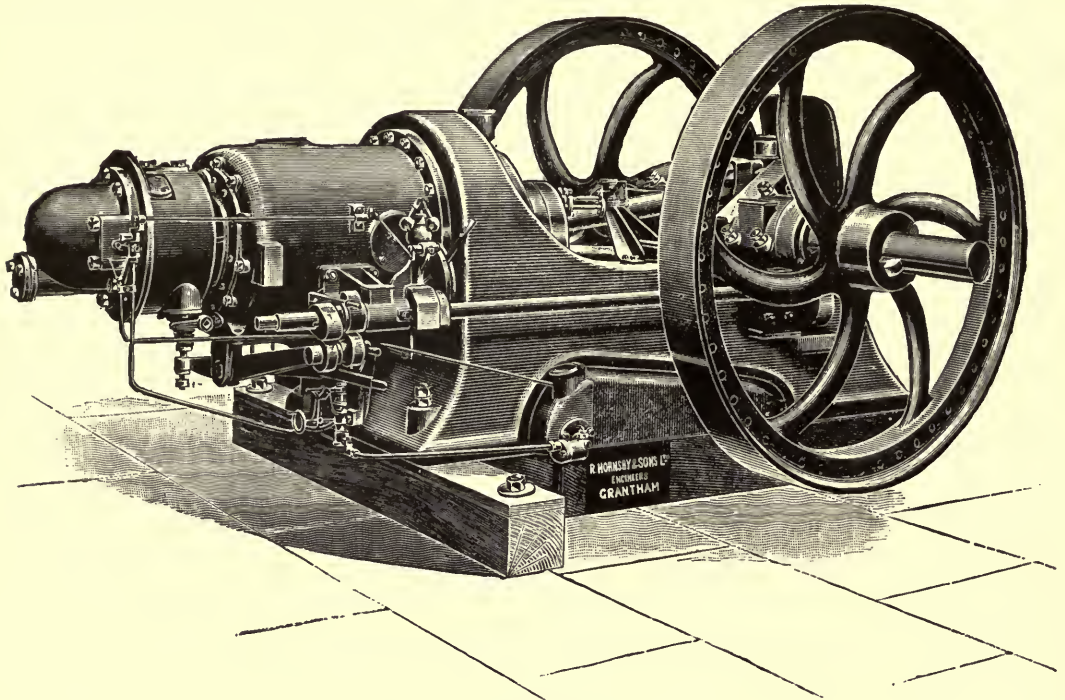

FIG. 215.—Hornsby-Ackroyd Oil Engine.

a gas engine, *i.e.* they are opened by separate levers, each actuated by its own cam,
mounted on a horizontal shaft, which is driven from the cam shaft by skew gearing, so geared as to make one revolution to two of the crank shaft. The cylinder is water-jacketed as in the gas engine.
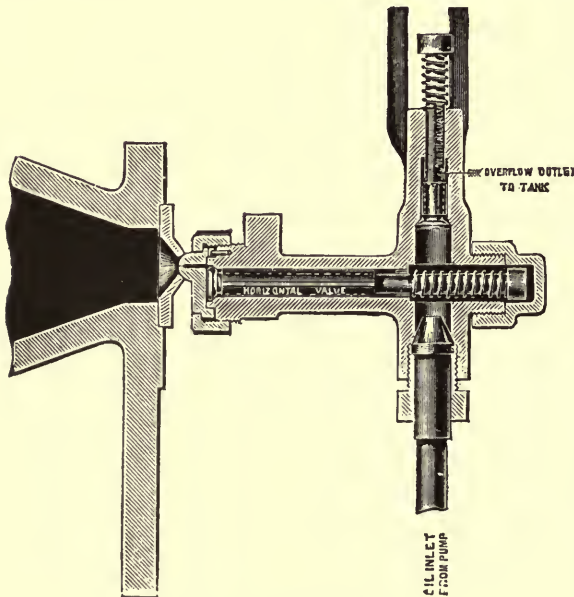
We have already described the vaporiser. The oil sprayer is shown in Fig. 216—on a larger scale. This sprayer has a horizontal and a vertical valve held down by springs; the horizontal one is a back pressure valve, which is forced open by the oil under pressure from the oil pump. The vertical valve is an overflow valve operated by levers from the governor. When the engine runs fast the governor opens this valve, and the oil escapes to the reservoir instead of entering the vaporiser. The air is drawn into the cylinder and the oil into the vaporiser during the suction stroke, and then compressed.

FIG. 216.—Oil Sprayer.

Fig. 217 illustrates the air inlet valve and lever, also the small oil pump worked by same lever.

In Fig. 218 is shown a sectional elevation, and in Fig. 215 a complete view of the engine.

Different oils have different flash points, so that to enable the engines to give the best results with different oils a recess is made in the combustion chamber, which can be varied in volume by conical plugs (see Fig. 219), and thus alter the maximum pressure of compression. For Russian oils No. 3 is used; but if higher compression is required No. 4 is used; for lower compression American oil No. 5, and for lower flash oils No. 6, is used. For Russian oils the cap of the vaporiser requires internal ribs. American oils work with shorter ribs, or none at all in the larger sizes of engines. If the brand of oil which is to be used is once decided upon, the makers send out the engines with all these adjustments properly made.

The flash point does not depend upon the specific gravity or weight of the oil—benzolene weighing 7 lbs. per gallon requiring the highest compression, while for

FIG. 217.—Cross Section.

Solar oil weighing 8.85 lbs. about the lowest compression is required.

The following tables give the general results of tests made by Professor William
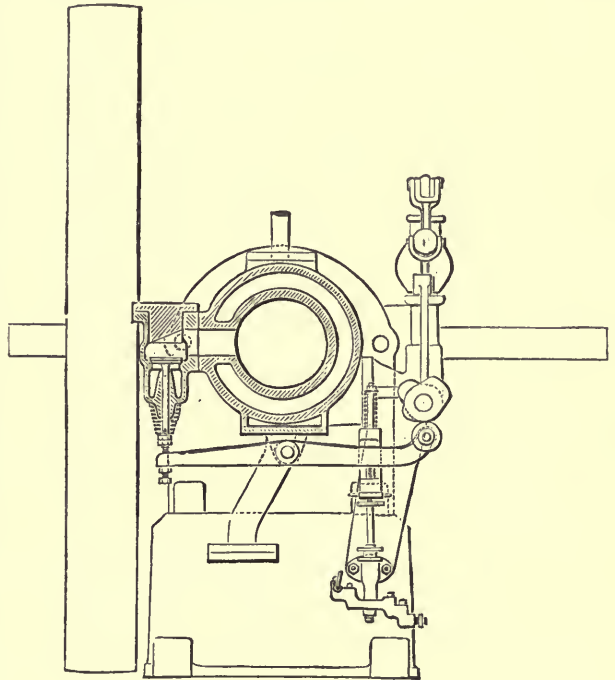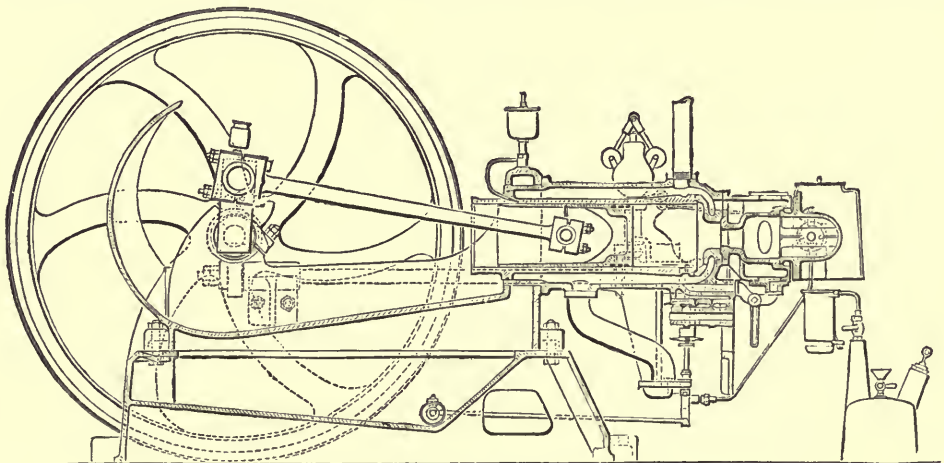

FIG. 218.—Longitudinal Section.

Robinson, M.I.E.E., etc., of University College, Nottingham, on a 5 brake horse-power engine, and a report of the judges at the mining exhibition in Australia.

Brand of Oil used in Trials.—A Russian petroleum called russoline was used as fuel, being a similar oil to that generally used in oil engines.

TABLE XV.

	20th October 1893. Sample 1.
Specific gravity at 60° Fahr.	0.8235
Flashing point (Abel close test)	88° Fahr.

Dimensions of Engine.—5 brake horse-power "Hornsby-Ackroyd" Oil Engine. The following are the exact dimensions of the engine measured during the trials, and employed in the various calculations:—

Diameter of cylinder	8.0175 inches.
Stroke of piston	14.000 inches.
Area of piston	50.485 square inches.
Volume swept out per stroke . .	0.409 cubic feet.
Diameter of fly-wheel . . .	51.125 inches.
Thickness of leather strap . . .	0.25 inches.
Effective circumference of brake on fly-wheel	161.4 inches = 13.45 feet.

General Results.—The general results of the trials were as below, over 100 indicator cards being taken and averaged:—

TABLE XVI.—TRIALS OF HORNSBY-ACKROYD OIL ENGINE.

	20th Oct.	20th Oct.	17th Nov.	20th Oct.	20th Oct.	20th Oct.
Date of trial	20th Oct.	20th Oct.	17th Nov.	20th Oct.	20th Oct.	20th Oct.
Trial	1	4	6	5	2	3
Power	Full	Full	Full	Full (dynamo)	Half	Light
Brand of oil used . . .	Russoline	Russoline	Russoline	Russoline	Russoline	Russoline
Mean revolutions per minute	213.82	213.93	214.3	214	215.73	215.9
Mean effective brake load (lbs.).	57.21	56.72	56.6	Dynamo 50.6 Amp. 52.6 Volts	31.5	0.0
Effective electrical output H.P..	...	...	...	3.57	...	...
Mean B.H.P. . . .	4.986	4.947	4.952	...	2.77	0.0
Mean indicated H.P. . .	6.081	6.015	6.075	5.97	3.87	1.104
Mechanical efficiency of engine	0.820	0.822	0.815	...	0.715	...
Oil used per hour (pints) .	4.8194	4.532	5.038	4.643	3.278	2.446
Oil used per I.H.P. per hour (pints)	.792	.752	.829	.777	.847	2.214
Oil used per B.H.P. per hour (pints)	0.963	0.916	1.015	...	1.183	...
Temperature of cooling water (Fahr.)	107°	119°		119°	114°	116°

TABLE XVII.—COST OF OIL PER HOUR.

	Average Quantity of Oil used per H.P. per Hour.		Price per Pint of Oil. (Pence.)	Cost of Working per H.P. per Hour.	
	With Full Load. (Pints.)	With Half Load. (Pints.)		Full Load per Hour. (Pence.)	Half Load per Hour. (Pence.)
Per I.H.P. per hour	.787	.847	.412	.35	.37
Per effective H.P. per hour . .	.964	1.183	.412	.42	.52
	.964	1.183	.383	.39	.48

The exhaust gases analysed gave the following results :—

TABLE XVIII.

Constituents.	Composition by Volume of Gas.		
	Sample 1. Per Cent.	Sample 2. Per Cent.	Average Per Cent.
Carbonic acid . . .	8·60	8.86	8.73
Carbonic oxide . . .	0.0	0.0	0.0
Olefines and Benzine .	0.0	0.0	0.0
Hydrogen	0.0	0.0	0.0
Oxygen	9.32	8.86	9.09
Nitrogen	82.08	82.28	82.18
	100.00	100.00	100.00

These results indicate that the oil is completely burned in the engine cylinder with excess of oxygen. The products of combustion formed consist mainly of steam and carbonic acid diluted with nitrogen and oxygen, no traces of carbonic oxide being detected, so that this exhaust is not objectionable.

REPORT OF TRIALS

This relates to a trial of horizontal engine of $3\frac{1}{2}$ brake horse-power, at 230 revolutions per minute, having a cylinder 7 inches in diameter and 12 inches stroke. The ignition takes place without the aid of tube or slide, simply by the compression of the charge in the vaporiser. This part had to be heated by the auxiliary lamp at starting, urged by a small hand blower, but afterwards is kept hot by the combustion of the charge of air and oil in the cylinder.

The auxiliary lamp having been in action for six minutes, the engine

FIG. 219.—Plug Regulators.

was started with the utmost facility, and ran for an hour, the power being used to drive a stamp battery. Indicator diagrams showed a maximum pressure of 150 lbs. per square inch, and a mean effective pressure of 37 lbs. per square inch. The revolutions varied from 212 to 214 per minute, the average being $213\frac{1}{2}$. The indicated horse-power was 4.62, which, allowing 25 per cent. for friction, corresponds to 3.47 brake horse-power. Had the engine not been so heavily loaded, and so allowed to attain its full speed, it would have given 3.75 brake horse-power.

The consumption of "Coronet" water white 150° test kerosene was $3\frac{1}{2}$ pints, giving .751 pints per indicated horse-power per hour, and 1.01 pints per brake horse-power per hour. The auxiliary starting lamp used .6 of a pint.
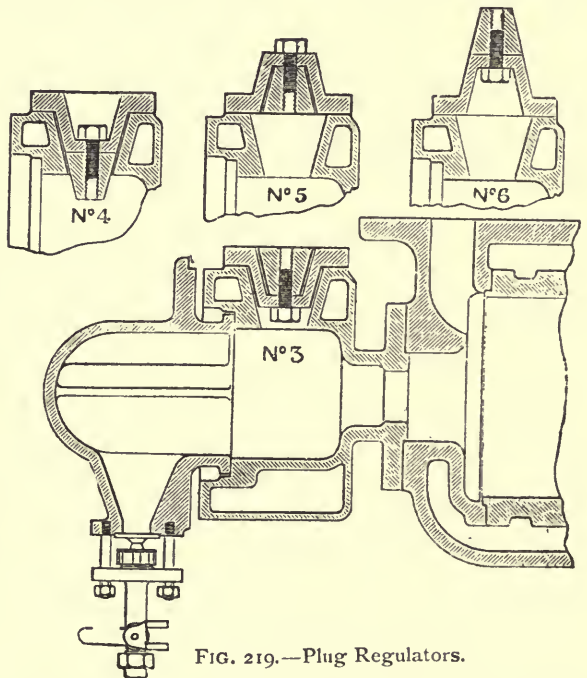
The engine was strong and well made, and fitted with a heavy centrifugal governor in lieu of the simple pendulum governor used on the other engines, and a blower, and the mechanism used for starting. Its performance was admirable in every way ; it started with the utmost facility, ran smoothly, and with a clear exhaust, showing no trace of unconsumed oil whatever.

It carried off the prize for this class of engine. This engine could be worked equally well by injecting the oil into the hot compressed air at the beginning of the working stroke same as in the Diesel engine, but much higher compression would be necessary. And it is a question whether the necessary increase of weight, and strains, and fly-wheel energy required and incurred by the extremely high pressures would be compensated by the increased economy.

Fig. 220 shows a typical cylinder diagram of this engine. The complete view (Fig. 215) is of the 100 horse-power engine.
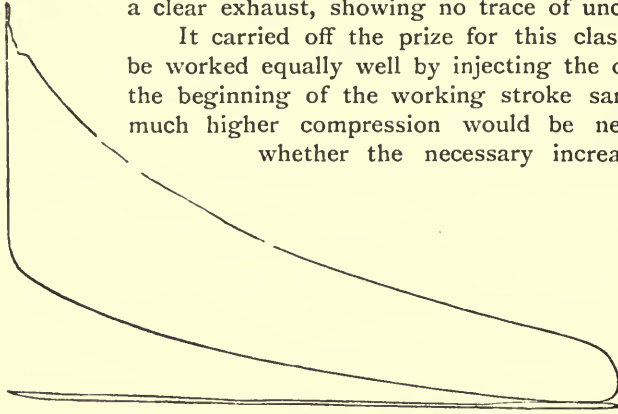
FIG. 220.—Indicator Card, taken from a 5 Brake Horse-Power Engine. Scale $\frac{1}{60}$.

THE PREMIER ENGINE

This engine, in one of its largest sizes, forms the subject of the full-page plate illustration No. VII. It is patented by Mr. J. H. Hamilton, and made by the Premier Gas Engine Company, Sandiacre. A special feature is called the positive scavenging, whereby the remains of the exhaust gases are blown out of the cylinder by introducing the air at some pressure instead of sucking it in under atmospheric pressure. The single engine is described in the patent specification as follows :—The front part B of the cylinder A (Fig. 221) forms an air pump for scavenging the cylinder. The cycle is completed in four strokes : on the out-stroke air is drawn into B and A through the valve F and chamber D, and gas into A also ; on the in-stroke both charges are compressed ; on the next out-stroke both expand, that in A being ignited ; and on the in-stroke the products in A are exhausted, and the air in B is compressed, and towards the beginning of the next suction stroke allowed to enter A before the exhaust valve closes. By this means the air entering blows the exhaust out. The pressure of the air at its maximum is about 4 lbs. per square inch. The gas is not admitted until the exhaust closes.

The little hand pump is used for starting the engine. The engine is barred round to the beginning of the explosion or working stroke about $\frac{1}{4}$ stroke forward. A 3-way cock connects the pump to the cylinder and the gas suction of the pump, and a number of strokes given to the pump introduces a fixed quantity of gas into the combustion chamber A. Next, the cock is turned to close the gas off and open the pump to the air, and air is pumped in until the piston begins to move under the pressure. As soon as this happens the timing valve is pushed open on the ignition tube, which has previously been made red hot. This fires the charge and sends the engine off. The tandem engine, by the same patentee's Specification No. 24,384 of 1893, is shown in Plate VII. and part in section as described in the specification, in which the front cylinder has the enlarged piston head for air pump. In Plate VII., however, the engine is shown with a small diagonal pump for the air compressing in larger engines.

Two engines in tandem can be made to give an impulse every revolution to the crank thus :—
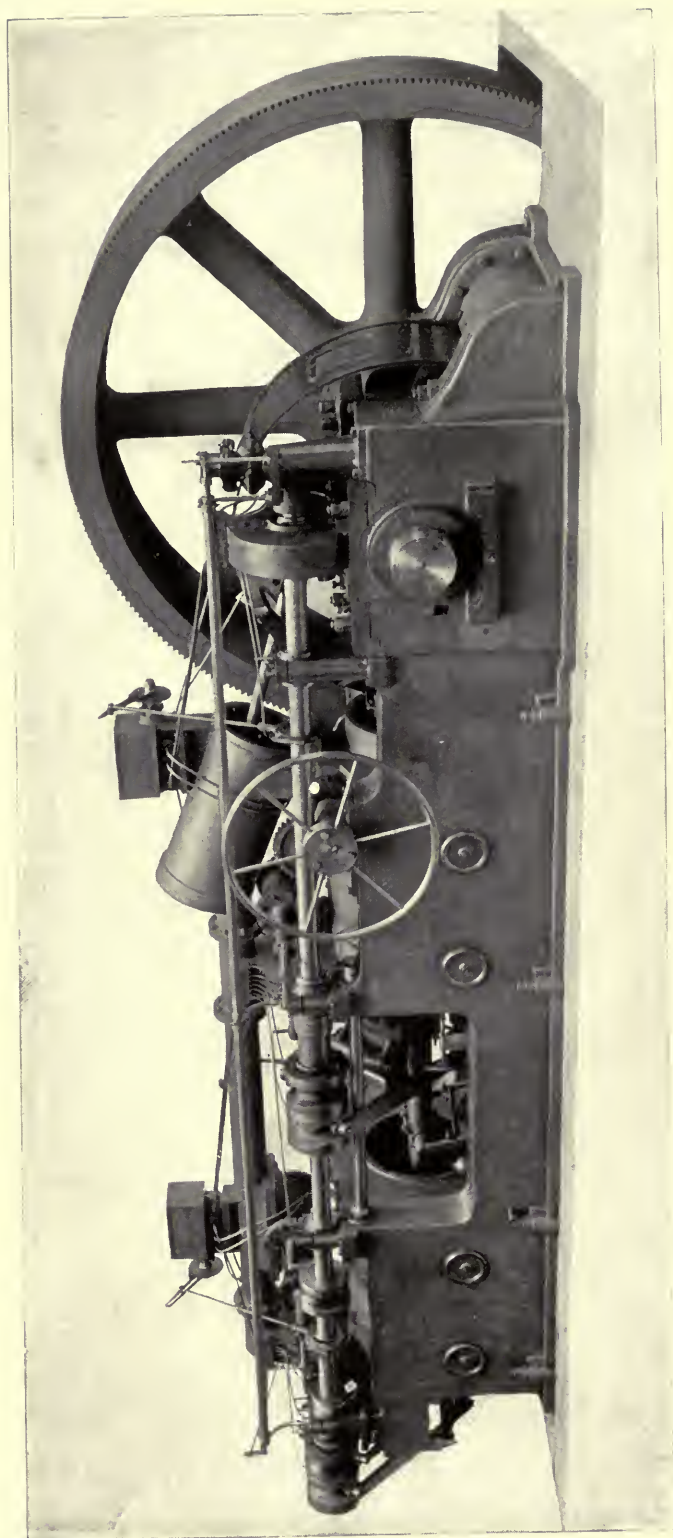
PLATE VII.—750 HORSE-POWER PREMIER GAS ENGINE FOR POWER GAS.

Stroke.			Cylinder No. 1.	Cylinder No. 2.	
1st	.	.	.	Compresses ⟵⟶	Charge ⟵⟶ } One revolution.
2nd	.	.	.	Fires ⟶	Compresses ⟶
3rd	.	.	.	Exhausts ⟵	Fires ⟵ } One revolution.
4th	.	.	.	Charge ⟶	Exhausts ⟶

This design is particularly adapted for cheap fuel or producer gas, and a great many of them are in use with gas producers.

The sectional view of the Premier tandem engine is shown in Fig. 222.

The enlarged front end of the piston F slides in the large cylinder L. In this cylinder are two ports, or rather one port P at the back end, and a series of ports Q near the middle. The bars between these ports prevent the piston rings from springing out in passing the ports.

The ports Q lead directly from the atmosphere through the space M, which is in free communication with it, but between the port P and the atmosphere is an automatic non-return valve or series of valves N. The port P is in free communication with the passage R, which conveys the air to the motor cylinders.

The ports Q are placed so as to be covered and uncovered by the large end of the piston F, and the latter is made long enough to keep the ports covered when it is full back.

The action of this arrangement is as follows :—

On the commencement of a forward stroke air is drawn through the valve N from the space M, and part of this air passes into that motor cylinder which happens to be making its suction stroke, while the remainder passes into the cylinder L. After the piston passes the ports Q the air has a direct passage from the atmosphere to both these cylinders for the remainder of the stroke. On the return stroke, the admission valve of the motor cylinder being closed, the charge is compressed in the usual manner, while during the first part of this return stroke the air is being expelled from the cylinder L through
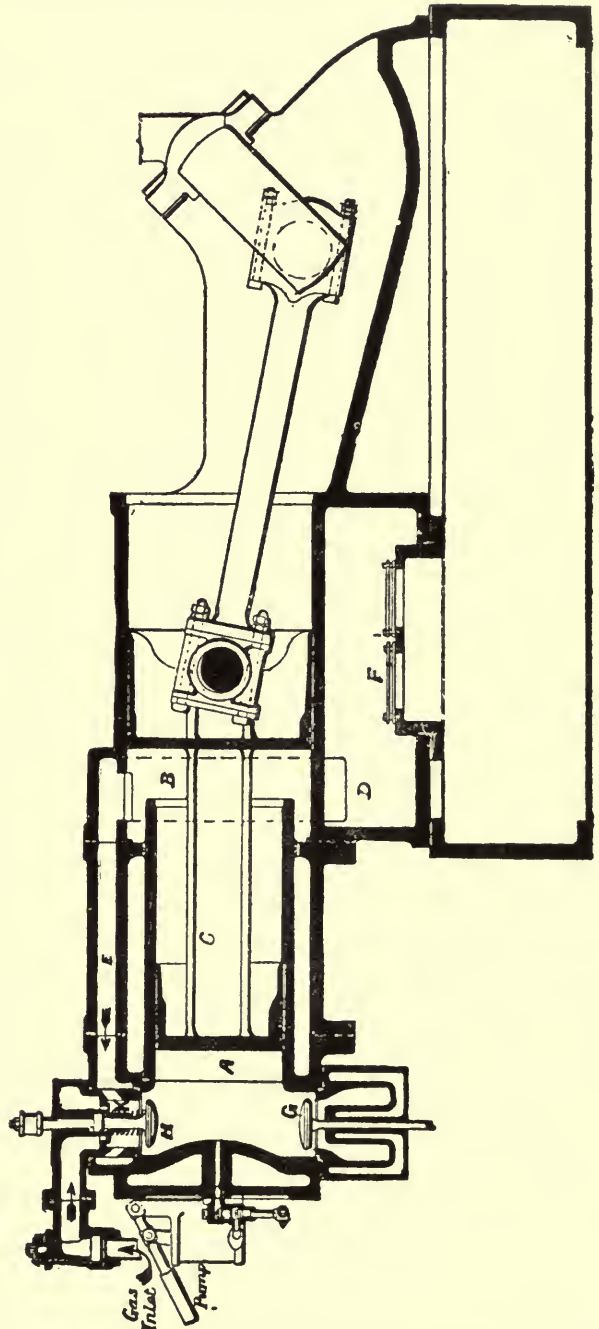
FIG. 221.—Premier Engine. Sectional Elevation.

the ports Q ; but after these ports are covered by the piston the air is slightly compressed, and then forced through the admission valve of the other motor cylinder in
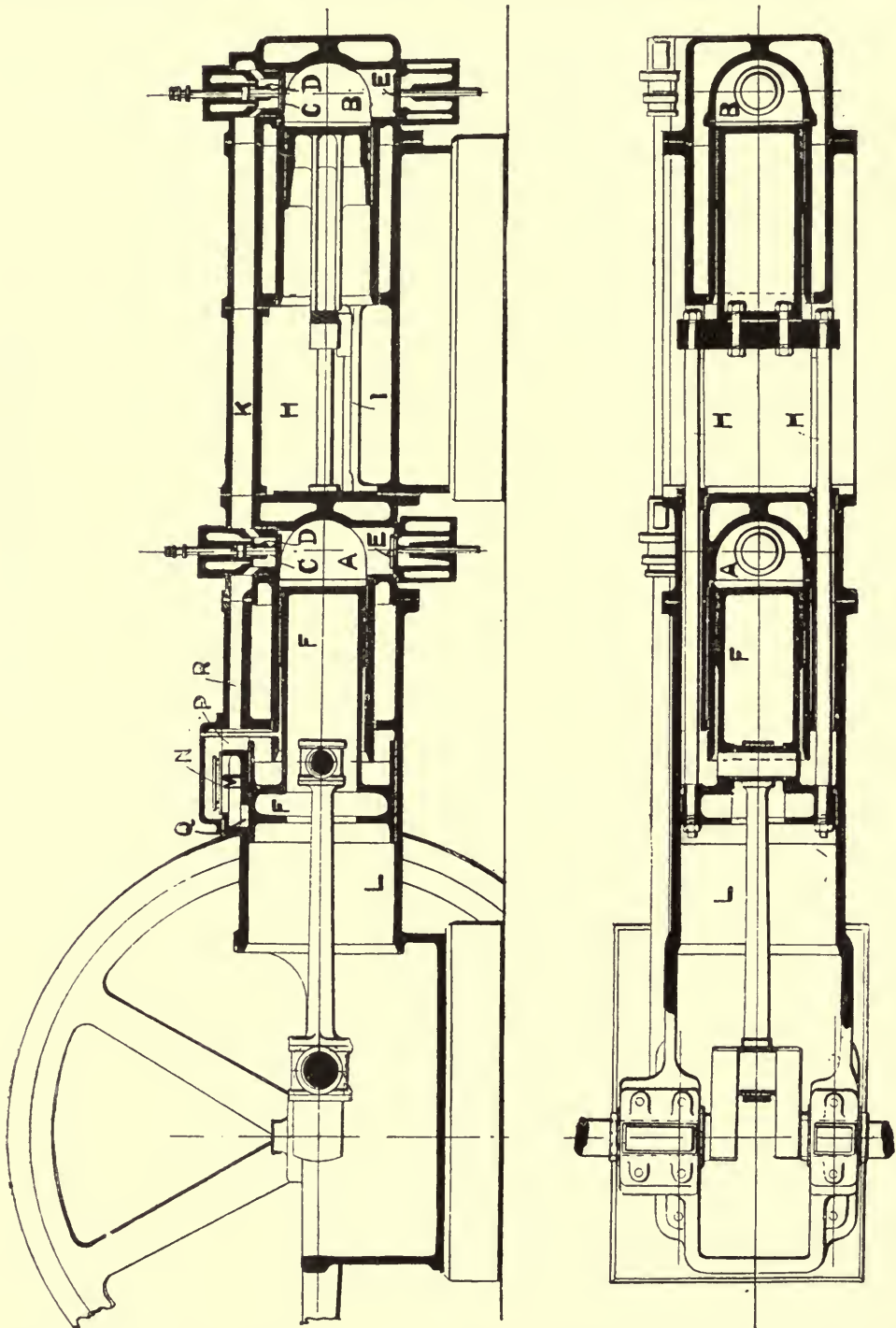

FIG. 222.—Tandem Premier Engines.   (See also Plate VII.)

which the piston is making its exhaust stroke.   The admission and exhaust valves, being held open, allow the air to pass through the combustion chamber and sweep out

the products of combustion therefrom. The exhaust valve is preferably held open till after the crank has passed the centre, thus giving time for the air to be discharged from the cylinder L. During the next revolution the same series of operations takes place, except that the back motor cylinder now takes the place of the front one in this series, and *vice versa.*

By placing the ports Q farther back or forward the amount of air which is passed into the combustion chambers of the motor may be changed. The air is thus discharged at the right time, namely, during the latter part of an exhaust stroke.

The advantages claimed for the scavenging principle are :—(1) Increase of power. (2) Reduced temperatures, owing to the charge being cool before ignition. (3) Absence of premature explosions, or back firing, as there are no hot gases left in the cylinder to ignite the incoming charge. (4) Absence of explosions in the exhaust, because, first, the ignition is more certain and there is less risk of an explosive charge passing into the exhaust pipe ; and secondly, should a charge pass into the pipe, the scavenging air comes between it and the next exhaust, thus preventing ignition of the explosive charge. (5) The engine does not get overheated and fall off in power after a few hours' run. If overloaded it slows down, but does not miss fire. (6) Good mechanical construction. (7) Clean working. (8) The valves, being kept cool by the passage through them of scavenging air, do not get burned or corroded, and very seldom require to be cleaned or ground to their seats. (9) The shocks are less than in ordinary engines, because the initial pressure is not so high and does not rise so rapidly, though the mean pressure is greater. The ignition is effected by electrical means and is fitted in duplicate, so that should a failure of one part occur it may be replaced without stopping the engine.

The speed of the engine is controlled by the cutting out of the ignition by the governor, which is driven from the crank shaft by bevel wheels with the machine-cut teeth. The fly-wheel of this size of engine is 12 feet diameter, and weighs 14 tons, and the crank shaft is supported at the outer end by a massive plummer block, having vertical and horizontal adjustments for the position of the brasses, so as to render alignment with the other bearings easy.

According to an indicator card taken from it, the mean pressure is 113 lbs. The maximum pressure is only 310 lbs., so that, although the mean pressure is greater, the shock due to the explosion is less than in the average gas engine.

In the large tandem engines the motor cylinders (see full page Plate VII.) are 27 inches diameter, the stroke 27 inches, and the speed 150 revolutions per minute. In this engine the side rods used with the 650 horse-power engine are dispensed with, and the two pistons are joined by a tail rod passing through a gland in the front cylinder. All the valves are positively driven from an elevated side shaft, and are both opened and closed mechanically. The levers for this purpose carry conical rollers, engaging in grooved cams ; and when two engines are placed side by side to give a 1000 horse-power combination the same side shaft and cams serve for both, thus making a very simple and compact arrangement.

The governing is effected by varying the stroke of the gas valve in the following manner :—On a short arm operated by the cam is fixed a notched and hardened steel plate, and to the gas valve is pivoted a hardened steel blade, connected to the governor in such a manner that when the latter is in its highest position the blade engages with the notch nearest the pivot of the rocking arm, and thus receives a minimum movement, and when in its lowest the blade engages with the notch farthest from the pivot, and thus receives a maximum movement.

Intermediate positions give intermediate movements to the gas valve, and thus the power is varied.

This gear also allows of the strength of the charge being reduced to a certain point, and beyond that of the gas being omitted altogether, and thus combined throttling and hit-and-miss governing is obtained.

The pistons and exhaust valves are water cooled, the former by means of water ad-
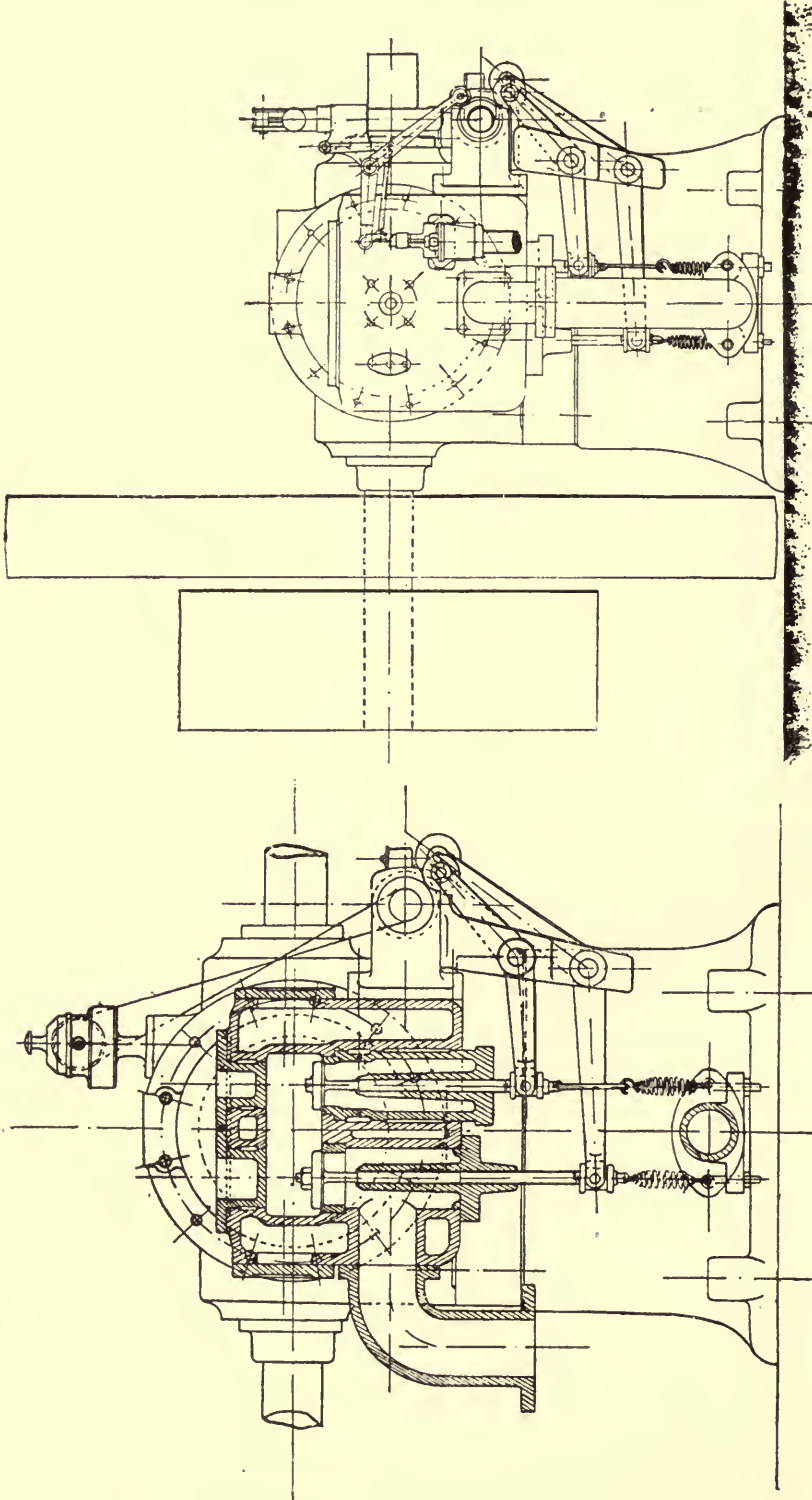mitted through a patent water service consisting of hollow swinging arms and trunnions

FIG. 224.—Robey's Gas Engine.   End View.

FIG. 223.—Robey's Gas Engine.   Section through Valves.

to the hollow piston rod, and thence to the water spaces in the pistons. The alternate acceleration of the pistons forward and backward is used to assist the circulation, and ensures equal distribution of water to both pistons. These engines have been thoroughly tested with Mond and other gas. At Sandiacre the Mond plant makes 63 cubic feet of gas per lb. of common free slack, including coal for the steam boiler, the gas having a calorific value of 150 ⊖ per cubic foot at 60° Fahr. at ordinary pressures. The gas used is 50 cubic feet per indicated horse-power-hour. The thermal efficiency is 26 per cent. more than double that of a steam boiler and engine. The produce and engine combined converts one-fourth of the available heat in the slack coal, and 1 lb. of slack gives 1 brake horse-power. The mechanical efficiency of the
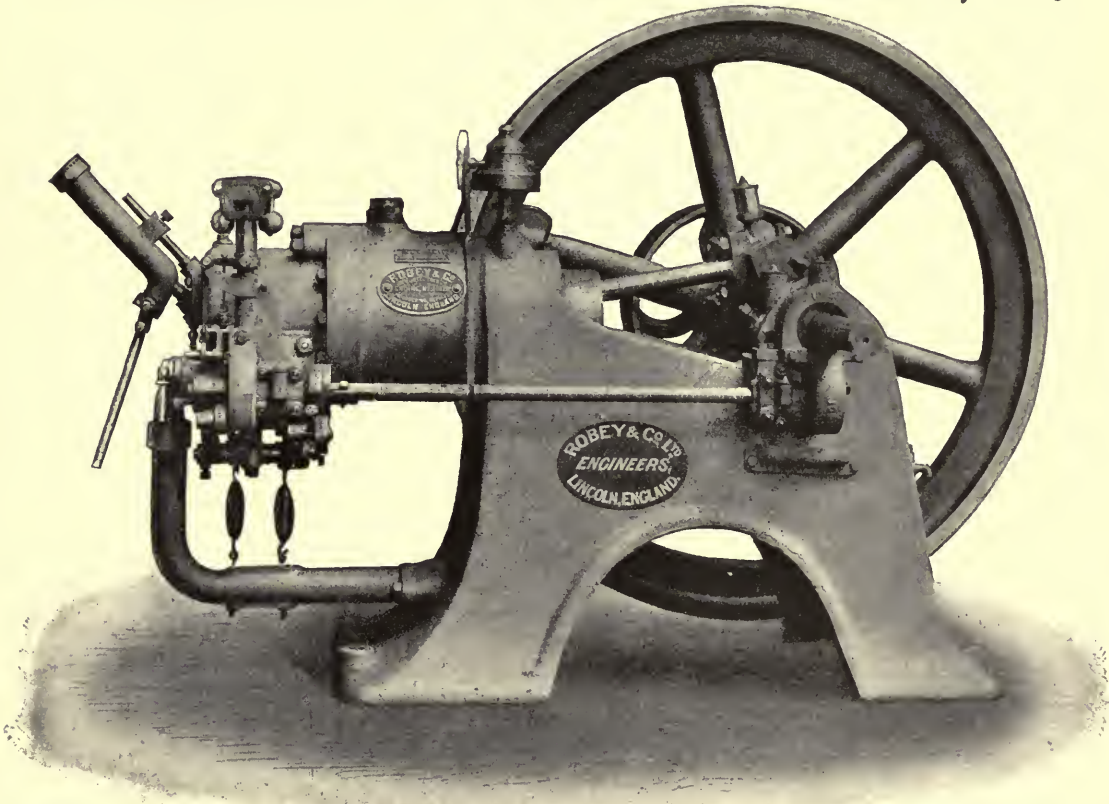
FIG. 225.—Robey's Gas Engine.

engine is 80 per cent., and with a combined dynamo and engine the electrical efficiency is about 70 per cent.

That such results as these—combined with the results of large gas engine working by Cockerill, Körting, Mather & Platt, Crossley Bros., Richardson, Westgarth & Co., and many others—have been well known to practical engineers for two or three years without attracting the attention of advising electrical engineers, who go on installing the old steam plants, is amazing, to say the least of it. More will be said on this point in the volume on POWER GENERATION AND DISTRIBUTION.

ROBEY'S GAS ENGINE

Made under the patents of Richardson and Robey, Fig. 225 shows the single acting type 4-stroke engine, complete with a centrifugal governor working on the hit-and-miss

principle. The question of gas engine governors will, however, be better considered, as a whole, in a separate section. In the cross section of the cylinder (Fig. 223) the exhaust
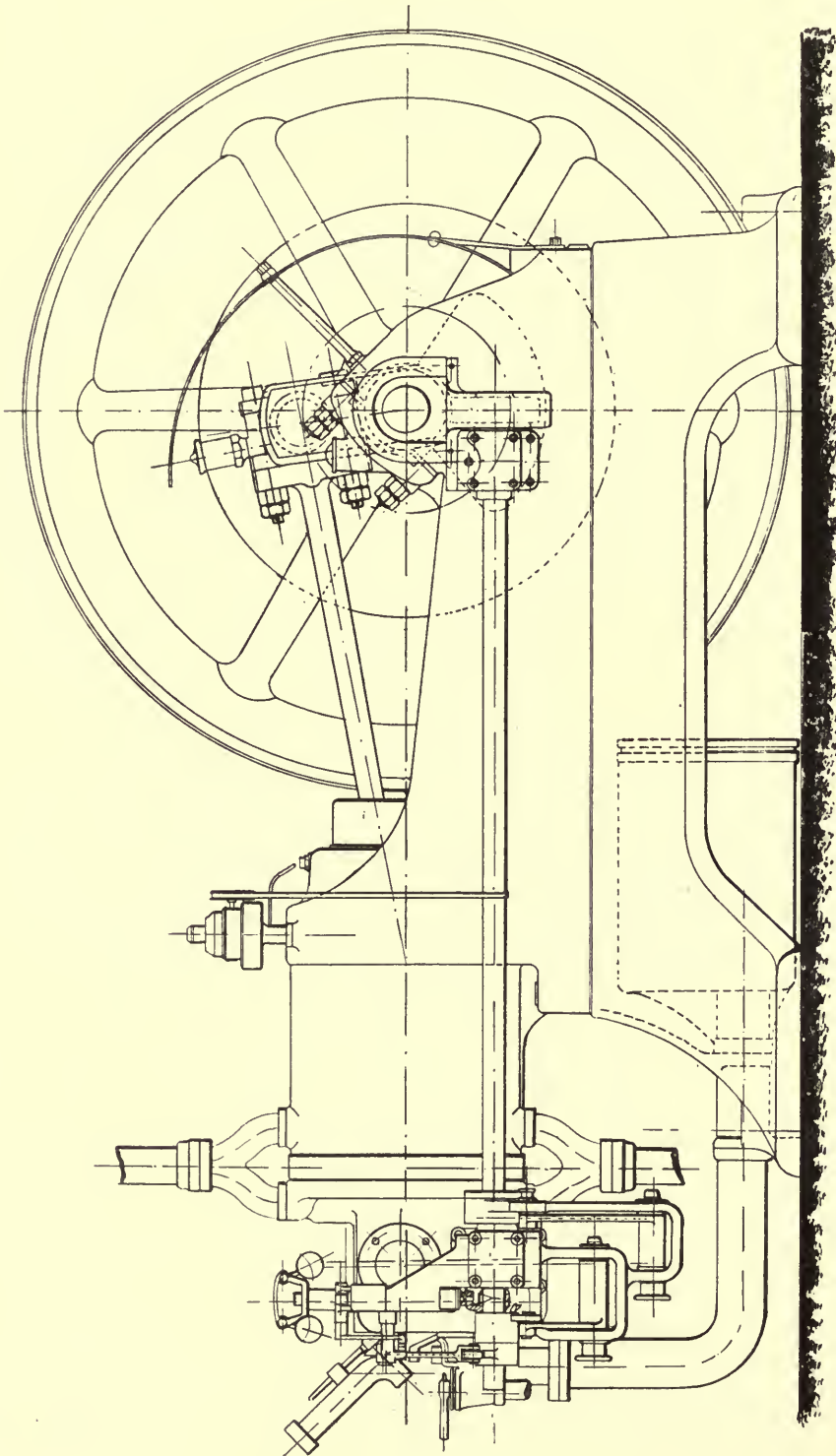

FIG. 226.—Robey's Gas Engine. Elevation.

valve is shown to the left, and the gas and air inlet to the right, with their respective cam levers and opposing springs, an arrangement simple and effective. The covers above the valves shown in this section illustrate a good design in providing ready access to important organs of an engine.

Fig. 224 is an end view showing the arrangement of the hit-and-miss governor, controlled by a centrifugal governor, and Fig. 226 is a complete side elevation showing the leading dimensions of the ordinary type of engine. The connecting rod ends are of the usual marine engine type, and the circulating cooling water is divided between the cylinder and cylinder head by the λ-shaped supply pipes, separately, so that a sound joint may be made between the cylinder and its head, and that the head may be readily removed without disturbing the cylinder joints. The ignition is by hot tube shown on the cylinder end, inclined at an angle thereto. The governor employed is shown on the cylinder head driven from the cam shaft, which is driven from the crank shaft at half speed by the usual skew gear wheels. The following are some particulars of Robey's patents on oil engines :—

The combustion chamber C (Fig. 227) of a petroleum engine acts as a vaporiser, and may be readily detached from its casing A^1 on the cylinder cover A. In the form shown
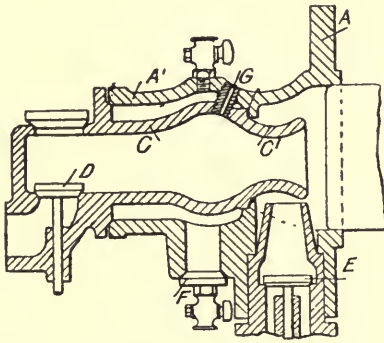
FIG. 227.—Vaporiser.
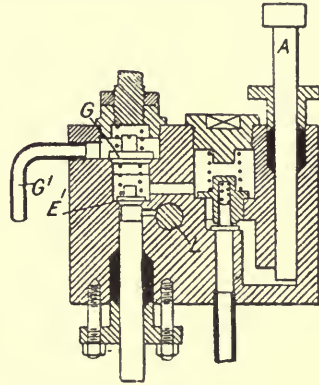
FIG. 228.—Oil Pump.

it is heated at starting by a flame from F, and afterwards by the combustion therein. The exhaust escapes by the valve E, and the air is admitted by the valve D and petroleum through G. In modifications the casing A^1 is hollow, and the air supply is heated therein. The oil may be vaporised on the exterior of the chamber C, and the chamber may be divided by a partition, on one side of which the exhaust passes, and on the other the air supply. The chamber is always reduced at C^1.

To obviate risk of failure of an oil engine owing to leaking back of the oil when the pump supplies measured charges, the pump is made to deliver oil in excess past the admission valve, which allows the requisite quantity to pass to the cylinder, while the excess is returned to the reservoir. Fig. 228 shows one modification. The pump A delivers an excess of oil past the admission valve E^1; the excess of oil returns through the valve G and pipe G^1 to the reservoir, and the charge passes through a hand-actuated cock L to the cylinder. The pump may be actuated by cams or eccentrics, or by hand at starting, and it may be immersed in oil to dispense with packing. The space between the valves may be connected to an air vessel. The valves E^1 may be of the flat slide or piston type. The bowls on the admission or exhaust valve lever, or both, are moved by the governor out of the path of their respective cams when the speed is excessive.

GRIFFIN OIL ENGINES

Fig. 229 illustrates the ordinary Griffin oil engine complete as now made for general purposes, and Fig. 230 is an end view of the gas engine showing the governing arrangements and the governor.

In this governor the gas is admitted through holes in the seat of the air valve. When the speed is excessive both the admission and exhaust valves are thrown out of
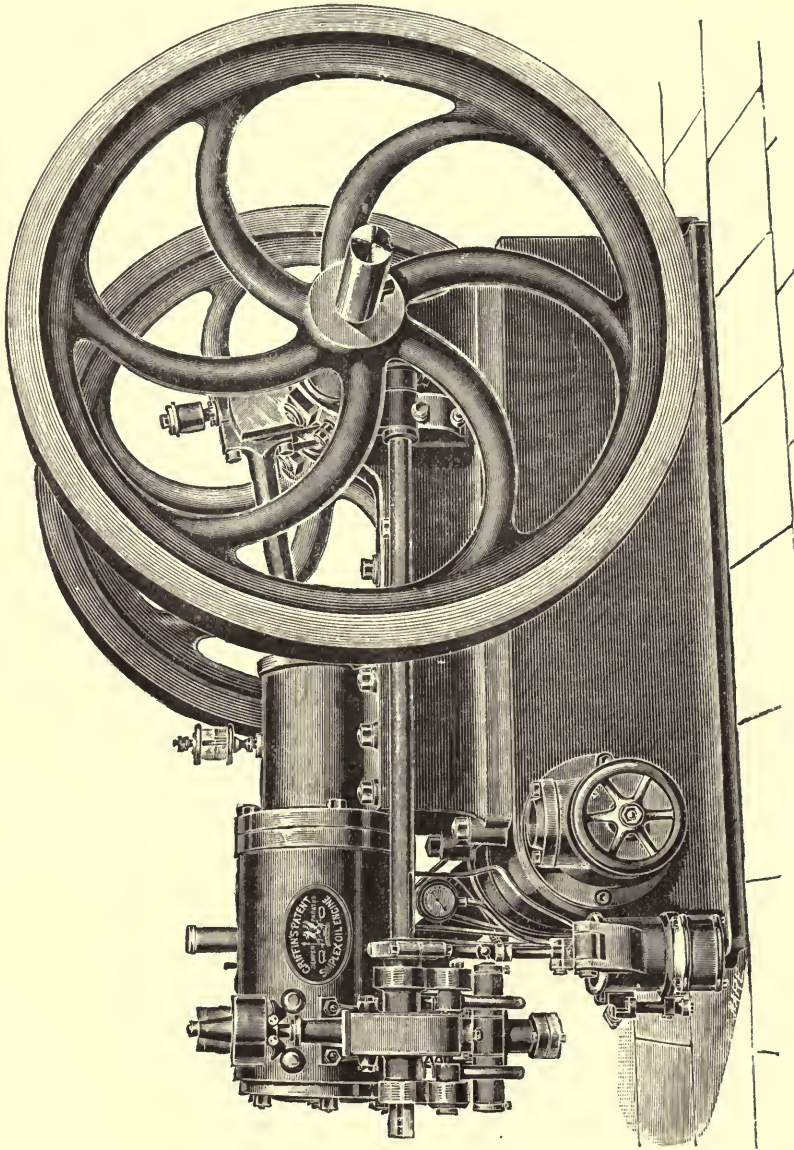

FIG. 229.—Griffin Oil Engine.

gear by a governor withdrawing the striking plates S^1 through the rod I. There is a spring connection K in the rod I, in order that the striking plate may not be drawn aside when once it is engaged by the tappet T^1. A swell F^1 is formed on the exhaust valve cam F, so that the tappet shall engage the striking plate of the exhaust valve as soon as the admission valve is opened, and ensure the opening of the exhaust valve after every explosion.

Another governor valve by Mr. S. Griffin is shown in Fig. 231. It is interesting as a useful valve for governing where the hit-and-miss principle is objectionable.

The air valve C and gas valve B are both mounted on the same spindle under the
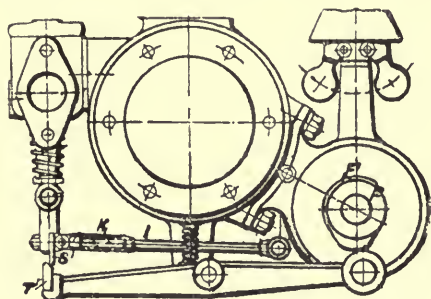
FIG. 230.—End of Cylinder.
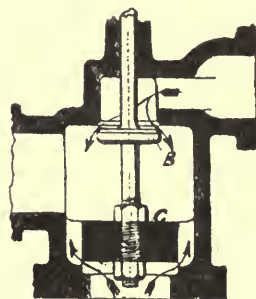
FIG. 231.—Governor Valve.

control of the governor, in such a manner that when the speed is excessive the gas valve closes and the air valve opens, and *vice versâ*

We have already fully described the Griffin's vertical oil engines for marine propulsion

TANGYE ENGINES

Fig. 232 is an outside view of this gas engine made to work with their own gas producer plant, or from town's gas. The combustion chamber is specially designed for gradual combustion and thorough mixing of the gas and air.
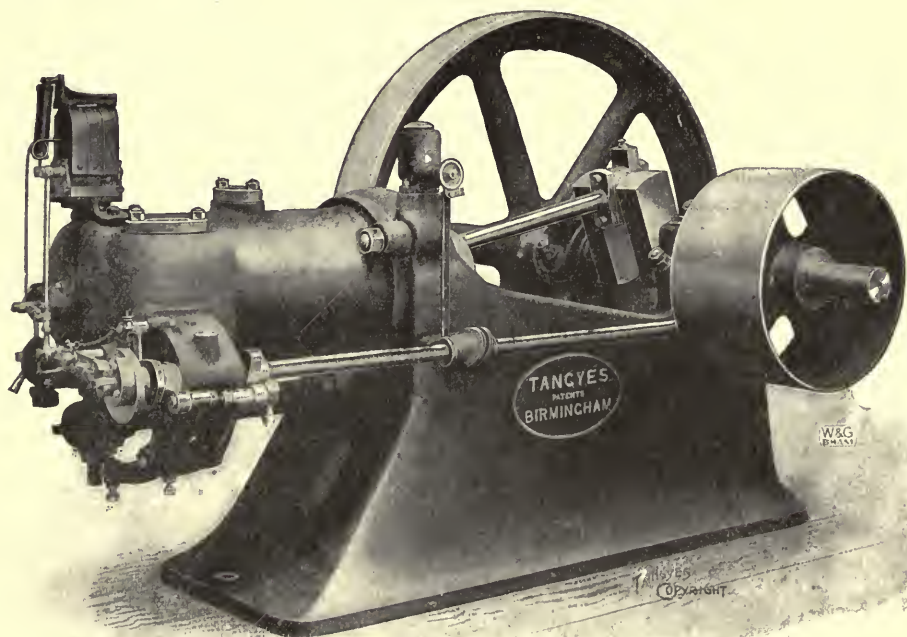
FIG. 232.—Tangye Gas Engine.

With town's gas at 2s 6d. per 1000 it is said to produce 1 kilowatt-hour for an expenditure of one penny, thus giving 5 candle-power light per cubic foot of gas ; and

with producer gas from anthracite coal the coal consumed per brake horse-power per hour is less than 1 lb.

Lubrication is forced from the side shaft by an oscillatory cam. The cylinders have a liner of specially hard cast iron, which when worn can be withdrawn readily and replaced. It is shown with magneto ignition.
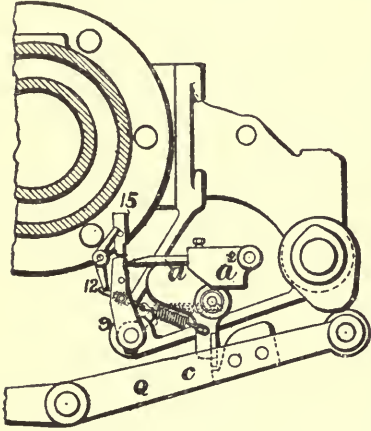

FIG. 233.—End Section.

The end view part in section (Fig. 233) shows the governing arrangement according to one of the patents. When the speed is excessive the tappet *a* is thrown up and, impinging against the lever 15, causes the valve to the vaporiser to close and that to the chimney to open.

When the speed decreases sufficiently the tappet hits the lever 9, which through the lever 12 returns the lever 15 and the valves to their normal position. The governor also fails to remove a stop *c* from the path of the exhaust valve lever Q when the speed is excessive, and the valve is consequently held open through a complete cycle.

The foregoing refers to the oil engine shown in Fig. 234 as an outside view. We have already described the vaporiser. This engine is also governed by the incline governor, holding the exhaust open when the speed is too high, in such a way as to prevent a vacuum forming in the cylinder during the suction stroke, so that no oil can enter.

The air and oil are sprayed into the cylinder, the oil being measured. The mixture passes through the vaporiser into the cylinder. On the compression stroke the mixture
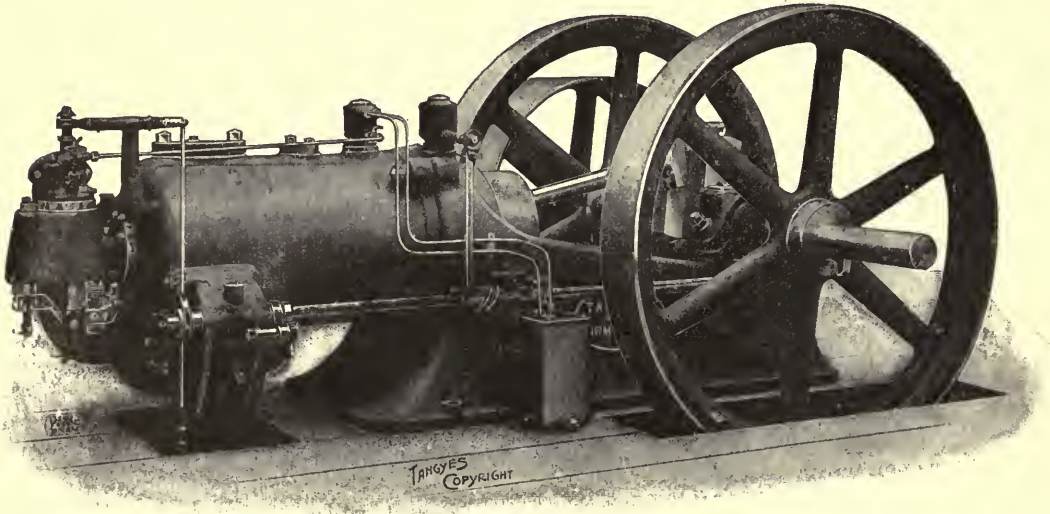

FIG. 234.—Tangye Oil Engine.

is compressed into the vaporiser and combustion chamber, and fired by an ignition hot tube or magneto spark.

This engine, which is shown in Fig. 234, will give 30 brake horse-power, and is tested before leaving the works to 34 brake horse-power and 43 indicated horse-power.

It has a heavy bed to ensure stability and steady working; tube ignition, sensitive governor, steel crank shaft cut from the solid forging, machined all over and running in long adjustable bearings, two turned fly-wheels each 66 inches diameter by 8 inches wide,

pulley 45 inches diameter by 19 inches wide, wrought-iron connecting rod with adjustable bearings and "continuous" crank-pin lubricator, machine-cut gear wheels, steel side shaft and machined cams.

The engine is arranged to run at 180 revolutions per minute. Each engine is supplied with six water tanks, main oil supply tank of sufficient capacity for a day's run, with connecting pipe to engine, oil tank for vaporiser lamp with feed pipe, exhaust silencer, a set of spanners and cleaning tools, and the following spare parts :—one piston ring, one spring of each size used on the engine, one burner coil, one ignition tube, one burner and two lead joints, two pump valves and one spring.

A patent starting arrangement, by which one man can easily put the engine in motion, is fitted to this engine.

THE FORWARD GAS AND OIL ENGINES

This engine, the invention of Mr. T. B. Barker, and made by Kynochs, Birmingham, is shown in Fig. 235 in outside view, and in Fig. 236 a section through the com-
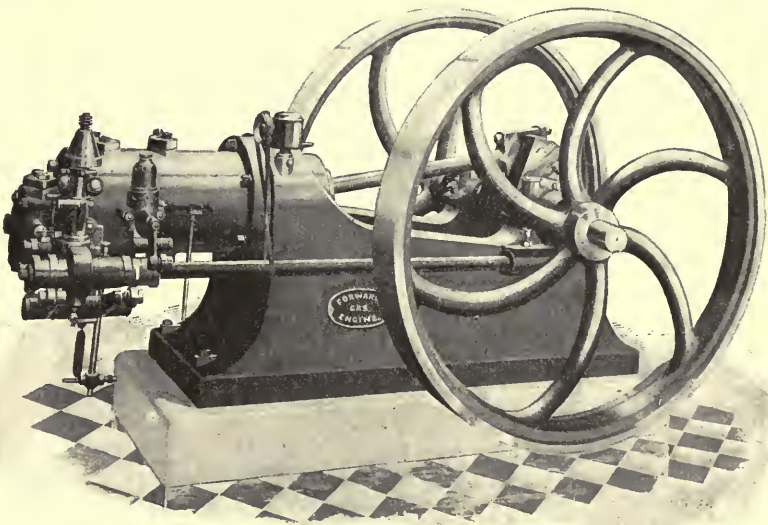

FIG. 235.—Forward Gas Engine.

bustion chambers and valves, in which P is the combustion chamber, C the cylinder, E the exhaust valve, and V the air and gas inlet.

The oil engine is shown in Fig. 237, and the following is a report on one of these engines, with a section of the cylinder and valves shown in Fig. 238.

The engine has a $6\frac{1}{2}$-inch cylinder, and is rated at 5 horse-power. When run at 7 brake horse-power it consumed .675 lb. of russoline oil per brake horse-power per hour ; and when run at the lower load of $5\frac{1}{4}$ brake horse-power it consumed .755 lb. of royal daylight oil per brake horse-power per hour. These are most excellent results for an engine of this size, and show what great economy can be realised by careful design.

The reduction in oil consumption is largely due to the high compression which is used. The last few years have seen a largely increased compression in gas engines, but there has been a difficulty in applying the same source of improved efficiency to oil engines, because they are liable to early ignition with heavy compression. If a timing valve be used the compression can generally be carried higher than without, but only at

the cost of increased complexity and wear and tear. In this engine there is no timing valve, but by a very pretty device of great simplicity the portion of the charge in which ignition is commenced is artificially cooled, so that it will only explode in contact with the hot metal of the vaporiser under heavy pressure. This result is gained in the simplest manner by placing the vaporiser some distance behind the cylinder and interposing an air inlet valve (Fig. 238). The incoming air cools the passage, so that on the compression stroke premature ignition is avoided.

This engine fires by compression and the heat of the vaporiser. There is no pump, the oil being drawn in by suction, and governing is by hit-and-miss governing. Referring to the sectional view, the vaporiser A is separated from the cylinder by the air passage C. The air valve is opened by mechanical means, and its opening is delayed so as to produce the partial vacuum required to draw in the oil into the vaporiser. At starting a lamp is used at D which heats the

FIG. 236.—Section of Cylinder Head and Valves.

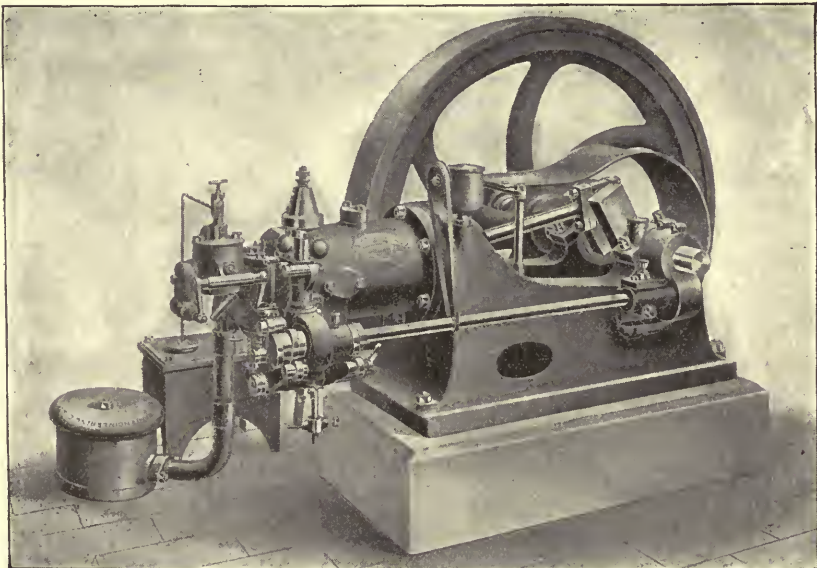ignition tube D and vaporiser at same time.

FIG. 237.—Forward Oil Engine.

In the connection between this reservoir and the vaporiser is a screw-down valve,

by which the amount of oil drawn in at each aspiration can be regulated. This valve is mounted over the central tube G (Fig. 238) of the vaporiser. Between this central tube and the external walls there are a number of radial partitions, cut away alternately at the top and bottom, so as to form a sinuous or undulating passage, which the vapour must traverse in its circuit from the central tube to the vapour valve F. There is an air inlet (11), by which air enters the vaporiser to mix with the oil vapour, and to carry it forward through the sinuous passage between the inner tube and the outer wall. The air that passes through the vaporiser is not nearly enough for the combustion of the vapour,

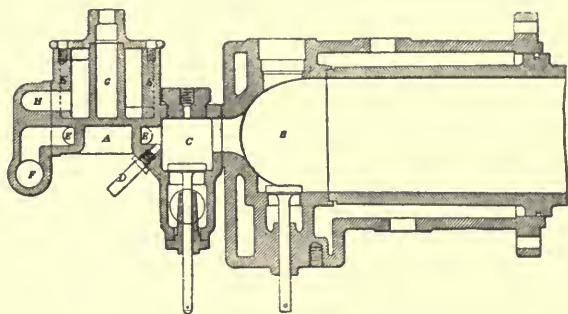Fig. 238.—Cylinder Section.

and additional air, as already explained, enters by the valve C.

It is not necessary to describe in detail the remainder of the engine, as it follows the usual construction.

The following is the result of a test by Messrs. H. Lea & Son :—

Mean indicated horse-power for whole run, 7.79 indicated horse-power.

$$\frac{\text{Brake horse-power}}{\text{Indicated horse-power}} = \frac{5.209}{7.790} = 67 \text{ per cent.}$$

Pounds of oil used per indicated horse-power per hour $\frac{35.4}{70.11} = .5049$ lb.

Pounds of oil used per brake horse-power per hour $\frac{35.4}{46.88} = .755$ lb.

The efficiency of the engine works out as follows :—

1. Useful work done = 16.8 per cent. of gross heat value in the oil, with lamp.
2. Useful work done = 17.65 per cent. of net heat value in the oil, without lamp.