

The air is pre-heated by the heat of gases in the heater *C*. The opening *b* is used to try the gas during firing up. Arrangements of scrubber and purifier are similar to those already described.

Poetter. The Poetter producer,* Fig. 7-6, is especially designed for bituminous coal. The fuel charged is distilled while still in the hopper, the gases formed are drawn off by special steam blower and are led through the pipe *Cd* under the grate. Air for blast is provided through *e f*. The gas made escapes at *a*, and is first used to raise the steam required in a boiler. It is then led through cooler, scrubber, coke- and sawdust purifier to the gas holder. Schöttler, in describing a plant of Poetter producers at Johannesburg, surmises that their operation might cause trouble, although the kind of coal used at Johannesburg is not stated.

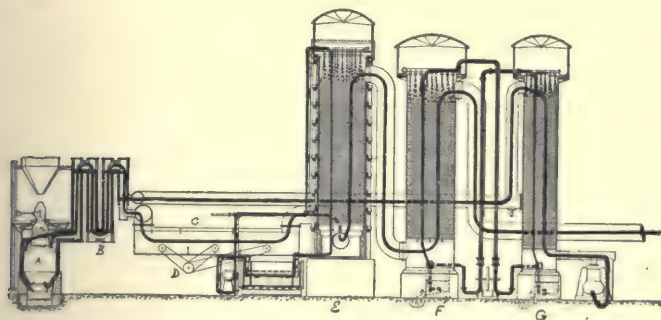


FIG. 7-7. — Mond Producer Plant.

Mond. When a producer is blown with a large excess of steam, a great deal of it will go through undecomposed. At the same time, however, the quality of the gas made undergoes some radical changes. The quantity of H in the gas will be high, sometimes up to 25 per cent, while on account of the low producer temperature, a great deal more of the C is burned to CO_2 than is ordinarily the case. A further, and important, change is that a great deal of the N is changed to ammonia, a reaction which does not take place in producers run under the ordinarily higher temperatures. To recover this ammonia is an important consideration. This is the process of Mond.

A Mond gas plant consists essentially of two parts, the producer and the condensing and recovery plant, Fig. 7-7.

* Rev. Mec., 1904, p. 484.

The details of the producer *A* do not differ much from those already described. It is of the water-bottom type. The gas made passes through the regenerators *B*. These consist of double wrought-iron tubes united alternately top and bottom. The hot gases pass through the inner tubes, heating the mixture of steam and air, used for blowing the producer, which flows through the outer tubes in the opposite direction. The gas next passes through the washer *C*. This is a large chamber partly filled with water. By means of dashers, driven by *D*, the chamber is kept filled with water spray. The gas is cooled considerably in passing through *C*, the water vapor in the gas being condensed to a great extent. Up to this point all of the apparatus is necessary even if no ammonia recovery is attempted.

For a gasification capacity of less than 30 tons of coal in twenty-four hours it is not usual to install a recovery plant on account of the high cost of installation. Beyond this capacity the installation is justified. A recovery plant consists of the acid tower *E*, the gas cooling tower *F*, and the air heating and saturating tower *G* (see Fig. 7-7).

The gas after leaving the condenser *C* enters the tower *E* at the bottom and flows upward through firebrick checker work. In doing so it meets a descending rain of sulfuric acid liquor containing about 4 per cent of free acid, and by this the free ammonia in the ascending gas is fixed, being changed to sulfate. The acid liquor is circulated by a special pump, and kept at the proper strength by drawing off the sulfate liquor and adding a corresponding amount of fresh acid solution from time to time.

The gas then enters the cooling tower *F*, at the bottom, and in its ascent is cooled by descending cold water. The gas gives up its burden of steam, which in turn heats the descending cold water. The gas is then conveyed to the gas mains.

The hot water leaving the gas-cooling tower is pumped to the top of the air-saturating tower. Here it flows downward through checker work, and in its descent saturates and heats the air, which is driven upward through the tower by blowers. Leaving this tower, the air-water vapor mixture then goes to the regenerator *B*, where it is further pre-heated before entering the producer.

Sexton* states that the amount of steam used is about 2½ tons per ton of fuel, and estimates that about two tons of this go through undecomposed.

The method has the advantage that slack coal may be gasified with success. The recovery of ammonia amounts to about 1 ton for 23 tons of coal gasified, or adding the fuel required for making steam, about 1 ton for 28.5 tons of fuel.

The average analysis of Mond gas is, by volume,

11 per cent CO, 17.1 per cent CO₂, 1.8 per cent CH₄, .4 per cent C_nH_{2n}, 27 per cent H, and 42.5 per cent N.

This gas is free from tar and excess of moisture, and burns with a non-luminous flame.

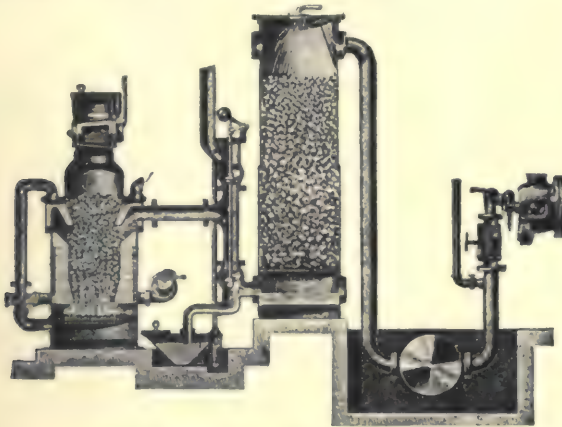


FIG. 7-8. — Deutz Suction Producer.

SUCTION PRODUCERS. — *Deutz.*† In the Deutz suction producer, Fig. 7-8, the vaporizer is arranged around the top of the generator. During the suction stroke of the engine, fresh air enters the vaporizer, is here mixed with water vapor, and then, flowing through the connecting pipe at the left side of the generator, reaches the under side of the grate. The gas made leaves the generator through the pipe at the right and enters the wet scrubber at the bottom. From here it passes to the engine through a

* Sexton, *Producer Gas*, p. 90.

† Güldner, p. 386.

regulator. Just before entering the engine the gas passes a vessel containing a wire brush for a final cleaning of tar. The larger Deutz suction installations show a somewhat different construction.

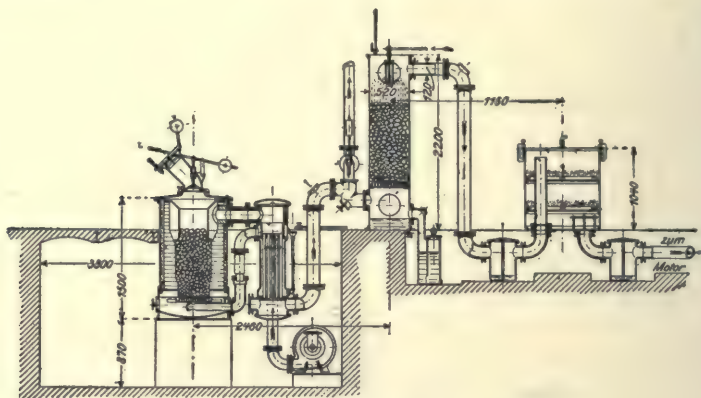


FIG. 7-9. — Koerting Suction Producer.

*Koerting.** Fig. 7-9 shows a Koerting suction plant designed for from 30-35 horse-power. In this case the vaporizer is independent of the generator. The latter is heated by the hot gases on their way to scrubber and purifier. During the heating-up period, the air is furnished by the blower shown. The smoke escapes through a pipe which branches off beyond the vaporizer, so that this will be heated during the blowing-up period.

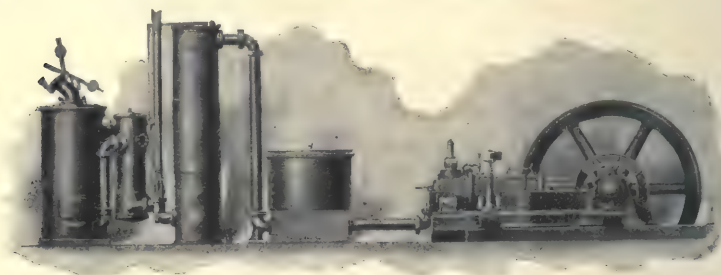


FIG. 7-10. — Koerting Installation.

A complete view of a Koerting plant is shown in Fig. 7-10.

* Güldner, p. 386.

American Crossley. The American Crossley suction gas plants in this country are built by the Power & Mining Machinery Company. Fig. 7-11 shows a complete plant. The producer is of conventional design. The fuel bed rests on a shaking grate. The fuel is admitted as shown. The waste heat boiler or saturator surrounds the feed tube. The water level in this saturator is automatically regulated. During the firing-up period the producer is blown by means of the fan shown, the gases escaping by the purge pipe. A new idea seems to be the saturating of only part of the air supply. The makers point out the difficulty of

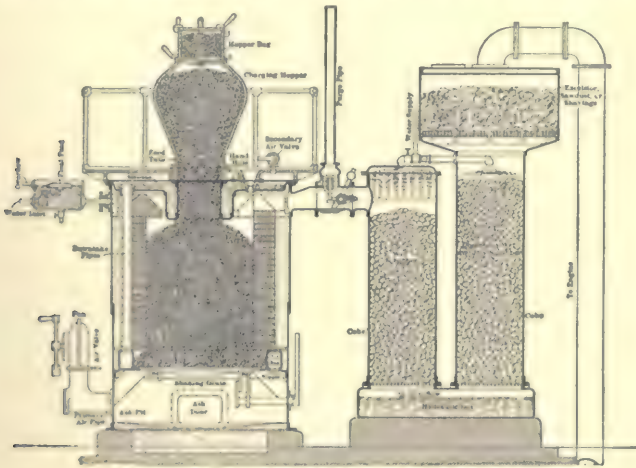


FIG. 7-11. — American Crossley Producer.

making uniform gas at all, especially at low, loads, owing to the difficulty of controlling the amount of steam admitted. To remedy this, part of the air only passes through the saturator, while the rest is directly admitted to the ash pit. Valves on these two air inlets can be set so as to give satisfactory gas over wide ranges of load.

Another arrangement in which this producer plant differs from most others is that of the cleaning apparatus. This consists of a wet scrubber, an hydraulic box, and a combination wet and dry scrubber. The gas enters the first and passes downward, passing upward in the combination scrubber. The operation is shown plainly in the cut.

Fairbanks-Morse. Fig. 7-12 shows a Fairbanks-Morse installation for 21 horse-power, the producer itself being shown in Fig. 7-13, in greater detail. The general design of the producer is very

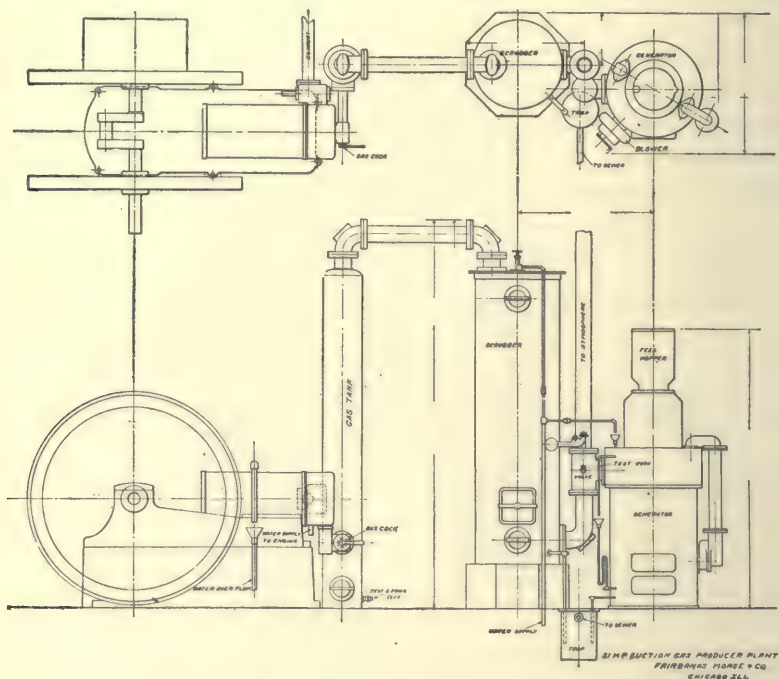


FIG. 7-12. — Fairbanks-Morse Installation.

similar to that of the American-Crossley, except that all of the air passes through the vaporizer. Apparently only a wet scrubber is provided, it being evidently intended to use anthracite only. A gas tank of considerable volume is interposed between scrubber and engine.

The suction producers so far described have been for anthracite, coke, or charcoal. The desire to utilize soft coal, lignites, etc., has led to special designs, of which the following are a few examples. In some of these all of the gas made from the fuel is passed through other highly incandescent but gas-free fuel to fix the tar-forming gases, in others only the gases of distillation are so treated.

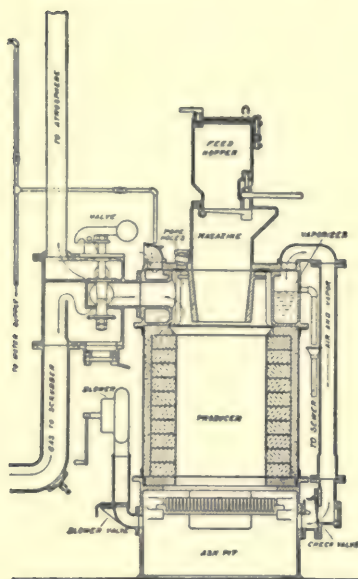


FIG. 7-13. — Fairbanks' Producer.

Riche. * Riche's producer, Fig. 7-14, is especially designed for wood, but it may also be used for hard coal and coke. The

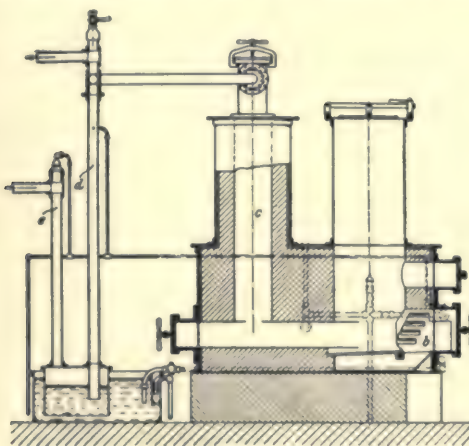


FIG. 7-14. — Riche's Producer.

* Génie Civil, 1901-2, p. 398.

column at the right serves as a magazine for the fuel bed at *b*. The gases formed are sucked up through *C*, which is kept filled with incandescent charcoal. The fixed gas passes through pipes *d* and *e*, being washed by means of sprayed water in its passage.

Lencauchez. * Instead of using two separate stacks, the two fuels may be put together in one furnace, as is done by *Lencauchez*, Fig. 7-15. Long-flaming bituminous coal is charged through *a*, while through *b* coke from coke ovens or gas works is charged. Water is evaporated in the ash pit. The openings *c* and *d* show only black smoke, while *e* shows a colorless gas. The gases from the soft coal are fixed in passing through the incandescent coke layer. *Schöttler* mentions that this gas is not used as power

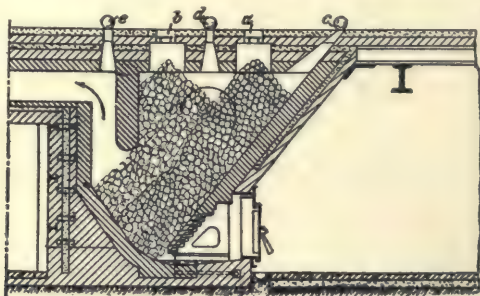


FIG. 7-15. — *Lencauchez* Producer.

gas but for heating purposes. The proportions of the charge are about 20-25 per cent coke to 80-75 per cent soft coal.

Lencauchez. † Another way of reaching the same end, that is, fixing the tarry gases, is by the use of so-called double generators. In these generators the charge burns both top and bottom, the gases being drawn off at about the middle of the producer. Fig. 7-16 shows a generator of this type designed by *Lencauchez*. It consists essentially of three conical parts. The upper one serves as a magazine. In the middle one the fire burns on top, in the bottom one at the bottom. Air enters at *D* and *B*. Water is introduced at *A* and evaporated in the ash pit. The air and gas currents are shown by the arrows. The gases of distillation formed in the magazine are drawn downward through the

* *Zeitschrift des Vereins deutscher Ingenieure*, 1905, p. 1903.

† *Zeitschrift des Vereins deutscher Ingenieure*, 1905, p. 1905

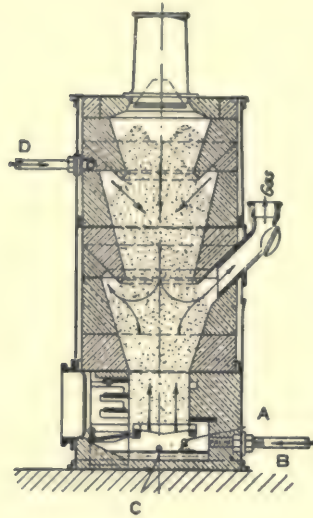


FIG. 7-16. — Lencauchez Double Zone Generator.

incandescent fuel in the middle section and are so fixed. Any unburned coked fuel then passes on toward the grate and is gasified on reaching the incandescent zone in the lower section.

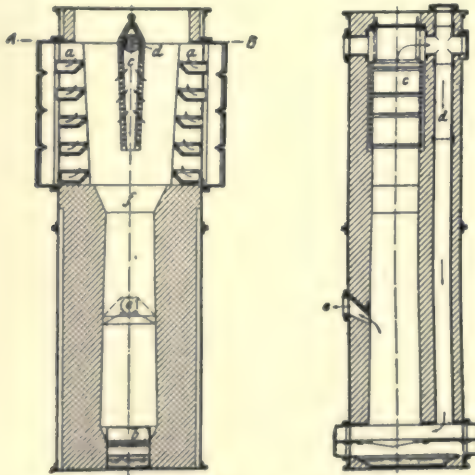


FIG. 7-17. — Koerting Producer for Peat.

Koerting. * Koerting's producer for peat, Fig. 7-17, is built along lines similar to the above. The producer consists of two parts, of which the upper and larger one is fitted with step grates, *a a*, the lower one with an ordinary grate *b*. When in operation, the charge of peat in the upper parts burns only near the grates *a a*, while the inner core of peat is only coked. The gases so formed pass into the perforated pipe *c* and are led through *d* under the grate *b*. The coked peat formed in the upper part passes downward and is gasified over the grate *b*. The gases from *d* pass through the incandescent layer above *b*, are fixed, and together with the gases formed over *b* pass out at *e*. One would naturally assume at first sight that the gases of distillation would pass directly downward and out at *e*, instead of entering *c* and passing through *d*. The direction of the movement is regulated by creating a slight vacuum under the grate *b*, and by contracting the producer section at *f*. This contraction produces an extra resistance to the passage of gases downward, and they consequently take the more convenient way through *c* and *d*. Schöttler gives the analysis of a peat gas so made as

14 per cent CO_2 , 4 per cent CH_4 , 15 per cent CO , 10 per cent H ,
and 57 per cent N ,
producer efficiency being about 75 per cent.

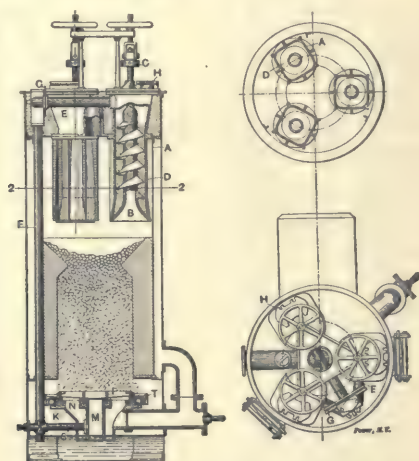


FIG. 7-18. — Crossley Producer.

* Zeitschrift des Vereins deutscher Ingenieure, 1905, p. 1909.

COMBINATION SYSTEMS. — *Crossley*. The Crossley producer, Fig. 7-18, is suitable for bituminous coal, or other fuel high in volatile matter. The fuel is first charged into the retorts *A*, and is there distilled by the sensible heat of the gases formed below. When charging, the valve *B* is drawn tightly against its seat, and the fuel is projected downward by turning the spiral *D* by means of the capstan. When the distillation is complete the casting *B* is lowered and the coked fuel is thrown into the main part of the producer by turning *D*. At the same time it is broken up by the spirals. The gases of distillation are drawn out of the retorts through the pipe *F*, and pass under the grate *T*, at *M*. The suction is produced by a fan blower, which at the same time draws air and steam to the main bed of fuel, and discharges the resulting producer gas into a holder at suitable pressure.

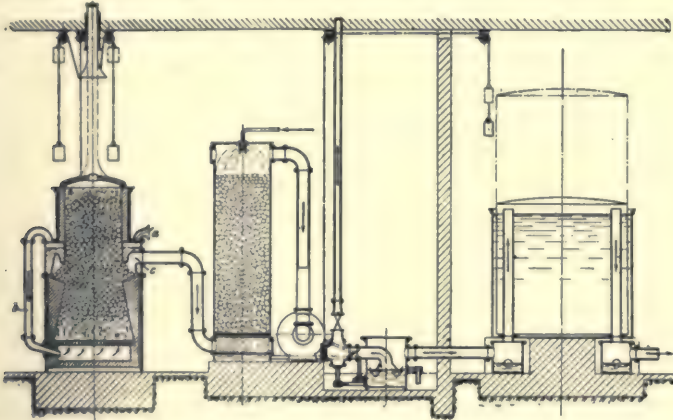


FIG. 7-19. — Deutz Double Zone Producer.

Deutz. The Deutz plant for bituminous coal is shown in Fig. 7-19. The producer is of the double-generator type. The air enters the vaporizer at *a*, and reaches the ash pit through pipe *b*. The fire burns top and bottom. Green coal is charged at the top. It is distilled, the gases formed pass downward through incandescent fuel and are so fixed, passing out at *c*. The greater part of the fuel coked near the top passes downward and is finally gasified in the lower part of the producer, the gases also passing out at *c*. Suction is maintained by a fan connected beyond the coke scrubber. Owing to the fixing of the tarry gases it is found

that a coke scrubber is all that is required. The fan, which is almost a necessary part of such a plant, owing to the increased friction entailed by the design of the producer, delivers the gas to a holder. The holder regulates the make of gas by controlling the fan. During the firing-up period, a purge pipe is lowered over the top of the generator, which has no special charging bell. The same fan is then used as a blower to furnish air to the producer, by-passing the scrubber.

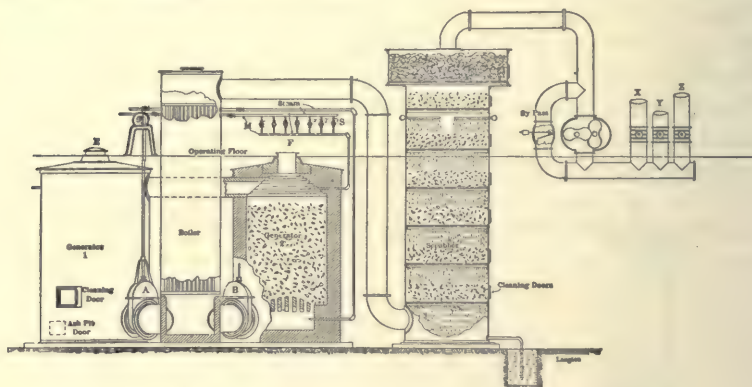


FIG. 7-20. — Loomis-Pettibone Producer.

*Loomis-Pettibone.** The Loomis-Pettibone gas apparatus, Fig. 7-20, may be used for the making of producer gas alone, or for alternate manufacture of water gas and lean power gas. Each plant consists of two producers, a boiler, a combination wet and dry scrubber, and an exhaustor which delivers the gas made to the proper holder or the purge pipe, depending upon the positions of the valves *x*, *y* and *z*. The producers are charged through the top. Through the same doors the air also enters. Thus the gases pass downward through incandescent fuel, so that any kind of fuel may be employed. Leaving the producers at the bottom, the gases pass through the boiler, where they are cooled, and then through the scrubber and purifier. The make of gas is controlled by the speed of the exhaustor, the suction pressure being ordinarily from 12 to 24 inches, the delivery pressure about 6 inches of water.

Suppose it is desired to make water gas. The feed doors *E*

* The Power Plant of the Montezuma Copper Co., John Langton.

and *F*, and the valve *B*, are closed. Steam is then admitted under the grate of producer No. 2, the right-hand producer in Fig. 7-20. The water gas formed in No. 2 is passed through the top connection to No. 1, passes down No. 1, out at *A*, and thus up the boiler and through the scrubber to gas holder. The next time water gas is run, the directions are reversed, or this may be done when one half of a water-gas run is completed. To make water gas, the aim is to blow the producers up with air as hot as possible, and then pass steam only through them until a great deal of it goes through undecomposed. Then air alone is again used to get the fires hot. This procedure means a wide range of temperature in the producer, and while this does not affect the quality of the water gas seriously, it does affect the producer gas made during the blowing-up periods, as a great deal of CO_2 is formed when the producers are comparatively cool. In a large plant where several producers are at one time delivering to the same gas holder, this irregularity is not much felt at the mixing valve of the engine where the two gases are mixed in proper proportion. For a single set plant this feature of varying producer gas make is more serious, and for this case the producers may be operated in a different manner.

To this end the steam connections, *M*, are used so that steam may be introduced along with the air, thus making water gas and lean gas concurrently, maintaining the producer temperature fairly constant for a long time; in other words, true producer gas is made. To get around the too fine adjustment of air and steam for constant temperature, somewhat less top steam than could be used is employed, thus allowing the temperature to slowly rise. A short water-gas run brings it down again to the proper point. The water gas made is slowly fed from its holder to the main gas holder through a controlled throttle valve so that its rate of feeding approximately equals its rate of production.

4. Some Producer Details. — Mathot, in *The Engineering Magazine*, May, 1905, gives the following data for suction producers:

To get the greatest production of H and the most effective reduction of CO_2 , make the cross-section of the base of the producer from 0.6 to 0.9 of the piston area of the engine. This is for a single cylinder 4-cycle engine at from 600-800 feet piston

speed. The depth of fuel bed should be from 3 to 5 times the diameter at the base, for $\frac{1}{2}$ -inch to $\frac{3}{4}$ -inch lump coal. Amount of water dissociated is from 0.8 to 1.2 times the weight of coal consumed.

More than twenty analyses give the following average figures: CO, 24 per cent; CO₂, 5 per cent; H, 17 per cent; N, 54 per cent. Calorific power from 135 to 150 B. T. U. per cubic foot. Average coal used shows 89 per cent C, 2 per cent H, 4 per cent O + N, and 5 per cent ash. Best size coal is from $\frac{1}{2}$ -inch to $1\frac{1}{4}$ -inch lump with 8 to 10 per cent of ash, and not more than 8 to 10 per cent volatile matter.

Water in the ash pan is satisfactory for steam production if the air is pre-heated. But preference is now given to internally heated vaporizers. Tubular vaporizers produce sufficient steam after 10 to 13 minutes. With well-designed apparatus, any suction plant should be in operation 25 minutes after lighting up.

The volume of the scrubber should be from 6 to 8 times that of the producer. Its height should be from 3 to 4 times its diameter. The filling is coke in pieces 3 to 4 inches in diameter, the coarser pieces near the bottom, the smaller near the top. Amount of water used for washing is from 3 to 5 gallons per horse-power per hour for anthracite gas.

According to the DeLavernne Company, the impurities to be removed from one ton of fuel are, for anthracite, from 1 to 2 pounds of ammonia, traces of sulfur, and from 5 to 10 pounds of tar; for bituminous coal, from 4 to 5 pounds of ammonia, sulfur from traces to 5 per cent, and from 10 to 12 gallons of tar.

The Morgan Construction Company point out the effect of sulfur on the formation of clinker. A coal with a large per cent of ash may work satisfactorily in a producer provided the sulfur does not exceed 1 per cent. Above 3 per cent the effect of sulfur in forming clinker is badly felt unless special facilities are at hand to break up such formations.

The same company makes the following statements regarding pressure-producer capacities. The best rate of combustion seems to be about 10 pounds of bituminous coal per square foot cross-section per hour, the coal carrying 10 per cent of ash and $1\frac{1}{2}$ per cent of sulfur. With coals of lower ash content the rate

may be increased to 12 pounds, and in some special cases to 15 pounds. For poorer coals, however, the rate may sink to 6 or 8 pounds. Regarding the size of gas flues and pipes, the statement is made that each square foot of gas flue will take care of a gasification of 200 pounds of coal per hour, and will serve a gas-making area of 16 square feet in the producer.

CHAPTER VIII

THE GAS-ENGINE FUELS: LIQUID FUELS, CARBURETER AND VAPORIZERS

1. The Crude Oils and their Distillates.—The crude petroleum oils are practically mechanical mixtures of various hydrocarbon families. It is therefore to be expected that crude oils from various fields show compositions considerably different. From these crude oils we obtain by distillation all of the mineral oils now so widely used for a great variety of purposes. Of these oils the various gasolines, kerosenes, and the so-called "distillates," besides crude oil itself, are used for gas-engine fuels.

CRUDE OIL.—The following table* gives a few analyses of crude oils from different parts of the world. These oils are usually of a dark green color, the specific gravity is between 0.80 to 0.90 at 32 degrees, and the flash point between 76 and 93 degrees Fahrenheit.

	Sp. Gravity at 32°	C	H	O and Impuri- ties	Lower Heating Value per pound
Heavy crude W. Virginia	.873	83.5	13.3	3.2	18324
Light crude W. Virginia	.841	84.3	14.1	1.6	18400
Heavy crude Pa.	.886	84.9	13.7	1.4	19210
Light crude Pa.	.826	82.0	14.8	3.2	17930
Heavy crude Ohio	.886	84.9	13.7	1.4	19210
Salt Creek, Wyoming	—	—	—	—	19463
Bothwell, Canada	.857	84.3	13.4	2.3	20410
Lima, Ohio	—	80.2	17.1	2.7	21600
Schwabwiller, Lower Rhine . .	.861	86.2	13.3	.5	18781
Gallicia, East	.872	82.2	12.1	5.7	18010
Gallicia, East	.885	85.3	12.6	2.1	18416
Light Crude, Baku	.884	86.3	13.6	.1	19440
Heavy Crude, Baku	.956	86.6	12.3	1.1	19496
Keudong, Java	—	85.0	11.2	2.8	18330

* Poole, the Calorific Power of Fuels.

GASOLINE. — After the distillation of the very light products from crude oil, we obtain a series of gasolines of varying flash points and gravity. The first of these is 86 degree gasoline, as measured on the Beaumé scale. This forms a mixture with air so readily even at ordinary temperature that it is somewhat dangerous and not often used. The next gasoline, the original liquid gas-engine fuel, is 74-degree gasoline. Owing to the much greater consumption of gasoline, due to the introduction of the automobile mainly, the gravity of gasoline and also the flash point have slowly gone up, until to-day 69-degree gasoline is quite common.

Gasoline vaporizes readily at ordinary room temperatures, and it is therefore necessary to keep it covered, not only to prevent loss but also accidents due to explosions. Insurance companies usually specify that any quantity of it must be kept in an underground tank outside of the building, and that is undoubtedly the best way.

Data on the heating value of gasoline is not at all plentiful. A sample the writer had the opportunity of testing recently gave the following figures:

Specific gravity, Beaumé 69.5 at 60 degrees Fahrenheit.

Composition, 84.76 per cent C, 15.24 per cent H.

Lower heating value as computed from analysis, 20411 B. T. U.

Heating value as determined by Junker's calorimeter, higher value 19606, lower value 18482 B. T. U.

It should be noted that this is one of the instances where the heating value as computed is much higher than the actual value, nearly 2000 B. T. U. = 10 per cent in this case. It shows the necessity of calorimetric determination for accurate work.

KEROSENE. — Kerosene, the next heavier distillate beyond gasolines, is not as extensively used as gasoline in this country for gas engines. It will not form an explosive mixture with air at ordinary temperatures, and therefore requires more elaborate apparatus for the formation of such a mixture. The following data is given by Mr. S. A. Moss for ordinary American kerosene:

Sp. Gr. at 60°	Flash point	C	H	Lower Heating Value
	open	by weight		per lb. B. T. U.
.80	100°	.85	.15	18520

Further reliable data on kerosene is given in a lecture by Diesel in 1897, in connection with Schöttler's test of the Diesel engine.

Specific gravity at 24°C (75.2° F.) .789.

Average composition, C 85.13 per cent.

H 14.21 per cent.

O .66 per cent.

Lower heating value computed from analysis, 19874 B. T. U.

Lower heating value by Junker's calorimeter,
average of five tests, 18242 B. T. U.

DISTILLATES. — A distillation product resembling kerosene in its general properties is sometimes used as fuel. These so-called distillates are not as well refined as kerosene, but are handled the same when used for engine work.

The following table, due to Hofer and transposed from Güldner, shows a good method of presenting the various distillation products from crude oil:

(a) *Volatile Oils.*

SP. GR., .65-.75, FLASH POINT BELOW 70° F., BOILING-POINT
BELOW 300°

	Sp. Gr.	Boiling-Point
Petroleum Ether	.65-.66	95°-122° F.
Benzine	.66-.68	112°-158°
Various Gasolenes	.67-.74	149°-300°

(b) *Illuminating Oils.*

SP. GR., .78-.86, FLASH POINT 70°-158°, BOILING-POINT
ABOVE 300° F.

	Sp. Gr.
American Kerosene	.78 -.81
Russian Kerosene	.82 -.825
Standard White	.808-.812
Prime White	.80 -.806
Astralin	.85 -.86

SP. GR., .86-.96, FLASH POINT 374-482° F.

	Sp. Gr.
Solar Oil	.86-.88
Lubricating and Cylinder Oils.	.88-.90, etc., can be used as lubricating oils only.

Ethyl alcohol,* whose chemical formula is C_2H_6O , may be made in various ways, but the commercial alcohol of to-day is the result of fermentation, generally of grape sugar, in the final stage. The raw materials are various. Thus, according to Sand † they may be divided into three classes:

1. Those containing starch — potatoes, with 15 to 24 per cent starch.
rye, with 50 to 56 per cent starch,
corn, with 60 per cent starch,
2. Those containing sugar — sugar beet, with 8 to 18 per cent sugar,
sugar cane, with 12 to 16 per cent sugar.
3. Those containing alcohol — wine with 9 to 16 per cent alcohol.

† Sand, *Zeitschrift des Vereines deutscher Ingenieure*, 1894, p. 933.

The method of manufacture, of course, varies with the raw material, but need not be described in detail here. Theoretically, 100 pounds of grape sugar should yield 51 pounds of pure alcohol; in reality the yield is from $\frac{1}{3}$ to $\frac{1}{4}$ less than this amount.

A second method of producing alcohol, notably mentioned by Witz in his "Moteurs à Gaz et à Pétrole," is to start with calcium carbide as a raw material. This, by a somewhat complicated process, can be changed from CaC_2 through the stages of C_2H_2 and C_2H_4 to alcohol, $\text{C}_2\text{H}_6\text{O}$. Barium carbide or strontium carbide can be used in the same way. Witz states that from 1 kilogram (2.2 pounds) of calcium carbide 0.8 liter (1.69 pints) of alcohol can be obtained; this is equivalent to 0.096 United States gallons of alcohol from 1 pound of carbide. Estimating the price of carbide at 3 cents per pound, which is even now somewhat below the market price, 1 gallon of alcohol would therefore cost, in raw material alone, 31.2 cents, to say nothing of the cost of the chemical operations. The by-products in the case of the calcium carbide do not amount to much. There is consequently little likelihood that the so-called synthetic or mineral alcohol will ever seriously compete with gasoline or kerosene for power.

The heating value of alcohol cannot be accurately computed from its chemical composition, because nothing definite is known of the arrangement of the atoms entering the composition. We therefore have to depend upon the calorimeter. The figures determined for absolute alcohol by various experimenters are as follows:

	Higher Heating Value per pound	Lower Heating Value per pound
Thomson.....	13310 B. T. U.	12036 B. T. U.
Favre & Silberman	12913 B. T. U.	11664 B. T. U.

The value 11664 B. T. U. is the one most generally used. Absolute alcohol has a specific gravity of 0.7946 at 15 degrees Centigrade (59 degrees Fahrenheit), so that one gallon of pure alcohol weighs 6.625 pounds, and has a lower heating value of 77274 B. T. U.

One pound of C_2H_6O contains 0.522 pound carbon, 0.130 pound hydrogen, and 0.348 pound oxygen.

According to this there will be required for the combustion of one pound of absolute or 100 per cent alcohol,

$$\frac{(0.522 \times 2.66) + (0.130 \times 8) - 0.348}{0.23} = 9 \text{ pounds of air.}$$

This is the equivalent of 111.5 cubic feet of air at 62 degrees Fahrenheit, per pound of C_2H_6O . Commercial alcohol, however, is never pure, but nearly always contains a certain quantity of water, the admixture being measured according to volume per cent. Thus, 90 per cent alcohol means that the mixture carries 10 per cent by volume of water. The heating value of such alcohol is of course correspondingly reduced from that of 100 per cent alcohol according to the following table, due to Schöttler:

Absolute alcohol volume—per cent	Specific gravity	Absolute alcohol weight—per cent	Lower heating value per pound B. T. U.
95	0.805	93.8	10880
90	0.815	87.7	10080
85	0.826	81.8	9360
80	0.836	76.1	8630
75	0.846	70.5	7920
70	0.856	65.0	7200
70	0.856	65.0	7200

It is required by law, in countries where alcohol is now used in the industries, to so fix the fuel that it is rendered undrinkable. This process is called "denaturizing" the alcohol. The bill passed by Congress at the last session provides for the same thing. The materials used for this purpose differ in the various European countries. Some of them try to keep the process a secret, hence some of the information given in the following table * is based upon analyses.

* Zeitschrift des Vereines deutscher Ingenieure, June, 1905.

MATERIALS USED TO DENATURIZE ETHYL ALCOHOL

Country	Sp. Gr. of Denaturized Alcohol at 15° C	Methylene (wood alcohol) and its impurities per cent	Pyridine or Pyridine Bases per cent	Acetone per cent	Benzol per cent	Benzine per cent
France	0.832	7.5	—	2.5	—	0.5
Germany						
Denat. Alcohol ..	0.819	1.5	0.5	0.5	—	—
Motor Alcohol ..	0.825	0.75	0.25	0.25	2.0	—
Austria						
Denat. Alcohol ..	0.835	3.75	0.5	1.25	—	—
Motor Alcohol ..	0.826	0.5	trace	trace	2.5	—
Russia	0.836	10.0	0.5	5.0	—	—
Italy						
Motor Alcohol ..	0.835	6.5	0.65	2.0	1.0	—
Switzerland	0.837	5.0	0.32	2.2	—	—

It will be noted from the table that the material most used for denaturizing ethyl alcohol is wood alcohol. The heating value of the fuel is by the addition of the denaturizing liquid changed but little in most cases.

Benzol, C_6H_6 , besides being used for denaturizing, is sometimes used in larger quantities than indicated in the above table, for the purpose of increasing the heating value of the fuel mixture per pound. Benzol has a specific gravity of 0.866 and a heating value of 17190 B. T. U. per pound. A mixture of x per cent by weight of absolute alcohol with y per cent of benzol, will therefore have a heating value of

$$[11664x + 17190y] \text{ B. T. U. per lb.}$$

If the alcohol is not absolute, its proper heating value should be substituted from the table above given. In this way from 10 to 40 per cent of benzol is sometimes employed, thus raising the heating value of the fuel, and at the same time decreasing the specific heat cost, *i.e.*, the cost per heat unit.

There is a second reason why benzol is employed. Under certain circumstances there will be formed acetic acid in the products of combustion of alcohol. This causes rusting of the engine parts. On examination it will be found that this is due to a combustion

with insufficient air supply, and the surest way to prevent rusting, therefore, is to use a good excess of air, and to have a perfect mixture. Under such conditions there will be no danger of corrosion. It is also found that a good addition of benzol acts as an additional safeguard. It should not be forgotten in this connection, however, that the great advantage possessed by alcohol in its odorless exhaust is sacrificed to some extent by the use of benzol.

3. Mixing Devices for Liquid Fuels. — As has been already pointed out, the fuel mixture of a gas engine is always a gas or vapor mixed with air. Hence in the case of liquid fuels special devices are required to convert these fuels into gases or vapor. Such devices are indiscriminately known as carbureters, vaporizers, mixers, or mixing valves. In the strict sense, a carbureter is a device in which the mixture is formed by passing air over or through the liquid fuel. When no special heating of the fuel is done, these devices are applicable to the more volatile fuels only, as gasoline. The name carbureter, however, is also used when in this device gasoline is mechanically atomized or sprayed into the current of incoming air. The term vaporizer is usually employed when considerable heat for gasification or vaporization is required, as is the case for kerosene, crude oil, and alcohol.

MIXING DEVICES FOR GASOLINE: CARBURETERS. — Carbureters in which the air is passed over or through gasoline have the drawback that when the carbureter chamber is filled with fresh gasoline the lighter constituents of the liquid distil off first. The parts harder to vaporize remain behind, so that the fuel mixture is anything but constant, growing leaner as the vaporization progresses.

Atomizing or spraying carbureters are not open to this objection, a definite amount of gasoline being injected each time. Hence they are much used, especially in automobile work.

Figure 8-1 shows a carbureter which is of what has been very aptly termed the bubbling type. The suction stroke of the engine establishes a partial vacuum in *a* through the check valve *c*, and the chamber *d*, interposed for reasons of safety. This causes air to enter through the screen *b*, rising through *c* in a spray. Bubbling up through the gasoline it carries with it some of the vaporized liquid and goes through *d* and *e* to the engine,

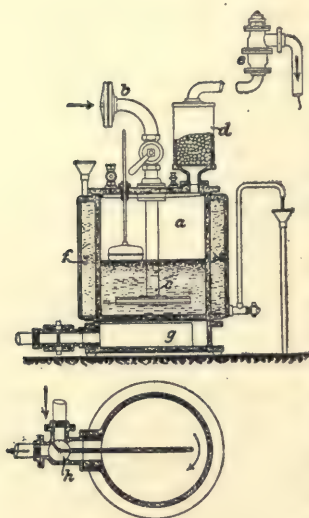


FIG. 8-1.

where a normal combustion mixture is formed by the addition of more air. The jacket water from the engine may be circulated through *f*, assisting in the vaporization. In special cases a part of the exhaust gases may also be circulated through the bottom, *g*.

Figures 8-2 and 8-3 are properly termed surface carbureters. In the former, the Reithman carburetor, the gasoline is fed from the reservoir *a* in drops into the chamber *b*, where it is absorbed by broad suspended wicks. From the surfaces of these the gasoline vaporizes, adding itself to the air which strikes through chamber *b* on every suction stroke. Chamber *f* is filled with clean gravel or wire

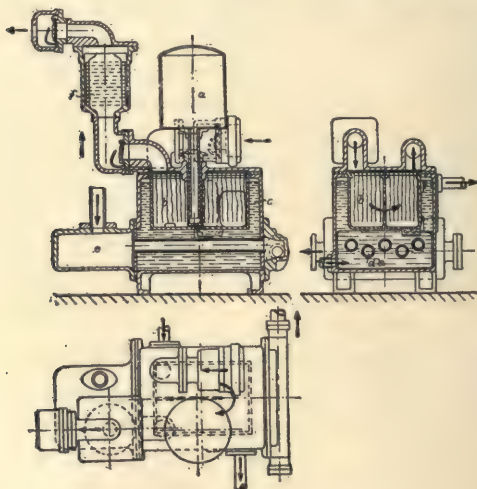


FIG. 8-2 — Reithman Carburetor.

screens, to act as a safety device against possible back firing. Chamber *b* is surrounded by a water jacket, the water in which is heated by the exhaust gases passing through the tubes *d d*.

The Petreano carbureter, Fig. 8-3, will serve for either gasoline or alcohol. The exhaust gases pass through a central pipe, *r*, which is surrounded by a jacket, *V*. The pipe *r* has a covering, *d*, of spongy asbestos film which is constantly kept moist with the liquid to be vaporized. The liquid fuel enters by one opening in the top, the air by another. The chamber *V* has four cones, as shown, two of which are also partially covered with asbestos. By means of these cones the fuel vapor and air are thoroughly mixed before entering the chamber *M* and finally the suction pipe to the engine. The small openings, *o*, are for the purpose of drawing off the heavier parts of the liquid, those that vaporize less easily, if there be any, in order not to interfere with the regularity of carbureting.

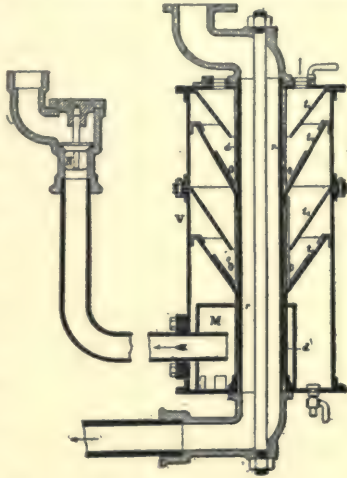


FIG. 8-3. — Petreano Carbureter.

Atomizing or spraying carbureters are, however, much more frequently employed, and the following to be described are all of this type.

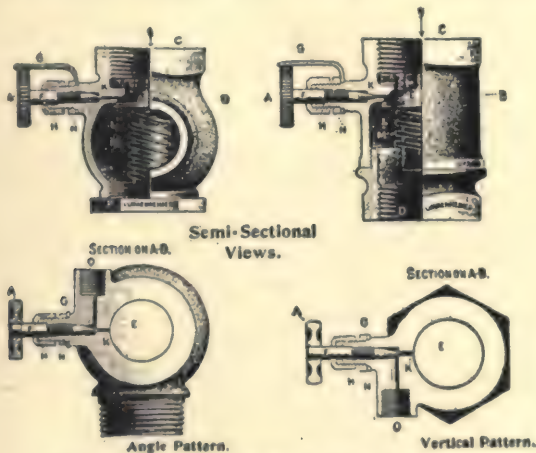
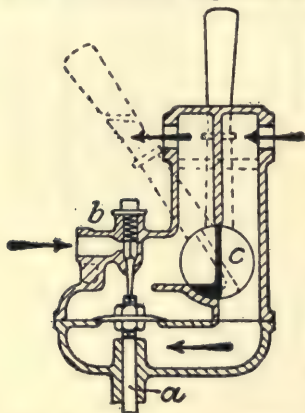


FIG. 8-4. — Lunkenheimer Mixing Valves.

The simplest design of this type of carbureter is shown in Fig. 8-4, which shows two of the Lunkenheimer carbureters. In either design, gasoline is furnished through the opening *O*, and its admission to the valve seat of the main suction valve *E* is regulated by the needle valve *A*. On the suction stroke of the engine the valve *E* automatically lifts, and the air rushing through this opening carries with it a certain amount of gasoline flowing from the small hole *K*. It is quite evident that this type of carbureter gives best service on hit-and-miss engines. For any other type a varying load would probably cause trouble, as there is no automatic regulation of the gasoline supply.



Still of very simple design, but capable of regulation of the gasoline supply, is the Sinto carbureter, Fig. 8-5. The lift of the gasoline needle valve *b* is regulated by the lift of the mechanically regulated suction valve *a*. By means of the cock *c* it is possible to admit part of the air uncarbureted to the cylinder.

Figures 8-6 and 8-7 are examples of the so-called float-feed type of carbureters.

The Daimler, Fig. 8-6, is well known. A float, *B*, in the chamber, *A*, operates a pair of counterweight levers, *E*, and through them the valve spindle, *D*, which controls the admission of gasoline at *C*, keeping it at a constant level in the nozzle. Gasoline enters at *N* from a tank under slight pressure or at a higher level. *O* is a cloth filter and the plug *P* serves to catch any grit that may be brought in. The float chamber is vented through a small hole in the cap over the valve spindle to relieve any pressure which may be formed due to varying positions of the float *B*. The action of the carbureter is as follows: At each charging stroke of the engine air is drawn into the annular chamber *H* and passes with great velocity through the drop tube *F*, surrounding the gasoline nozzle. The gasoline is drawn in a jet from the nozzle and, with the air, striking the deflector *K*, the two are very thoroughly mixed, passing to the engine through *M*. An aux-

iliary air supply can be admitted through the cap at the top, the openings through which can be regulated.

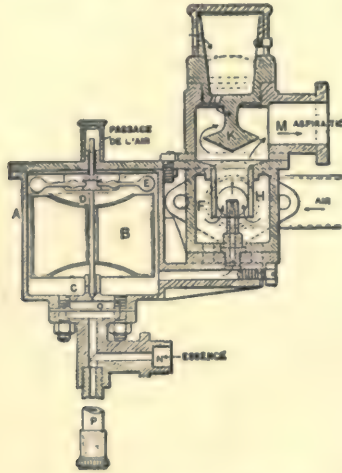


FIG. 8-6. — Daimler Carbureter.

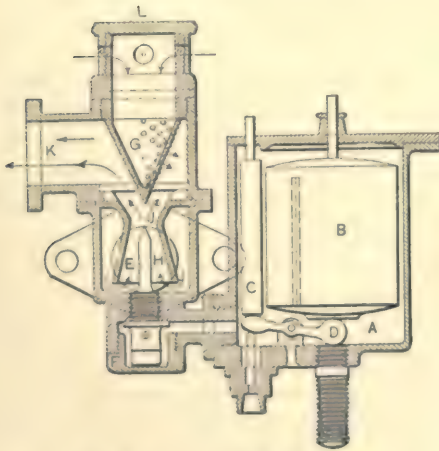


FIG. 8-7. — Abeille Carbureter.

The Abeille carbureter, Fig. 8-7, embodies the same idea as the Daimler. The float *B*, by operating the lever *D*, opens and closes a needle valve at the lower end of the weighted spindle *C*, to maintain a constant level just below the opening in the nozzle

E. On the suction stroke, air enters at *H*, and rushing up through the double cone draws the gasoline from the nozzle, atomizing it by striking the perforated cone *G*. A secondary air supply is admitted through the cap *L* and the holes in *G*, being regulated by the position of the cap *L*.

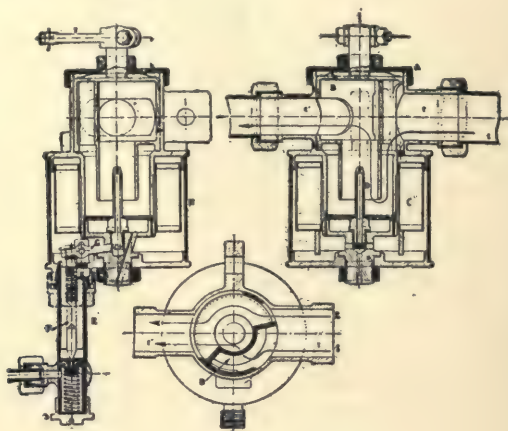


FIG. 8-8.— De Dion Carbureter.

Of more complicated design, but in principle the same as the other float-feed carbureters, is the De Dion, Fig. 8-8. Air is admitted through the tube *t*. By the position of the valve *V* (see horizontal section), which position can be regulated by the lever *I* (see vertical section), part of the air goes directly into the discharge pipe *t'*, while the rest is deflected downward to be carbureted. The course of this latter body of air is indicated in the right vertical section by the arrow. The level of the gasoline in the nozzle *D* is again kept constant by the annular float *C* in the chamber *H*, operating the lever *G* and through it the valve *F*.

It will be noted that none of the atomizing or spraying carbureters for gasoline so far described are heated in any manner. Occasionally, however, we find one in which the atomizing is assisted by heat. The W. Hay vaporizer, Fig. 8-9, is of this type. Gasoline enters the annular chamber, *a a*, through the pipe *d*. From this chamber a number of small openings lead through the seat of the suction valve *E*. Some of these openings are provided with adjusting screws as shown at the left. On

the opening of *E*, the inrush of air atomizes the gasoline flowing from these small openings, and the current of air and gasoline striking the wings *e* of the fan *h*, supported on the spindle *j*, sets the fan in motion, thus promoting a thorough mixture of air and vapor before the fuel finally passes through *x* to the admission valve *A*. The exhaust gases from *B* are passed through the chamber *F*, finally escaping through the slotted openings *g*. In their passage they heat both the gasoline storage chamber *a a* and the fan chamber.

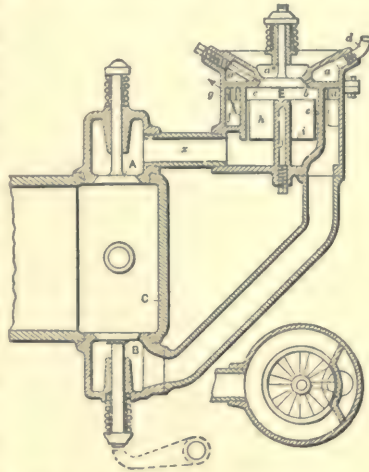


FIG. 8-9. — W. Hay Vaporizer.

Occasionally we also find carbureters which combine the several principles of those described. Thus in the Gautier carbureter, Fig. 8-10, the gasoline is admitted through *A*, the supply being regulated by the valve

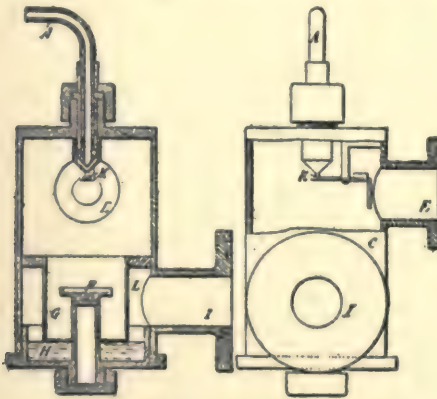


FIG. 8-10. — Gautier Carbureter.

K, which opens at the proper moment owing to suction through pipe *E*. Part of the supply falls on to the saucer *F*, and from there into the reservoir *H*. Into the liquid at *H* dips a pipe *G*,

supported as shown. The air supply through *I* circulates through the chamber *L*, bubbles through the liquid at *H* into the chamber surrounding the saucer *F*, licks up some of the gasoline in the saucer, and the mixture finally escapes through *E*.

VAPORIZING DEVICES FOR CRUDE OIL AND KEROSENE. —

While it is fairly easy to satisfactorily atomize or vaporize gasoline and to maintain the mixture, the thing is a little more difficult with kerosene, and much more so with crude oil. In either case the agency of heat is required, and this is applied either in a separate vaporizer or retort, or the kerosene or crude oil is injected directly into the cylinder, the vaporization taking place in the combustion chamber.

One trouble with kerosene is the readiness with which some of the vapor is condensed on striking comparatively cool surfaces. This may happen on the mixture striking parts of the water-cooled walls. In such a case part of the fuel may go through the cylinder unburned, and this is a point that should be carefully guarded against when a special vaporizer for kerosene is employed.

In the case of crude oil, the heating in the vaporizer results in the distillation of the lighter products first. The amount of vapor formed will naturally be less and less as the distillation proceeds, resulting in a constant impoverishing of the fuel mixture. The remedy would therefore seem to be a constant supply of fresh oil and a removal of the old before it has commenced to seriously decrease its yield. This is what is actually done in some devices. The method, however, naturally results in the fact that the plant can only use part of the crude oil. It is claimed by some that only 10 per cent of the oil is so withdrawn from the vaporizer, but this seems extremely doubtful.

A crude oil-air mixture is open to the same objection as a kerosene mixture as regards condensation of some of the heavier hydrocarbons and consequent loss. Both of these mixtures are also subject to cracking; that is, a breaking up of the heavier hydrocarbons into the lighter with a consequent deposit of carbon.

For large power plants the best solution in the case of crude oil would seem to be the use of some type of oil-gas producer. Some of these are in actual use along the Pacific coast, and will be described later.

Figure 8-11 shows the kerosene atomizer used on the Hornsby engine. With it is combined the regulating valve. Kerosene is pumped up through the lower right-hand pipe in the sectional cut. The governor regulates through *c* the position of the over-flow valve *b*, the surplus kerosene flowing back through *d* to the reservoir. The kerosene at the moment demanded by the engine

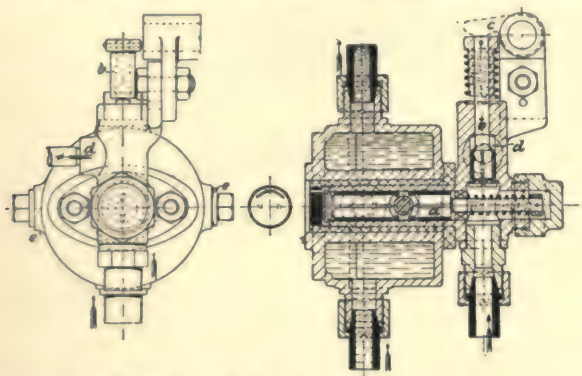


FIG. 8-11. — Hornsby-Akroyd Atomizer.

is forced by the pump through the plug *a*, issuing from its end in a fine spray. This plug is kept cool by a water jacket as shown.

Another atomizing kerosene carbureter is the Gibbon, shown in Fig. 8-12. In this a valveless pump *x w*, actuated by a cam, injects kerosene from the tank up through the atomizing opening into the chamber *U*. This is furnished with wings, *U'*, to present a larger surface for heating. Chamber *U* is directly connected with the combustion chamber, and is surrounded by a light case to prevent radiation. At the start it is heated by a lamp, but after a short period of operation the charge ignites by compression, as is the case also in the Hornsby engines.

In the Crossley vaporizer, Fig. 8-13, a certain fixed amount of oil is measured and drawn into the vaporizer by the air on the opening of the valve. In this case ignition

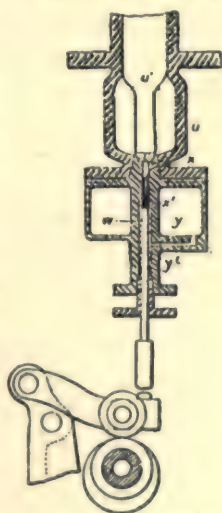


FIG. 8-12. — Gibbon Kerosene Vaporizer.

is produced by means of a hot tube, and the engine is of course governed on the hit-and-miss system. The lamp heating the hot tube at the same time heats the vaporizer.

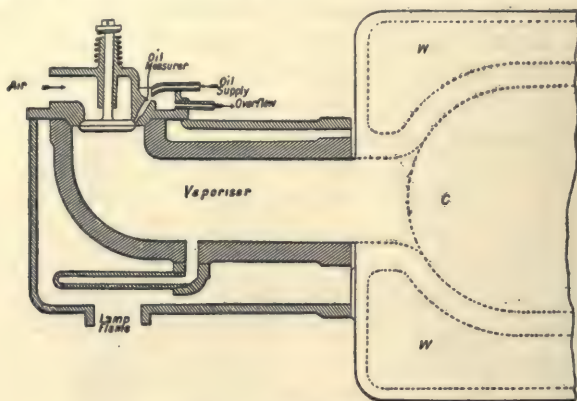


FIG. 8-13. — Crossley Vaporizer.

The Priestman engine is designed for either crude oil or kerosene. Its vaporizer is shown in Figs. 8-14 and 8-15. Oil is admitted to the spraying nozzle *K* from a reservoir under pressure.

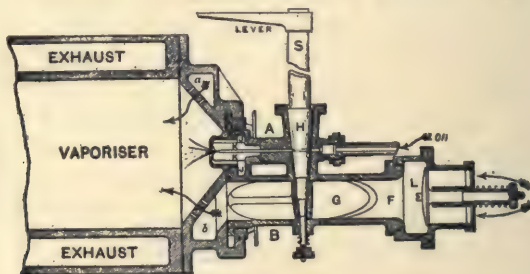


FIG. 8-14. — Priestman Vaporizer.

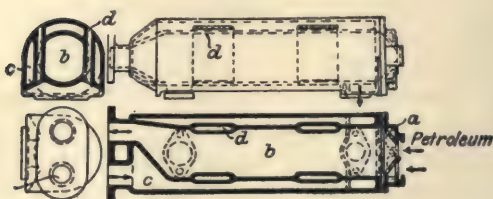


FIG. 8-15. — Priestman Vaporizer.

The pump furnishing the air for this purpose also furnishes air to the annular space *J*, surrounding the nozzle *K*, for the purpose of atomizing the oil. The finely divided oil enters the vaporizer chamber and, mixing with the larger body of air admitted on the suction stroke to the vaporizer chamber through the valve *L*, passes on to the cylinder. The vaporizer chamber, Fig. 8-15, is heated by the exhaust gases passing through the jacket space *C*, thus vaporizing the oil spray in its passage. On starting, the vaporizer chamber is heated by a lamp whose hot gases pass through the jacket spaces *d*. The governor, by regulating the position of the plug valve *H*, regulates at the same time both the oil and the air supply to the vaporizer.

A crude oil vaporizer quite extensively used on the Pacific coast is the "Economist" retort, Fig. 8-16. This consists of

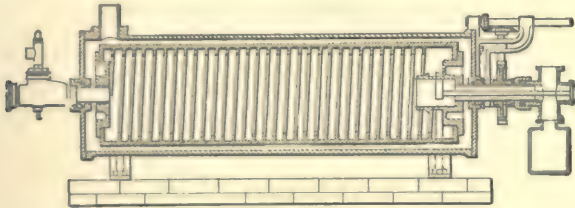


Fig. 8-16. — "Economist" Crude Oil Vaporizer.

two concentric shells as shown. In the jacket space between them the engine exhaust gases are circulated to furnish the heat for vaporization. The inner drum is slowly rotated upon its axis, as shown by the gearing at the right, and it is furnished on the interior with a continuous spiral rib. The crude oil is admitted through the central pipe at the left. By the rotation of the drum it is carried up the sides, turned over and over, thus exposing a thin sheet all the time to the action of the heat, which is most favorable for complete vaporization. At the same time, owing to the action of the spiral rib, the oil is slowly carried forward through the drum. The residue is finally discharged through an outlet at the right, in a manner not clearly shown. The makers claim that during the progress of the oil through the drum the temperature is maintained just high enough to get all the gas from the oil. The method of regulation by this device is not clearly stated. If it is done by regulating the oil

supply to the retort according to the load, there would be considerable lag in the regulation; if done by regulating the air supply through the retort there would be a large variation in the composition of the mixture. An auxiliary air supply between generator and engine would help, but whether this is used or not is not stated.

Retorts as above described are made up to from 125 to 150 horse-power. Beyond this they become unsatisfactory, and other devices have to be employed. The one that seems to promise best at present is an oil-gas generator of the type of the Lowe.

The principle of the Lowe system is to heat up to a very high temperature a mass of firebrick checker work contained in a firebrick-lined steel shell, by means of a crude oil-air blast. When the desired temperature is reached the chimney connection to the generator is closed off, and crude oil and superheated steam in an intimate mixture are sent down through the highly heated checker work. The result is the formation of an impure oil water gas with a good deal of lampblack as a by-product. This by-product may be utilized as fuel to furnish the power necessary for blowing engines, etc., around the plant. The gas itself is washed in the ordinary manner, and is a high-grade gas of good illuminating power. The production of this gas is therefore carried on in the two stages, a heating-up period and a period of make. From published figures the efficiency of these oil-gas producers is as yet not very high. In the *Journal of Electricity, Power and Gas*, September, 1904, a consumption of 11.22 gallons of oil per 1000 cubic feet of gas made is given as the average for one plant for July. Other plants have shown 9 and 10 gallons per 1000 cubic feet of gas of about the same heating value. Assuming the crude oil to weigh 7 pounds per gallon, its heating value at 19000 B. T. U. per pound, and the heating value of the gas at 650 B. T. U. per cubic foot, the efficiency of generation on cold gas would be for the most favorable case above given

$$\frac{1000 \times 650}{9 \times 7 \times 19000} = 54.3 \%$$

VAPORIZING DEVICES FOR ALCOHOL. — The alcohol engine has perhaps received its greatest development in Germany.

It is for that reason that we shall have to turn to the literature of that country for the best and latest information on the details of alcohol engines.

The following material is a reprint from an article published by the writer on the alcohol question in *Marine Engineering*, June, 1906. The information is mainly due to the work of E. Meyer and of A. Schöttler, also to the discussions by Güldner, Diesel, and others.*

Regarding the formation of the fuel mixture with alcohol, it is found that it is less volatile than gasoline, but easier to handle than kerosene. In nearly all of the vaporizing devices for alcohol now on the market, the agency of heat, usually the exhaust heat of the waste gases, is used to aid in the formation of the mixture. This scheme has the drawback that no heat is available at the start when the engine is cold. To avoid an open flame for the purpose of heating the vaporizer at the start, which is both dangerous and cumbersome, the engines in most cases are started with gasoline, and when, after a few strokes, enough heat is available, the change is usually made by throwing over a single lever. In tests of ten different engines made by Meyer, it was shown that this change to alcohol could be made in the slowest case in 6 minutes and 40 seconds, the time of the fastest being 55 seconds.

Based on the manner of heating the vaporizer, we can distinguish the following classes:

1. Those in which no heat is employed.
2. Those in which the air is pre-heated.
3. Those in which the mixture is heated and superheated.

Of the first type is the Deutz, Figs. 8-17 and 8-18. When the engine is regulated by the throttling method, and not by the hit-and-miss system, it has been found that no pre-heating of air or fuel mixture is required. The reason for this is undoubtedly that in a hit-and-miss engine, under less than normal load, a succession of misses cools the cylinder down so far as to throw down some of the alcohol vapor on the next explosion, unless it is superheated. The Deutz engine is governed by throttling. The inlet valve *f* is actuated, through the levers

* E. Meyer, *Zeitschrift d. V. d. I.*, 1903, pages, 513, 600, 632, 669; R. Schöttler, *Zeitschrift d. V. d. I.*, 1902, pages, 1157, 1223; H. Güldner, *Zeitschrift d. V. d. I.*, 1902, page 623; Diesel, *Zeitschrift d. V. d. I.*, 1903, page 1366.

shown, by the cam *a*, which is of taper form and under the control of the governor Fig. 8-17. Upon the position of *a* depends the length of time the valve *f* is open. Through the bell crank *c d e* the cam also acts upon the plunger of the fuel pump *h*, operating in such a way as to cause suction during the first part of the cam movement, and pumping of the liquid during the second. Thus the fuel is injected during the second half of the suction stroke only, insuring a rich mixture around the igniter.

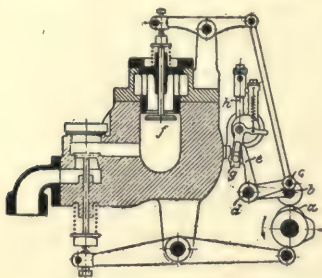


Fig. 8-17. — Deutz Alcohol Vaporizer.

The alcohol is forced through the sprayer or atomizer *i*, Fig. 8-18, into the current of air which enters through the valve *k*. Thus no pre-heating whatever is done, but the atomizing is thorough; and the ports into the cylinder are as direct and short as possible, hence no vapor is thrown down.

The Altman vaporizer, Fig. 8-19, is of the second class. The air pipe *a—b* is surrounded at its lower end by the exhaust pipe; the air is thus pre-heated by the exhaust gases. A regulating valve for the air is placed at *e*. This, when drawn upward, decreases the amount of air passing, but always makes the air current strike through the upper part of the pipe, in this manner directing it always against the fuel nozzle *d*. The inlet valve *c* is operated by the lever *f*, actuated by the cam *l*, through the pendulum hit-and-miss governor *o m p*. This valve lever *f* at the same time opens the fuel valve *d*, through the reach rod shown and the finger *h i*, Fig. 8-21. How this is done is shown in Fig. 8-20. The lever *f*, on being depressed, forces down the point of the screw *k*, thereby turning the reach rod about its axis, which depresses

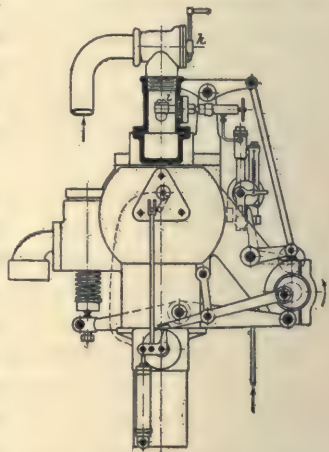


Fig. 8-18. — Deutz Alcohol Vaporizer.

the point *i*, Fig. 8-21, opening the valve *d*. The amount of opening depends upon the position of the screw *k*, and this can be very finely adjusted by the worm and wheel arrangement shown. In this vaporizer the fuel supply is atomized partly by the current of air, and is afterward's vaporized by the heat of the pre-heated air.

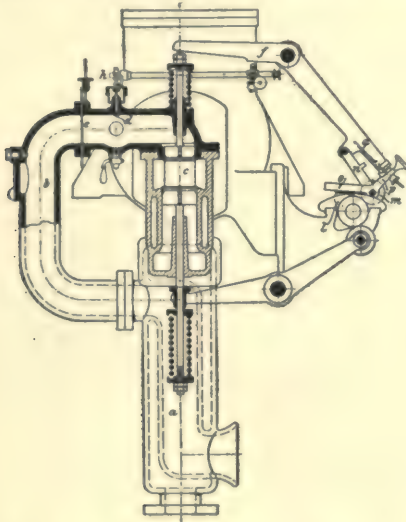


FIG. 8-19. — Altman Alcohol Vaporizer.

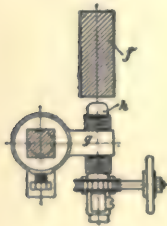


FIG. 8-20.



FIG. 8-21.

The following three vaporizers are of the third class. Fig. 8-22 shows the Swiderski-Longuemarre. Here also the exhaust gases are used for heating. They pass through the annular chamber *a*, and their action is aided by the radiating webs *b b*. The float *d* maintains a constant level in the supply chamber. From this chamber the flow of alcohol is regulated by the needle valve *f*.

The liquid flows into the space *g*, and overflows through a number of small openings *h h*. Air entering through *i* is made to pass partly outside, partly inside, the concentric spaces created

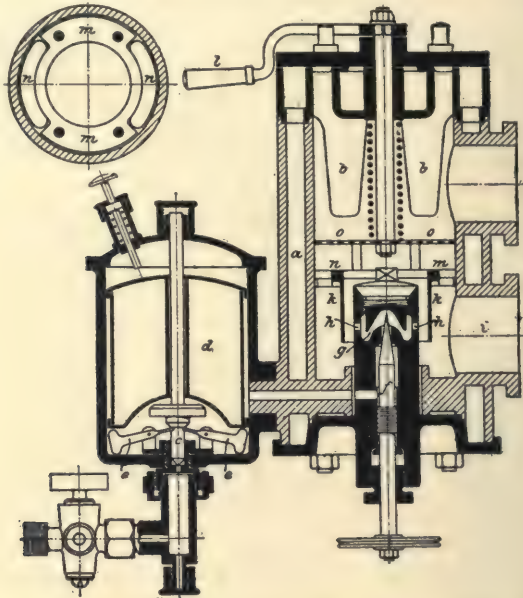


FIG. 8-22. — Swiderski-Longuemarre Alcohol Carbureter.

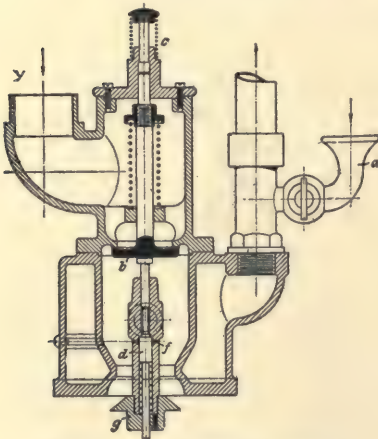


FIG. 8-23. — Dresden Alcohol Vaporizer.

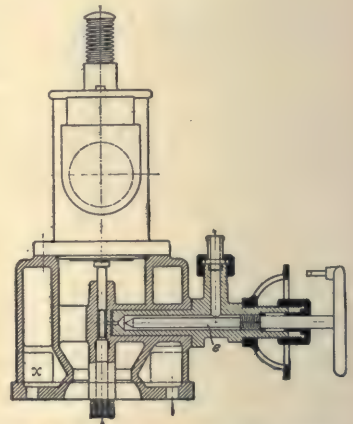


FIG. 8-24. — Dresden Alcohol Vaporizer.

by the sleeve *k*. The amount of air passing outside is regulated by the openings *n n* which are controlled by the lever *l*. The air currents passing upward carry along with them some of the liquid, the mixture being heated by the exhaust gases in *a*. The perforated plate *o* tends to aid in forming a uniform mixture.

The vaporizer of the Dresdener Gasmotorenfabrik is shown in Figs. 8-23 and 8-24. In this case the warm cooling water of the engine is used for heating. It enters the water space at *x*, Fig. 8-24. On very cold days the vaporization may be assisted at the start by pouring some hot water into the funnel *a*. Air enters at *y*, 8-23. The inlet valve *b* is automatic. It may be pushed down at will at the start by pressing down on the projecting stem *c*. The downward movement of the inlet wave opens the fuel valve *d*, to which alcohol is furnished through the needle valve *e*, Fig. 8-24. Through a number of fine openings the fuel flows into the current of air and is carried along with it, the thorough mixing being assisted by the current striking the cone *g*. As will be seen from the drawing, the heating of the charge cannot be very high. In the first place only the comparatively cool jacket water of the engine is used, and secondly the mixture itself is not in the heated chamber for any length of time.

In contradistinction to the Dresden vaporizer, the Dürr, Fig. 8-25, produces a highly heated mixture. Air enters at *x* and its amount is regulated by the throttle valve *a*. The inlet valve *b* is automatic. Alcohol is supplied through the needle valve *c*, as shown, so that when *b* is closed no flow of alcohol takes place. The current of air charged with alcohol particles passes down through *d*, up the annular space *e*, and out at *y* to the cylinder. The exhaust gases enter at *z*, and by means of baffle plates

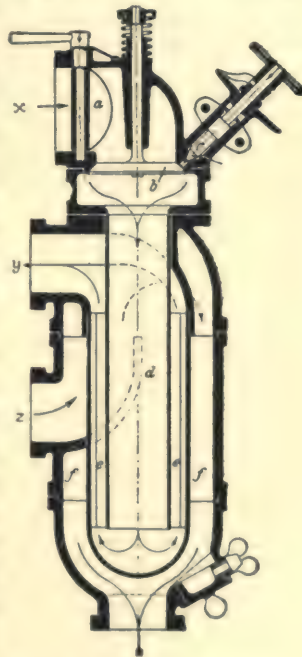


FIG. 8-25. — Dürr Alcohol Vaporizer.

are made to take the course shown by the arrows, through the space *f*. Further, the space *e* is filled with a large number of metal spirals, which connect the outside wall of *e* with its inside wall, thus furnishing a large heated surface to the passage of the charge, and facilitating the transfer of heat from the space *f* to the space *d*. Every possible way is therefore made use of to apply the heat of the exhaust gases, and this vaporizer consequently furnishes a mixture more highly superheated than that of the others.

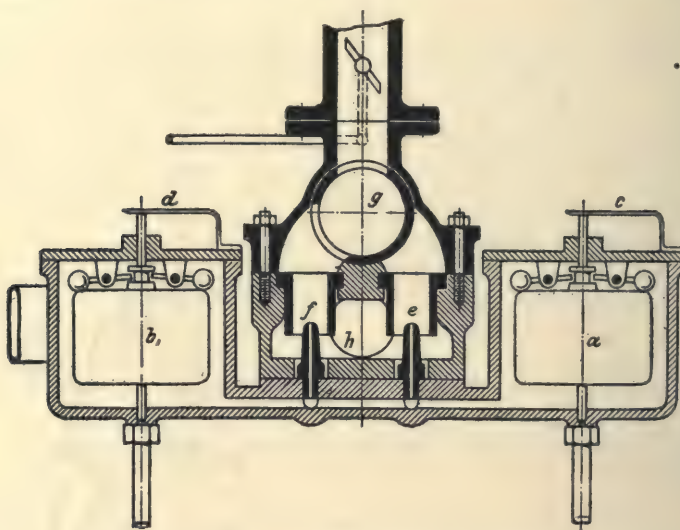


FIG. 8-26. — Gasoline-Alcohol Vaporizer.

Finally, Fig. 8-26 shows what may be called a double float carbureter, which is the form that alcohol vaporizers are likely to take. This is used on the Marienfelde machines. Assume that the chamber *a* is used for gasoline, *b* for alcohol. The needle supply valves can be held closed by the springs *c* and *d*, as shown.

On starting with gasoline, the chamber *a* is used. Spring *c* is pushed aside so that fuel can enter, being kept at constant level by the float. The valve *g* is so set that the path is open for the air from *h* past the gasoline nozzle *e*, through *g* into the cylinder. At every suction stroke the in-rushing air is then charged with gasoline issuing in a small jet from *e*. If it is desired to change to alcohol, spring *c* is pushed into place, spring *d*

is pushed aside, and valve *g* is thrown over into the position shown in Fig. 10, all the work of a moment. The air supply to this vaporizer is pre-heated.

It is quite evident from an examination of the vaporizers above described that the final temperature of the mixture is very different in the different devices. Upon this temperature, however, depends in a great measure the only other point of difference between gasoline and alcohol engines, *i.e.*, the amount of compression. All other things being the same, that fuel mixture entering the cylinder at the highest temperature will soonest give rise to pre-ignition, or at least to pounding, under an increase in compression. High temperature of charge also effects engine capacity unfavorably. It therefore becomes important to determine approximately the *lowest* practical temperature of vaporization, and the heat necessary.

Of course the amount of heat required depends upon the amount of alcohol (and its purity) per pound or cubic foot of air. Assuming that 90 volume-per cent alcohol is used, the theoretical amount of air required for perfect combustion is 7.8 pounds. Assuming that an excess of 50 per cent of air is used, which is a desirable allowance, 1 pound of 90 per cent alcohol would require in round numbers 11.7 pounds of air. With the air temperature at 60 degrees Fahrenheit, and the atmospheric pressure 14.7 pounds per square inch, this amounts to 0.0065 pound of 90 per cent alcohol per cubic foot of dry air.

90 (volume) per cent alcohol is equivalent to 87.7 (weight) per cent, so that 1 pound of air will carry, according to the above assumed ratio of mixture,

$$0.877 \times \frac{1}{11.7} = 0.075 \text{ pound of absolute alcohol,}$$

$$\text{and } 0.123 \times \frac{1}{11.7} = 0.010 \text{ pound of water.}$$

To compute the air temperature required so that it may take up the above quantities of alcohol and water vapor, we must know the relation between the temperature and the degree of saturation. Meyer in his computations used the data contained in the Physikalisch-Chemische Tabellen of Landolt & Börnstein.

Temperature Degrees F	Vapor Tension Inches Mercury		1 pound of air contains in saturated condition, in pounds			
	Alcohol Vapor	Water Vapor	At 28.95 inches Hg. Press.		At 26.05 inches Hg. Press.	
			Alcohol Vapor	Water Vapor	Alcohol Vapor	Water Vapor
50	0.950	0.359	0.055	0.008	0.061	0.009
59	1.283	0.500	0.075	0.011	0.084	0.013
68	1.733	0.687	0.104	0.016	0.117	0.018
77	2.325	0.925	0.144	0.022	0.162	0.025
86	3.090	1.240	0.200	0.031	0.227	0.036
104	5.270	2.162	0.390	0.063	0.450	0.072
122	8.660	3.620	0.827	0.135	1.002	0.164

For our purpose the figures of the table have been transposed into English units.

In the ordinary case the air drawn into the vaporizer is not dry, but contains a certain quantity of water. Assume that the air is at a temperature of 59 degrees and just saturated. At a pressure of 26.05 inches of mercury this would correspond to 0.013 pound of water per pound of air in its initial condition. Now in the case of the average mixture above computed, the temperature of vaporization must be high enough to vaporize an additional 0.010 pound of water, making the total 0.023 pound that the air must contain per pound. It is seen from the table that a temperature of 77 degrees is quite sufficient to do this. It is also seen that at this temperature the air may take up 0.162 pound of absolute alcohol, while the quantity in the above mixture is only 0.075 pound per pound of mixture. At a temperature of 77 degrees the mixture ready for the cylinder may therefore contain the alcohol vapor in a state of some superheat. If therefore the temperature of the walls with which the mixture comes in contact is not less than 77 degrees, no fear of condensation of alcohol vapor need be entertained. In this connection a statement in the *Engineering Record* is of interest. It is there claimed that the consumption of alcohol with the jacket water leaving at 60 degrees Fahrenheit is 100 per cent higher than with jacket water leaving near 212 degrees; *i.e.*, with cooling by

vaporization. In the light of the above facts, some such increase in the consumption is quite possible.

In order to convert the liquid alcohol into vapor, a certain quantity of heat is required. According to Regnault, this amount is, for the various temperatures given, and computed above 32 degrees Fahrenheit, as follows:

At 32° F	425.7 B. T. U. per pound
68° F	453.6 B. T. U. per pound
122° F	475.2 B. T. U. per pound
212° F	481.1 B. T. U. per pound

The specific heat of liquid alcohol is close to 0.6, so that in order to convert the quantity of 90 volume-per cent alcohol contained in the assumed mixture to alcohol vapor at 77 degrees Fahrenheit would require approximately, assuming the liquid alcohol at 60 degrees Fahrenheit, $0.075 \times [458 - (28 \times 0.6)] + [0.010 \times 1100] = 44.1$ B. T. U., where 1100 B. T. U. is assumed as the heat of vaporization of water under the existing conditions.

Now the heating value of 90 volume-per cent alcohol has been shown to be 10080 B. T. U. per pound, so that the heating value on one pound of our assumed mixture will be $0.075 \times 10080 = 756$ B. T. U. The heat of vaporization required is therefore $\frac{44.1}{756} = 5.8$ per cent of the heating value of the fuel. It can be shown that the amount of heat is easily obtainable from the exhaust gases. It can also be shown that the problem may be solved by pre-heating the air only, for, assuming that the specific heat of air at constant pressure is 0.238, we would have to pre-heat the air for the assumed mixture to $\frac{44.1}{.238} + 77 = 262$ degrees Fahrenheit, which is easily possible.

If, on the other hand, not the air but the mixture is heated, then the walls need to have a temperature only sufficiently higher than 77 degrees to transfer the required amount of heat for vaporization to the mixture in the time available. To furnish more heat than this is harmful, if anything, for it affects unfavorably both the possible degree of compression and the capacity of the machine. The cooler the mixture after formation and vaporization, the better.

CHAPTER IX

GAS-ENGINE FUELS: GAS FUELS

OUTSIDE of producer gas, which has been treated in a previous chapter, the gases used for gas engine fuel are:

1. Illuminating gas. 2. Oil gas. 3. Coke oven gas. 4. Blast furnace gas. 5. Acetylene. 6. Water gas. 7. Natural gas.

1. Illuminating Gas. — Illuminating gas is made by distilling bituminous coal in retorts. From 100 pounds of average coal are obtained about 400–450 cu. ft. of cooled gas, 50–70 lb. of coke, 4.25–4.75 lb. of tar, and 8–10 lb. of ammonia liquor. Each 100 pounds of coal also require about 20 pounds of coke for the heating of the retort.

The composition of the gas varies constantly somewhat even in the same plant. The average composition is about 45–48 per cent by volume of hydrogen, 35–38 per cent CH_4 , 5–8 per cent CO , and the rest heavy hydrocarbons, oxygen, nitrogen, and carbon dioxide. The gas owes its illuminating power to the heavy hydrocarbons it contains. Its heating value, however, is not proportional to its candle power. To determine the heating value the best way is to use a calorimeter. It may, however, with sufficient accuracy be computed from the analysis of the gas. Varying somewhat in this same locality, the average lower heating value is probably not far from 600 B. T. U. per cubic foot. Its density averages about .4, air being 1.0, its average weight per cubic foot, therefore, being not far from .032 lb.

The following table shows a few typical analyses of illuminating gas.*

* Mostly from Poole, the Calorific Power of Fuels.

	H	CH ₄	Hydro-carbons	CO ₂	CO	O	N	B. T. U. cu. ft. Lower Value
Newton, Mass.	50.59	34.80	5.23	1.16	6.16	—	2.06	599
Cleveland	34.80	28.80	11.20	.20	10.40	.40	14.20	657
Boston	47.49	38.67	5.21	1.04	6.74	—	.85	651
Cincinnati	45.85	39.26	5.17	.82	4.78	.41	3.71	645
Birmingham	40.23	39.00	4.76	1.50	4.05	.36	10.10	671
Glasgow	39.18	40.26	10.00	.29	7.14	.06	3.0	830 ¹
Liverpool	36.44	44.28	7.90	1.70	3.39	.19	6.10	792 ¹
Hanover	46.27	37.55	3.17	.81	11.19	—	1.01	661
Paris	50.10	33.10	5.80	1.50	6.30	.50	2.70	667
Average	43.44	37.30	6.49	1.00	6.68	.32	5.77	686

2. **Oil Gas.** — Oil gas is made by vaporizing and superheating crude oils. It may be made by vaporizing these oils in retorts which are externally heated, as in the case of the Pintsch method, or the manufacture may be carried on as in the Lowe process, in which, as previously described, the generator is first internally heated by burning crude oil, the oil to be gasified being then sent into the heated chamber together with steam under exclusion of air.

Pintsch gas, much used for railway car illumination, contains, according to Güldner,*

17.4 per cent C_2H_4 , 58.3 per cent CH_4 , and 24.3 per cent H by volume.

Another gas obtained from a by-product paraffin oil showed the following composition by volume:

28.9 per cent C_2H_4 , 54.9 per cent CH_4 , 5.6 per cent H, 8.9 per cent CO, and 9 per cent CO_2 .

Oil gas as made by the Lowe process is a water gas; the composition will therefore show much more H than is indicated in the above analysis of Pintsch gas.

Wyer † in his *Gas Producer* gives the following figures:

32 per cent H, 48 per cent CH_4 , $16\frac{1}{2}$ per cent C_2H_4 , 3 per cent N, .5 per cent O.

¹ Values evidently too high.

* Güldner, *Entwerfen und Berechnen der Verbrennungsmotoren*.

† Wyer, *Producer Gas and Gas Producers*.

Güldner estimates that the yield of gas from 1 pound of oil in the Pintsch process is from 7–10 cu. ft. of cooled gas, about .75 lb. of coke being used in the same time for heating. This amounts to about 100 lb. of oil or about 14 gallons of oil per 1000 cu. ft. of gas, in the most favorable case, as against 9–10 gallons per 1000 cu. ft. in the Lowe process. The heating value per cubic foot of the Pintsch gas, however, is higher than that of the Lowe in the ratio of about $\frac{900}{650}$, so that on the basis of thermal efficiency the two methods of making oil gas are probably not very far apart, with the chances in favor of the Lowe system on account of the coke used for heating in the other system, which must, of course, be considered in making thermal calculations.

3. Coke Oven Gas. — Coke oven gas when made in the old type Bee-hive oven is fundamentally the same as illuminating gas. Compare the following analysis given by Wyer of a sample of this gas with the average analysis given for illuminating gas on page 208.

H, 50.0 per cent; CH_4 , 36.0 per cent; C_2H_4 , .4 per cent; N, 2 per cent; CO, 6 per cent; O, 5 per cent; CO_2 , 1.5 per cent.

When made in modern by-product ovens, however, the gas yield is sometimes divided and that part of the gas used for fuel has a somewhat different composition. From a diagram published by the United Coke and Gas Company of New York,* it appears that the gas evolved during the coking of the charge in a retort is divided into two parts. The entire coking period covers nearly 25 hours. The gas evolved during approximately the first ten hours, called the surplus or rich gas, is separated from that made during the rest of the period, called fuel gas. The surplus gas is high in illuminating power and in heating value, approximately 720 B. T. U. per cubic foot. The fuel gas has an average heating value of about 560 B. T. U. per cubic foot. The figures quoted are for a medium volatile coal. The rich gas from a ton of this coal in an actual case amounted to 4300 cubic feet, which was 46 per cent of the total yield per ton, this part of the gas carrying 52 per cent of the total heat value of the gas. A ton of this coal therefore yields about 9400 cu. ft. of gas.

The same treatise above quoted gives the following gas

* The United Otto System of By-product Coke Ovens.

analysis for a coal carrying from 30-32 per cent of volatile matter:

	Illuminating or Rich Gas	Fuel Gas
Illuminants	5.8	2.8
CH ₄	40.8	29.6
H	37.6	41.6
CO	5.6	6.3
CO ₂	3.7	3.2
O	.4	.4
N	6.1	16.1
	<u>100.0</u>	<u>100.0</u>
B. T. U. per cu. ft. higher value	730.3	551.3

Where no illuminating gases are desired the entire gas yield is recovered together. The gas is excellent for power purposes except for the somewhat high percentages of H which render the fuel mixtures liable to pre-ignition under high compression in the cylinder.

4. Blast Furnace Gas. — The blast furnace is really a large gas generator, with the difference that to the charge of fuel is added the burden of ore and of flux, and that the blast is air alone without admixture of steam. Owing to the calcination of the flux, which is limestone ordinarily, and to the fact that no steam is used, the gas is high in CO₂ and contains little H, the main combustible being CO. This gas had been used a long time in hot blast stoves for blast heating and under boilers to produce steam for power purposes around the works. It was Thwaite in England and Lürman in Germany who about twenty years ago called attention to the fact that this gas, although low in heating value, could be readily burned in gas engines when suitably compressed. The credit of having carried out this idea first on a large scale belongs to the Société Cockerill of Seraing, Belgium, who about 1898 put a 150 horse-power engine using this gas into operation.

It is estimated roughly that for every ton of pig iron produced one ton of coke is required, the combustion resulting in about 5 tons of gas. Taking a furnace, therefore, with an average daily capacity of 200 tons of pig iron, the gas available per hour amounts

to about 41.6 tons or 1,000,000 cu. ft. Estimating that 500,000 cubic feet are necessary for the operation of the hot blast stoves, this leaves 500,000 cu. ft. available, which if directly used in gas engines would develop about 5000 I. H. P. Of this amount 1000–1200 horse-power are probably required for power purposes around the furnace, leaving from 3800–4000 horse-power available for other work. The same amount of gas, if used under boilers, would have resulted in only about 1200 boiler horse-power, or perhaps about 2400 horse-power total in steam engines, leaving 1200 horse-power available for other purposes.

The composition and heating value of blast furnace gas naturally varies somewhat in different furnaces, and even in the same furnace under varying accidental conditions of operation. A large number of determinations led M. Witz * to the conclusion that the average heating value of a standard cubic foot was 110 B. T. U. and that it very rarely fell below 95 B. T. U., or rose above 118 B. T. U.

The average composition of the gas, according to Ledebur, appears to be

	% by Volume by Weight	
CO	24.0	24.0
CO ₂	12.0	17.0
H	2.0	.2
CH ₄	2.0	.8
N	60.0	58.0

The above analysis shows no water vapor, some of which is present in the gas as it leaves the stack, and it therefore probably refers to cleaned gas. It is apparent that it is an excellent gas for internal combustion engines. Its low content of H makes it suitable for high compressions, thereby overcoming any objection that may be made regarding its low heating value and difficulty of ignition.

The most serious trouble encountered in the use of blast furnace gas is the fact that it carries more or less dust, which renders cleaning of the gas imperative before use in engines. It is also apt to carry metallic vapors, which do not, however, become

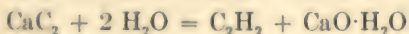
* *Moteurs à Gaz et à Pétrole*, p. 267.

harmful until after combustion in the cylinder. The amount of impurities carried depends altogether upon the kind of ore reduced in the furnace. In some cases it is so slight that the ordinary dust settlers combined with a scrubber of some sort are quite sufficient to reduce the amount to below the allowable limit. This is, however, the exception, and the fact that the gas must be cleaned, and thoroughly cleaned, cannot be emphasized too strongly.

It is comparatively easy to take out the coarser dust carried by the gas by appliances which have long been in use for this purpose to prepare the gas for stoves and boilers. The fine dust, however, causes more trouble, and special cleaning apparatus is necessary to reduce the amount carried.

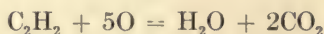
The ordinary method of procedure is to give the gas a preliminary cleaning by allowing the coarse dust to settle. The fine dust, together with the water vapor and the metallic vapors, are then taken out by passing the gas through washers, of which there are various forms, as spray towers, centrifugal fans, etc. Coke scrubbers are not satisfactory on account of the clogging up by dust which soon takes place. A dry scrubber, filled with sawdust or shavings, is sometimes used to complete the outfit of cleaning apparatus. The amount of water used in the washers varies with different types. It may be from 5-50 gallons per 1000 cu. ft. of gas cleaned, depending upon the efficiency of the apparatus. The amount of dust finally carried by the gas should not be higher than about .2 grains per cubic foot.

5. **Acetylene.** — It is only in recent years that the means for making acetylene gas in any quantity were found. To-day calcium carbide is made in quantity in the electric furnace. The gas is produced by decomposing this carbide by means of water, as per following reaction:



The generators employed usually regulate the amount of water supplied to the carbide receptacle. The gas is led to a holder, which by the position of its bell regulates the water supply. The amount of gas produced per pound of carbide should be theoretically 5.45 cu. ft. of dry acetylene gas. Owing to impurities, how-

ever, this is usually reduced to about 4.8 cu. ft. Combustion of this gas takes place according to the formula



Its heating value is 20673 B. T. U. per pound, or 1499 B. T. U. per cubic foot lower value.

The gas is distinguished by low temperature of ignition, lower than that of H, approximately 865 degrees Fahrenheit, high velocity of flame propagation at the best ratio of air to gas, about 12 to 1, and high maximum temperature of explosion owing to the high heating value. The first of these, low-ignition temperature, leads to pre-ignition and requires the use of comparatively low compression pressures.

6. Water Gas. — The theory of the production of water gas has been already outlined in a previous chapter. The average composition of the gas may be taken to approximate by volume 42 per cent CO, 44.5 per cent H, 3.5 per cent CO₂, the rest being O and N.

In medium sized well-handled generators each pound of coke will yield about 32 cu. ft. of gas, each pound of good anthracite coal from 24–30 cu. ft. The average lower heating value of the gas may be taken at 290 B. T. U. per cu. ft.

7. Natural Gas. — Natural gas is found in many parts of the world. It has, however, perhaps received the most extended use as a fuel for power in the United States. It is there found in New York, Pennsylvania, Ohio, Indiana, West Virginia, Kentucky, Tennessee, Colorado and California. This gas is not of constant chemical composition in the different wells, and not constant even in the same well. Marsh gas, CH₄, however, is nearly always the main constituent. According to Poole, the Ohio and Indiana fields yield a gas of the most constant composition. The following is the composition at Findlay, Ohio, and is typical of the field.

H	CH ₄	C ₂ H ₄	O	CO	CO ₂	N	H ₂ S
1.64	93.35	.35	.39	.41	.25	3.41	.20 per cent by vol.

The above composition, however, is sometimes radically changed. Thus a gas well near Pittsburg changed the composi-

tion of the gas in three months from 9.64 per cent H to 35.92 per cent H, mostly at the expense of Marsh gas.

The heating value of this gas is high, the above Findlay gas showing a lower heating value of 962 B. T. U. per cubic foot as computed. It is a good fuel for gas engines, as it is cheap and not very liable to pre-ignition when the hydrogen is low. It is, however, of decreasing importance on account of the gradual failure of the supply.

The following table, and Fig. 9-1, give a recapitulation of the most important data for the fuel gases most often found in gas engine practice. It is to be remembered that the figures given represent approximate average results only, but for rapid calculation they are sufficiently accurate.

AVERAGE APPROXIMATE DATA FOR FUEL GASES

No.	Kind of Gas	Wt. per cu. ft. Standard in pounds	Density Air=1	Lower Heating Value per cu. ft. B. T. U.	Least air required for Combustion cu. ft. per cu. ft.
1	Illuminating gas	.032	.40	565	5.25
2	Natural gas	.045	.55	950	9.10
3	Blue water gas	.057	.71	290	2.45
4	Oil gas, Pintsch	.056	.70	1000	9.50
5	Oil gas, Lowe	.040	.49	650	7.75
6	Coke oven gas	.029	.36	545	5.00
7	Producer gas from coke	.075	.93	135	1.00
8	Producer gas from anthracite	.065	.80	145	1.15
9	Producer gas from soft coal	.073	.90	145	1.25
10	Blast furnace gas	.079	.98	100	.70

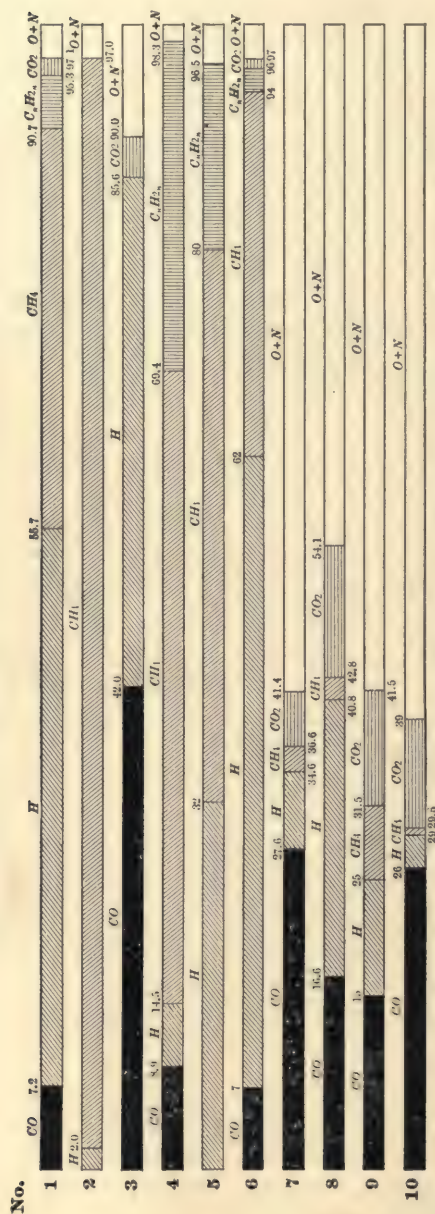


Fig. 9-1. — Approximate Composition of Fuel Gases. For Key to the different lines, see Table, p. 213. Numbers indicate per cent by volume.

CHAPTER X

THE FUEL MIXTURE, EXPLOSIBILITY, PRESSURE, TEMPERATURE

1. **Explosibility.** — When we mix a combustible gas or vapor with air there result explosive mixtures if certain ratios of air to combustible are used in each case. For each of these various mixtures the products of combustion attain certain pressures and temperatures under the same conditions. It is also found that the time interval between ignition and attainment of highest pressure varies with the ratio of mixing, *i.e.*, that the velocity of flame propagation differs.

That mixture in which just enough oxygen is present to complete the combustion of the charge of gas or of vapor shows the highest explosive pressures and temperatures, and also very nearly the highest velocity of flame propagation. Queer, and as yet not explained, is the fact that according to Clerk the highest velocity of propagation is found when the gas is a little in excess of the theoretical ratio in the mixture.

As the proportion of oxygen or of air is decreased from or increased beyond the theoretical amount for complete combustion, the resulting maximum pressures and temperatures are not so high, the explosion occurs more and more slowly, until, at the outside limits of explosibility, it approximates slow combustion.

There is therefore a range of mixtures for each gas and vapor in which range the mixture is explosive. When there are constituents present other than those resulting from mixtures of gas or vapor and air, such as burned gases, the results are again modified.

The following table shows the volume of air required per cubic foot of various gases, under standard conditions, for complete combustion, *i.e.*, for what might be called the true explosive mixture. To facilitate computation to a weight basis, a column giving the density of the gases or vapors with air = 1 = 0.08072

pounds per cubic foot standard is added. The table also shows average heating values, and finally the heating value of the true explosive mixture. It will be noted that the heating values of the mixtures show much less difference than do the gases themselves.

	Vol. of Air for true explosive mixture cu. ft.	Density of gas Air = 1 = .08072 lbs. per cu. ft.	Av. lower heating value of gas B. T. U. per cu. ft.	Av. lower heating value of true explosive mixture B. T. U. per cu. ft.
CO	2.35	.967	342	102
H	2.35	.069	297	89
CH ₄	9.60	.554	952	90
C ₂ H ₂	11.75	.915	1499	118
C ₂ H ₄	14.10	.974	1564	103
Av. natural gas	9.00	—	880	88
Av. illuminating gas	5.25	.40	560	90
Av. water gas	2.30	.72	290	87
Av. producer gas from coke	1.00	.93	135	68
Av. producer gas from anthracite	1.15	.80	145	68
Coke-oven gas	5.00	.36	545	91
Blast-furnace gas	.70	.98	100	59

To give volume ratios for the liquid fuels is not so easy, because the volume of vapor obtained from a certain weight of a liquid fuel is not constant but depends upon the temperature. Experiments along this line are not numerous. Those made indicate that for light and medium heavy oils there is a 200-fold increase in the original volume at ordinary temperatures, while the increase is about 400 fold at the ordinary vaporizer temperature. It appears also that for heavy oils a temperature exceeding 1400 degrees is required to anywhere near complete vaporization. This explains in part the difficulty encountered in the use of crude oil in vaporizers. With the above increase in volumes the ratio of air to oil vapor by volume probably is in most cases between 25 and 30.

It is much more usual, however, to calculate the air-liquid fuel ratios by weight. This ratio for the petroleum oils is approxi-

mately 15, and for alcohol about 9, for the true explosive mixture. To get some idea of the heating value per cubic foot of the explosive mixture the volume added to the air by the vapor is sometimes neglected. This gives results which are close enough for most purposes. In the following table, however, account has been taken of the vapor volume by assuming a 300-fold increase in the volume of the liquid due to vaporization:

Liquid Fuel	Weight of air required per lb. of fuel for true explosive mixture	Av. Sp. Gr. at 60° F H ₂ O = 1.0	Average lower heating value per lb. of fuel B. T. U.	Average lower heating value per cu. ft. of true explosive mixture B. T. U.
Heavy Pa. crude	Approximately 15.0 lb.	.886	19210	99.2
Light Pa. crude		.826	17930	92.0
Heavy W. Va. crude		.873	18320	94.6
Light W. Va. crude		.841	18400	95.0
Kerosene.....		.80	18520	95.8
74°		.69		
Gasoline	13.4		19000	97.7
69°		.71		
Benzol, C ₆ H ₆		.866	17190	99.3
Alcohol, 100 per cent	8.6	.794	11664	103.0
Alcohol, 90 per cent	7.8	.815	10080	104.0

To make sure of complete combustion of the charge, which is one of the primary objects, it is not usual, however, to work with the theoretic air supplies above computed, mainly because a perfect mixture is hardly ever obtained. An excess of air is therefore employed in nearly all cases. This acts beneficially in several other ways. The maximum explosion temperatures are reduced, and pre-ignition is rendered less likely. Especially is this noticeable with a gas carrying much hydrogen or with acetylene. The only limit set to the amount of excess air that can be used is the limit of the explosive range of the particular gas or vapor. But this range is in most cases so wide that in practice the limit is rarely reached. Under full load an excess of air of from 30-40 per cent is usual, and for the rich mixtures even more may be used. This excess decreases the heating value of the

mixture correspondingly below those computed above for the true explosive mixtures.

The amount of excess air any given gas can carry and still form an explosive mixture varies with the kind of gas. Experiments have been made not only on pure gas-air mixtures* under ordinary conditions of pressure and of temperature, but also on mixtures to which had been added inert gases, as CO_2 , to test the effect burned gases would have upon a fresh charge. The following table shows the upper and lower limits of explosibility for some of the most common gases, together with the theoretical ratio. It is hardly necessary to point out that the real lower limit of operation, as far as economy is concerned, is the theoretical ratio:

Volume of air per unit volume of gas for	CO	H	C_2H_2	CH_4	C_6H_6	Ave. Ill. gas	Gasoline
Upper explosive limit.	5.1	9.6	28.6	15.4	36.7	11.7	40.7
Theoretical ratio	2.35	2.35	11.75	9.60	25-30	5.25	25-30
Lower explosive limit.	.33	.51	.91	6.81	14.38	4.24	19.41

Dr. Eitner's results have been graphically represented in Fig. 10-1 by F. E. Junge and published in *Power* for August, 1906. From this diagram it can be seen at a glance how much wider the explosive range is for some fuels than for others. Thus, for instance, one cubic foot of mixture will be explosive under ordinary conditions of pressure and temperature when it contains anywhere between 16 and 74 per cent of CO, a range of 58 per cent. The range for illuminating gas is 11.2 per cent, and for gasoline only 2.5 per cent.

Regarding the experiments with admixtures of inert gases, it can be said in general that the result is a narrowing of the explosive range, *i.e.*, the effect is harmful. Raising the temperatures of mixtures thus contaminated has a noticeably beneficial effect in the case of hydrogen and illuminating gas mixtures only. Regarding the effect upon the explosive limits of increasing the initial pressure of the mixture, nothing definite is known.

Carbon monoxide and hydrogen are the two most important

* Professor Eitner, in the *Journal für Gasbeleuchtung*, 1902.

constituents found in our power gases, and the question as to the most desirable amount of each of these in the gas has often been raised. This point is taken up by F. E. Junge * as follows:

"The temperature at which hydrogen ignites is considerably below that of carbon monoxide, and the rapidity of flame propaga-

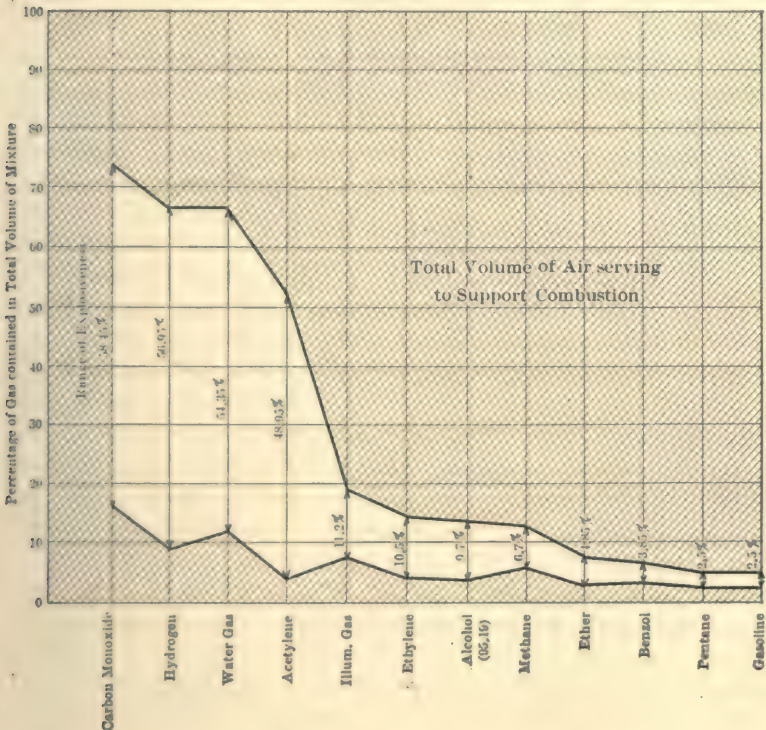


FIG. 10-1.

tion at atmospheric pressure is about 30 times greater. Its diffusion properties are by far more favorable than those of carbon monoxide, so that its admixture with air is accomplished in a much shorter time. Its presence, therefore, determines the manner of ignition and the temperatures prevailing at various points of the inner walls. On the other hand, minor variations

* Power, August, 1906.

in the hydrogen content are of great influence on the speed of ignition or rather of flame propagation throughout the whole mixture, and therefore on engine output and consumption.

"A gas to be of ideal composition for the engine builder must, therefore, not contain too much hydrogen, so as not to make the engine over-sensitive to premature explosions, but enough so as to assist the slow and after-burning carbon monoxide, and to accelerate flame propagation throughout the mixture."

2. Pressure and Temperature after Combustion.— It has already been mentioned that the pressures and temperatures realized in explosive combustion are not as high as those calculated by the ordinary method of assuming specific heat constant. The determination of the causes of this phenomenon has always been a favorite subject for experimentation with investigators, and this is fully warranted by its importance to the theory of internal combustion engines. It will hardly be necessary to review the earlier efforts in this field. For them the reader is referred to the works of Clerk *, Grover †, Robinson ‡, Witz, § and others. The subject has already been briefly discussed in Chapter IV of this book under the head of "Combustion and Expansion Strokes." The entire question seems on analysis to narrow down to *variation of specific heat with temperature and to after-burning*. Dissociation as one of the causes tending to produce the effects mentioned is now regarded by most writers as possible but improbable.

The most important work of recent years along the lines under discussion has been done by Langen || and by Clerk. ¶ It would seem that these two investigations, combined with the earlier one of Mallard and Le Chatelier, should lead to some fairly definite conclusions. They will therefore be reviewed in some greater detail.

Langen in his experiments used a cast-steel spherical vessel, about 15 $\frac{3}{4}$ inches in diameter. This was furnished with the neces-

* Clerk, The Gas and Oil Engine.

† Grover, Modern Gas and Oil Engines.

‡ Robinson, Gas, Oil and Air Engines.

§ Witz, Moteurs à Gaz et à Pétrole.

|| A. Langen, Zeitschrift d. V. d. I., Vol. 47, p. 622.

¶ D. Clerk, Proc. of the Royal Society, A, Vol. 77, 1906.

sary connections for exhaust pump, gas supply cylinders, indicator gages, etc. The igniter reached to the center of the sphere. The vessel itself was surrounded by a water bath with thermometers at inlet and outlet, so that the temperature of the body of gas in the vessel could be accurately determined. The indicator was of the ordinary type except that the oscillating motion of the drum was changed to continuous motion. The details of the entire construction were very ingenious. The pressing of a single button sufficed, by electrical means, to first press the pencil against the drum, and immediately afterward to fire the charge. It was only necessary to break the current when the decrease in pressure, due to cooling of the burned gases, had become so small in two revolutions of the drum that the lines interfered.

The method of test was to exhaust the vessel and then to fill it with air a number of times until it was fair to assume that all burned gases from a previous explosion had been replaced. The vessel was then again exhausted to such a degree that, by filling with combustible gas and inert gases of the kind desired, the vessel would, at atmospheric pressure, be filled with combustible and inert gases in the proportion required. After enough time had been given for diffusion and the thermometer showed that constant temperature had been reached, the charge was fired and the diagram taken.

In order to obtain a common basis for comparison with the work of previous experimenters, Langen recomputed all of his results and those of Bunsen, Berthelot and Vieille, and Mallard and Le Chatelier, on the assumption that the temperature at the moment of explosion was 0 degrees Centigrade. Figs. 10-2 and 10-3 * show graphically the results of all of these experiments, the first for CO, the second for H as the fuel gas. In the diagrams π_0 stands for the ratio of explosion pressure observed to the pressure before ignition if the temperature of the fuel mixture is 0 degrees Centigrade at the start. m is the ratio of the volume of inert gases compared with the volume of fuel gas. These inert gases were N, O, H or CO, or any mixtures of these four as indicated. The results marked e were obtained for air-fuel gas mixtures.

* Zeitschrift d. V.d. I., 1903, p. 623.

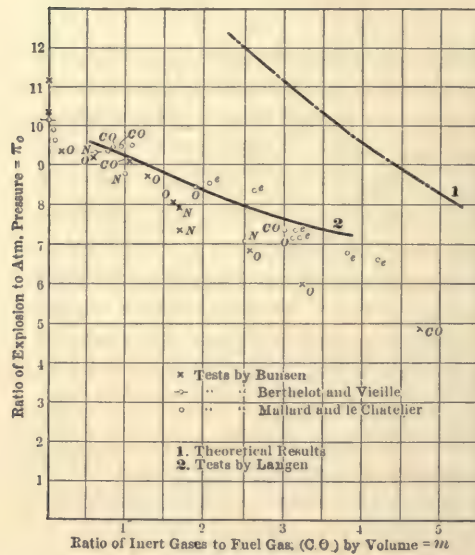


FIG. 10-2.

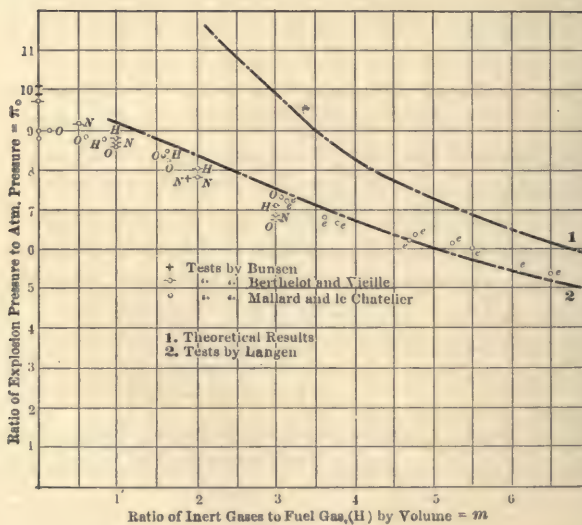


FIG. 10-3.

Langen, in analyzing the results shown in the above diagrams, makes the following observations:

1. The computation of explosion pressures on the assumption of constant specific heat and complete combustion furnishes values which considerably exceed those actually observed.

2. For equal ratios of inert diatomic gases to fuel gases, the *kind* of inert gas used seems to have no influence upon the explosion-pressure, *as far as the same observer is concerned*. This would lead to the conclusion that the molecular heats of the so-called simple or diatomic gases are equal to each other, at least up to 4500 degrees Fahrenheit.

Regarding the results of his own experiments, Langen is of the opinion that in fuel mixtures containing CO, dissociation of CO₂ sets in when the temperature exceeds 1900 degrees Centigrade (3450 degrees Fahrenheit). He bases his opinion on the abnormal position of the cooling curve as observed on the diagrams taken for such mixtures. And since the amount of this dissociation is indeterminate, no definite equation expressing the relation of maximum pressure to initial pressure can be established, at least for temperatures exceeding 3400. For hydrogen mixtures, on the other hand, the cooling curves on the diagrams are always normal. Hence the dissociation limit for steam does not seem to have been reached even with the strongest mixtures.

From that part of his experiments for which complete combustion can be assumed, Langen derives equations for mean molecular heat of diatomic gases, and for carbon dioxide and steam. The temperature limits for the field so covered are not very wide, 1500–1700 degrees Centigrade (2730–3100 degrees Fahrenheit), and further it was assumed that the molecular heat is a linear function of the temperature. Transposed to read mean specific instead of mean molecular heats, these equations are as follows:

$$\text{For CO}_2, C_v = .152 + .0000591 t.$$

$$\text{For H}_2\text{O}, C_v = .328 + .000119 t.$$

$$\text{For N}, C_v = .171 + .0000215 t.$$

$$\text{For O}, C_v = .150 + .0000188 t.$$

where t is in degrees Centigrade.

The formulæ of Mallard and Le Chatelier agree with the

above as regards the diatomic gases, O and N. For CO₂ and H₂O these observers obtained results which gave the following relations:

$$\text{For CO}_2, C_v = .143 + .0000834 t.$$

$$\text{For H}_2\text{O}, C_v = .312 + .000182 t.$$

These formulæ show a somewhat more rapid increase of C_v with temperature than do those of Langen. Langen observes in explanation of this discrepancy that Mallard and Le Chatelier's formula for CO₂ is obtained from results for which the temperatures were from 1700 to 2000 degrees Centigrade, and that the formula for H₂O is based on experiments for which the temperatures were very much higher than for his experiments. In the former case dissociation was shown to be more than likely, in the latter the formula gives results which do not seem to apply very closely for the important temperature range between 2250 and 4000 degrees Fahrenheit. It is plain, therefore, that Langen's formulæ promise greater accuracy.

The second important investigation in this field was made by Clerk, and by him reported to the Royal Society. His method of operation is so decidedly different from that of Langen and the earlier experimenters that it becomes both interesting and important to see how far his results agree with those already mentioned.

The method of experiment is best described in Clerk's own words:

"It consists in subjecting the whole of the highly heated products of the combustion of a gaseous charge to alternate compression and expansion within the entire cylinder while cooling proceeds, and observing by the indicator the successive pressure and temperature-falls from revolution to revolution, together with the temperature and pressure rise and fall due to alternate compression and expansion. The engine is set to run at any given speed, and at the desired moment after the charge of gas and air has been drawn in, compressed, and ignited, the exhaust valve and charge inlet valves are prevented from opening, so that when the piston reaches the termination of its power stroke, the exhaust gases are retained within the cylinder, and the piston compresses them to the minimum volume, expands them again to

the maximum volume, and so compresses and expands during the desired number of strokes."

To attempt to explain the method of evaluating the expansion and compression lines so obtained would lead too far for the scope of this book. The reader is referred to the original article.*

The engine operated with coal gas. The average composition of the working fluid, as calculated from the analysis of the gas, was H_2O (assumed gaseous), 11.9 per cent by volume; CO_2 , 5.2 per cent; O, 7.9 per cent, and N, 75 per cent. The mixture as actually used varied somewhat from this composition, but since the percentage of N is nearly constant, this variation can have but small effect upon any specific heat calculations.

For this mixture, Mr. Clerk, on the basis of his experiments, found the following mean specific heats, expressed in foot pounds per cubic foot of working fluid at 760 mm. and $0^\circ C$.

Range of Temperature		Mean specific heat in ft. lbs. per cu. ft. at 760 mm and $0^\circ C$.
$^\circ C$	$^\circ F$	
0— 100	32— 212	20.3
0— 200	32— 392	20.9
0— 400	32— 752	21.9
0— 600	32—1132	22.8
0— 800	32—1472	23.6
0—1000	32—1832	24.6
0—1200	32—2192	24.6
0—1400	32—2552	25.0
0—1500	32—2732	25.2

Now to compare these results with those of Mallard and Le Chatelier and of Langen, the easiest way would be to reduce them to the ordinary specific heat basis, and then to compute a series of specific heats for the same temperature ranges and for the same mixture as used by Clerk by the aid of Mallard's and of Langen's formulæ. This involves the assumption that these formulæ hold for the lower temperature ranges. The following table shows the figures so obtained, and Fig. 10-4 gives a graphical comparison.

* See foot-note, page 221.

MEAN SPECIFIC HEAT FOR MIXTURE CONTAINING BY VOLUME 11.9 %
H₂O, 5.2 % CO₂, 7.9 % O, and 75 % N.

Temperature Range		Mallard & Le Chatelier	Langen	Clerk
°C	°F			
0—100	32—212	.1805	.1826	.1854
0—200	32—392	.1843	.1858	.1910
0—400	32—752	.1930	.1922	.2000
0—600	32—1132	.2006	.1985	.2083
0—800	32—1472	.2083	.2047	.2157
0—1000	32—1832	.2161	.2112	.2202
0—1200	32—2192	.2238	.2176	.2248
0—1400	32—2552	.2315	.2239	.2284
0—1500	32—2732	.2355	.2271	.2303

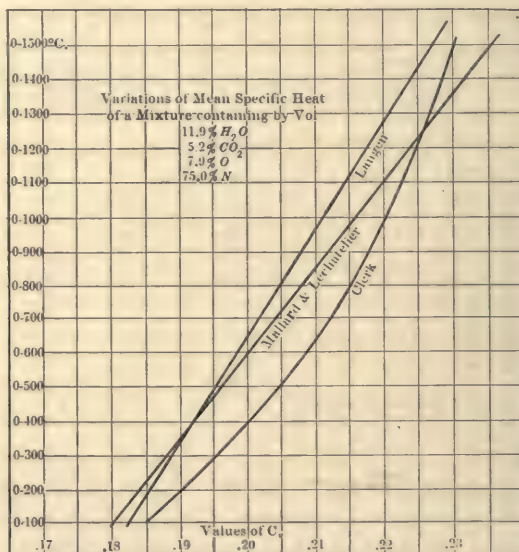


FIG. 10-4.

It is plain from Fig. 10-4 that the question of the variation of specific heat with temperature cannot be considered entirely solved. It is true that Stevens * made experiments on air which check the results of both Mallard and Le Chatelier and of Langen

* Ann. d. Phys., 1902.

very closely. It is therefore fair to assume that the formulae derived for diatomic gases are correct. The discrepancies observed between the results plotted in Fig. 10-4 are therefore with strong probability due to error in the available data for H_2O and CO_2 . Further work is therefore required, and a check of Clerk's results is especially desirable.

3. Velocity of Flame Propagation and Time of Explosion. — Experiments on the velocity of flame propagation in a given mixture, like the experiments on specific heat, have not led to any definite result. And although definite information on this point is desirable, on account of the connection between velocity of flame propagation and possible maximum engine speed, in any given case there are so many factors affecting the problem in actual practice, that the application of the results of laboratory experiments to actual conditions is of doubtful value. Thus the velocity with which the flame spreads through a mixture depends upon the kind of fuel, the composition and purity of the mixture, its temperature and pressure, and upon the location of the igniter and the shape of the combustion chamber. Further than this, the degree of mechanical agitation in the mixture at the moment of explosion has a marked influence upon the velocity.

If we ignite a mixture in a tube, closed at one end, from the closed end, the pressure generated seems to project the flame ahead of the pressure wave toward the open end of the tube with a much higher flame velocity than would have been observed if the ignition had taken place from the open end. The same effect should be observed in a tube closed at both ends. Ignition from the open end gives the true velocity, as the flame then spreads by contact only. In an actual engine cylinder, with the volume increasing with the movement of the piston, we may expect the velocity of propagation to be somewhere between those found for ignition from the open end of a tube and those for ignition in a closed tube.

Mallard and Le Chatelier used the open-tube method, measuring the time interval between the passage of the pressure wave between two points on the tube. Their results, as given by Clerk, for hydrogen were as follows:

Mixture	Velocity of Pressure Propagation ft. per second
1 vol. H + 4 vols. air	6.56
1 vol. H + 3 vols. air	9.20
1 vol. H + 2½ vols. air	11.10
1 vol. H + 1¾ vols. air	12.40
1 vol. H + 1½ vols. air	14.30
1 vol. H + 1 vol. air	12.30
1 vol. H + ¾ vol. air	7.55

The true explosive mixture for hydrogen and air is 1 vol. of H to 2½ vols. of air. It might be supposed that this would be the mixture showing highest velocity of propagation. For some unexplained reason a certain excess of hydrogen shows the highest

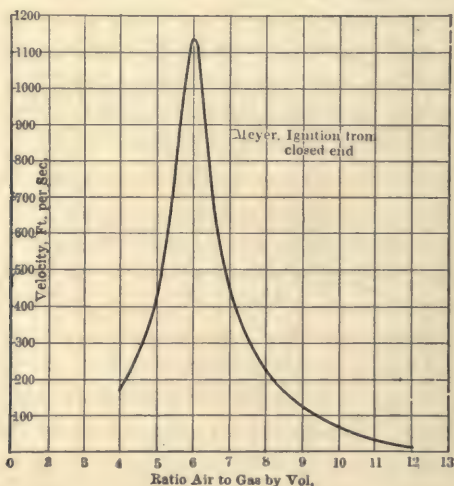


FIG. 10-5.

result. A similar phenomenon was observed with coal gas and air mixtures by these observers.

Meyer* used an apparatus very similar to that of Mallard and Le Chatelier, except that very sensitive platinum thermometers were employed to measure the passage of the flame, instead of diaphragms to measure the passage of the pressure wave. The fuel employed was coal gas. All tests were made with the mix-

* E. J. Meyer, Sibley College thesis, 1905.

ture at atmospheric pressure at the time of ignition. Figs. 10-5 and 10-6 show the results graphically, the former being obtained for ignition from the closed end, the latter for ignition from the open end. The much higher velocity of the first curve bears out the statement previously made. The fact that the maximum velocity occurs with the same gas-air ratio shows that the true rate of inflammability has not been changed, but that mechanical actions alone are responsible for the difference in the observed results.

Closely connected with the velocity of flame propagation, and subject to the influence of accidental accompanying conditions to the same degree, is the time of explosion. The most extensive work in this field was done by Clerk. The apparatus employed by him was very similar to that used by Langen in his specific

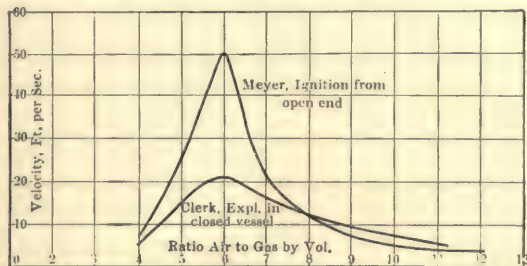


FIG. 10-6.

heat experiments. The fuel mixture was ignited at constant volume and a pressure diagram obtained on the rotating drum of an indicator. Unfortunately the experiments were confined to coal gas, a few figures only being obtained for hydrogen and none for the power gases so important to-day. The figures found for hydrogen were as follows, the time of explosion being the time interval from the moment of ignition to the attainment of maximum pressure.*

Mixture by Volume		Time of Explosion in seconds
Air	Hydrogen	
6	1	.150
4	1	.026
2.5	1	.010

* Clerk, *The Gas and Oil Engine*, p. 101.

Clerk's results for mixtures of air and Oldham coal gas are represented in Fig. 10-7. The volume ration showing fastest time of explosion, *i.e.*, 6 to 1, agrees with the mixture for which Meyer found the greatest velocity of flame propagation. This mixture also showed about the highest pressure development in Clerk's experiments, 90 pounds per square inch.

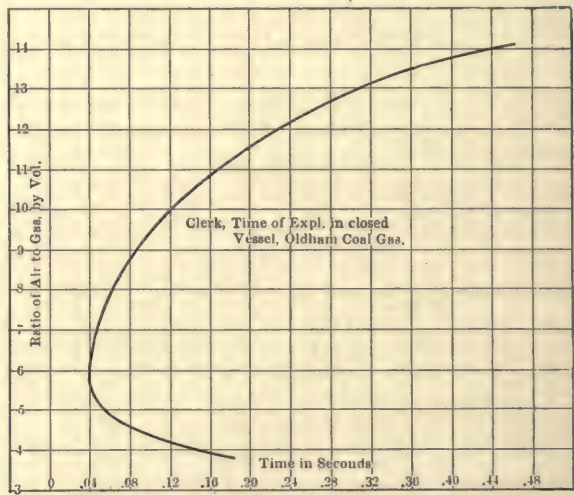


FIG. 10-7.

In Clerk's experiments the pressure at the moment of ignition was atmospheric in each case. Koerting * carried on similar experiments with coal gas but used compressed mixtures, although the pressures used were low. The summary of his results is as follows:

Mixture by Vol.		Pressure before Ignition Lbs.	Time of Explosion seconds	Velocity of Propagation ft. per sec.
Air	Gas			
7.5	1	{ 15.0	.032	23.0
		{ 37.0	.036	20.4
5.42	1	{ 15	.01	74.0
		{ 37	.0125	59.0

* Koerting, Zeitschrift d. V. d. I.

This table shows that compressing the mixture retards the velocity of flame propagation, but that the amount of retardation is less in lean than in rich mixtures of the same fuel.

Koerting's figures do not agree well with those of Clerk, although they were obtained with similar apparatus. From Fig. 10-7 the time of explosion of a 7.5 to 1 mixture would have been about .056 seconds according to Clerk, as against .032 seconds found by Koerting. This is too great a difference even assuming a considerable difference in the composition of the fuel. The length of Clerk's vessel up to the indicator piston was about 10 inches, which, with a time explosion of .056 seconds, gives a velocity of propagation in a closed vessel of 14.8 feet per second as against 23 feet found by Koerting.

For the purpose of comparing Clerk's results with those of Meyer on flame propagation, the times of explosion as shown by Fig. 10-7 have been transposed to the basis of velocity in feet per second. The resulting curve has been drawn in on Fig. 10-~~7~~ with Meyer's results. 10-6 It is seen that the velocity of propagation in a closed tube according to Clerk is lower than that found by Meyer for ignition from the open end of a tube, except for ratios exceeding 8 to 1, and here the difference is inconsiderable. This is contrary to what might be expected, because, as before explained, and also mentioned by Clerk, if explosion takes place at constant volume in a closed vessel, the part of the mixture first ignited instantly expands and shoots the flame into the rest of the mass, thus increasing the velocity of propagation. As compared with Meyer's results for ignition from the closed end of a tube, Clerk's results are very much lower, in fact only about $\frac{1}{10}$ at the best ratio for the gas. Koerting's figures, on the other hand, slightly exceed Meyer's results for ignition from the open end.

CHAPTER XI

HISTORICAL SKETCH OF THE INTERNAL COMBUSTION ENGINE

1. Origin obscure. — The origin of the internal combustion engine is imperfectly known; as it exists at the present time it is the result of a long-continued development which began first with a period of speculation which, through the efforts of numerous inventors, finally resulted in a practical, operative machine. No single person can be considered as the inventor of the internal combustion engine. Its history shows the existence of three periods: (1) that of speculation and invention; (2) that of development, and (3) that of application.

2. The Period of Speculation and Invention. — The gas engine previous to 1860 was not a practical, commercial machine nor had it been used to any great extent for the purposes of producing power. Previous to that time various publications and patents show that nearly all of the types known at the present time had been discovered, although the records are imperfect as to the actual and practical use of such machines. It is reasonable to believe that many of the forms described or patented were actually built and operated experimentally if not commercially.

Aimé Witz gives the credit * for the first internal combustion engine to the Abbé Hautefeuille, who describes an engine in 1678 in which water is raised by utilizing the partial vacuum which results from burning gunpowder in a cylinder and cooling the gases remaining.

A similar engine was described by Huygens in a memoir entitled "Une nouvelle force mouvant par le moyen de la poudre a canon et de l'air," which appeared in 1680. Denis Papin constructed an internal combustion engine similar to that described by Huygens in 1690, but on account of imperfect workmanship

* Moteurs a Gaz et a Pétrole.

obtained results very much inferior to those produced by a steam engine and abandoned the powder engine as an impractical machine.

In the powder engines the method was a fairly practical one; a small quantity of gunpowder exploded in a large cylindrical vessel expelled the air through check valves, thus leaving, after cooling, a partial vacuum below the piston. The pressure of the atmosphere did work by moving the piston downward.

For a long time after this attempt, the internal combustion engine seemed to have been practically forgotten, as the next description of its construction was not written until after Watt had developed and improved the steam engine. Considering the low condition of the state of the mechanical arts and the difficulty of obtaining good workmen and proper materials, which Watt experienced and which he was only able to overcome by spending years of time, it can be readily understood why little or no substantial progress was made. Watt not only solved the problem relating to the method of improving the engine, but he also developed in a very great measure the art of constructing such engines and of producing proper materials for their manufacture.

The greater portion of the information relating to the design and improvement of the gas engine during the period previous to any extensive commercial use is obtained from the records of the English, French and American patent offices. These records have the advantage over other publications of being definitely dated and of concisely and accurately describing the machine and its mode of operation.

The first internal combustion engine described in the patent records was patented by Robert Street in England on the 7th of May, 1794. It consists of a motor cylinder, with a piston, the bottom of which is heated by fire. The patent shows a pump driven by a lever. The fuel is described as a small quantity of tar or turpentine which is projected onto the hot part of the cylinder so that the liquid is instantly converted into an inflammable vapor. The raising of the piston by means of a lever sucks in external air and also flame for ignition, which causes the explosion. The details as described are crude, but the principle of operation is the same as in the Lenoir engine which was patented in 1860.

Phillippe Lebon patented in France, in 1801, a gas motor in which the gas was compressed in a cylinder external to the working cylinder previous to ignition. In this patent there is described the use of an air pump for compressing atmospheric air, a gas pump for compressing gas, and the use of electricity for ignition. Lebon died September 22, 1804. Witz states "that it is probable that the industry of building gas engines would have dated at the beginning of the century as a practical commercial industry, instead of 1860, had he lived."

Various inventors early in the century proposed the use of

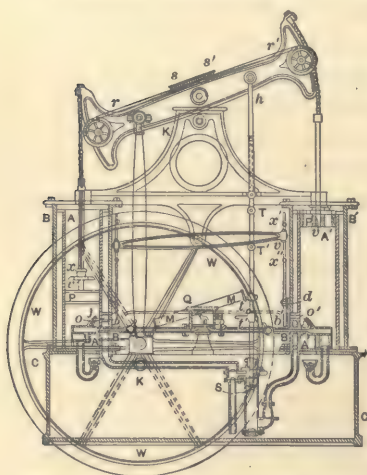


FIG. 11-1. — S. Brown, 1823-26.

explosive powders, of air saturated with hydrocarbon and of hydrogen gas produced by chemical means, as fuels for internal combustion engines, but these did not, so far as can be ascertained, result in any practical improvement.

In 1823 and 1826 Samuel Brown obtained English patents for an ingenious atmospheric air engine which, although very cumbersome and uneconomical, was applied to practical uses. The engine, Fig. 11-1, was operated by burning the combustible in a vessel adjacent to the

working cylinder, which resulted in expelling a portion of the air it contained. A jet of water was then thrown in which lowered the temperature and by so doing produced a vacuum. Motion was produced by the atmospheric pressure acting alternately on the sides of the piston in the working cylinder, which was arranged adjacent to the vacuum-producing chamber and put in alternate connection with it by means of a proper valve motion. This engine, although referred to by Clerk "as being the first gas engine undoubtedly put at work," is an external combustion gas engine somewhat similar to the Wilcox engine already described, except that there was vacuum rather than pressure in the combustion vessel. According to the

Mechanics Magazine, published in London, a boat was fitted with a Brown engine and ran experimentally upon the Thames. Another engine was made in combination with a road carriage (see *Mechanics Magazine*, December 24, 1825); this is also referred to in a Report of a Committee of the House of Commons, reprinted as a public document in the United States in 1832.

W. L. Wright obtained an English patent (No. 6525 of 1833) for an internal combustion engine in England. This patent is accompanied with elaborate drawings giving in detail the proposed construction. The engine, Fig. 11-2, is shown as double acting, the piston receiving two impulses for every revolution of the crank shaft. It is also shown as provided with pumps adapted to compress the air and gas a few pounds above the atmosphere previous to their introduction into the cylinder. The engine was provided with a fly-ball governor for controlling the quantity of gas and air as required to produce uniform speed. The charge is ignited when the working piston is at the end of its stroke by an external flame, burning in air, which is connected with the charge at the proper time by a valve opened by the mechanism of the engine. The charge was not under sensible compression

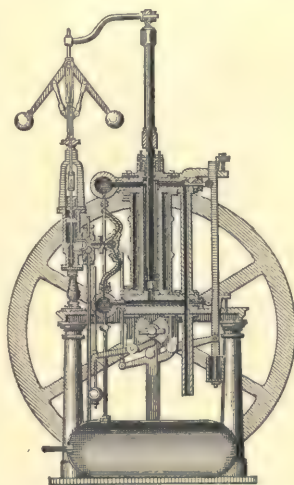


FIG. 11-2. — Wright, 1833.

at the time of ignition. The engine as shown has water-jacketed cylinder and piston, poppet exhaust valves operated by cams, and appears well proportioned throughout. Much credit is due to the governing device shown, and it would be difficult to state why the motor did not succeed, unless it may have been due to the lack of demand for any other motor than the steam engine.

James Johnson took out an English patent in 1841 for a gas engine to be operated by hydrogen gas. In this engine the piston is forced to the end of the cylinder by the explosion of the gas, after which a vacuum is formed underneath the piston and the piston is returned by atmospheric pressure. It illustrates the

expansion of the products of combustion below atmospheric pressure, a method which as yet has not met with much practical success in the operation of gas engines.

William Barnett obtained a patent in England (No. 6015, of 1838), which describes the construction and mode of operation of a two-cycle gas engine, single and double acting, in which the explosive mixture is compressed previous to ignition. It shows three forms of engines, one type in which the compression is entirely performed outside the working cylinder and which is shown as both single and double acting. It also shows another

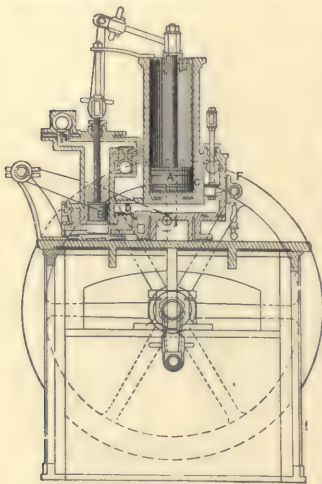


FIG. 11-3. — Barnett, 1838.

type in which the compression is completed inside the working cylinder, this latter form being almost identical with the modern two-stroke cycle engine which has already been described.

Barnett also shows an igniting device, described in Chapter XIII, which is adapted to ignite the gaseous mixture while under compression. This method of ignition is of interest as it was used in a slightly different form by Otto in the Otto engine in 1877. Barnett also describes a method of igniting by bringing the explosive mixture in contact with spongy platinum which is located in a cavity near the head of the cylinder.

Figure 11-3 is reduced from patent drawing and shows a section of the single-acting engine in which *A* is the motor piston. The cylinder is open at the top, *B* is a double-acting pump which serves to supply atmospheric air to form an explosive mixture on one side and to exhaust the products of combustion on the other; the pump for supplying fuel gas under compression stands back of the air pump and is not shown in the figure. During the ascent of the piston, *A*, the air and gas pumps have been drawing in air and gas, which on the descent of the pump pistons are forced into the receiver, *D*, which is separated from the working cylinder by the piston slide valve, *E*. In the meantime the piston *A* has discharged the exhaust gases through the valve *E*.

This valve closes communication with the air when *A* reaches the lower dead center and opens communication with the receiver *D*. At this instant the charge is ignited, and the gases under compression pass into the working cylinder through the slide valve *E*. The igniting device shown at *F* is operated by the motion of the valve.

The gases at the time of explosion are in the receiver *D*, and flow through the port after ignition precisely as steam would do. The pressure in the motor cylinder falls by expansion with increase in volume due to motion of piston.

Barnett's second engine is identical with his first except that it is double acting.

Barnett's third engine, shown in Fig. 11-4, is of great interest since it is the forerunner of the modern two-cycle engine. The engine shown in the figure is double acting. Like the first engine it has three cylinders, motor cylinder *A*, air pump *B*, and a gas pump not visible in the figure. The air and gas pumps are single acting but are operated by means of gearing so as to make twice as many strokes as the working piston. The ignition is performed by spongy platinum with which the gases under compression are brought in contact. The operation of the engine is as follows, supposing that when the piston is in the position shown in the drawing it is moving upward and the upper end of the cylinder is charged with air and gas under compression. When the piston has completed its up stroke, the contact of the platinum with the compressed mixture, produced by the ascent of the piston, causes explosion, which in turn impels the piston to the bottom of its stroke. During the first part of the descent and until the piston passes the port, *M*, at the center of the cylinder, the products of combustion below the piston are being exhausted, either into the atmospheric air or into an

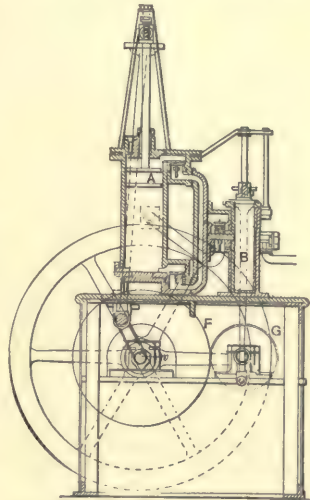


FIG. 11-4. — Barnett's Third Engine.

exhaust pump, which may be used if desired. At the same time the air and gas pumps draw in their respective charges. During the latter half of the descent of the piston the air and gas pumps are forcing the mixed air and gas into the cylinder below the piston where it is further compressed and exploded at the end of its stroke, in which case the piston is forced upwards and the operation is repeated.

Stuart Perry patented in the United States, May 25, 1844, and in Great Britain through the agency of Joseph Robinson (No. 9972 of 1843), a gas or vapor engine which was provided with means for compressing the charge previous to ignition. The method of ignition in the Perry engine was similar to that in the Wright engine. The engine was especially designed for the use of liquid hydrocarbon, and for this purpose it was provided with a carbureter through which a portion of the air on its way to the engine is forced and which may be heated by the exhaust gases. The Perry engine is double acting and provided with a rotating valve which by means of gearing can be reversed in direction, thus reversing the engine.

The Perry patent of 1844 was followed by one in 1846 which showed an engine with poppet valves and with means for igniting by a hot tube consisting of a platinum cup kept hot by a gas flame. In this latter engine the charge was under compression at the time of ignition. In the latter patent reference is made to the actual use of a gas engine with carbureting device, from which it would appear that Perry at least anticipated in design many later constructions.

A. V. Newton obtained a patent in England (No. 562 of 1855), for an ignition device which was identical with that formerly patented in America by Drake, and which is now known as the hot-tube method of ignition. The igniting arrangement consists of a cast-iron tube, closed at the outer end, which projects into a recess formed in the side of the cylinder. A gas flame, Fig. 11-5, keeps a section of this tube at a temperature sufficient to

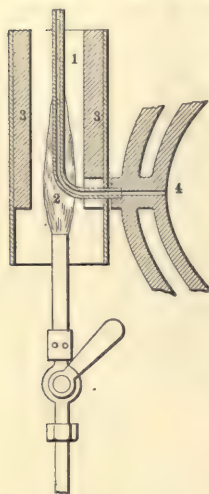


FIG. 11-5. —
Newton's Hot Tube
Igniter.

explode the charge when the piston uncovers the opening. The engine shown in the Newton patent is a non-compression double-acting engine with water jackets.

Barsanti and Matteucci of Florence, Italy, took an English patent (No. 1655 of 1857) for a free piston vacuum engine, which is of interest from the fact that it was of essentially the same class as a successful type of engine which was introduced some years later by Otto and Langen. In this engine the force of the explosion was utilized in moving the piston when free from the connecting rod, the work being done on the return stroke by the weight of the piston and by atmospheric pressure acting on its upper side.

In construction the cylinder of the engine is vertical, open at the top and very long, Fig. 11-6. The charge consisting of gas and air enters when the piston is drawn up a short distance and is exploded by an electric spark. The piston rod carries a rack which is in engagement with a gear wheel connected by a ratchet and pawl to the main shaft. When the piston is shot rapidly upward the gear wheel turns without moving the main shaft. When the piston returns the ratchet connects the gear wheel of the main shaft so that it is turned in the direction for producing work.

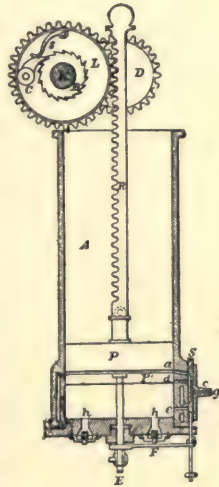


FIG. 11-6.—Barsanti and Matteucci.

Clerk states that the method illustrated in this engine possesses three advantages: rapid expansion, a large amount of expansion, and also some of the advantages of a condenser.

3. Period of Development.—LENOIR. The first internal combustion engine to attain any marked degree of commercial success was patented by J. J. E. Lenoir, in France, January 4, 1860, and in the United States March 19, 1861.

The Lenoir engine was of simple construction and belonged to a type which had been previously described by several inventors. Its success was evidently due to the good proportions which characterized the design. The engine cylinder is shown

in section in Figs. 11-7 and 11-8. This engine belongs to the class in which the ignition takes places while the charge has practically constant volume and, in the case of the Lenoir engine,

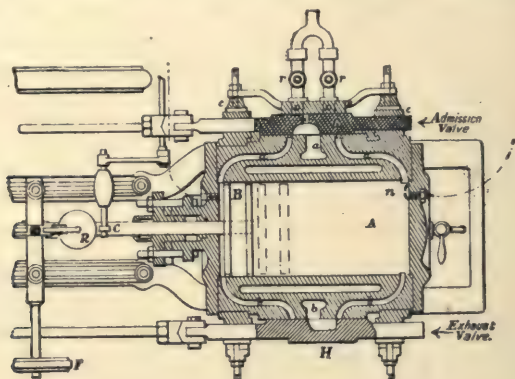


FIG. 11-7. — Lenoir Engine, 1860.

had not been compressed previous to ignition; it is devoid of any compression mechanism. In structure it resembles that of a double-acting steam engine with separate slide valves for the

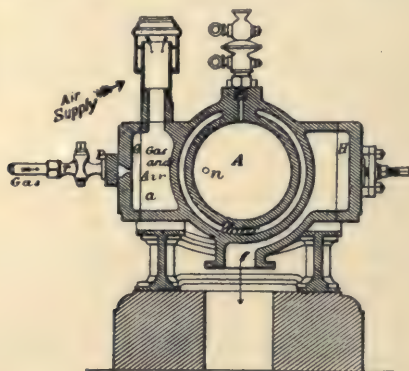


FIG. 11-8. — Lenoir Engine, 1860.

admission and exhaust. Thus in Fig. 11-7 the charge is admitted by the slide valve *G*, and is exhausted by the slide valve *H*. It is drawn into the cylinder by the partial vacuum produced by the motion of the piston, the slide valve being arranged to open the ports at the beginning of the stroke and

close them at about the center of the stroke. The charge is exploded by electrical means when the piston is at about the middle of its stroke, and produces the requisite pressure to force the piston onward and keep the engine in motion. The exhaust valve opens to discharge the products of combustion during the return stroke. The operation of both ends of the engine takes place alternately and tends to produce a uniform motion of the fly-wheel.

The engine is shown provided with cross-head, connecting rod, and governor similar to a steam engine. The governor is arranged to throttle the supply of gas as required to produce uniform speed. The engine was provided with a device for timing the electrical spark. The source of electricity was a primary battery arranged to intensify the current by an induction coil.

Although the consumption of gas by this engine was always high and the power produced in porportion to the cylinder very small, yet it possessed certain advantages. Its mechanism is simple, its explosion nearly without shock, and its action very smooth. This engine was sold in large numbers and manufactured both in France and England.

Dugald Clerk quotes from an article in the *Practical Mechanics Journal* of August, 1865, showing that from 300 to 400 engines were at that time at work in France. He also states that the Reading Iron Works Co., at Reading, England, made and delivered 100 engines.

Witz states that this engine was received with great enthusiasm and that many predicted that the last hours of the steam engine had sounded and that the star of Watt paled before that of Lenoir. This enthusiasm resulted in a marked exaggeration both as to economy and capacity, which was followed by a reaction during which time the engine was called a humbug and many were broken up for old iron. It was, however, appreciated at its full value at a later time, as it was found extremely well adapted for small establishments requiring from $\frac{1}{2}$ horse-power to 4 horse-power. For such uses the consumption of gas was guaranteed to be less than 70 cu. ft. per horse-power hour and this guarantee seems to have been usually realized. Juries at the expositions of London in 1862, of Paris in 1867, of Vienna in 1873, recognized the merit of Lenoir.

The Lenoir engine is described as adapted to be operated either with gas or with the vapor of liquid hydrocarbon, and in a French patent of 1861 a carbureter is shown for mixing the vapor of oil with air.

The engine of Lenoir was used for various purposes, for instance, printing, pumping water, driving lathes, and also for the purpose of propelling a vehicle and a road carriage.

In the report of the Vienna Exhibition of 1873, R. H. Thurston quotes the following statements of M. Claudel in reference to the experiments of M. Tresca on the Lenoir engine:

"The speed of the engine is variable."

"The failure to ignite a single charge will stop it."

"To start it it is necessary to give it several revolutions by hand."

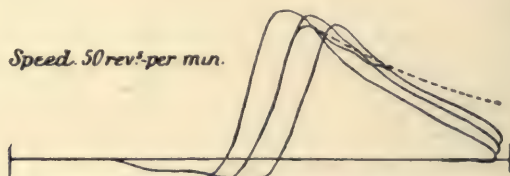


FIG. 11-9. — Diagram Lenoir Engine.

"Lubricant must be abundant and the amount of oil cannot be estimated at less than 0.5 kilogram (1.1 lbs.) per day."

"To obtain the best effect, it is necessary to open the inlet before the complete closing of the exhaust valve."

"A machine of 0.24 meter (9.5 inches) diameter of cylinder produced very nearly one horse-power."

The best performance claimed for the Lenoir engines is 70 to 74 cu. ft. of gas per horse-power per hour. M. Tresca reported a consumption of 95.28 cu. ft. A typical indicator diagram from a Lenoir engine is shown in Fig. 11-9.

HUGON. — It has been shown that Hugon had experimented with an engine of the Lenoir type two years before Lenoir.* But while the obvious disadvantages of the construction did not prevent Lenoir from putting his engine on the market, Hugon was not satisfied with the solution of the problem and turned his attention to the indirect acting engine of the type of Barsanti

* *Memoirs des Ingenieurs Civils*, 1860, p. 159.

and Matteucci. Only after the Lenoir engine proved in a certain manner a commercial success did Hugon return to his former engine, and, making some improvements on Lenoir, brought the engine out in 1864. In this machine, Figs. 11-10 and 11-11, electric ignition was replaced by flame ignition, which was much the surer method of igniting a charge in those early days, and

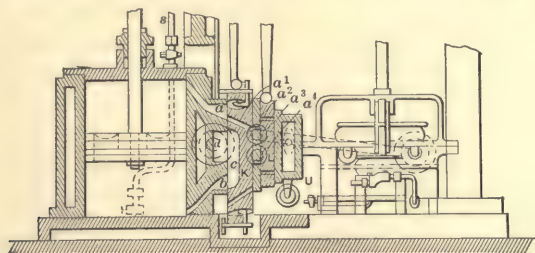


FIG. 11-10. — Cylinder, Hugon Engine, 1864.

both exhaust and inlet were operated by one valve in order to give this valve the advantage of cooling by the incoming cold mixture. To overcome the very serious defect of the Lenoir engine existing in the extremely rapid wear of the valves, Hugon reduced the temperatures of the cycle by injecting water into the charge.

The Hugon engine was somewhat superior to that of Lenoir

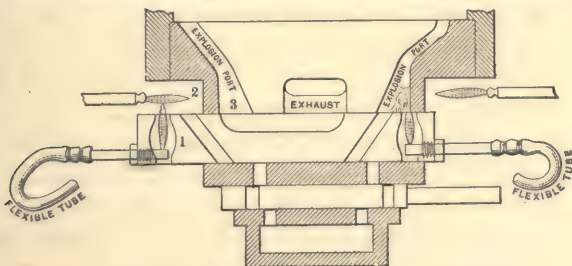


FIG. 11-11. — Hugon's Flame Ignition Valve.

in both fuel and lubricating oil consumption, but it did not find the degree of application of the latter, because apparently the means were not at hand to exploit it to the extent done with the Lenoir machine.

BEAU DE ROCHAS, 1862. — In a patent taken out in Paris by Alph. Beau de Rochas on January 7, 1862, he states the conditions required for the highest efficiency in an internal combustion

engine, and he also distinctly describes the working cycle which in his opinion is necessary to produce the highest efficiency.

According to this investigator, the conditions necessary for highest efficiency are four in number: (1) the greatest volume of the cylinder possible having a minimum surface of periphery; (2) highest possible velocity of motion; (3) greatest possible expansion; (4) greatest possible pressure at the commencement of the expansion. He states that for highest efficiency it is necessary to execute the following operations in the period of four consecutive strokes in each end of the cylinder.

(1) Aspiration during an entire out stroke of the piston.

(2) Compression during the following in stroke.

(3) Ignition at the dead point and expansion during the third stroke.

(4) Discharge of the burned gases from the cylinder during the fourth and last stroke.

The operations which are described above characterize the four-stroke cycle engine which was first actually built by Otto in 1876 or 1877. The importance of the pamphlet of Beau de Rochas was not recognized and it was probably little read until Otto had established the practical value of this method of operation. Five years before his death in 1887 Beau de Rochas was given a prize by the Société de Encouragement pour l'Industrie Nationale as a recognition of the important part which he had played in the development of the internal combustion motor.

Although the importance of compression previous to ignition in increasing both the efficiency and capacity of the internal combustion engine was fully pointed out by Million in his English and American patents and by the pamphlets of Beau de Rochas, little or no practical progress was made in the construction of compression engines for the next twelve years. The practical applications were confined in a large measure to the production of non-compression engines of the same type as that of Lenoir.

OTTO AND LANGEN. — Early in 1861, N. A. Otto, in trying to improve Lenoir's engine by giving it a full power stroke, hit upon the idea, in the course of his investigations, to break the igniter circuit of one of these machines, keep the exhaust valve closed at the end of the out stroke, then to turn the engine back in the other direction by hand, and when the piston reached the

inner dead center, having compressed the charge, to cause the spark to jump. He thus half unconsciously reproduced the suction and compression strokes of our modern four-cycle engines, and the result was that the engine received a sudden impulse which kept it spinning for several revolutions. As near as Otto thus came to the solution of the question, as proposed by Beau de Rochas in 1862, practical difficulties encountered, together with his own failures to realize the full importance of the thing, caused him to turn aside and invent an engine of an entirely different type. Not until thirteen or fourteen years later did he return to the old problem with success.

The result of his labor in the early sixties was the so-called free piston engine. The idea had been already worked out by Brown in 1832 and by the Italian Barsanti in 1858, but it remained for Otto and Langen to make it a commercial success.

After several years of experimentation the first machine was exhibited at the Paris Exposition in 1867.

Flame ignition was used and much better economy was obtained than with the Lenoir or Hugon engine. Clerk states that "it completely crushed Lenoir and Hugon and held almost sole command of the market for ten years, several thousands being constructed in that period."

A section of the engine is shown in Fig. 11-12. It consists of a tall vertical cylinder water-jacketed through a part or the whole of its length with the top open to the air. The fly-wheel shaft is supported by bearings on the top and carries a gear which engages with a rack attached to the piston rod of the engine. The gear turns freely on the shaft while the piston is moving upward, but is connected with it by an ingenious clutch when the piston moves downward. A slide valve S, operated by an eccentric on a shaft geared to the main shaft, controls the admission, ignition, and exhaust intermittently as determined by the governor of the engine. When operating at full load the piston is lifted a few

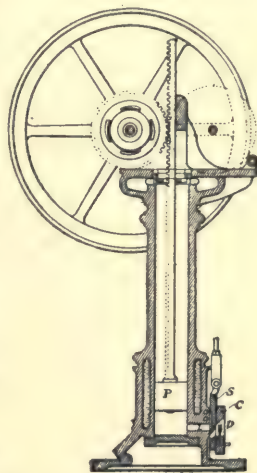


FIG. 11-12.—Otto-Langen Free Piston Engine.

inches and takes in the charge through the slide valve, which soon moves further and brings in the igniting flame. The resulting explosion projects the piston upward with high velocity. The pressure beneath it rapidly falls by expansion until lower than that of the atmosphere. On the return stroke of the piston the clutch is in engagement with the shaft and performs work due to the weight of the piston falling freely into a partial vacuum. The exhaust gases in the meantime are displaced through a port in the valve.

The clutch of the Otto-Langen engine was a very ingenious construction and one of the main points of the invention. It is shown in detail in Fig. 11-13 and consists of a part *a* keyed to

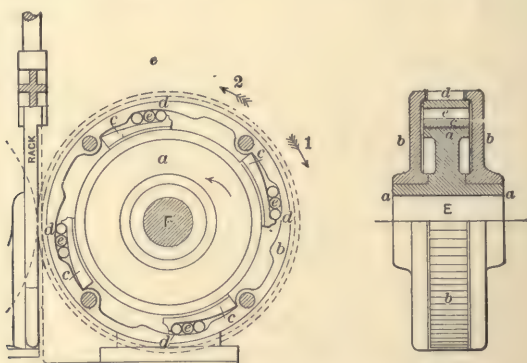


FIG. 11-13. — Clutches, Otto-Langen Engine.

the shaft, on which runs the part *b* carrying the teeth engaging the rack. The part *a* revolves freely with the shaft and is disconnected from the part *b* while the piston is moving upward or is stationary, but is fastened to the part *b* when the piston is moving downward. The parts *a* and *b* are engaged by small rollers, *e*, moving over wedge-shaped clips, *cc*, when the part *b* moves in the same direction as the part *a* and at a higher rate of speed. The parts are clamped together by the rollers wedging in between the two inclined surfaces and the steel clips *cc*. It will be seen that as soon as the part *a* moves with a higher velocity than is imparted to *b* by the rack, the clutch releases automatically.

Dr. R. H. Thurston, in the report of the Vienna exhibition in

1873, states that several of these engines were on exhibition and the results of several series of tests made by M. Tresca are given. The dimensions of the engine tested were as follows: diameter of piston, 8.75"; maximum stroke, 41.3"; diameter of water jacket, 15.75"; height of water jacket, 28.0". The following are the results of four trials:

Trials	1	2	3	4
Pressure of gas, millimeters	30.5	36	36	
Duration of experiments, hrs.	4	1	0.5	0.5
Revolutions per min.	85.7	82	81.5	79.9
Brake H. P.	0.896	0.857	0.426	0.418
Total gas per hr., litres	1017.5	1085	560	560
Gas per H. P. hr., litres	1135.6	1266	1314	1339.7
Gas per H. P. hr., cu. ft.	39.4	44	45.5	46
Gas used for igniters per hour, cu. ft.	2.12	2.30		

The above results, however, have been surpassed in tests by Meidinger in 1868. The engine tested had a cyl.-diameter of 5.9", a maximum stroke of 38.7", and was rated at $\frac{1}{2}$ horse-power. At maximum load this engine developed .635 B. H. P. and showed a gas consumption, including that of the ignition flame, of 29.5 cu. ft. per B. H. P. hour. This corresponds to a thermal efficiency on the brake of 13.7 per cent. Curiously enough a still better economy was shown at a lower load. With a B. H. P. of .35, the efficiency was 15.4 per cent. The fuel mixture in both cases contains 12.5 per cent of gas.

Respecting the engine tested at Vienna, Dr. Thurston states that it has always worked well and has greatly reduced the consumption of gas over that used by earlier engines. It is very noisy in operation and the exceptional fuel economy is its only special recommendation. This economy is probably due principally to the extreme rapidity with which the piston is projected upward at each explosion of gas, the work of expansion being thus utilized before sufficient time has elapsed for any serious amount of condensation to occur by contact with cold surfaces. A diagram from a 2 horse-power Otto-Langen engine from Clerk's work on the gas engine is shown in Fig. 11-14. This diagram shows that the expansion during the working stroke continues below that of the atmosphere, the piston evidently being taken to the

top of its stroke by the energy stored in the fly-wheel at the instant of explosion.

The igniting device used consisted of a constantly burning flame outside the working cylinder which was put in communication by a slide valve with the explosive charge at the proper time. The large sizes of this engine were governed by controlling the velocity of discharge of the exhaust gases. The more the exhaust outlet was throttled, the slower the descent of the piston, and hence the fewer the number of cycles in unit time.

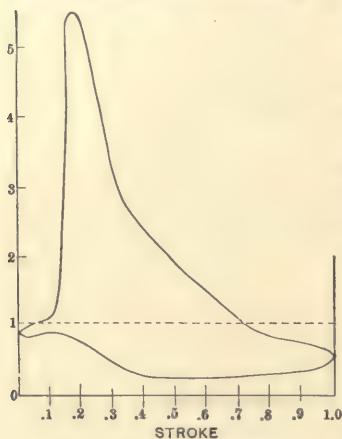


FIG. 11-14. — Diagram,
Otto-Langen Engine.

BRAYTON. — In point of time the next important invention in the art of producing internal combustion motors was made by an American, George B. Brayton. His engines were built in large numbers and possessed many advantages

over any previously made. They had the remarkable distinction of being the only motors which had been designed in which ignition takes place at constant pressure, the form of the diagram, already shown in Chapter I, being similar in many respects to that of the steam engine.

Brayton took two American patents for his engines; first the earlier one dated April 2, 1872, covered an engine adapted to burn gas; the later one, patented June, 1874, covered an engine adapted to burn liquid hydrocarbon or petroleum. Both engines have essentially the same principle of operation, the air and combustible are supplied to the working cylinder under pressure for a portion of the stroke, ignition continues during the admission of the air and combustible, causing an increase of volume without change of pressure. The supply valve closes when sufficient combustible has entered, and the piston finishes its stroke by expansion. Ignition was produced by a constantly burning flame in the power cylinder. Wire diaphragms were used to keep the flames from striking back.

Of the two forms of Brayton engine, the gas engine never

found much application on account of the fact that, due to puncturing the diaphragm, the ignition flame would sometimes strike back and explode the compound mixture stored in the reservoir.

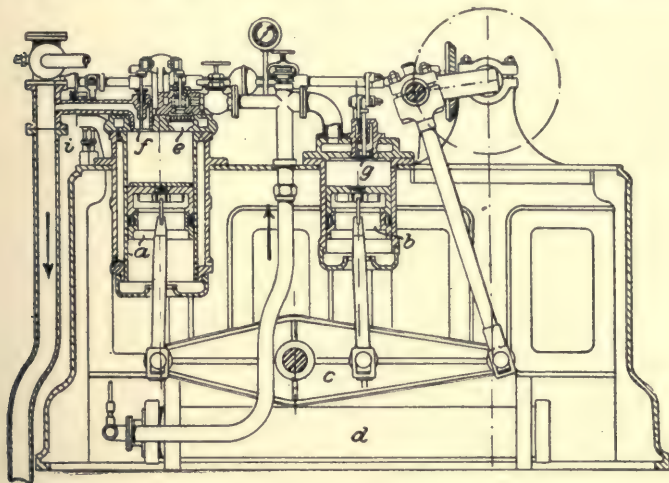


FIG. 11-15.— Elevation, Brayton Oil Engine.

This action together with the high price of gas led to the development of the petroleum engine. Figs. 11-15 and 11-16 show the construction of this engine very clearly.* The engine

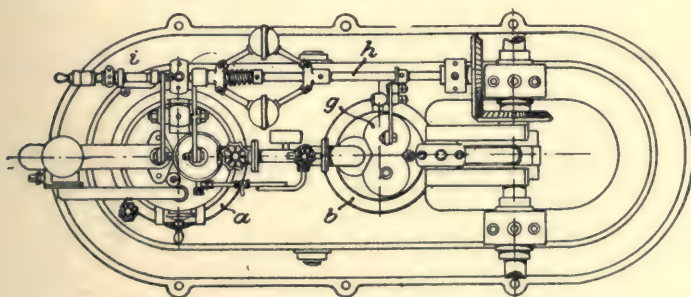


FIG. 11-16. — Plan, Brayton Oil Engine.

consists of a power cylinder *a* and an air-compressor cylinder *b*, the pistons of which are connected to the walking beam *c*. The air, drawn into the cylinder *b* through an automatic valve, is

* Güldner, Entwerfen und Berechnen der Verbrennungsmotoren, p. 91.

discharged through the valve *g* into the receiver *d* when the pressure has reached the desired point. From *d* the compressed air flows into the power cylinder when the valve *e* is opened by the lever shown, through the action of a cam on the auxiliary shaft *h*, Fig. 11-16. On its way through the valve the air is saturated with the vapor of gasoline or petroleum by passing a layer of saturated felt held between two perforated plates. The small pump *i*, shown in both figures and actuated from the cam shaft *h*, serves to keep the felt saturated. Just below this carbureting device, a needle flame, kept supplied with gasoline by the pump *i*, is kept constantly burning, igniting the charge as it passes. The admission valve is opened as the working piston reaches its upper end of the stroke. The mixture therefore burns as the piston is traveling downward, and the rate of combustion is so regulated that the pressure remains practically constant during the time of admission. Fig. 11-17 shows a typical work

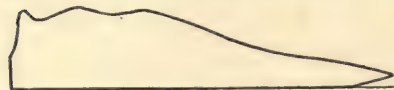


FIG. 11-17. — Power Card, Brayton Engine.

diagram. The card from the air cylinder is of course just like the ordinary air-compressor diagram.

The engine was governed by cutting off the mixture at the desired point. This was accomplished by making the admission valve cam conical and sliding it along the shaft *h* by means of the governor shown, thus varying the time of opening of the valve.

This oil engine was a thoroughly practical machine and found considerable application. Regarding its economy, a test by Clerk showed the following figures:

Diameter of Motor Cylinder	8"
Stroke of Motor Cylinder	12"
Diameter of Air Cylinder	8"
Stroke of Air Cylinder	6"
Mean R. p. m.	201
Mean B. H. P.	4.26
Net Indicated H. P.	5.40
Pump H. P.	4.10
Total I. H. P.	9.50
Mechanical Efficiency, %	79.0
Petroleum pr B. H. P.-hour, gals	.323

The fuel consumption shown amounts to a thermal efficiency of 6 per cent on the brake.

THE OTTO ENGINE. — The Otto engine was patented by Nicholas A. Otto of Deutz, Germany, in the United States, August 14, 1877, and in England about one year earlier. The engine was shown with great success at the Exposition of 1878. It was called the "Silent" engine, probably in contradistinction to the free piston engine of the same inventor.

The patent taken out by Otto is devoted principally to a description of an improved method of introducing air and gas into the cylinder of a gas engine, in layers or strata so as to make the explosion less violent in its nature. The patent describes three kinds of engines to which his process could be applied, viz., a non-compression engine, an engine of similar structure to the non-compression engine but in which the charge is compressed by external means before passing into the cylinder, and lastly the now common four-cycle engine in which the compression is performed in the working cylinder and which followed in its mode of operation the principles laid down in the French patent of Beau de Rochas in 1862.

The Otto method of introducing air and gas in separate layers to produce slow combustion did not prove to be of practical value, but the construction described in Claim 3 of the American patent not only revolutionized all previous methods of gas engine construction but formed the basis for all subsequent practice. This claim is stated as follows:

3. A gas-motor engine wherein, by one out stroke of the piston, separate charges of combustible gaseous mixture and air are drawn into the cylinder, which charges are compressed by the in stroke and then ignited, so as to propel the piston, which by its return stroke expels the products of combustion.

The Otto engine was so greatly superior to all the earlier ones in economy and capacity for a given weight and regularity of operation that it soon distanced all competitors. Its success led to numerous infringements in Germany and England and in each of these countries a patent suit was brought; in Germany the Otto patent was declared invalid because of the earlier patent to Beau de Rochas, but in England it was sustained. In the United States no patent suit was brought, although there were doubtless many infringements before the patent expired in 1894.

Figures 11-18 to 11-20 show a horizontal cross-section, a side

view and an end view of an Otto engine of 1884.* In this engine the admission of the fuel mixture and its ignition are controlled by the slide valve, *b*. This valve is actuated by a crank, *d*, and moves forward and backward across the cylinder head. The gas

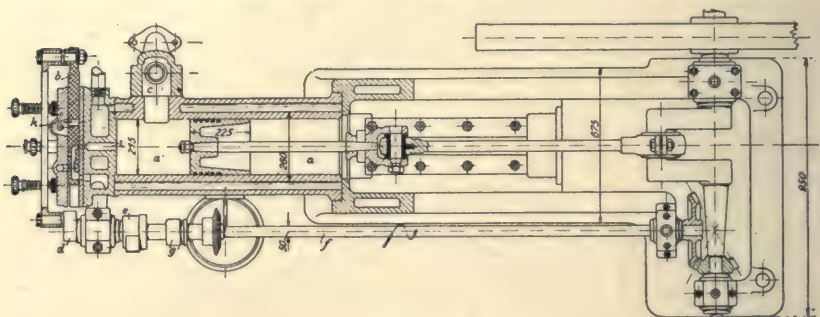


FIG. 11-18. — Horizontal Section Otto Engine of 1884.

valve, *g*, is actuated by a cam, *g'*, upon the side shaft, *f*, while the exhaust valve, *c*, of the now usual poppet type, is actuated through a lever by means of a cam, *e*, upon the same shaft. This shaft, *f*, turns with one half the speed of the crank shaft. The

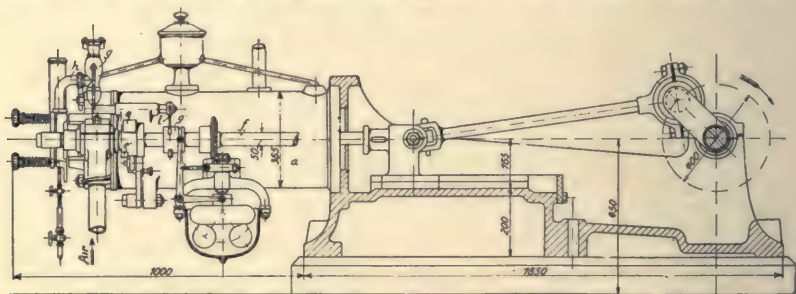


FIG. 11-19. — Elevation of Otto Engine of 1884.

admission slide valve is held against its seat by a cover plate. This plate contains the ignition arrangements and air and gas ports, which latter coincide with other ports through the valve proper and into the combustion chamber, *a'*, in certain positions of the valve. The gas valve is connected to the gas port in the plate by a bent pipe, *d*, while gas is furnished to the ignition apparatus by the small forked pipe shown in Fig. 11-20.

* From Güldner, p. 43.

To explain the operation of the engine, suppose that in the position shown in Fig. 11-18 the piston is just commencing its suction stroke. The exhaust valve, *c*, has just closed and the port in the valve coincides with the port, *i*, into the cylinder. As the piston moves outward, only air is drawn in for the first part of the stroke, because the cam has not yet opened the gas valve, *g*. A little later *g* opens and the mixture is drawn in for the rest of the stroke. At the outer dead center the valve has closed the port, *i*, and compression next takes place. By the time the piston has reached the inner dead center, the valve has moved far enough over to bring the ignition cavity, *k*, in front of the port, *i*. The flame in *k* strikes in, causing the charge to explode. Expansion and exhaust follow.

The above method of drawing in the charge was by Otto supposed to result in stratification, *i.e.*, according to his views there would be a layer of burned gases next to the piston, then a layer of air and last the layer of mixture.

He also claimed that this arrangement was not disturbed during compression. His argument was that, ignition taking place in the rich mixture, the pressure wave would soon reach the leaner mixture and the layers of air and burned gas in succession, and "tone down," so to speak, in its intensity so as to avoid shock to the engine mechanism. The opinions of experts regarding the soundness of this theory are divided even to-day. See Chapter IV.

The ignition apparatus used in the earlier Otto machines, up to the general introduction of electric ignition, was very similar to that employed by Otto in the free-piston engine some ten years earlier. Fig. 11-21 shows a cross-section through the ignition

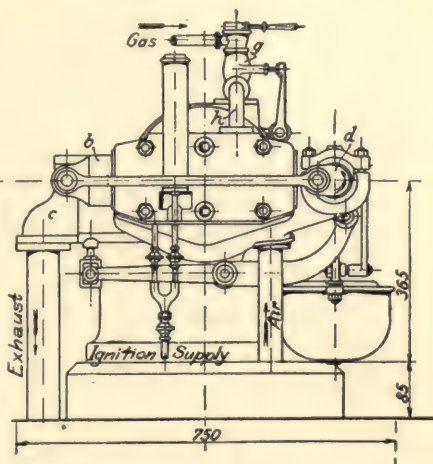


FIG. 11-20. — End View of Otto Engine of 1884.

cavities in plate and slide. One branch of the forked pipe, shown in Fig. 11-20, supplies a constantly burning flame, *G*, Fig. 11-21, while the second branch fills the cavity, *B*, with gas which gets its air supply through the port, *C*, the mixture igniting when it strikes the flame, *G*, as shown. When near the time of ignition, cavity *B* in the slide is cut off from its air and gas supply, but enough burning mixture is left in the cavity to ignite the charge in the cylinder when *B* registers with the port into the cylinder. Since the pressure in the compression chamber is so much higher

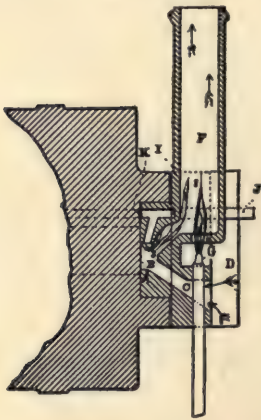


FIG. 11-21. —
Ignition Arrangements,
Otto Engine of 1884.

than that in the cavity, there is danger that the flame will be blown out when communication is first established. To prevent this, just before the cavity and the inlet port commence to register, communication is established with the combustion chamber through a very fine opening, thus equalizing the pressures in inlet port and cavity.

The governing arrangements were simple and effective. The gas valve cam, *g'*, Fig. 11-19, was arranged to slide on the shaft, *j*. A fly-ball governor controlled its position, and when the speed rose a certain amount above normal, the cam was pulled far enough to the left to cause it to miss the valve lever, *l*.

Thus the engine received no gas and an impulse was missed.

Economy tests on early Otto engines were made by Slaby and Brauer, 1881, Teichman and Boecking, 1887, and by others. The thermal efficiencies on the brake ranged from 9 to 12 per cent. The best figure obtained by Brauer in 1886 on a Deutz 4 horse-power horizontal engine was a total gas consumption of 29.9 cu. ft. per B. H. P. hour, which corresponded to a thermal efficiency of 15.5 per cent. Tests made by Brooks and Stewart at Stevens Institute, Hoboken, in 1882 on a 6 B. H. P. engine show about the same results.

The engine shown in Figs. 11-18 to 11-20 is from the design standpoint a well-built machine, and shows a very marked advance in this respect over all earlier forms. It will be noted that

the cross-head was still used. This was, however, soon dispensed with, substituting a trunk piston, and thus shortening the length of the machine. Another change soon instituted was the substitution of electric for flame ignition.

CLERK. — The disadvantage, inherent in all four-cycle machines, of receiving a power impulse only once in four strokes, led other inventors to experiment with the two-cycle engine which gets a power impulse every turn. The change from the four- to the two-cycle principle seems very simple, but is in reality

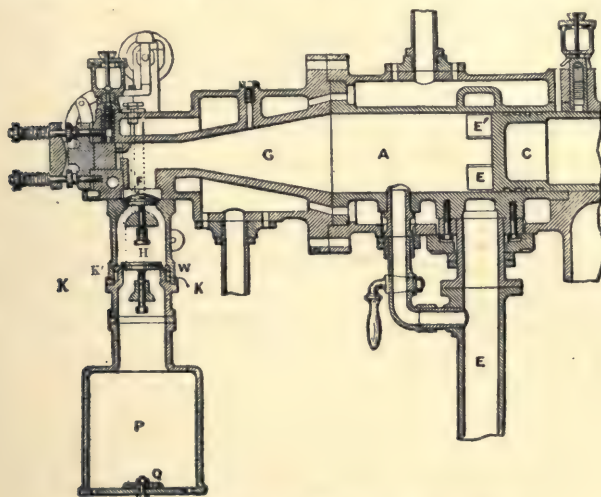


FIG. 11-22. — Vertical Section, Clerk Engine.

beset with many difficulties. Perhaps the earliest fairly successful worker was Clerk, who commenced to experiment upon two-cycle engines soon after Otto perfected his four-cycle machine. It was, however, not until 1880 that he succeeded in producing a serviceable machine. Figs. 11-22 and 11-23, both from Clerk, "The Gas and Oil Engine," show a vertical and horizontal cross-section respectively. The operation of the engine is as follows: In Fig. 11-23 the power piston, *C*, has just reached the outer dead center and the main bulk of the exhaust gases have escaped through the ports *EE'*. In the meantime the displacer piston, *D*, which on its previous suction stroke has drawn a mixture of air and gas into *B*, has completed about half of its in stroke and

displaced the mixture into *G* and *A* through the connecting pipe, *W*. About the time *D* has completed its stroke, the power piston, *C*, has covered the exhaust ports on its return stroke, and compression ensues in the main cylinder. The cylinder volumes are so proportioned that in theory no mixture can be lost through the exhaust ports. At the inner dead center of the power piston, *C*, or just before, the igniting cavity, *O*, Fig. 11-23, comes opposite the port, *N*, and the charge is fired. The piston is impelled forward and the next charge, drawn into *B* in the meantime, commences to enter the space *G* as soon as the pressure in *A* has fallen enough, after the beginning of exhaust, to cause the valve in the pipe between *B* and *G* to lift. The intermediate valve

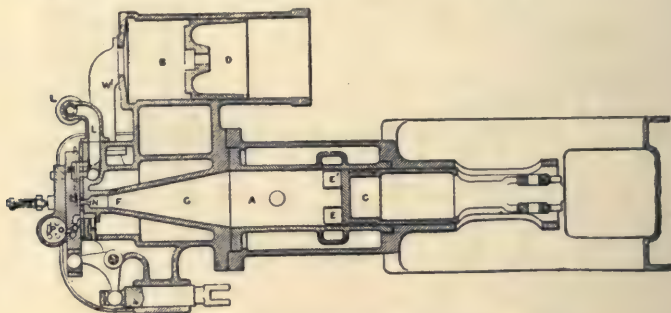


FIG. 11-23. — Horizontal Section, Clerk Engine.

arrangement is shown in Fig. 11-22. *P* is an air chamber. The air drawn in by the suction of the displacer piston, *D*, passes through the valve, *H*, and in so doing is mixed with gas which enters through a number of fine holes in the seat of the valve from the annular space, *K*. On the in stroke of the displacer piston the mixture under some pressure comes in under the valve, *F*, which it lifts as soon as the pressure of the exhaust gases above it has fallen low enough.

The difficulty under which the engine labored was loss of mixture through the exhaust ports and consequent low economy. Although the respective volumes of the two cylinders may be in the proper ratio, the charge expands by heat on the transfer, and mechanical agitation favors the loss. In spite of this defect shop tests on 2, 4, 6, 8, and 12 horse-power engines in 1885 gave results fully equal to those obtained on the four-cycle machine

of that day. The following table shows the results of some of these tests.

Horse-power	2	4	6	8	12
Dia. Motor Cyl., inches...	5	6	7	8	9
Stroke Motor Cyl., inches.	8	10	12	16	20
Dia., Displacer, inches....	6	7	7½	10	10
Stroke Displacer, inches...	9	11	12	13	20
R. P. M.	212	190	146	142	132
I. H. P.	3.62	8.68	9.05	17.38	27.46
D. H. P.	2.70	5.63	7.23	13.69	23.21
Mech. Eff., %	74.7	65.0	80.0	78.8	84.5
Gas per B. H. P.-hr., cu. ft.	40.0	37.3	30.42	26.58	24.12

Figures 11-24 and 11-25 show a power diagram and a pump diagram from a 6 horse-power engine.

4. Period of Application. — It is intended in what follows to give merely a brief résumé of the further development of the internal combustion engine say up to 1897 and to reserve a more detailed description of the most important forms in the market to-day for the next chapter.

On account of the Otto patent, which practically amounted to a monopoly, other manufacturers were forced to turn their attention to the development



FIG. 11-24. — Power Card, Clerk Engine.

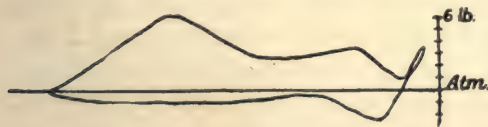


FIG. 11-25. — Pump Card, Clerk Engine.

of the two-cycle engine. How Clerk solved the problem with fair success has been already shown. He was followed by Wittig and

Hess (1880), Benz (1884), Söhnlein, Güldner (1893-1898), Oechelhäuser (1896) and Koerting (1898) in Germany, Robson, Southal, and Samson in England, Benier (1894) in France, and Mietz and Weiss in the United States. Many of these engines are in the market to-day, and some are described in the next chapter.

With the fall of Otto's claims in Germany about 1885 the field

became free, and many manufacturers of the two-cycle engine abandoned it for the more simple four-cycle. The fall of this patent was, in a sense, a misfortune as far as the two-cycle engine was concerned, as it held back the development of that type of machine at least ten years. It is only within the last six or eight years that the very obvious advantages of the two-cycle principle again received the attention they deserve. On the other hand, the development of the four-cycle engine after 1885 was extremely rapid. Thus while the limit of power was about 4 B. H. P. in 1878 and units of from 15-20 horse-power could be had in 1880, the limit soon rose to 100 horse-power in 1889 and 200 in 1893. Blast furnace gas called for units of 600 horse-power in 1898, while to-day engines developing up to 4000 horse-power are being built. With the increase in size up to the neighborhood of 200 horse-power, there comes an increase in thermal efficiency. Thus a Crossley engine of 12 horse-power soon showed a gas consumption of 24.3 cu. ft. of illuminating gas per B. H. P. hour. To-day efficiencies exceeding 25 per cent on the brake, with lean power gases, are not rare, and Guldner, by intelligently applying sound principles of construction, has succeeded in obtaining economic efficiencies exceeding 30 per cent.

It would lead too far for the scope of this book to describe even a fair percentage of the various four-cycle engines brought out between 1885 and 1898. The most prominent names connected with the development of these engines are perhaps Loutzki in Germany (1888), Delamare-Deboutville & Malandin, who in 1900 brought out the first large blast furnace gas engine, in Belgium, Charon in France, Crossley Brothers in England (1892 and 1898), and Westinghouse in the United States (1896). Four-cycle constant-pressure oil engines were developed by Capitaine (1889-91), Brunnler (1893-4), and Diesel (1893-97) in Germany. The Diesel engine is to-day one of our most important internal combustion engines, and is considered in greater detail below. Among the developers of the four-cycle constant volume oil engine, Daimler's work in connection with the high-speed engine deserves special mention. Other engines of this type brought out in this period are Spiel (1884), Capitaine (1885-90), Priestman (1889), Hornsby-Akroyd (1892), Banki (1894), and Haselwander (1898).

One of the greatest achievements of this period is the development of the Diesel engine.

DIESEL. — The history of the Diesel engine is interesting. It began in 1893 when Rudolf Diesel, in a pamphlet entitled "Theory and Construction of a Rational Heat Motor to replace the Steam Engine and other existing Heat Engines," laid down the following "fundamental requirements for a perfect combustion."

1. Attainment of the highest temperature in the cycle, not by means of combustion and during the same, but before and independent of it by compression of air alone.

2. Gradual injection of atomized fuel into this highly compressed and heated air so that during combustion no rise of temperature takes place, *i.e.*, the combustion shall be isothermal. For this purpose the process of combustion cannot after ignition be left to itself, but must be governed from the outside to maintain proper relation between pressure, volume, and temperature.

3. Correct choice of weight of air with reference to the heating value of the fuel and the desired compression temperature, so that the practical operation of the machine, lubrication, etc., shall be possible without water-cooling.

It is interesting to follow out these points and to see in how far their object has been attained.

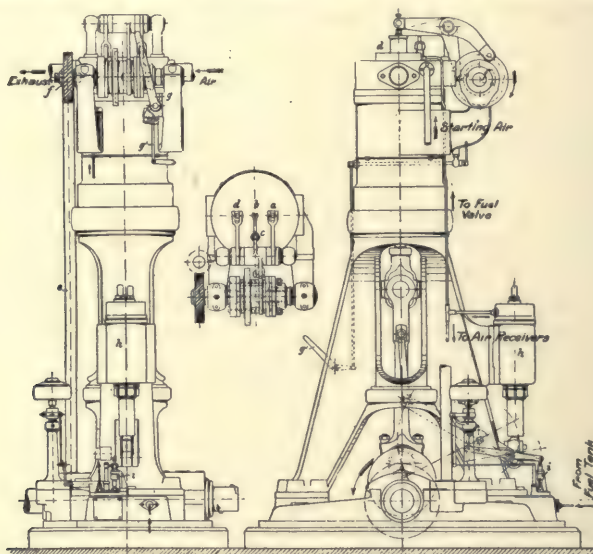
The intended fuel was coal dust, the cycle the Carnot. At the very outset, however, a modification was made in the cycle in cutting out the isothermal compression and substituting for it one stage adiabatic compression. But a jacket was not thought necessary, and in fact a non-conducting lining for the cylinder was demanded.

As a consequence of the above pamphlet, two firms, Krupp in Essen and the Maschinen-fabrik Augsburg, undertook the construction of experimental machines. As was to be expected, further changes from the original idea were necessary, the two most important of which were the substitution of oil for coal dust, and the use of a water jacket.

In 1898 the experimental stage had been so far passed that Schröter could report test figures which more than doubled the thermal efficiency of the then existing Otto engines. The final form of the engine as now constructed is shown in Figs. 11-26 to

11-28, which represents a Diesel engine built by Krupp in 1898.*

The internal-cylinder construction offers nothing new; *a* is the suction valve for air, *b* the fuel valve, and *d* the exhaust valve. *c* is the starting valve not in commission during ordinary operations. All are actuated through levers by cams on the shaft, *f*, which is operated from the crank shaft through the intermediate shaft, *e*; *h* is the air pump to furnish compressed air for fuel injection and for starting. Both of these are taken from steel



FIGS. 11-26 to 11-28. — Diesel Engine, 1898.

flasks into which *h* delivers; *i* is the oil pump under control of the governor which regulates the amount of oil per stroke to the load.

On the first down stroke, the engine takes air through *a* and compresses it on the return stroke to a pressure of about 460 pounds, with a temperature of about 1100 degrees Fahrenheit. Just before the end of the up stroke the fuel valve, *b*, is opened to a width of only a few hundredths of an inch, and the injection air, previously compressed to about 650 pounds by pump *h*, flows

* Güldner, p. 101.

into the compression chamber, carrying with it and finely atomizing the oil furnished by the pump, *i*. The oil ignites on entering, due to the high compression temperature. In spite of the fact that isothermal combustion is intended, the lack of outside control causes a rise not only in the pressure of from 80–100 pounds, usually not very noticeable on the indicator card, but also a rise of temperature approximating 1800 degrees Fahrenheit. Thus while the intended mean temperature of the cycle of Diesel's pamphlet was about 350 degrees, that realized in actual operation is about 950 degrees Fahrenheit. The time during which the fuel injection valve, *b*, remains open, is constant for all loads, but the effective stroke of the fuel pump, *i*, ends the sooner the lower the load, thus effecting regulation.

After the closing of *b*, expansion commences and is followed by exhaust through *d* on the return stroke.

The engine is started by the compressed air furnished by *h* during a previous operation and stored in a tank. To start, the cams on the shaft, *f*, are pulled to the right by the lever, *g*. This puts the valves *a*, *b* and *d* out of commission and starting valve *c* in commission. On placing the crank just beyond the upper center, and opening the tank valve, the engine takes compressed air for a few turns just like a steam engine takes steam. When the required momentum has been obtained, the cams are released and are snapped back into place by a spring at the proper time.

The history of the development of the Diesel engine is interesting in that the final construction departs so far from the patented ideal that the engine of to-day does not seem to be protected by the claims of that patent. The fact that no igniter was necessary was only incidentally considered by Diesel, and is not expressly covered by the patent.

The first test figures on a Diesel engine were published by Schröter in 1897. The dimensions of the engine were: Cylinder diameter, 9.85", stroke 15.7", rated B. H. P., 18–20. The fuel used was American kerosene having a heating value of 18400 B.T.U. The following table shows the results of two full load trials and compares them with some of the theoretical results figured by Diesel in his pamphlet of 1893.*

*Güldner, p. 107.

	Diesel Engine of 1897		Ideal Engine of 1893
Load	Full	Full	
R. P. M.	171.8	154.2	300
B. H. P.	19.87	17.82	?
Total I. H. P.	27.85	24.77	100
Pump H. P.	1.29	1.17	
Net I. H. P.	26.56	23.69	100
Oil per B. H. P.-hr., lbs.	.543	.523	247 lbs. of coal per I. H. P.
Cooling water pr B. H. P.-hr., lbs.	154	203	Zero
Compression Press., Atm.	32.5	32.5	250
Max. Comb. Pressure, Atm.	36	36	250
Temp. End of Compression, °C.	550	550	800
Temp. End of Combustion	1600	1600	800
Indicated Thermal Eff., %	33.7	34.7	73
Mech. Eff., %	71.0	72	
Thermal Eff. on Brake, %	25.2	26.2	?

It is clear from the above table that, although the engine did not realize the early expectation of its designer, the results shown

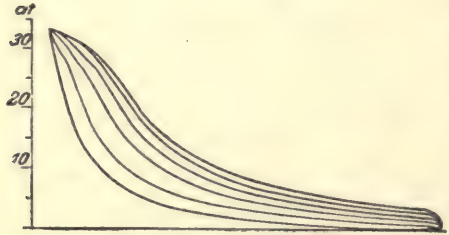


FIG. 11-29. — Regulation Diagram, Diesel Engine.

are a remarkable step in advance as regards the economy of the then existing internal combustion engines. To-day even better figures are frequently obtained. E. Meyer, for instance, has lately tested a Diesel engine showing an indicated thermal efficiency exceeding 42 per

cent. Fig. 11-29* shows the general form of the indicator card obtained from Diesel engine. This is a regulating diagram, the size of the card decreasing with the load by shortening the cut-off.

* Güldner, p. 109.

CHAPTER XII

MODERN TYPES OF INTERNAL COMBUSTION ENGINES

THE previous chapter brought the development of the internal combustion engine up to 1897. Since then expansion has been very rapid, until to-day we find that the design of gas engines has been standardized in the most important particulars just as was the case with the steam engine some decades ago. It is intended in the present chapter to give a brief description of the most important engines found in the market to-day. An examination of the market will show some fairly definite divisions among manufacturers as far as size of engine made is concerned. Thus there are but a half dozen firms in this country, and a few more than this in Europe, who make engines up to the very largest sizes. It is comparatively easy, therefore, to describe nearly all of these various engines, and this is very desirable on account of their importance. Next we find a somewhat larger number of medium sized engines of various types, and lastly a very large number of engines up to say 50 horse-power serving the general commercial field for small powers. It is of course impossible to cover the last two classes of engines to any great extent. The majority of these engines do not differ except in minor details, and for these reasons the following list has been confined to what seem to be the most representative machines of each class.

Regarding the *general features of design*, small engines are either horizontal or vertical. The cylinders are almost invariably single-acting, multiplication of power being obtained by increasing the number of cylinders. The vertical offers some advantages over the horizontal form, in that the foundation need not be as large or as heavy. Further it is claimed that it is easier to lubricate the cylinders uniformly, and that the wear on the cylinder is less. A favorite form of frame for this type of engine in this country is the box frame with enclosed crank case, using splash lubrication. Some European designers object to this

form, claiming that all supervision of crank pins and intermediate bearings is by this form of frame rendered impossible. The small two-cycle machine almost invariably uses the enclosed crank case for the pre-compression of the mixture.

What has been said of the small machine applies in general also to medium sized engines. Vertical machines here possess the added advantage that it is easier to dismount them by means of overhead crane than is the case with horizontal machines. The limit to a vertical engine comes in the head room required. For this reason all of the very large machines, as well as medium sized double-acting machines which require a cross-head, are horizontal. Another reason that may be cited is that it is easier to operate a medium sized or large horizontal engine than it is a vertical because all climbing or mounting platforms is avoided, and the whole installation is more completely under the operator's eye. Finally, the use of some of the industrial power gases favors the use of the horizontal machine, because any dust carried can be much more easily swept out of a horizontal than a vertical cylinder during regular operation.

The double-acting engine is perhaps not used as widely as it deserves to be, increase in power being generally sought by multiplying the single-acting cylinders. There is, however, to-day no reason why double-acting cylinders are not as reliable as the single-acting. For large machines, double-acting cylinders are almost an economic necessity, and the clumsy four-cylinder double-opposed large engine has become thoroughly obsolete. The largest engines of to-day are double or twin two-cylinder tandem double-acting engines.

The very obvious disadvantages of the trunk piston can be quite successfully overcome for small and medium sized machines, and hence it is almost universally employed for these sizes. But for large machines the use of the trunk piston is indefensible, being opposed alike by considerations of manufacture and of reliable operation. The fitting of large pistons of this type offers grave difficulties in the shop, and in operation proper lubrication is difficult; further, the main office of the piston is to confine the gases without leakage; to make it also act as the machine member to take up the lateral thrust of the connecting rod may, in large machines, seriously interfere with its main purpose.

The crank shaft of small and medium sized engines is nearly always of the center-crank type. This type is very rigid and, above all, transmits the stresses equally to both sides of the frame. In double or twin machines, however, such a shaft would call for four main bearings, the proper alignment of which might cause some trouble in large engines of this type. For this reason, some American makers prefer the side-crank shaft, which is a much less costly shaft to make, and reduces the number of bearings for a twin engine to two. Of course, the side-crank frame takes up the explosion stresses eccentrically, and therefore has to be designed heavier than the center-crank frame. On account of this fact and the generally higher stresses in gas engine frames as compared with steam-engine frames, European designers will not use the so-called side crank or Tangye form of frame.

The period of experimentation in design, and of freak design, has largely passed in gas-engine practice, and, as mentioned at the outset of this chapter, standardization has made welcome progress during the last few years. The alcohol engine, now in its development as far as the United States is concerned, does not call for any radical changes in the existing designs of liquid fuel engines. As far as further progress is concerned, it is not unlikely that the next step will be the development of a highly efficient constant-pressure gas engine after the manner of the Diesel liquid fuel engines, taking up the thread again where Brayton left it in the seventies.

A. Gas Engines

1. SMALL AND MEDIUM SIZED ENGINES. — Among the best known makers of small and medium sized gas engines in this country may be mentioned the Otto Gas Engine Works of Philadelphia, makers of the Otto engines; the Fairbanks-Morse Company; the Jacobson Machine Manufacturing Company, of Warren, Pa.; the Jacobson Engine Company, of Chester, Pa., the Struthers-Wells Company of Warren, Pa., makers of the Warren engine; the Bruce-Meriam Abbott Company, of Cleveland; the Westinghouse Machine Company; the Olds Gas Power Company, of Lansing, Mich.; the De LaVergne Machine Company of New York, makers of the four-cycle Koerting engines; the Weber Gas Engine Company of Kansas City, Mo.; the A. H. Alberger Company of

Buffalo, makers of the Buffalo tandem engines, the Foos Gas Engine Company of Springfield, Ohio, etc.

In most cases the small gas engine operates on illuminating gas, natural gas, or gasoline, but in many instances attachments are furnished so that the engine can be run on either gas or liquid fuel as desired. Producer gas is not usually employed for very

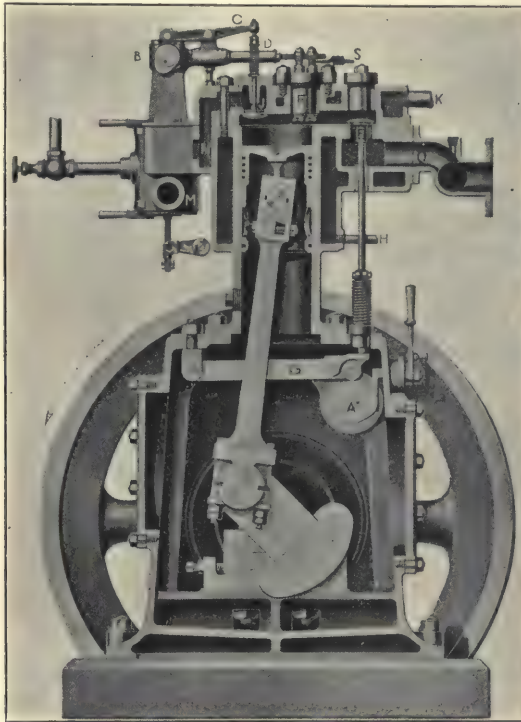


FIG. 12-1. — Westinghouse Engine.

small units. A 10 to 15 horse-power suction gas producer for hard coal is the present lower limit and perhaps the exception, while soft coal producers in their present state of development do not run less than 50 to 60 horse-power.

The Westinghouse Gas Engine. — The cross-sectional cut, Fig. 12-1, shows the essential parts of the Westinghouse vertical engine. In this type the crank mechanism is completely enclosed, and splash lubrication is depended upon for the proper oiling of

the intermediate bearings, the crank pins and the pistons. Both the inlet and exhaust valves are mechanically operated by cams and shafts driven from the main shaft; the inlet valve, *J*, by means of cam *B* and lever *C*, the exhaust valve *E* by cam *A* and the roller lever shown. The igniter, operated from the inlet cam shaft, is located at *F*. Gas and air, after passing the chamber *M* in the proper proportion, enter the passage *N* on their way to the inlet valves. The engine is governed by means of a governor of the fly-ball type which regulates the amount of mixture entering the passage *N* (see Chapter XIV). The smaller sizes of this

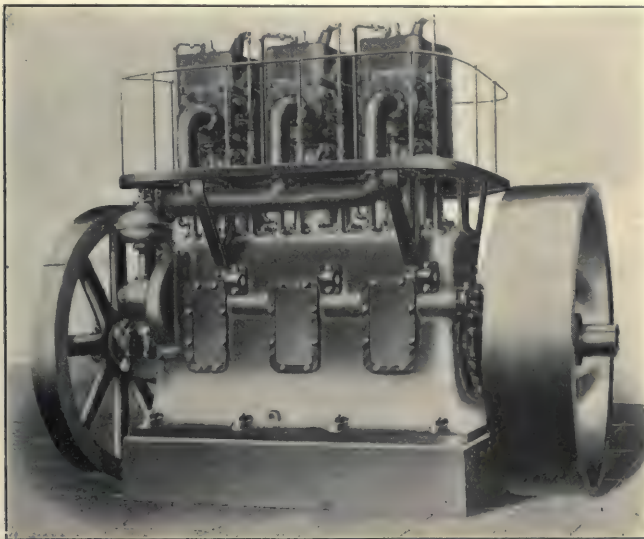


FIG. 12-2. — Westinghouse Engine.

machine have two cylinders, and can generally be started by hand; the larger sizes, above about 85 horse-power, have three cylinders and are generally started by compressed air, which is admitted to one cylinder, starting the engine, while the other cylinders operate normally. Figs. 12-2 and 12-3 show general views of three-cylinder machines.

Engines manufactured under the Jacobson Patents. — There are two firms manufacturing engines under these patents, the Jacobson Engine Company of Chester, Pa., and the Jacobson

Machine Manufacturing Company of Warren, Pa. The engines made are of three types, hit-and-miss, automatic cut-off, and throttling. The Warren Company make hit-and-miss engines from $2\frac{1}{2}$ to 25 horse-power and automatic engines from 8 to 27 horse-power. The Chester Company make hit-and-miss engines from 30 horse-power up, and automatic cut-off and throttling engines from 33 horse-power up. All of these engines so far mentioned are single-acting. The automatic cut-off and throttling

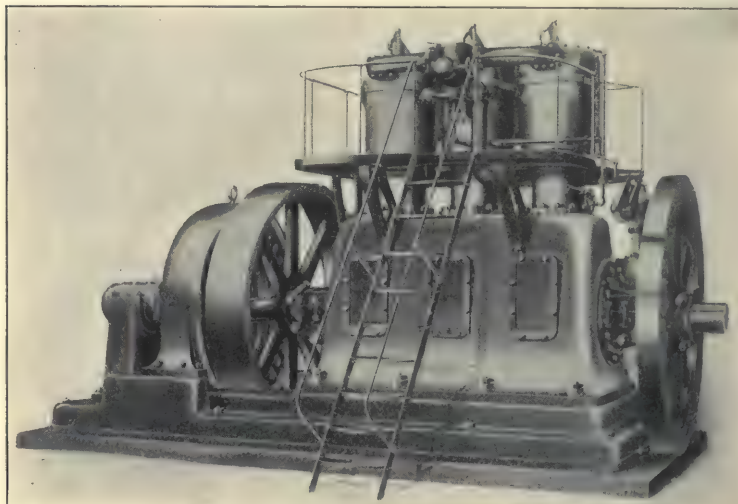


FIG. 12-3. — Westinghouse Engine.

types are built as single-cylinder or as tandem or twin-tandem units. The Chester Company now also undertake the building of double acting automatic cut-off or throttling engine as tandem or twin-tandem units up to any power desired.

The structural features of the engines built by the two companies mentioned are of course very nearly the same, so that one description will do for both.

The general features of the hit-and-miss machine are shown in Fig. 12-4. The most interesting detail of the design is perhaps the removable cylinder bushing, which is an unusual but highly commendable construction for small engines. This not only allows of choosing the proper grade of metal for the cylinder barrel, but thermal stresses are also avoided by admitting of

free expansion, in this case against the packing at the head of the bushing. On account of the manner of holding it, this packing can never be blown out.

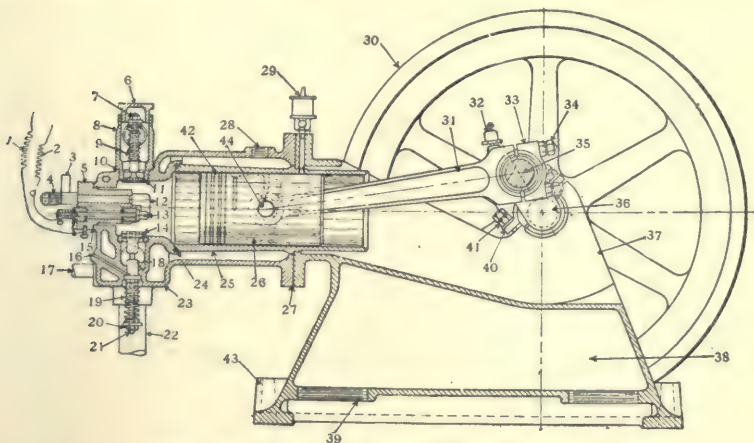


FIG. 12-4. — Jacobson Hit-and-Miss Engine.

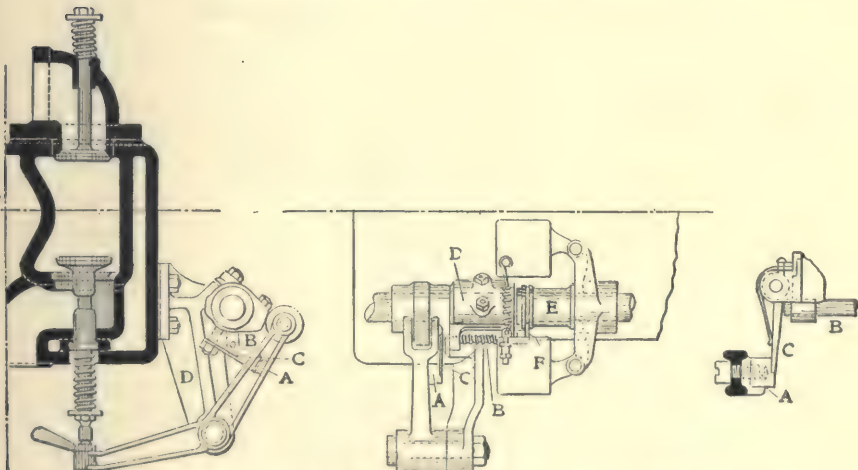


FIG. 12 5. — Governing Mechanism of Jacobson Hit-and-Miss Engine.

The inlet valve is automatic, and is held in a separate housing. The manner of operating the exhaust valve and the governor control are shown in Fig. 12-5. The side shaft is operated by means of screw gears, which is the most satisfactory way of

transmitting the motion. The governor is of the fly-ball type and is operated by the lay shaft. When the speed becomes too high, the blade, *C*, Fig. 12-5, put in position by the governor, engages the block *A* on the exhaust valve lever, prevents this lever from returning, thus holding the exhaust valve open.

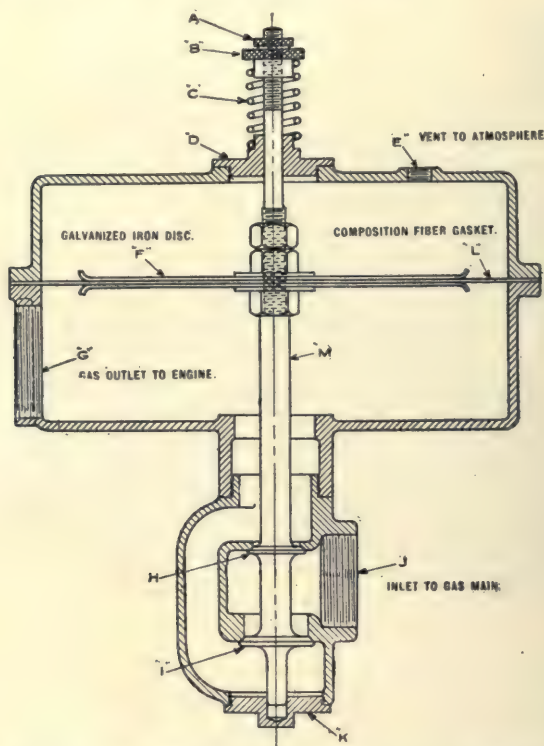


FIG. 12-6. — Gas Pressure Regulator for Jacobson Engines.

Figure 12-4 also shows the make-and-break igniter. One block contains both electrodes and the location of the spark is central as regards the volume of the charge.

This engine can be run on either gas or gasoline, depending upon whether a gas regulator or a carbureter is employed. The type of regulator used is illustrated in Fig. 12-6. Its construction is very simple, there is nothing apparently to get out of order. It is claimed that this regulator furnishes the gas to the engine

under atmospheric pressure at all times. The firm makes an attachment which allows of the change from one fuel to another at a moment's notice.

The general design of the automatic cut-off is the same as for the hit-and-miss engine, the difference being in the governor and the valve gear. Fig. 12-7 shows the method of operating the inlet and exhaust valves and the igniter. The valve gear is shown in greater detail in Fig. 12-8. The seats and stem bushings are all easily accessible and replaceable. The exhaust valve is operated in the ordinary way by a cam from the lay shaft. For the inlet valve lever an eccentric is used. As the eccentric rod *R* rises, it pushes upward the valve lever *Q* at the right end and opens the inlet valve. The inlet valve spindle carries two discs, the main inlet valve and the gas valve. Just before the exhaust valve closes, the gear commences to open the inlet valve, but only air enters since the gas valve *V* remains closed. The air thus entering serves to scavenge out the combustion chamber. A moment later the valve spindle has descended far enough for the set collar on the spindle to depress the gas valve, after which the mixture begins to enter the cylinder. Both valves close simultaneously when the nose of the eccentric rod *R* is forced off the end of the valve lever by the action of the inclined plane *P*. The position of this plane is determined by the governor, which is of the fly-ball type and directly driven from the main shaft. Thus the valve always opens at the same point, but it closes sooner or later, depending upon the load.

Figure 12-9 shows the general appearance of the automatic cut-off machine. They are built in sizes up to 27 horse-power by the Warren Company, and can be adapted to run on gasoline and natural, illuminating, or producer gas. The twin tandem type is shown in Fig. 12-10 and is built in sizes above 100 B. H. P. for producer gas and above 120 B. H. P. for natural gas by the

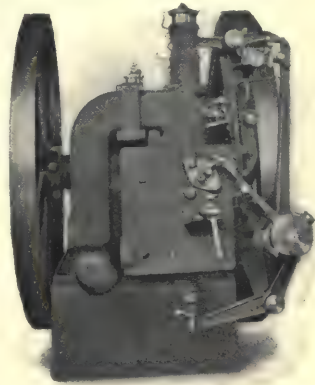


FIG. 12-7. — Jacobson Automatic Cut-off Engine.

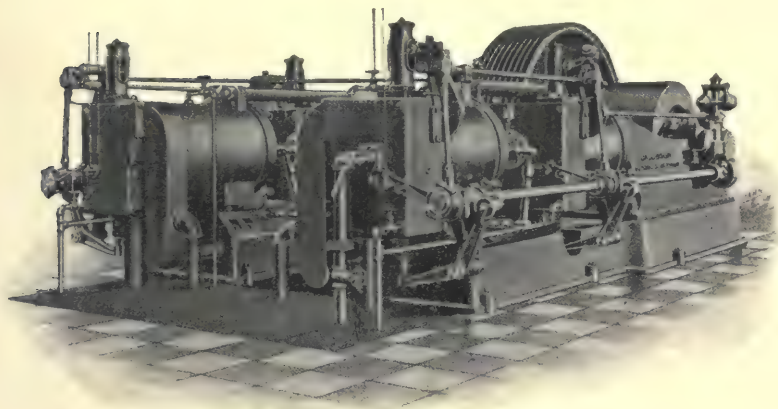


FIG. 12-10. — Jacobson Twin-tandem Automatic Cut-off Engine.

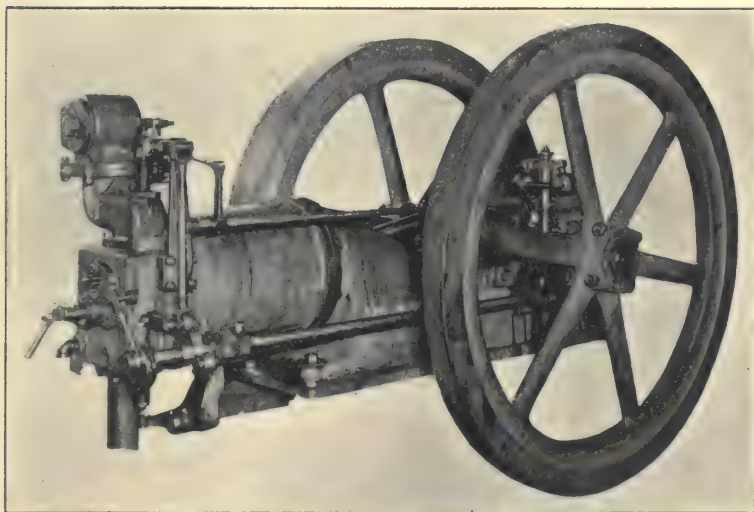


FIG. 12-11. — Jacobson Throttling Engine.

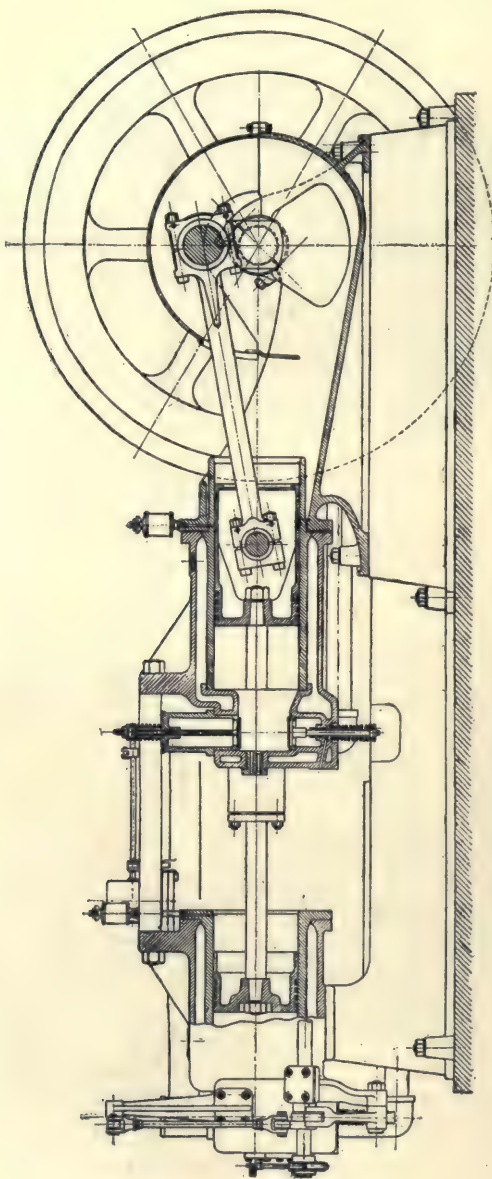


Fig. 12-12. — Jacobson Tandem Throttling Engine.

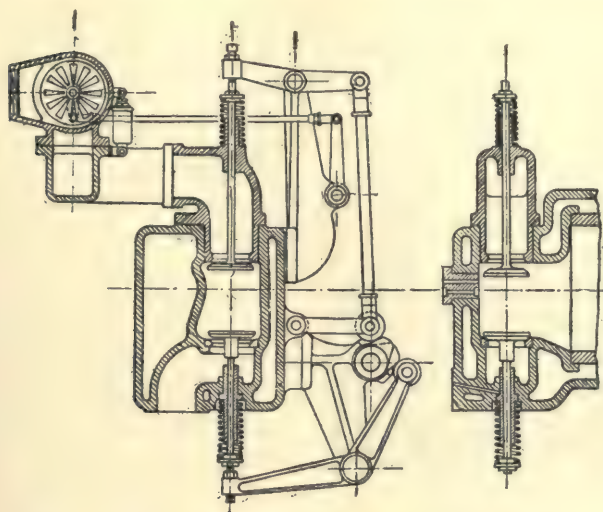


FIG. 12-13. — Valve Gear, Jacobson Throttling Engine.

illustrates the valve gear. Both valves are operated by cams. The charge passes the mixing and throttling valve, which is controlled by the governor through the reach rod shown.

The Bruce-Meriam-Abbott Engine. — The Bruce-Meriam-Abbott Company, located in Cleveland, Ohio, manufactures engines for natural, illuminating, and producer gas and for gasoline. The design used for natural and illuminating gas and for gasoline is shown in Fig. 12-14. The sizes range from 12 to 250 horse-power, two-cylinder up to 125 horse-power, and four-cylinder above that size. The design of cylinder and frame is along conventional lines. The cam shaft across the top of and between

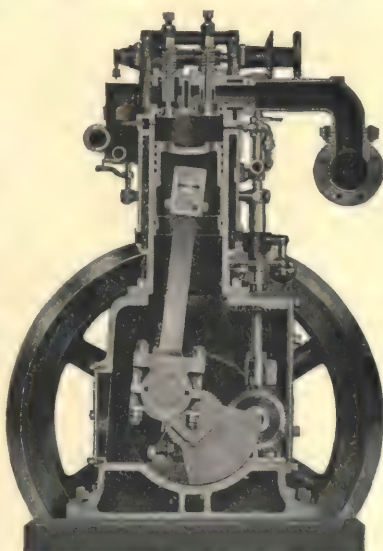


FIG. 12-14. — Bruce-Meriam-Abbott Engine.

the cylinders is operated through spur and bevel gears as shown. The valves are of the poppet type and are located in the head. Above 55 horse-power they are held in separate cages which are easily removable. The cam shaft operates these valves by rocker arms on either side. This construction is more clearly shown in

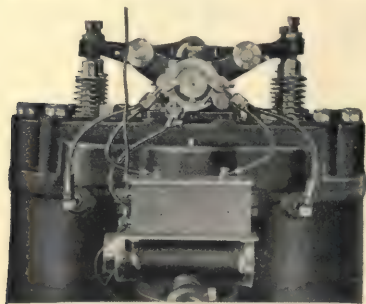


FIG. 12-15. — Detail of Bruce-Merriam-Abbott Engine.

Fig. 12-15. An excellent feature of the machine is the purely cylindrical form of the combustion chamber.

Governing is effected by a governor of the fly-ball type operated by the lay shaft. The governor sleeve operates one end of a lever passing between the cylinders, the other end supports the mixing valve, the details of which are shown in Fig. 12-16. Gas and air enter the annular space shown. On the suction stroke of the engine the gas flows into the space surrounding the piston valve and mixes with the air by flowing out through the port about half way up. The two combined then enter the interior of the valve through the six ports shown; from this chamber the mixture goes to the engine. The position of the valve controls the amount of throttling and thus regulates the weight of the charge going to the engine. It is stated that from full to no load this valve has to move only $\frac{1}{16}$ inch.

Jump spark ignition is used. The method of supporting the spark coil and the system of wiring is well shown in Fig. 12-15. The timer is very simple. There are two copper pins each about $\frac{1}{4}$ -inch diameter and $\frac{3}{4}$ inch long. One of them projects from the bottom of a small cup while the other is fastened to the end of a flat spring, and dips down in the same cup. The spring may be seen at A, Fig. 12-15. The cup is filled with oil and the points are normally held apart a small distance. Just before a spark is desired the spring is

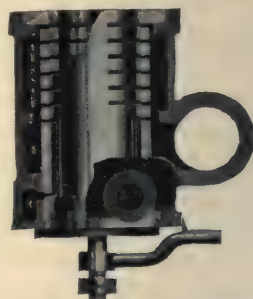


FIG. 12-16. — Mixing Valve, Bruce-Merriam-Abbott Engine.

depressed by means of a cam, the circuit is made by bringing the points in contact and the spark is produced at the moment the cam releases the spring. What amounts to an outside spark gap (see next chapter) is provided so that the spark may be watched.

To convert any gas engine of this design into a gasoline engine it is necessary merely to furnish a fuel pump and to replace the iron piston valve of the mixer by brass or bronze to prevent rusting. To retain the high compression used with gas, however, this company has adopted the Bánki principle of injecting water into the cylinder. The device is said to give entire satisfaction.

For producer and natural gas this firm makes engines ranging from 25 to 200 horse-power, two-cylinder units up to 90 horse-power, and four-cylinder above that. The design of these engines is apparently somewhat different from those above described, Fig. 12-17, the principal change being that the lay shaft evidently runs alongside the cylinders instead of between them. The cylinder and frame construction is otherwise the same, but the interesting feature about the design is the fact that the center line of the cylinder is offset about one-half the length of the crank from the center line of the main bearing, as near as can be scaled from the drawing. This is on the principle of the Ramsey crank mechanism, the idea of which is to equalize the wear due to the side thrust of the piston against the cylinder on both sides of the cylinder and to improve the turning moment. Both of these aims are attained with a moderate offset such as here used.

The Fairbanks, Morse & Company Engines. — The Fairbanks, Morse & Company manufacture a number of different types of engines, both vertical and horizontal, for gas and liquid fuel. The general features of the horizontal design are shown in Fig. 12-18. It appears from this that the exhaust valve, at the side of the cylinder, is mechanically operated, while the inlet valve placed in the head is automatic. The governor is placed in the fly-wheel and may be either of the throttling or hit-and-miss type. In the latter case it operates to hold the exhaust valve open. The ignition gear is of the make-and-break type, arranged so that at starting the spark may be retarded.

Engines above 9 or 10 horse-power are fitted with a self-starting device which consists of two parts, a match detonator and a hand pump. Both are shown in plan in Fig. 12-18 at the side

of the cylinder. The hand pump serves to pump a combustible mixture into the cylinder, with the crank just beyond the center, which mixture is fired by igniting a parlor match inserted into the detonator. The pressure so generated is sufficient to start the engine under some load.

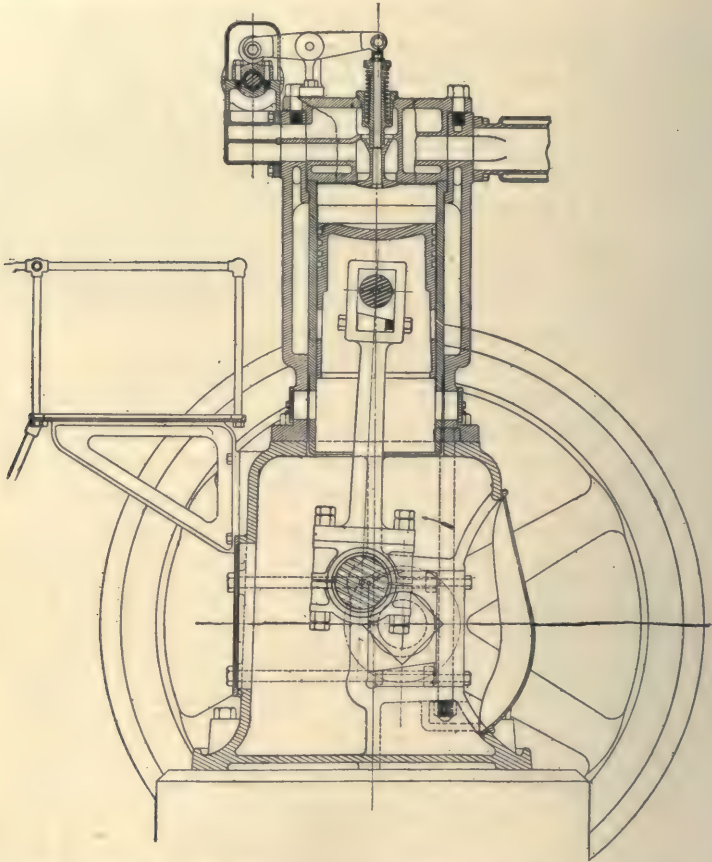


FIG. 12-17. — Bruce-Meriam-Abbott Engine for Producer Gas.

Engines are built for gasoline, naphtha and distillate, for kerosene, for alcohol, and for gas. In each case, of course, the fuel feeding and mixing arrangements differ somewhat. In the liquid fuel engines the feeding device acts positively, a pump being used to inject the proper quantity of fuel into the charge of air. In

the gas engine there is instead a mechanically operated gas valve. If desired the engine may be arranged to run on either gas or

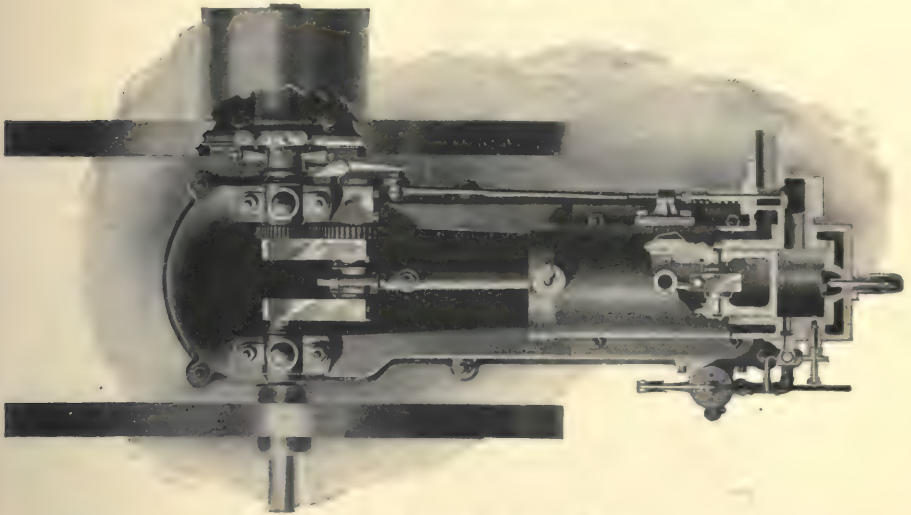


FIG. 12-18. — Fairbanks-Morse Engine.

liquid fuel. Fig. 12-19 illustrates an engine having these features.

The same company also builds two distinct types of producer gas engines. The first of these has the general features of the standard horizontal engine above described, the second is quite different, as shown in Fig. 12-20. In this design both valves are of the vertical poppet type, mechanically operated from the side shaft, the inlet valve on top, the exhaust at the bottom. As in the other Fairbanks engines, the ignition is by make and break. The governor is of the fly-ball type, operated from the lay shaft. Regulation is by throttling a mixture of constant proportion.

The general type of Fairbanks vertical engine is shown in Fig. 12-21. These engines are built for any kind of fuel.



FIG. 12-19. — Fairbanks-Morse Engine for Liquid or Gas Fuel.

Governing is effected by throttling the mixture; make-and-break ignition is used. Although the crank case is enclosed, lubrication

is positive instead of by the splash method usually employed in this design.

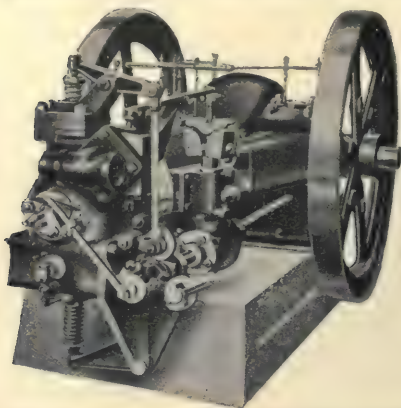


FIG. 12-20. — Fairbanks-Morse Producer Gas Engine.

The Koerting Four-cycle Gas Engine. — This German machine is manufactured in this country by the De La Vergne Machine Company of New York. The general features of the design are clearly shown in elevation, Fig. 12-22, and the two cross-sections, Figs. 12-23 and 12-24. The entire design gives the impression of being very sub-

stantial and thorough. The frame is a very rigid construction and the cylinder is supported by the frame throughout the length. The cylinder head is a somewhat complicated casting. The inlet and outlet valves are placed vertically over each other and are operated by cams from a lay shaft. The combustion chamber is divided by a water-cooled tongue projecting from the cylinder head. The purpose of this projection is to effectually cool the interior of the combustion chamber and to thus draw down the compression temperature, admitting of higher compression. The mixing valve, shown at the left of the transverse section in Fig. 12-24, is automatic. Regulation is effected by means of a governor of the Hartung type which

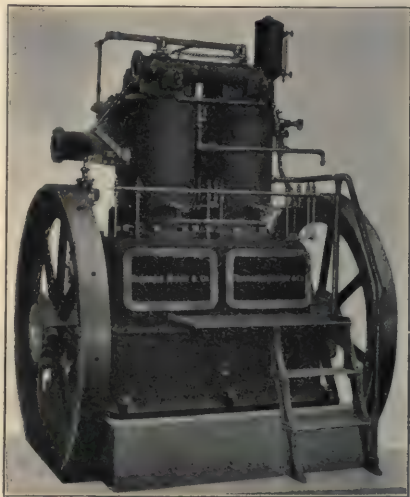


FIG. 12-21. — Fairbanks-Morse Vertical Engine.

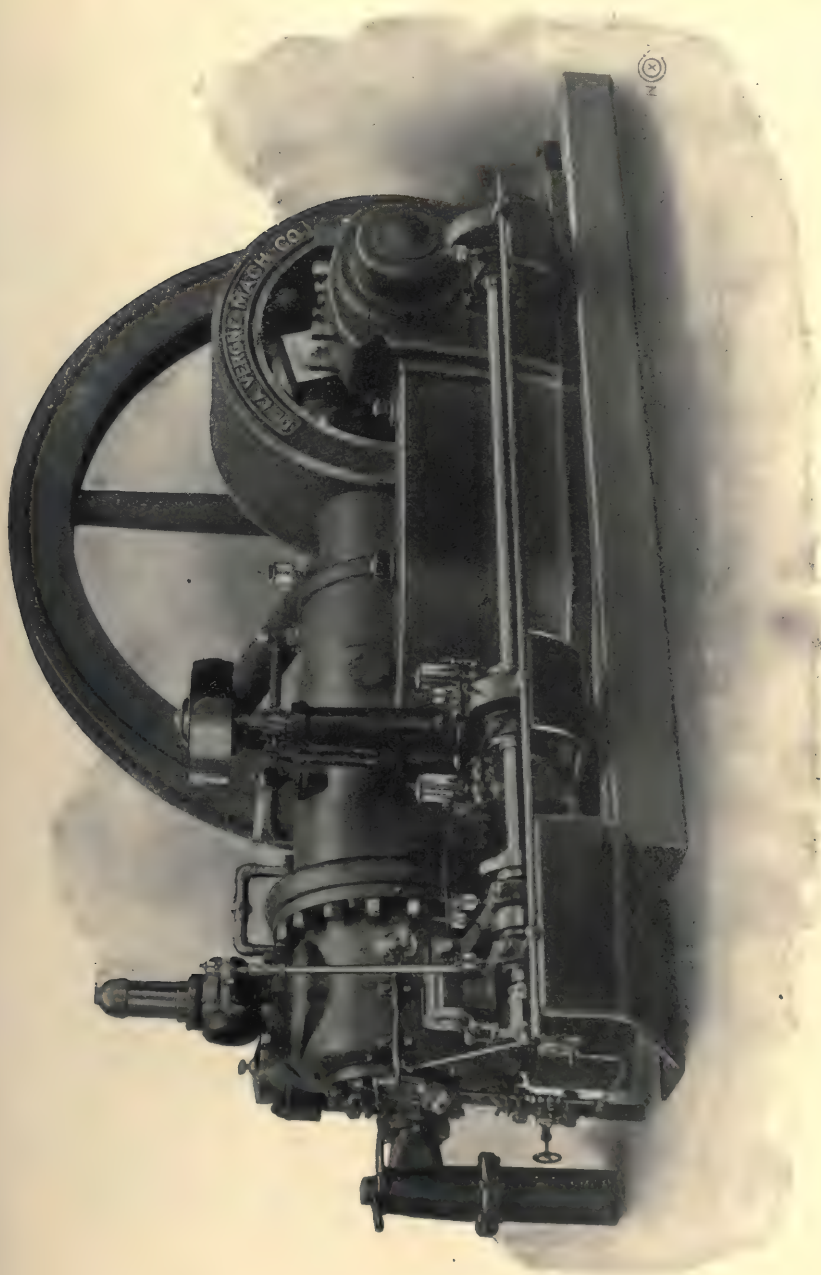


FIG. 12-22. — Koerting Four-cycle Gas Engine.

operates a butterfly throttle valve in the admission passage, as shown. The speed is thus controlled by throttling. In engines exceeding 100 horse-power the pistons are water-cooled. All engines above 12 horse-power have electric igniters while those

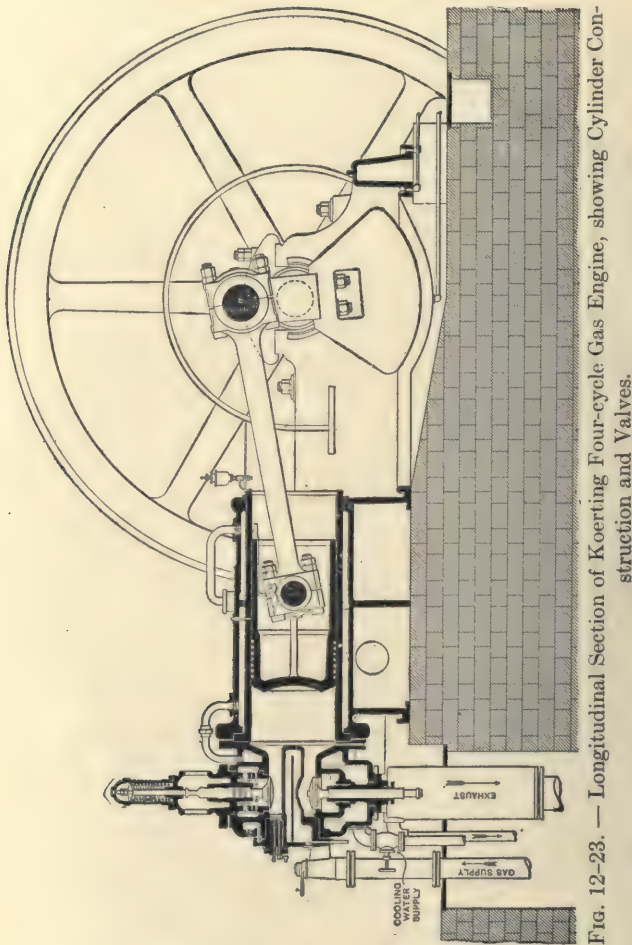


FIG. 12-23. — Longitudinal Section of Koerting Four-cycle Gas Engine, showing Cylinder Construction and Valves.

below this power use the hot tube, at least as constructed by the parent firm.

The Buffalo Tandem Engine. — This engine is made by the A. H. Alberger Company of Buffalo. A full description will be

found in an article in *Power* for February, 1907, from which the following illustrations are taken. Fig. 12-25 shows a general view, Fig. 12-26 a vertical cross-section, and Fig. 12-27 two cross-sections of the valve chest at right angles to each other.

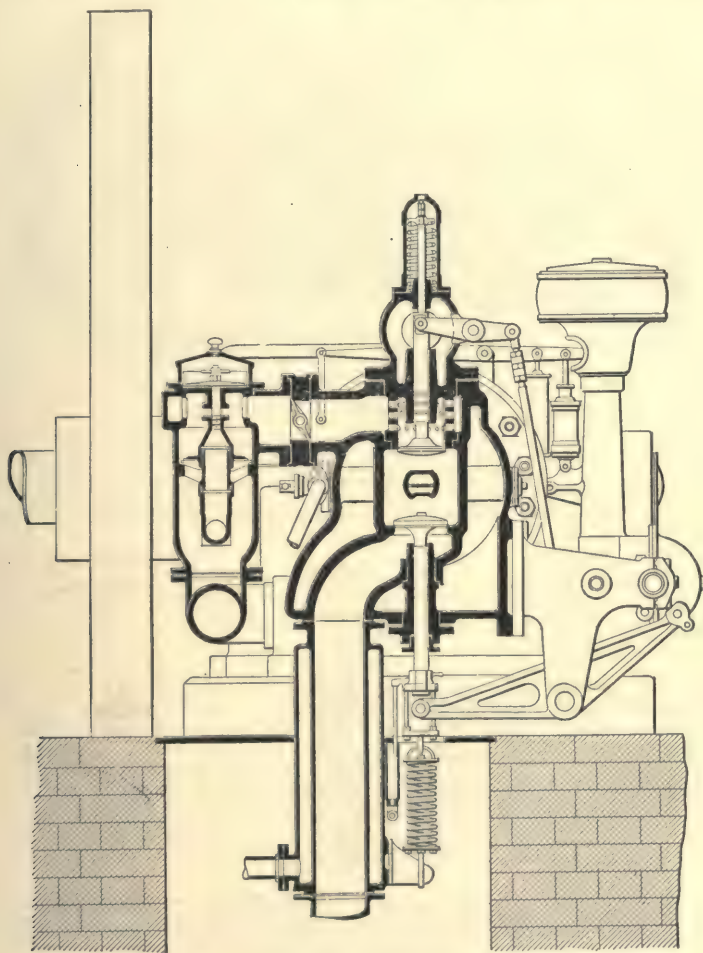


FIG. 12-24. — Valve Gear, Koerting Four-cycle Engine.

The engine differs materially from those previously described in having two cylinders in tandem, each acting on the four-cycle principle. The back piston is made like an ordinary steam engine

piston since there is no side thrust in this cylinder. Its piston rod passes through a water-cooled stuffing-box as shown. The back cylinder head is a simple flat plate not water-cooled; all

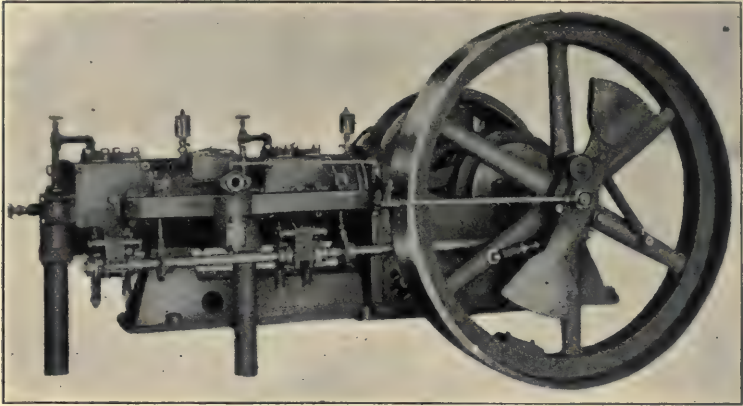


FIG. 12-25. — Buffalo Tandem Engine.

parts requiring it, however, are thoroughly cooled. The valves are of the double-guide poppet type and are placed side by side in a valve chest at the side of the cylinder, Fig. 12-27. Cams

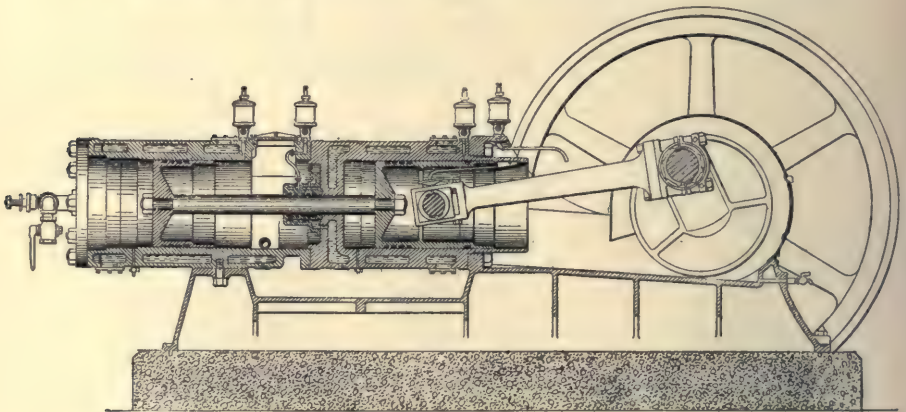


FIG. 12-26. — Section Through Cylinders and Pistons of Buffalo Gas Engine.

on a lay shaft operate these valves, as shown in the transverse section, Fig. 12-27. The make-and-break igniter, which is adjustable during operation, is placed over the inlet valve at the

right side of the valve chest. The exhaust pipe is fastened at the left side as shown in the longitudinal section of the valve

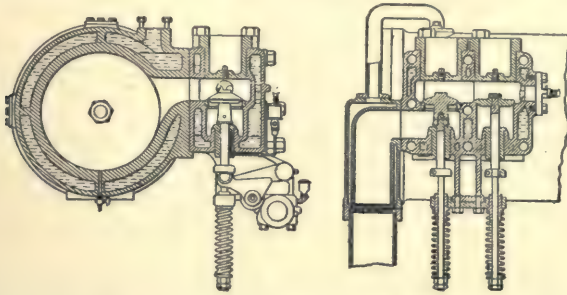


FIG. 12-27. — Valve Details of Buffalo Engine.

chest. The jacket water, after passing through the jacket, is made to enter the exhaust pipe, cooling the gases and thus acting as a muffler. The mixing and governing arrangements of this

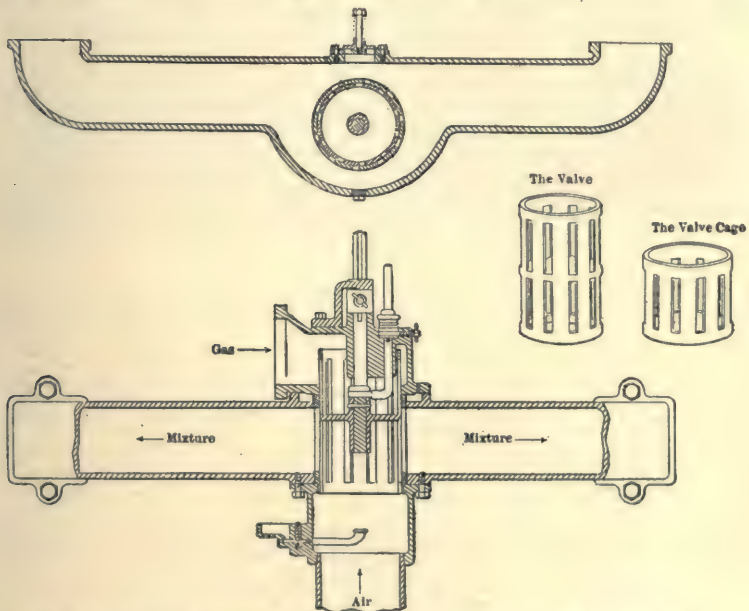


FIG. 12-28. — Mixing and Governing Arrangements Buffalo Engine.

engine are shown in Fig. 12-28. The two inlet valve chambers are connected by a header, as shown in Fig. 12-25. At the center

this header carries the mixing valve. This valve, Fig. 12-28, is a hollow cylinder divided into two parts by a transverse partition. Each half has a number of slotted ports which in certain positions of the valve register with other similar ports in the cage. The valve has two offices. Its position up or down in the valve cage controls the ratio of air to gas. If moved up the effective gas port area is reduced, while that of the air ports is increased by the same amount, and vice versa. Thus no matter what the gas used, the total effective area is in all cases the same. Rotary motion of the valve controls the cut-off of the mixture along the suction

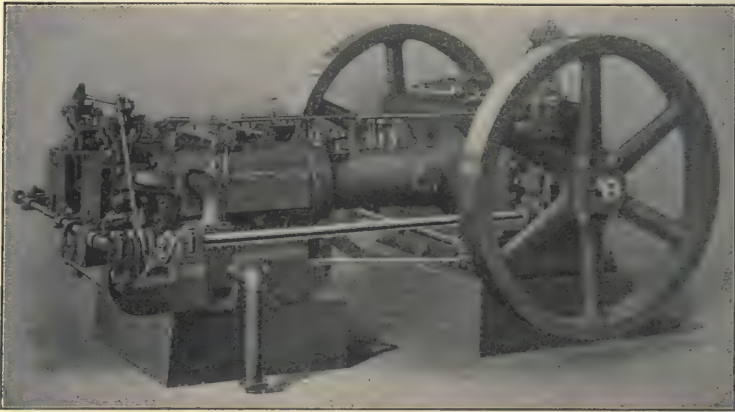


FIG. 12-29. — Buckeye Two-cycle Engine.

stroke. This action is controlled by a Rites inertia governor which operates through linkage as shown in Fig. 12-25.

The Buckeye Two-cycle Gas Engine. — This engine, made by the Buckeye Engine Company of Salem, Ohio, illustrates a type of medium sized two-cycle engine. The following description is taken from *Power*, September, 1906. It is a single-acting scavenging twin engine and can be made to operate also on gasoline or distillate.

The present engine has two motor cylinders, with cranks set at 180 degrees, two fuel pumps and two air pumps. Fig. 12-29 shows the side of the engine on which the secondary shaft is located and gives a good general view of the valve gear. Fig. 12-30 is a sectional elevation of one element of the twin engine. The piston 2 performs a double duty; in addition to delivering

the power of the explosions to the crank, it compresses the charge in the chamber 18 for delivery to the combustion chamber. The cross-head 6 is in the form of a plunger and acts as an air pump and compressor piston in the chamber 7. The exhaust ports are opened by the piston 2, as usual in engines working on the two-stroke cycle. These ports are shown at 14, 14, Fig. 12-30. Each piston compresses its own explosive mixture, but each cross-head plunger delivers compressed air for scavenging to the combustion chamber of the other half of the engine unit. The cycle of operation is as follows:

When the piston uncovers the exhaust ports, the scavenging valve 11 is opened by the valve gear and compressed air at about 8 pounds per square inch is admitted to the combustion chamber from the air pump of the other cylinder. This air blast sweeps out the

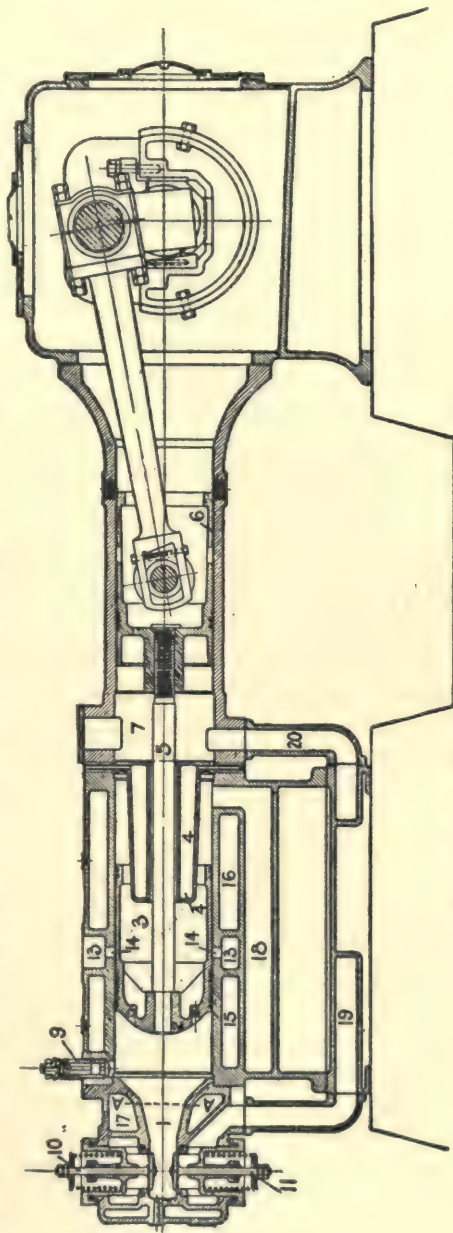


Fig. 12-30. — Section of Buckeye Two-cycle Engine.

burnt gases, and the admission valve 10 is then opened, admitting a charge of gas and air from the compression chamber 18; this charge is also at a pressure of about 8 pounds per square inch. The piston further compresses the charge on its back stroke, as usual, and it is fired by an electrical igniter. As the piston travels back, compressing the charge in the cylinder, it draws a fresh charge into the front end, 3, of the cylinder and the cross-head plunger of the other half of the unit similarly draws in a charge of air. The delivery of air from the chamber and passages 7, 20, and 19 is controlled entirely by the valve 11, but the intake of air by the plunger 6 is controlled by a piston valve 63, Fig. 12-31, which takes air from the chamber 68, connecting with the atmosphere through the base of the engine, and delivers it to the chamber 69, which is connected to the cross-head cylinder of the other half of the engine. The piston valve 62 takes in a mixture of gas and air through the chamber 67, which is connected with the supply source, and delivers it to the fuel pump 3, Fig. 12-30, through a balanced throttle valve 60, Fig. 12-31. The fuel pump then forces the mixture back through the throttle valve 60 to the admission valve cage. The throttle valve thus regulates both the quantity of mixture drawn in by the pump and the quantity delivered by the pump to the combustion chamber. The mixture and air-intake valves are operated by connecting rods from a rock-shaft, as indicated in Fig. 12-31; the rod 38 actuates the corresponding valves for the other half of the engine. This rock-shaft is oscillated by an eccentric on the main shaft and an eccentric rod.

The governor is of the fly-ball spring-opposed type and serves merely to control the position of the balanced throttle valves in the fuel passages. Since the cylinder is filled with scavenging air every stroke, the variation of the amount of mixture admitted does not vary the compression pressure but merely varies the richness of the cylinder contents.

The engine is equipped with both make-and-break and jump-spark igniters, but the former are ordinarily used.

The Fairbanks Engine. — The Fairbanks improved horizontal engine is of the four-cycle type and made to operate on gas or on gasoline, distillate or alcohol.

The general appearance of the engine is well shown in Fig.

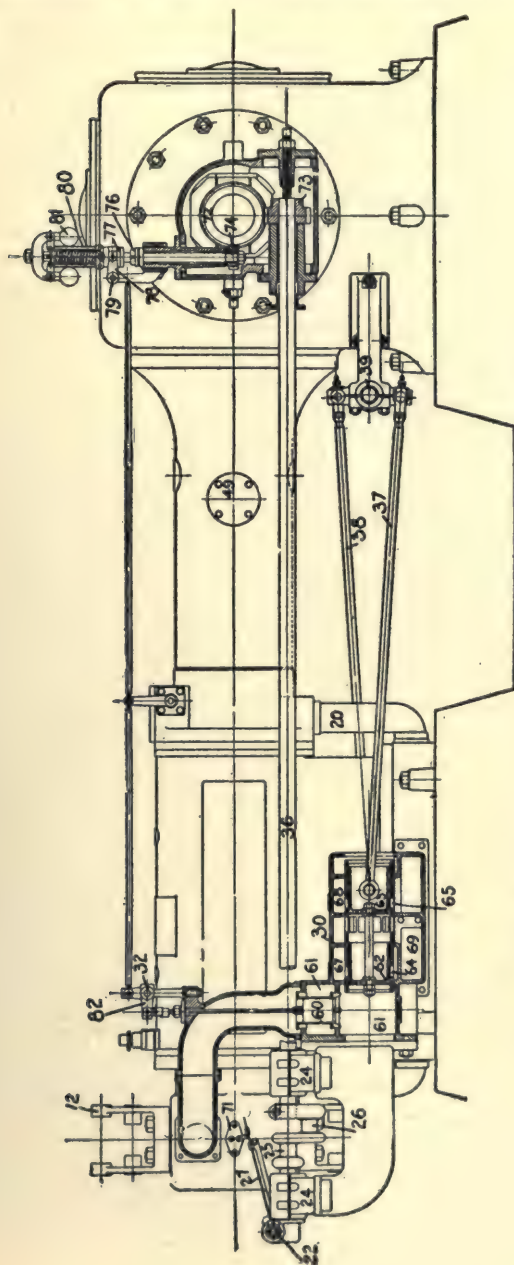


FIG. 12-31. — Governing Details of Buckeye Two-cycle Engine.

12-32 which shows the gas engine from the governor side, while

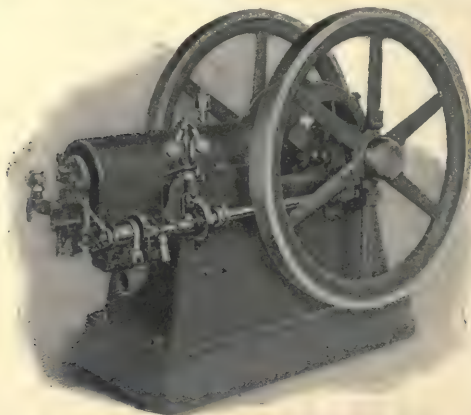


FIG. 12-32. — Fairbanks Engine.

Fig. 12-33 gives a front view of the same machine. The cylinder is partly supported by the frame, as shown. Cylinder jacket wall and cylinder head are cast in one piece, doing away with all joints. Both valves of the poppet type work upward and are mechanically operated. Fig. 12-34 shows the position of these valves at the head of the cylinder. Each valve is placed in a separate cage, and, when closed, the valve face is practically flush with the wall of the combustion chamber. This results in a combustion chamber of very simple form. The lay shaft at the side of the engine is driven by two-to-one gearing from the crank shaft. It carries, Fig. 12-32, first the bevel gear for operating the hit-and-miss fly-ball governor; second a clutch arrangement for making and breaking the connection between the inlet and igniter cam sleeve and the lay shaft; third, the exhaust valve cam, and lastly the sleeve carrying the inlet valve and igniter cams. The governor acts by interposing a pick blade, prevents the ex-

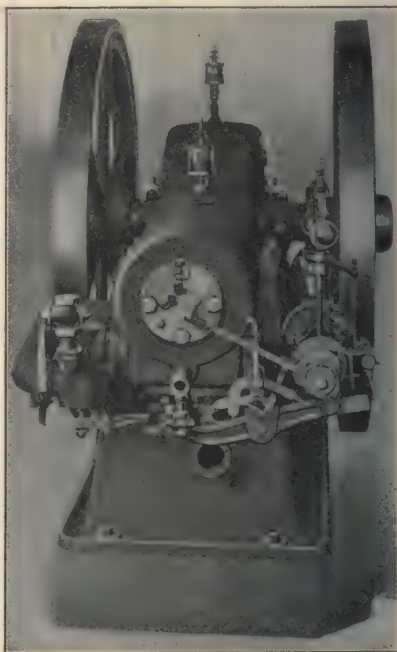


FIG. 12-33. — Fairbanks Engine.

haust valve lever from returning, and thus blocks the exhaust valve open. In this position a projection on the exhaust valve lever unlocks the clutch above mentioned, breaks the connection between lay shaft and inlet cam sleeve, causing the latter to remain stationary. The inlet valve then fails to open as long as the governor does not withdraw the blade. It is possible to change the speed of the engine through a certain range by adjusting the governor during operation.

The ignition system is of the make-and-break type, as is clearly indicated in Fig. 12-33. The electrodes are contained in one block, which is easily removable for inspection.

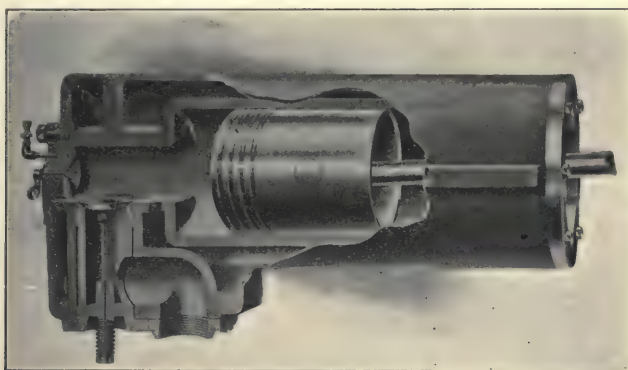


FIG. 12-34. — Cylinder Construction, Fairbanks Engine.

The method of operating the gas valve by means of the main inlet valve lever is also shown in Fig. 12-33.

The Fairbanks gasoline engine is in all respects similar to the gas engine above described, except that the mixing valve shown at the left of Fig. 12-33 is replaced by a simple type of overflow carbureter which is supplied by a gasoline pump operated by a cam on the lay shaft.

The Philadelphia Otto Engine. — The general features of the design of this engine are shown in Figs. 12-35 and 12-36. These particular drawings refer to a 30 horse-power illuminating gas engine, but the same design is carried out in all horizontal engines from 5 up to and including 40 horse-power. Excellent features of the construction are the separate cylinder liner and the remov-

able valve cages for gas, inlet, and exhaust valves. Make-and-break electric ignition operated by a crank from the end of the lay shaft is used.

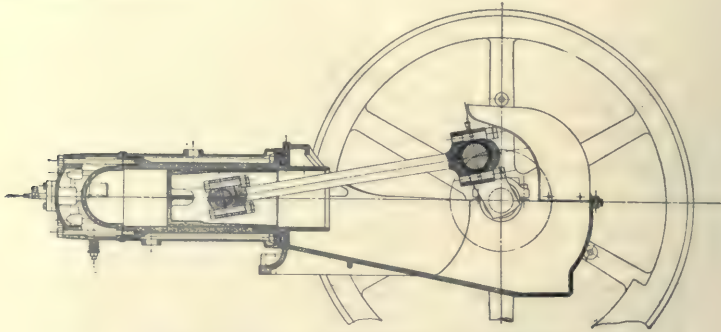


FIG. 12-35. — Philadelphia Otto Engine.

The producer gas engines made by this firm, the Otto Gas Engine Works of Philadelphia, show the same general make-up. Fig. 12-37 gives a general view of a type made in 60, 75, 95, and 120 horse-power sizes. This design differs from that of Fig. 12-35 mainly in that the cylinder is supported also near the end by an extension of the frame.

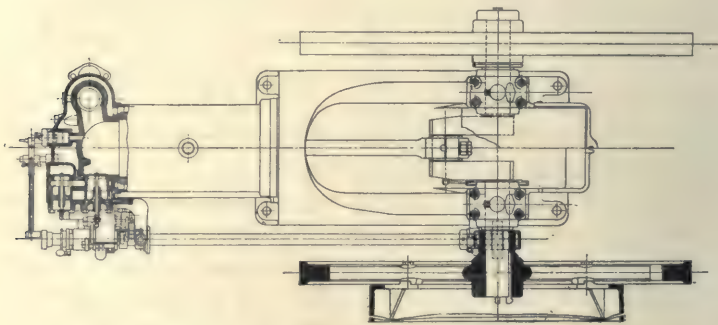


FIG. 12-36. — Philadelphia Otto Engine.

The suction gas engines are governed by controlling the fuel valve, regulation thus being effected by changing the quality of the mixture.

The Olds Gas Engine. — The Olds Gas Power Company of Lansing, Mich., build two types of gas engines: Type G from

8 to 100 horse-power and Type *K* from 25 to 300 horse-power, both being horizontal single-acting four-cycle engines.

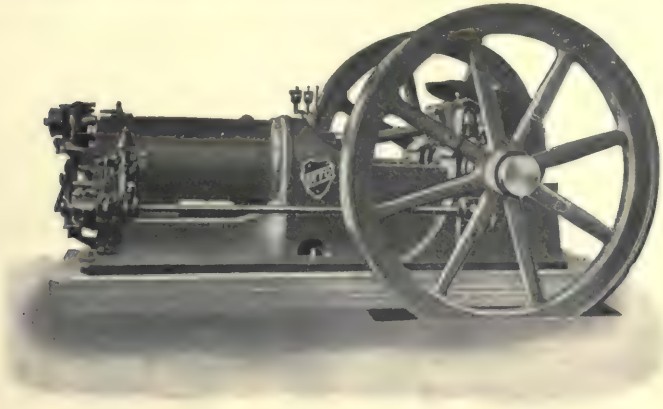


FIG. 12-37. — Philadelphia Otto Producer-gas Engine.

Type *G* is illustrated in Fig. 12-38. This engine may be used either for gas or gasoline. There appear to be no very unusual features in its general design. Both inlet and outlet valves are

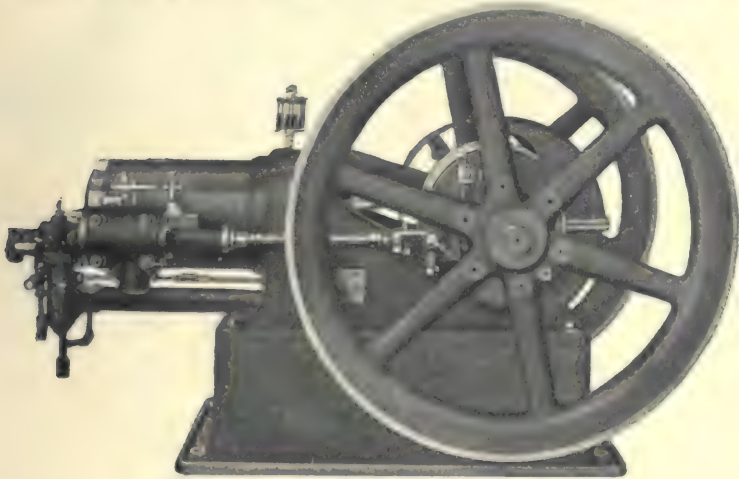


FIG. 12-38. — Olds Type G Engine.

of the poppet type, but an auxiliary exhaust opening is used to relieve the main exhaust valve. The exhaust valve is mechani-

cally operated by means of a straight push rod and cam. Ignition is by make and break. The governor is of the hit-and-miss type and operates to hold the exhaust valve open. The mixing arrangements are not specially described in the available information on this engine.

Type *K* engines are of somewhat different design and embody in their make-up the best and most advanced ideas. A general view of the machine is given in Fig. 12-39. Among the excellent features of this design are the following: The jacket wall is integral with the frame. The cylinder liner is made of a grade of

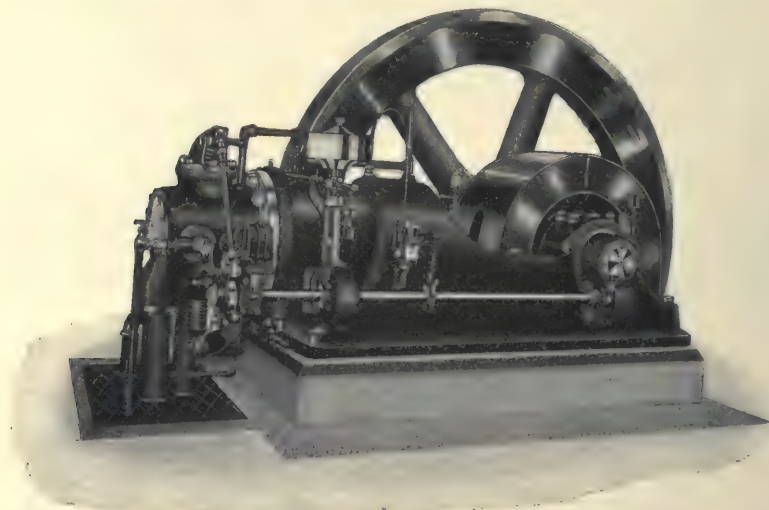


FIG. 12-39. — Olds Type K Engine.

metal especially adapted to the service and consists of a straight cylinder with a flange at the outer end. This flange is received into the frame and is held in place by the cylinder head. This construction allows of even and unrestricted expansion. The cylinder head contains the openings for the inlet and outlet valve cages and is designed with the greatest possible regard to expansion and cooling stresses. The following description of the valve mechanism is taken from the catalogue published by the company.

The inlet and exhaust valves are of the vertical poppet type,

mechanically operated and working in long guides in the same vertical axis with the inlet valve at the top and the exhaust valve at the bottom. The inlet valve and gas valve have a common stem and the cage is so arranged that a thorough mixing occurs just at the entrance to the cylinder. The gas valve opens slightly later than the air valve and by special construction used a perfect seating of both valves is assured at all times. On the smaller sizes, by removing the inlet valve cage the exhaust valve is perfectly accessible, while on the larger sizes the exhaust valve may be removed together with its hollow water-cooled seat without disturbing the inlet valve. This is easily done as its weight is counterbalanced. Both valves are operated by a single cam which is designed so as to have a quick, full valve opening, without noise or clatter. Valves and valve ports are of liberal sizes so undue throttling is avoided. The valve springs are of the highest grade spring steel, and rest on plates which, being supported on ball and socket joints, do away with side thrust. All parts and particularly all bearings are made of ample dimensions with provision for oiling every wearing surface. The lay shaft which is driven from the crank shaft through spiral gears operates the valve mechanism, governor and ignition mechanism.

The speed is controlled by a governor, apparently of the Hartung type, which is driven from the lay shaft and serves to throttle the mixture admitted to the cylinder.

Figure 12-40 gives a good view of the ignition arrangements. The current is supplied by a low-tension make-and-break Bosch magneto, the operation of which is explained in Chapter XIII. The point of ignition can be easily changed during operation by adjusting the lever along the row of holes *A-R*.

The Warren Engines. — The Struthers-Wells Company of Warren, Pa., manufacture various types of engines, both hit-and-miss and throttling, all operating on the four-cycle principle.

For ordinary power purposes the firm builds the single-cylinder hit-and-miss engine illustrated in Fig. 12-41. This engine is made in sizes from 10 to 90 horse-power. Above 30 H.P. the installations are equipped with special starting devices.

All of the other types are apparently governed by throttling. The next higher range of power, 35 to 200 horse-power, is covered

by the two-cylinder throttling engine shown in Fig. 12-42. The manner of governing is clearly indicated.

A special type of the two-cylinder engine, for which maximum economy and closest regulation is claimed, is shown in elevation in Fig. 12-43. This engine is made in two sizes only, 110 and 125 horse-power. From the vertical section, Fig. 12-44, showing the cylinder construction, it is seen that the cylinder barrel and jacket are cast in one piece. The valves are of the vertical poppet

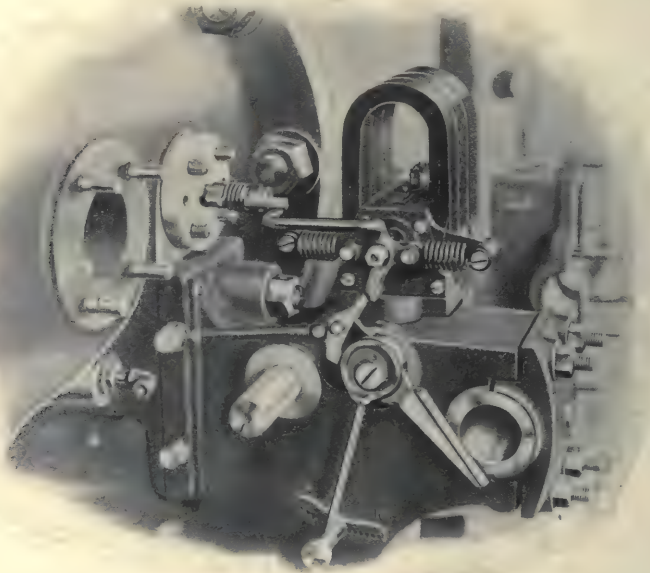


FIG. 12-40. — Igniter Details, Olds Type K Engine.

type, opening upward, and are placed in a valve cage integral with the cylinder head. The manner of operating these valves by cams and levers from a valve shaft running across the engine under the cylinders is shown in both Figs. 12-43 and 12-44. Governing is effected by throttling the mixture in the supply pipe just before it divides. The centrifugal governor and its linkage are indicated in Fig. 12-45. In some cases the governor is located between the cylinders as shown in Fig. 12-43. A cross-section through the valve chest, Fig. 12-46, shows the method of operat-

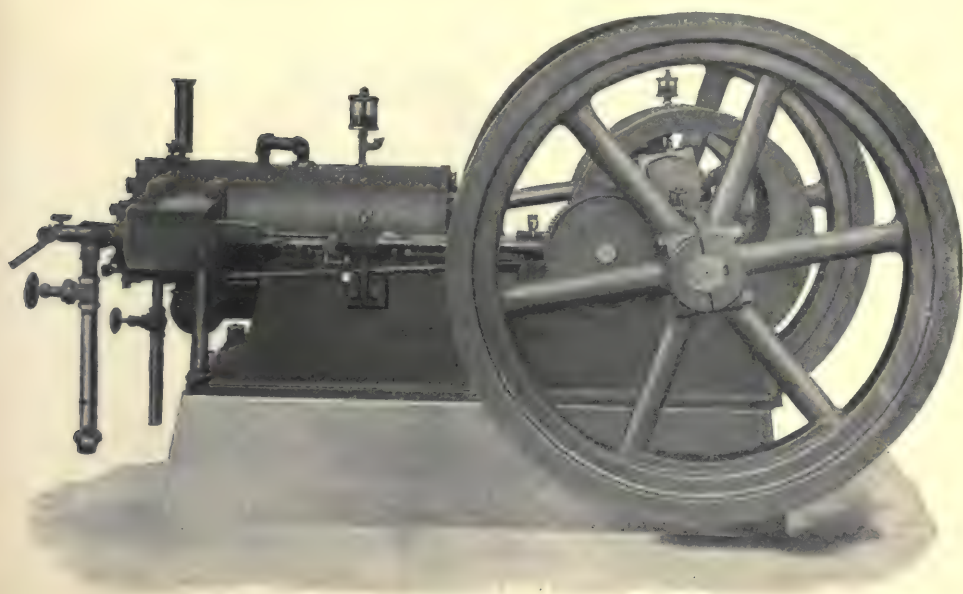


FIG. 12-41.

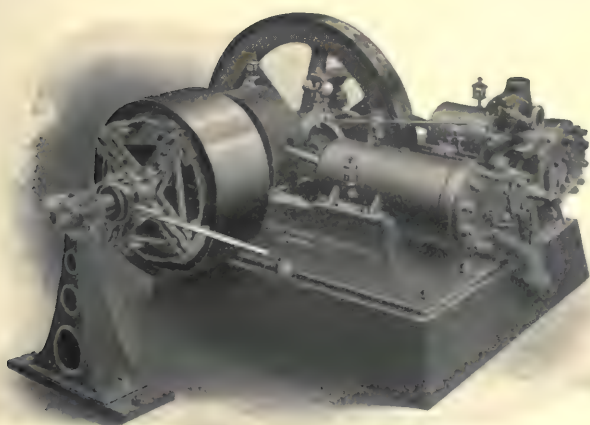


FIG. 12-42. — Warren Throttling Engine.

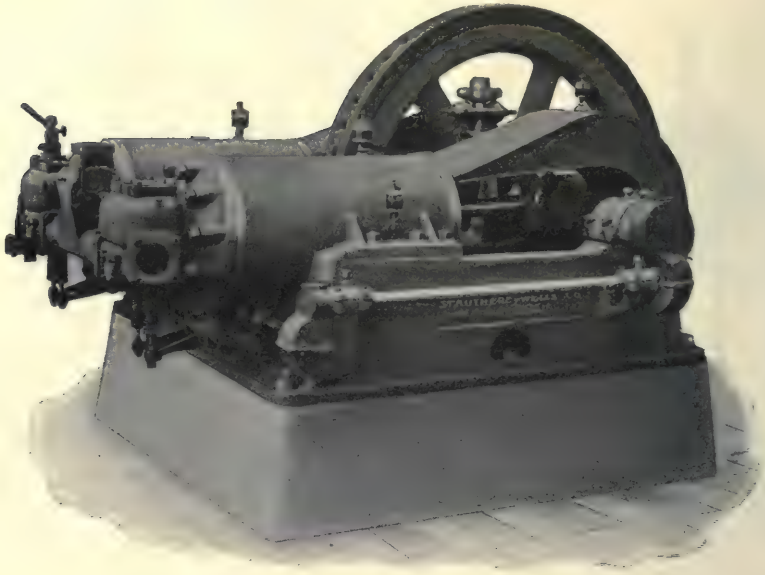


FIG. 12-43. — Warren Throttling Engine.

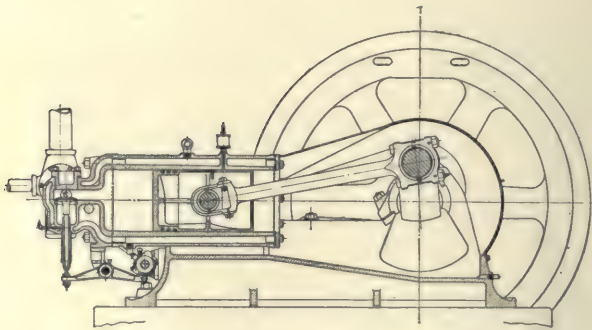


FIG. 12-44. — Vertical Section Warren Throttling Engine.

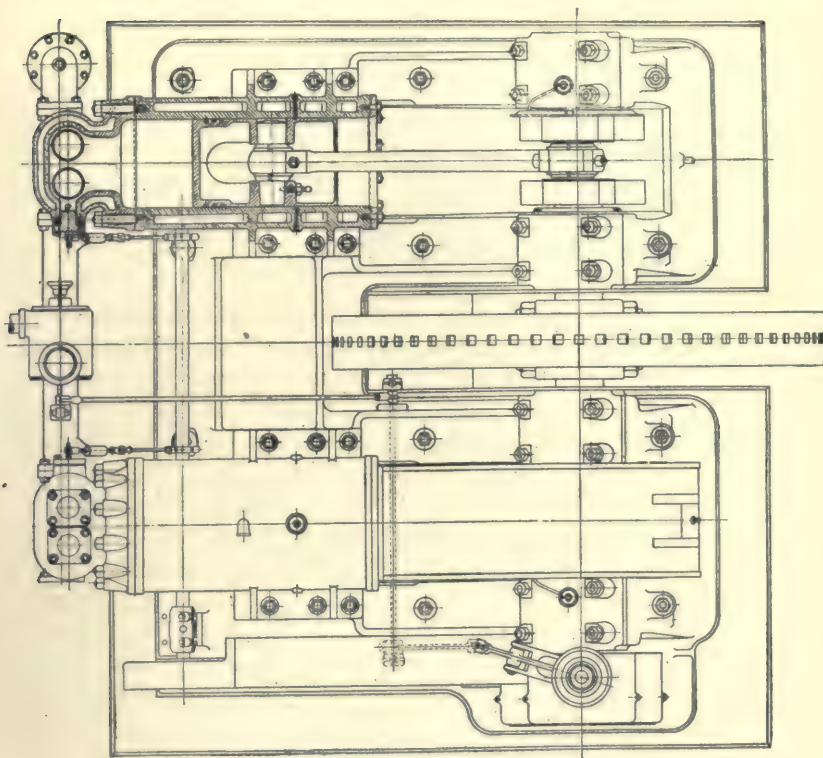


FIG. 12-45. — Plan of Warren Two-cylinder Engine.

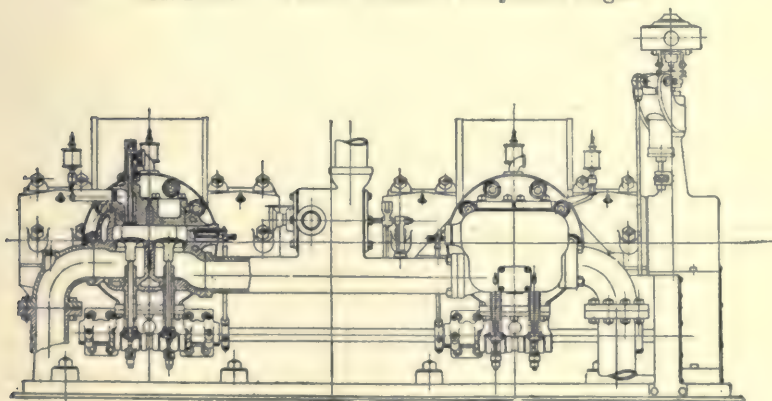


FIG. 12-46. — Cross-section through Valve Chest, Warren Two-cylinder Engine.

ing the make-and-break igniter, and the location of the starting valve in the valve chest cover just above the exhaust valve.

Warren engines, covering the range from 200 to 325 horsepower, are of the tandem single-acting type, a general view of which is shown in Fig. 12-47. The cross-section, Fig. 12-48, shows the cylinder construction, which is unique in some of its features. The back part of the main frame forms the jacket wall for the front cylinder. The cylinder barrel itself is cast in one piece with the cylinder head. The construction of the back cylinder is similar. The distance piece between the two cylinders rests on a separate base, and forms, for a portion of its length, the jacket wall for the rear cylinder. The front piston is of the ordinary trunk type. The back piston is longer than is usual in pistons not subject to side thrust. The method of water-cooling piston and rod is clearly shown.

The valves are of the vertical poppet type held in separate cages which are easily removable. The exhaust valves, at the bottom of the cylinder, are water-cooled. The valve gear is shown in detail in Fig. 12-49. Both valves are operated from the same cam on the lay shaft. The operation of the exhaust valve is clear. The motion of the inlet valve varies, depending upon the load. The valve opens and closes always at the same time, because the lift of the actuating cam is not changed throughout the entire range of load. The governor, however, through the linkage shown, controls the position of the sliding block above the valve lever, moving it in or out, depending upon whether the load falls or rises. This block acts as the fulcrum about which the valve lever turns, and hence the lift of the valve is made proportional to the load. The inlet valve stem carries the gas valve. The latter opens somewhat later than the main inlet valve. The manner of mixing gas and air is clearly indicated in the figure. Butterfly valves in the air and gas passages serve to help control the proportions of the mixture. The ignition system, operated from the lay shaft as shown in Fig. 12-49, is of the make-and-break type.

The Struthers-Wells Company also builds vertical engines up to 600 horse-power. The older multi-cylinder types of these machines are practically nothing but two or three separate engines direct connected. Thus a 450 horse-power unit now in operation consists of three engines with two fly-wheels between the cylinders.

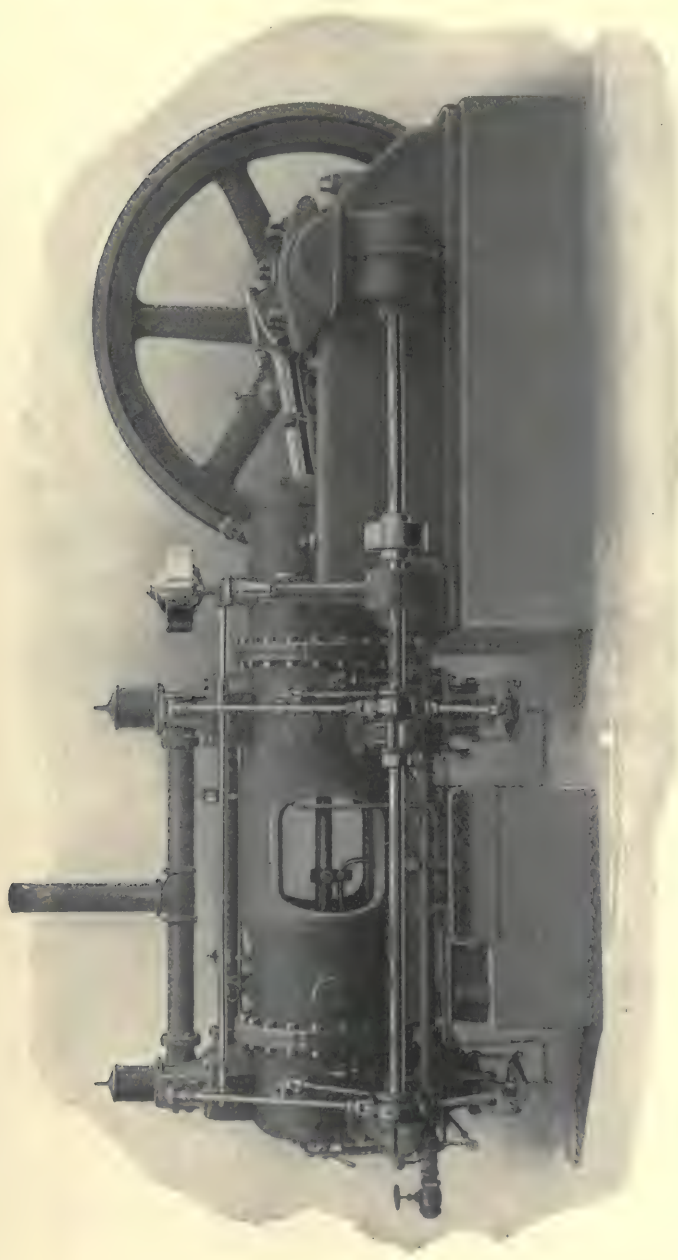


Fig. 12-47.

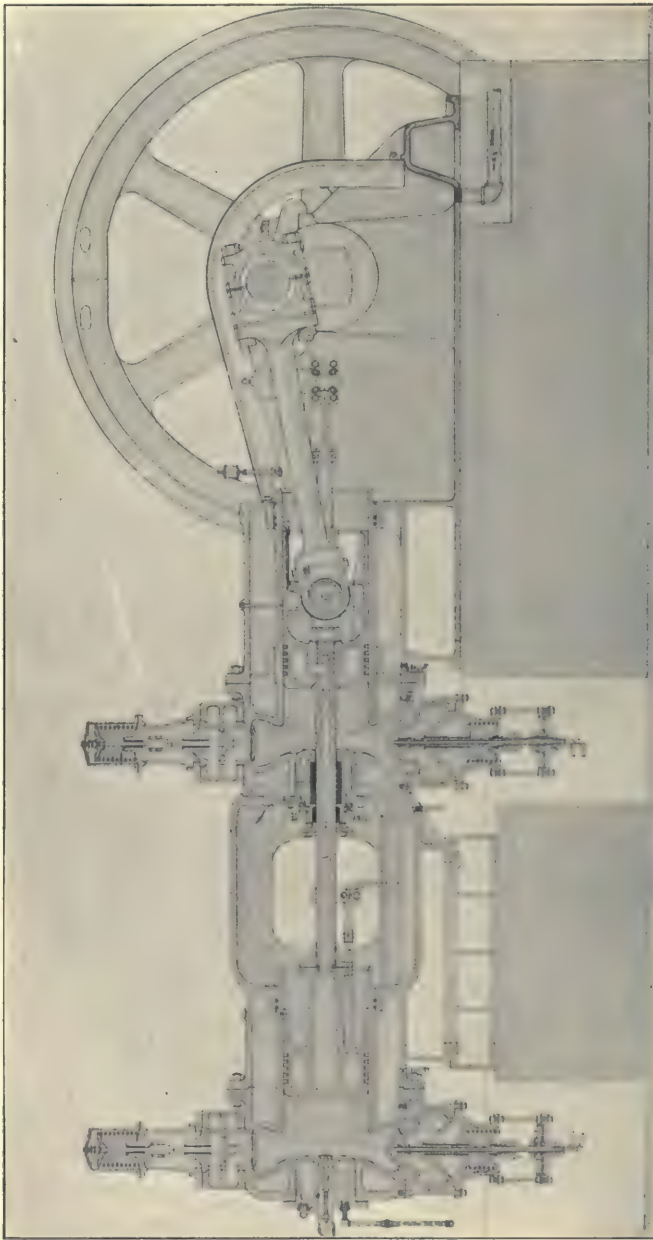


FIG. 12-48. — Cross-section of Warren Single-acting Tandem Engine.

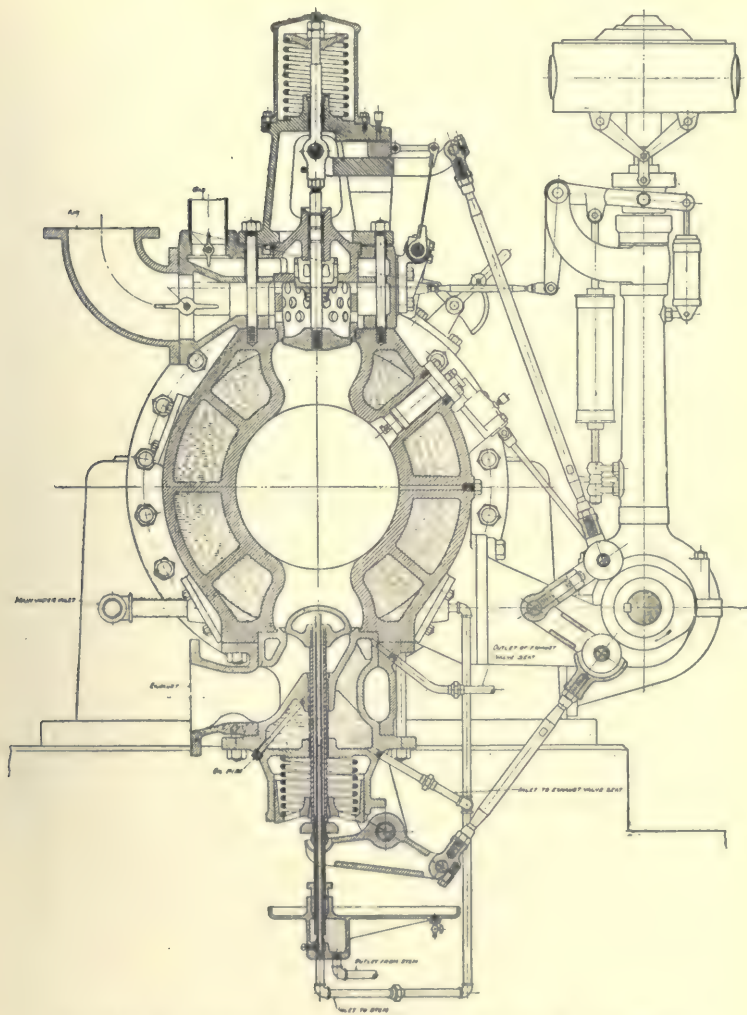


FIG. 12-49. — Valve Gear of Warren Single-acting Tandem Engine.

In the later designs this has been modified. A 600 horse-power vertical engine lately completed is of the four-cylinder A-frame type mounted on a solid bedplate with the fly-wheels at the ends.

2. LARGE GAS ENGINES. — Large gas engines of American design are manufactured by the Westinghouse Machine Company, by the William Tod Company, Youngstown, Ohio, by the Snow Steam Pump Company, Buffalo, by the Riverside Engine Company, Oil City, Pa., and by the Wisconsin Engine Co., of Corliss, Wis., makers of the Sargent engine. There are, however, a few other firms making large engines of foreign design. Thus the De La Vergne Machine Company of New York make the Koerting two-cycle engine, and the Power and Mining Machinery Company the Crossley engine. The Allis-Chalmers Company, who built the Nürnberg engine, have apparently an engine on the market that is not strictly of Nürnberg design. Besides these well-known machines made in this country, the Premier engine made in England, the Cockerill engine made in Belgium, and the German Oechelhäuser and Deutz engines, should be mentioned. The Oechelhäuser and Koerting engines are made under license by a number of firms in Germany, and in the case of the Koerting engine, also abroad. While it has in general been easy to get sufficient descriptive material on the above-mentioned engines, this does not apply to certain machines of American design, and the information given is hence somewhat meager.

The Westinghouse Horizontal Engine. — There seems to be available practically no definite information on the constructive details of the Westinghouse horizontal double-acting tandem engine.* The older type apparently used the center crank and the combustion, or at least the valve, chambers were placed at the sides of the cylinders. The later types of horizontal engines built by this company approach much nearer to established European practice. Thus the engines installed in the power plant of the Warren and Jamestown railway system have the valves in the central lines of the cylinders, as shown in Fig. 12-50. The latest design is shown in Fig. 12-51, which represents a 3000 horse-power unit for the power plant of the Carnegie Steel Company at Bessemer, Pa. In this type the side crank is used, but outside of this

* A full description of the Westinghouse Engine has just appeared in *Power*, April, 1908.

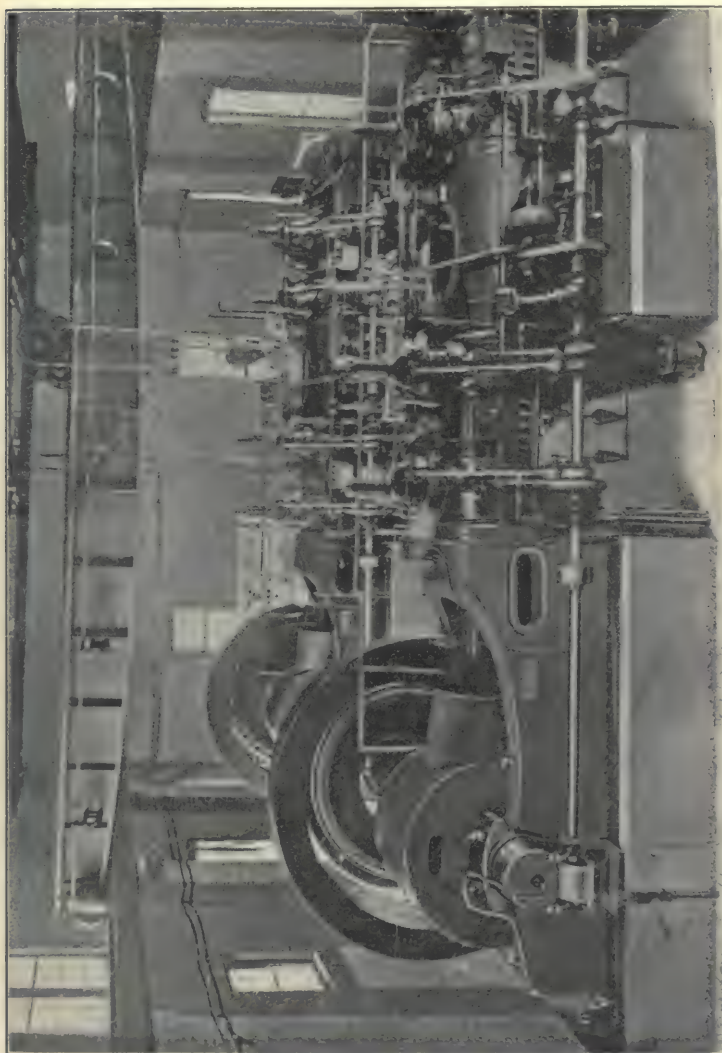


Fig. 12-50. — Westinghouse Double-acting Tandem Gas Engines.

nothing is definitely known to the writer regarding the mechanical details. An interesting development of very recent date is the

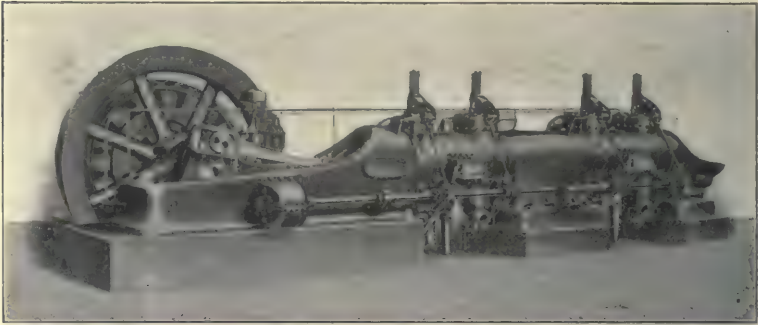


FIG. 12-51. — Westinghouse Double-acting Tandem Engine.

Westinghouse vertical single-acting tandem engine shown in Fig. 12-52. This engine was built by the British Westinghouse Electric and Manufacturing Company.*

The Tod Engine. — The following description of this engine is taken from the *Iron Age* of July 18, 1907:

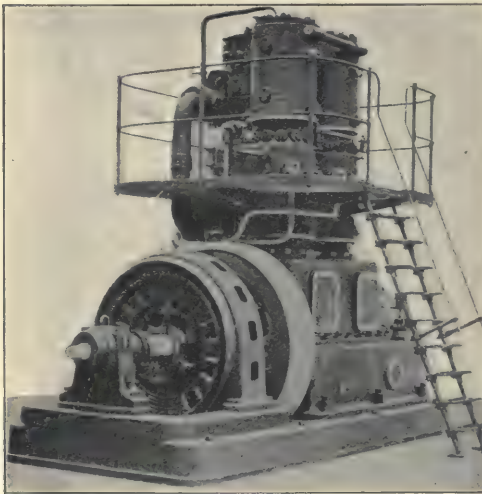


FIG. 12-52. — Westinghouse Vertical Single-acting Tandem Gas Engine.

"The general appearance of the engine is shown in Figs. 12-53 and 12-54. The cylinders are arranged in pairs, two cylinders being connected in tandem to each crank pin. The valve gear, igniter, switchboard and operator's hand wheels are all situated between the cylinders and are easily accessible from an operating platform placed just below the level of the center lines of the cyl-

* W. H. Booth, *Cassier's Magazine*, November, 1907.



FIG. 12-53. — Tod Double-acting Twin Tandem Engine.



Fig. 12-54. — Tod Double-acting Twin Tandem Engine.

inders and shaft. The foundation level under the cylinders being several feet lower than under the frames, leaves ample room below the cylinders to make the exhaust valves, etc., easily accessible, a very desirable but somewhat unusual feature.

"The cylinders and water jackets are integral and cast in halves, secured together with flanged joints at the center. The cylinders are not attached directly to the main bedplates nor to each other, but are supported by the tie pieces in such a way that the barrels themselves are entirely free. All strains are transmitted through four heavy forged steel tie bolts extending the entire length of the cylinders, and attaching directly to heavy lugs on the bedplate. This obviates the transmission of the strains through the cylinder walls, and contributes to accessibility and the easy removing of parts. The pistons are of steel, with cast-iron junk rings, and the pistons and rods are water-jacketed in the usual manner. Adjustable tail-rod supports take the weight of the pistons and rods from the cylinders.

"The valve gear is driven by eccentrics, eliminating entirely the cam drive, which has been an objectionable feature of many of the gas engines heretofore built. There is one eccentric for each end of each cylinder, which drives both the inlet and exhaust valves — an arrangement that reduces the number of parts. The eccentrics are mounted on two lay shafts running parallel to the axes of the cylinders. The latter are driven by a cross shaft, which, in turn, derives its motion from two eccentrics mounted on the main shaft. The inlet valves are on top of the cylinders, and the exhaust valves on the bottom. The inlet valve proper is of the mushroom type, sealing the ports from the pressure in the cylinders. The main valve is operated by a rolling lever and returned to its seat by a spring. The mixing valves and governor valves are of radial gridiron type, and are located in the upper section of the valve bonnet. The mixing valves may be operated individually or collectively by a suitable hand mechanism. The governor valve which controls the admission of gas has constant travel, the time of opening being controlled by the governor by either increasing or decreasing the angle of advance of the crank which operates them, since the engine is of the constant-compression type.

"The governor is of the fly-ball pattern and is in duplicate,

one controlling the operating valves on each side of the engine. The two are driven by Morse chains through a flexible coupling, and are connected by a cross rod which may be removed in case it is desired to operate either side of the engine alone.

"Each end of each cylinder is equipped with two igniters, one operated mechanically and the other by a solenoid. Either may be used independently or the two together. The igniters are under control of the governor, and when the engine is at rest are automatically thrown back to the dead center. The ignition is on the make-and-break system, using direct current at 90 volts, supplied by a motor generator set, which is so designed that either end may be used as a motor or a generator, or both may be used as generators by driving directly from the engine shaft. Connected in series with each igniter is a tell-tale lamp on the switchboard, giving a positive indication as to whether or not the igniters are sparking, short-circuited or burnt out."

The Sargent Engine. — The Sargent complete expansion engine, made by the Wisconsin Engine Company of Corliss, Wis., is shown in general elevation in Fig. 12-55 and in transverse section in Fig. 12-56. As far as the constructive details of this engine are concerned, it has the merit of great simplicity. The engine is built as a double-acting tandem. There is but one valve to control admission and exhaust for each end of each cylinder, and but a single cam to perform these various offices, while a second cam operates the igniter. The lay shaft is driven from the main shaft by a pair of worm gears. The governor is of the inertia type, the Rites, and operates to advance or retard the lay-shaft, thus controlling the time of cutting off the admission of the incoming charge to the cylinder. This construction is decidedly different from that used by other designers.

The combination valve is shown in cross-section in Fig. 12-56. Its operation is described as follows:

"Gas is piped to the chamber *A* in the sub-base and air to the chamber *B*, which pass through the cylinder supports to the chambers *A'* and *B'*, ready to pass into the mixing chamber when the cam depression *M N* passes the roller and the ports *F* in the piston valve register with the ports *E* and *D* in the bushing. When the piston valve goes down to this position, the confined air in the piston valve dash-pot forces open the poppet valve,



Fig. 12-55. — Sargent Complete Expansion Engine.

thus giving free admission to the charge. When the point *N* of the cam reaches the roller, it is forced down, while the other end of the lever goes up, carrying the piston valve which cuts off the admission. The poppet valve seats and both valves remain

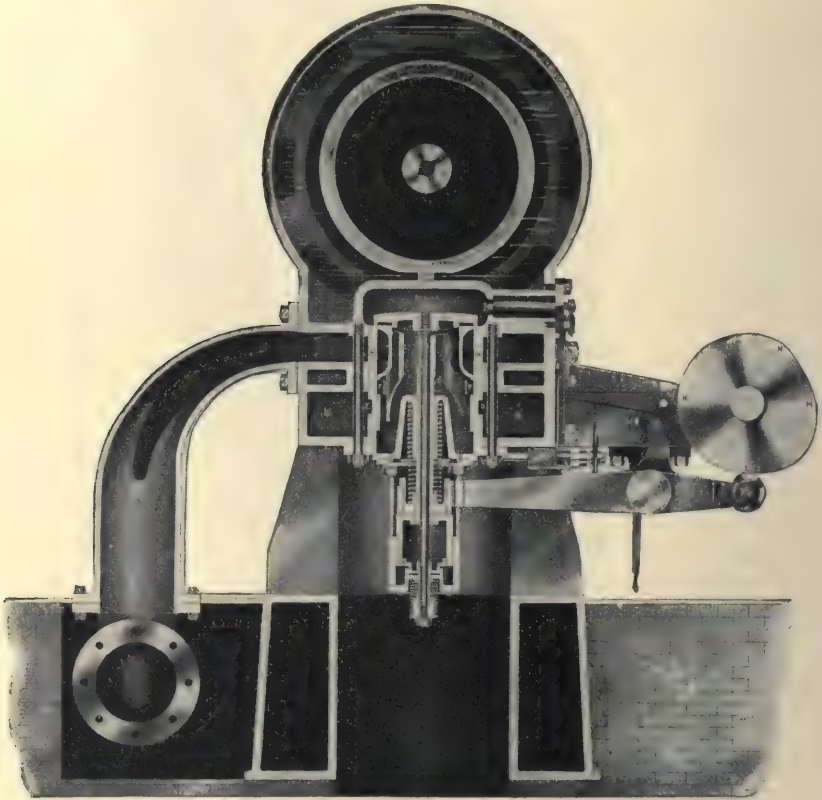


FIG. 12-56. — Transverse Cross-section Sargent Engine.

in normal position during compression, ignition, and expansion, or until the point *L* on the cam pushes the roller down and the piston up, which opens the poppet and the exhaust gases pass out through the ports *K* and the elbow *W* to the exhaust pipe under the floor.

"The poppet valve seals the opening in the combustion chamber during the compression and inflammation, and the piston valve,

holding against no pressure, works loosely in its bushing, cutting off the admission and guiding the exhaust.

"As the poppet valve controls both the inlet and outlet gases, both the valve and seat keep cool and need to be ground not over once or twice a year. The mechanism is simple and, as the roller is always bearing on the cam, the valve motion is practically noiseless."

By revolving the piston valve by the index wheel, the blind port *S* varies the mixture to suit the gas whether it has 100 or 1000 B. T. U. per cubic foot.

The fundamental idea of the Sargent engine is to get complete expansion of the charge in the cylinder. In the ordinary engine, which at full load draws in the charge to the full stroke of the piston, or nearly so, the terminal pressure is anywhere from 25 to 50 pounds, and the final temperature over 1000 degrees Fahrenheit. Sargent claims that his engine, cutting off the stroke at full load at three-quarters of the suction stroke, will show a terminal pressure slightly above atmosphere and a temperature of about 400 degrees Fahrenheit. The system of speed regulation by cutting off at various points along the suction stroke is one used by several makers, but in nearly all cases the engines cut off at nearly full stroke for full load, that is, at full load the ratio of compression is nearly equal to the ratio of expansion. In the Sargent engine the ratio of expansion always exceeds the ratio of compression, and a lowering of the terminal pressure and temperature is of course the result. There is no doubt that this lowering of the temperature has a great deal to do with any success that the use of a combination valve such as described above may have. In the Sargent engine the rated power is developed when the governor cuts the admission off at three-quarter stroke; the rest of the stroke may be considered potential over-capacity. In spite of the fact that ordinary experience shows a gas engine to be most efficient when it is developing its maximum, not the rated, load as long as normal speed is maintained, the claim is made for this engine that its best efficiency is obtained when cutting off at three-quarter stroke.

The Koerting Two-Cycle Engine. — The Koerting engine is of German design, made in this country by the De La Vergne Machine Company of New York. This is one of the two successful large

two-cycle gas engines in Europe, the other being the Oechelhäuser, not made in America. Koerting two-cycle engines are now made by several German firms, whose constructions differ somewhat among themselves and from the parent design, mainly in frame and governor details. The latter seem to have an important bearing upon the amount of work done by the pumps. The type made by the De La Vergne Machine Company is best illustrated from the catalogue of the firm. Fig. 12-57 shows a cross-sectional elevation and a plan of this machine, used in this case as a blowing engine. It is seen that the engine has but a single cylinder which is double-acting. There are thus exactly the same number of power impulses per turn as in a single-cylinder steam engine. The piston is very long, about seven-eighths of the stroke, and is of course water-cooled. This makes it necessary to support its weight at the cross-head and at a tail-bearing to save both cylinder and stuffing-boxes. At the side of the power cylinder there are a gas and an air pump which furnish gas and air by separate passages to the mixture inlet valves at the top of the cylinder. The manner of driving these pumps from a side crank and of operating the piston valves, which control them, by means of rocker arms driven by an eccentric from the main shaft, is clearly shown in Fig. 12-58. Fig. 12-59 illustrates the valve shaft side of a partially constructed machine and shows the manner of operating the inlet valves and igniter gear. The exhaust gases are taken care of by a ring of ports in the middle of the cylinder. These ports are uncovered by the piston alternately on each side (see Fig. 12-57).

The operation of the engine is as follows:

It will be seen from Fig. 12-58 that the pump crank is in the neighborhood of 100 degrees ahead of the main crank, *i.e.*, when the latter is at either dead center the pumps have completed about one-half their stroke. From the beginning of its discharge stroke the air pump B, Fig. 12-60, has forced its charge of air into the passage leading to the main inlet valve and has forced some of this air also partly up to the gas passage, which is the inner concentric passage surrounding the inlet valve stem. In the meantime the piston of the gas pump A, the motion of which has been exactly the same as that of the air pump piston, has been allowed to shove back part of its charge into the gas suction pipe.

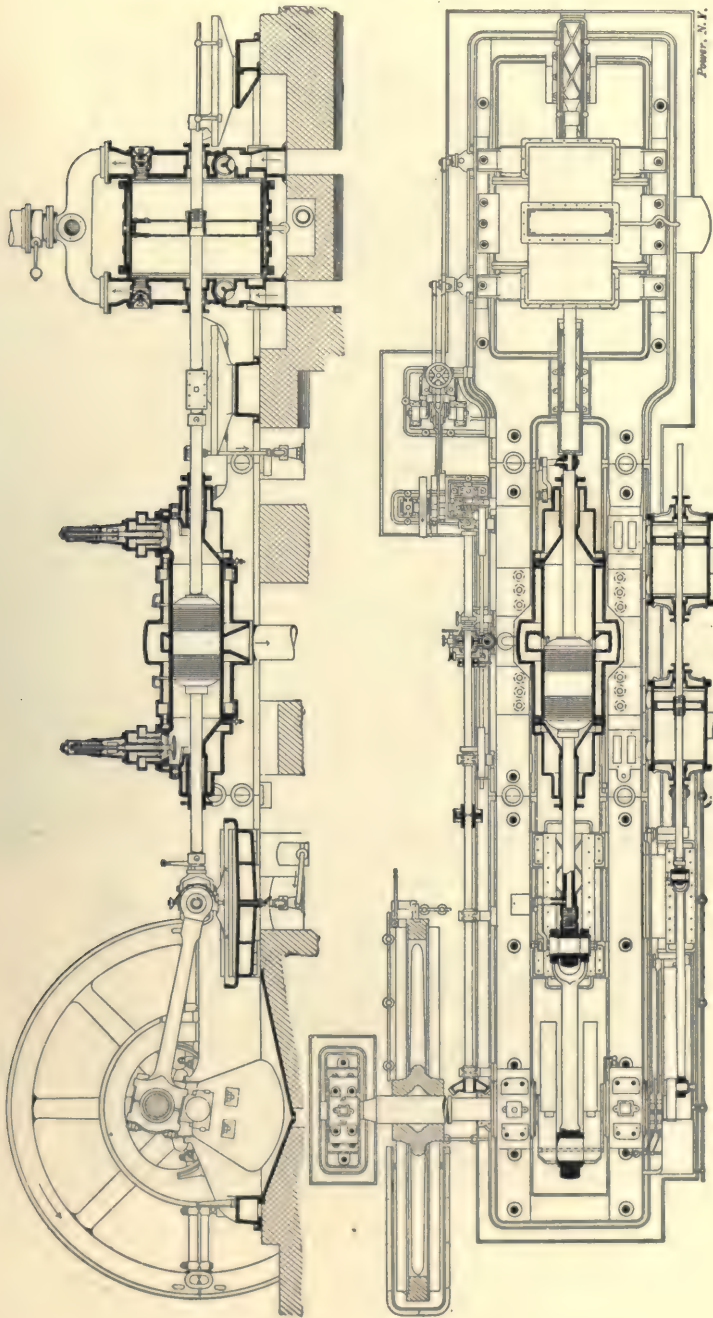


FIG. 12-57. — Koerting Two-cycle Engine, for Blowing Service.

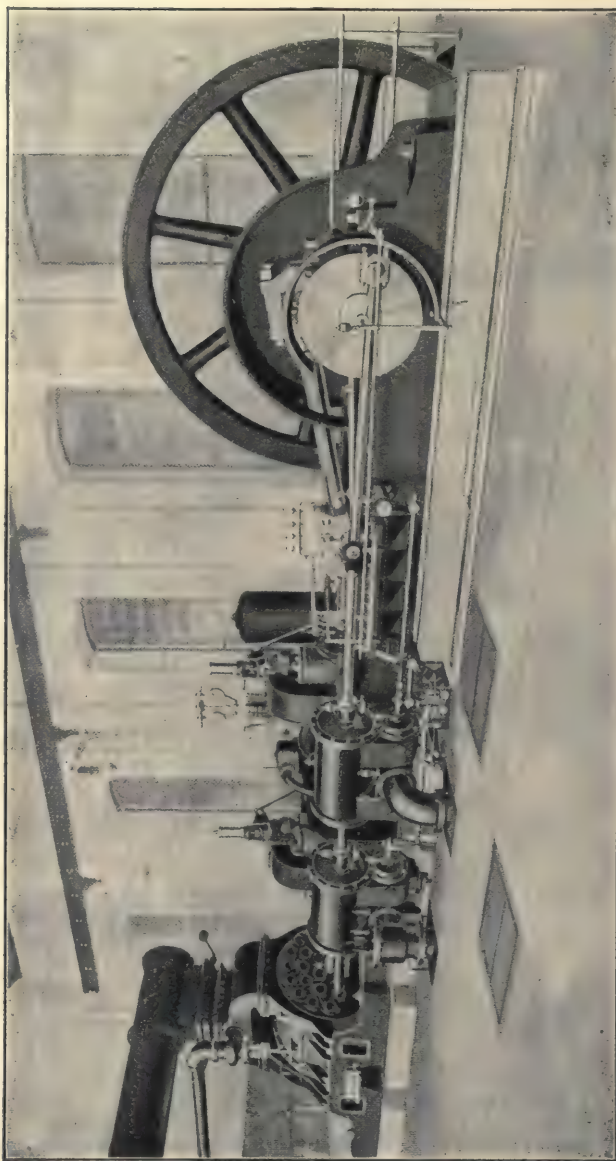


FIG. 12-58. — Pump Side of Koerting Two-cycle Engine.

At the moment, therefore, when the exhaust gases have nearly completely escaped from the main cylinder through the ring of ports, and the main inlet valve is opened, there is at first a rush of air from both the air and gas passages. This serves to drive the remainder of the exhaust gases out of the cylinder. A moment later the gas pump starts to deliver gas and the mixture enters the cylinder. By the time the power piston has covered the exhaust ports on its return stroke, the air and gas pistons

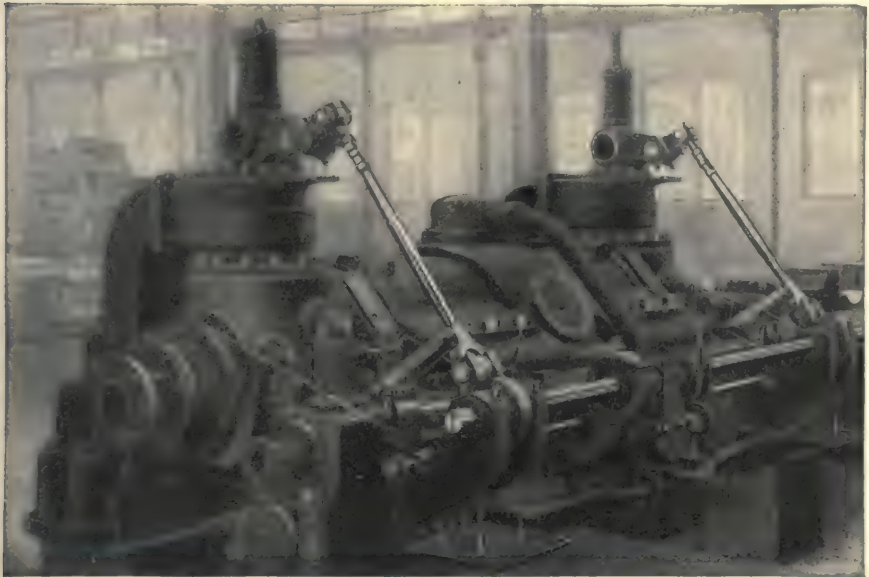


FIG. 12-59. — Valve Gear of Koerting Two-cycle Engine.

have reached the end of their stroke, the inlet valve closes and the mixture is compressed in the power cylinder. Ignition is by electric spark.

The speed of Koerting two-cycle engines is controlled by proportioning the amount of gas to the load. In the American type this is accomplished by putting butterfly throttle valves *f-f*, Fig. 12-60, in the discharge passages of the gas pump. The position of these valves is controlled by the governor, which, as some of the other illustrations show, is of the centrifugal type. This method of pump control is open to the objection that if the

gas used is at all dirty, the frictional resistances soon become so great as to render the governor inoperative. Some of the improvements of the later Koerting engines have been devoted to this very point. A modified design of gas pump is that of Klein Bros., Dahlbruch, Fig. 12-61.* In this construction the piston forces the charge back into the suction space through the ports shown at the middle of the cylinder, for one-half the stroke. The amount of gas delivered to the discharge passage during the last

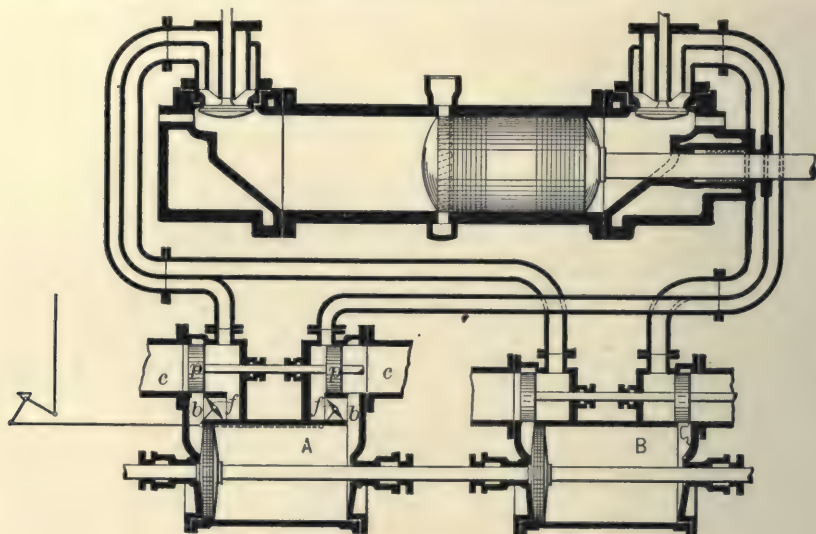


FIG. 12-60.

half depends upon the position of the small overflow piston valves near the bottom. This is controlled by the governor through the linkage shown. Another point that has given some trouble in the first designs of Koerting engines is the fact that the time available for the opening and closing of the inlet valve was but a very small part of the time of one revolution. The inertia actions were very severe and hence the engine speed was somewhat restricted. This difficulty has been overcome in an elegant way in the design of the Siegerner Maschinensban A-G as shown in Fig. 12-62. Here the lay shaft moves only at one-half the speed of

* Hoffman, Zeitschrift d. V. d. I., September 15, 1906.

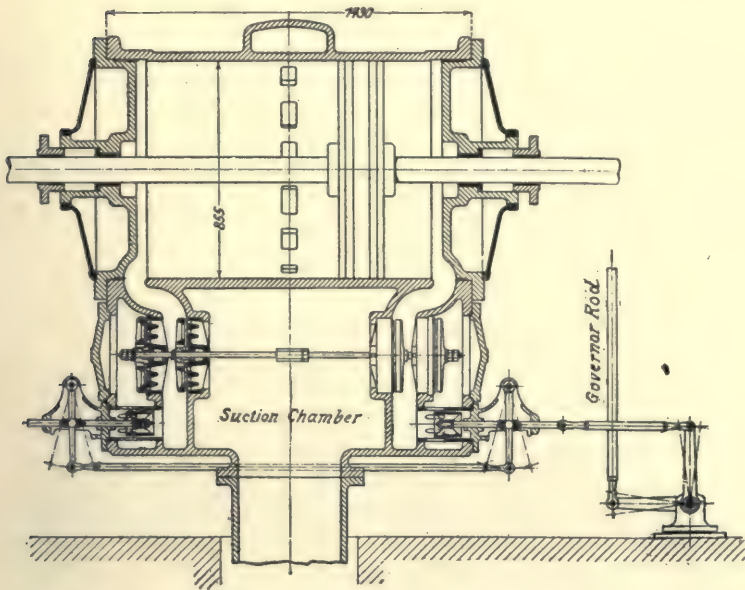


FIG. 12-61. — Gas Pump, Koerting Two-cycle Engine, Klein Bros.

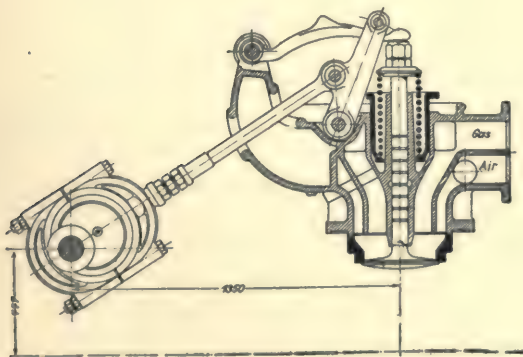


FIG. 12-62. — Modification of Inlet Valve Gear, Koerting Two-cycle Engine.

the main shaft, the same as in four-cycle engines, but the valve is opened twice for every turn of the shaft.

Reinhardt states that the Koerting engine is well adapted to blowing service because it starts easily under load and is certain in its operation through a wide range of speeds.

The Riverside Engine. — This engine is made by the Riverside Engine Company of Oil City, Pa., and embodies in its details several features decidedly different from those of other large engines. Fig. 12-63 shows the heavy duty double-acting tandem type and illustrates the peculiarity of the valve construction very clearly. Besides this type, this firm also builds single-acting,



FIG. 12-63. — Riverside Heavy Duty Double-acting Tandem Gas Engine.

single-cylinder and twin engines, and single-acting tandem engines. One of the single-acting, single-cylinder engines is illustrated in Fig. 12-64. The following is a description of the main features of the double-acting machine. It applies with little modification also to the single-acting type. Fig. 12-65 shows in cross-section the cylinder, valve and piston details of the double-acting engine and will serve as an aid in following the description of these parts.

The main frame or bed is of the heavy duty tangye rolling-mill type with bored guides and main bearings cast in a single piece, and is of great weight and extreme rigidity. The cylinder end of main frame is squared similar to cross-section of cylinder, and has machined holes for receiving the tie bars which attach the cylinder. The design of this frame, with its bored guideway, is such that a large portion of the metal is above the center line, making it exceptionally stiff.

The shaft is of side crank, built-up type and is machined all over.

The cylinders are made in two halves, with heads and valve chest cast integral without joints or packing, and are held rigidly to the main frame by four heavy steel tie bars which take all tension strains. The cylinders are mounted on a heavy cast-iron sole plate, having a machined top surface which keeps cylinders in alignment, permits perfect freedom for expansion and contraction, and by removing distance piece, cylinders can be slid end-wise on sole plate, giving easy access to interior of cylinder, pistons

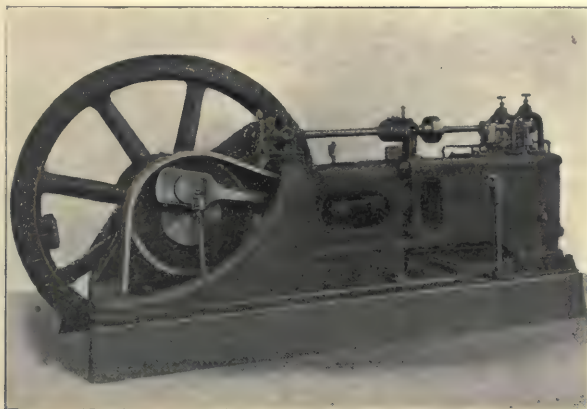


FIG. 12-64. — Riverside Single-acting Single Cylinder Gas Engine.

and piston rings. Rings can be cleaned or changed without disturbing piston or rod. The sole plate makes a drip pan under all the cylinders, keeping oil drip from foundation. The exhaust and inlet piping is attached to the sole plate, hence no piping except the water-jacket piping has to be disturbed when cylinders are moved. There is no overhead piping or wiring to interfere with traveling crane.

Both inlet and exhaust valves are of the semi-balanced water-cooled poppet type, operated in a vertical position. All water passing to the cylinder jacket passes through valves first, giving perfect and positive cooling without any attention whatever.

The balancing pistons run in renewable liners and are lubricated positively. These pistons form a large and perfect guide,

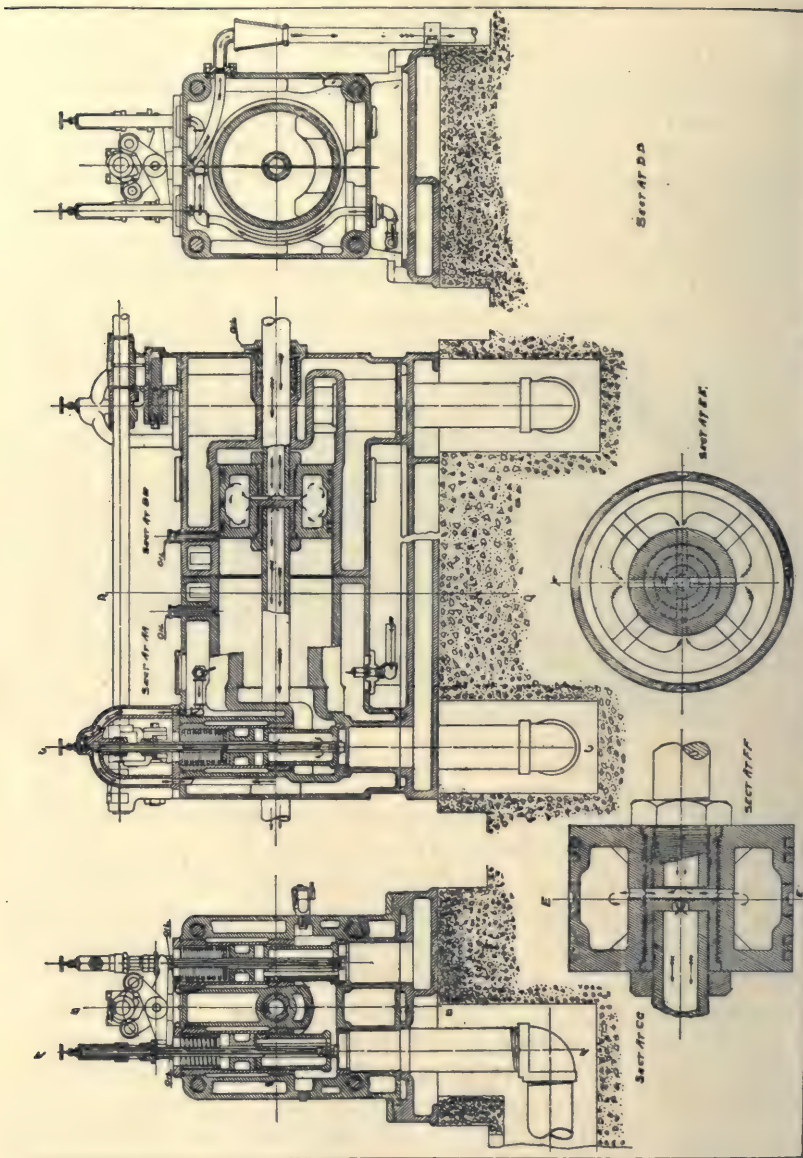


FIG. 12-65. — Details of Riverside Engine.

assuring positive alignment for these valves indefinitely. The valve seats are renewable and are located slightly below bottom of cylinder bore, so that all foreign substances are swept from the cylinder at each exhaust stroke. All valves are readily removed from the top of the cylinder without disturbing cam shaft.

Piston and piston rods are water-cooled, the water entering through a telescopic joint connected to side of cross-head. Circulation through each piston is positive and the overflow is so arranged that pistons are kept full of water. Water passages through piston and rod are large and easy so that not over ten pounds' pressure is required for circulation. The overflow is visible so that water cannot come to a boiling-point without attracting engineer's attention. A heavy tail-rod support and adjustable shoe is provided for carrying weight of pistons and rod. The construction of the piston rod is such that a piston in either cylinder can be removed without disturbing the other cylinder or the connecting rod, cross-head or any part of the valve gear.

The valve gear of the Riverside engine is very simple and consists of a single shaft mounted on top of the engine, running in self-oiling bearings. This shaft runs at one-half the speed of the main shaft and carries the inlet and exhaust cams, cams for operating the oil pumps, and the timers for ignition system. Power is transmitted to the inlet and exhaust valves by an inlet and exhaust lever hung on a single pin. All cams are keyed rigidly to the cam shaft. This construction makes a minimum number of joints subject to wear. Ample adjustments are provided for taking up wear.

Ignition is by an improved method throughout, consisting of two magnetically operated spark plugs in each cylinder. The sparking points being in series with the magnet coils give a positive external indication by the movement of the armature as to whether the spark takes place within the cylinder. The timing is electrical; no gearing or mechanical trips being used, simply a No. 14 stranded wire running through iron armored conduits leads to each plug.

The timer is mounted on the secondary shaft and is built in a heavy, substantial manner. The contacts are of the wipe type and are made of tool steel, and are adjustable for wear. A visible

indicating spindle shows the amount of contact. The entire wearing parts of timer are run in oil, which prevents burning of the contacts and reduces wear to minimum. Wiring from the timer to each spark plug is protected by a five ampere enclosed fuse; thus, should any spark plug become damaged or short-circuited, it would have no effect on the rest of plugs. Any spark plug can be removed and replaced while the engine is in operation.

The time of ignition in all cylinders can be adjusted simultaneously, and by an individual adjustment the time of ignition in any cylinder can be adjusted independently. All of these adjustments can be made when the engine is in operation.

The method of starting the double-acting engine is as follows:

A gas-engine driven air compressor is provided for supplying compressed air for starting this engine, air to be stored in a suitable steel receiver. The pneumatic starting gear on the engine consists of two shifter pistons mounted within the valve lever carrying pin. These pistons are shifted by throwing a small three-way cock which applies compressed air to one side of the piston, which in turn moves the valve levers $\frac{5}{8}$ inch, bringing the cam rollers in line with an auxiliary cam which puts all the valves in both ends of one cylinder into two-cycle action, or, in other words, makes a poppet valve air or steam engine out of this cylinder, which permits the engine being started on any stroke and on either quarter. The operation being entirely automatic, the engine will run as long as compressed air is applied. The other double-acting cylinder continues to operate as a four-cycle gas engine and takes up its explosions after the first revolution. Compressed air is then shut off from the starting cylinder and the three-way cock reversed, which permits the cam levers being returned to their normal position and that cylinder immediately goes into four-cycle action and takes up its explosions on the next revolution. The starting gear adds practically no complication to the engine as the regular inlet and exhaust valves are used for distributing the air. There are no extra shaft or auxiliary valves and no tappings into the cylinders. There is only one compressed air pipe leading to the sole plate, air being delivered into the fuel duct and entering the cylinders via the inlet valves.

The Crossley Engine. — This English engine is made in this

country by the Power and Mining Machinery Company of New York, and known as the American Crossley.

These engines are built as single-cylinder, two cylinder-opposed and double-opposed units, sizes ranging from 50 to 1300 B. H. P. This design differs radically from that of other large engines in that the single-acting cylinder is retained up to the largest sizes, *i.e.*, the design is in a way nothing but an enlargement of the small four-cycle machine. It is fundamentally the same design employed at first by the Deutz Company for their large engines, but has been given up by them some years ago in favor of double-acting engines.

Figures 12-66 and 12-67 show a general elevation and a cross-sectional elevation respectively of the single-opposed type. The cylinder castings are securely bolted to each end of a central frame casting. Both connecting rods work on one crank pin. The pistons are water-cooled. The cylinder proper is a separate liner, resting at the crank end in the jacket casting and held at the head end by the cylinder head. The head carries the gas and inlet valves, while the exhaust valve is placed in a separate casting. The position of inlet and exhaust valve is shown in Fig. 12-68. Both are operated in a horizontal position by means of bell cranks by cams on a lay shaft. In this respect the engine differs from most others in which the valves are nearly always vertical. The objection to the horizontal form is at least partly overcome by giving the exhaust valve a guide at each end. This valve is water-cooled, as is necessary in large machines. The lay shaft *s*, Fig. 12-66, is operated by spiral gears, and actuates the main inlet, the cut-off valve, the gas valve, the exhaust valve, and the igniter gear.

Gas and air enter the mixing chamber *M*, Figs. 12-66 and 12-69 through a proportioning valve, the air direct and the gas through a special gas valve. From here the mixture passes a multi-port cut-off valve, which surrounds the valve stem of the inlet valve and is shown in greater detail in Fig. 12-70. This cut-off valve is operated from the lay shaft through the rocker arm *C*, Fig. 12-71. The governor, shown in plan in Fig. 12-69, serves to shift the fulcrum *f* of the rocker arm *c*, Fig. 12-71, thus cutting off the mixture supply to the main inlet valve earlier or later as the load demands. Should the load drop so far that the com-

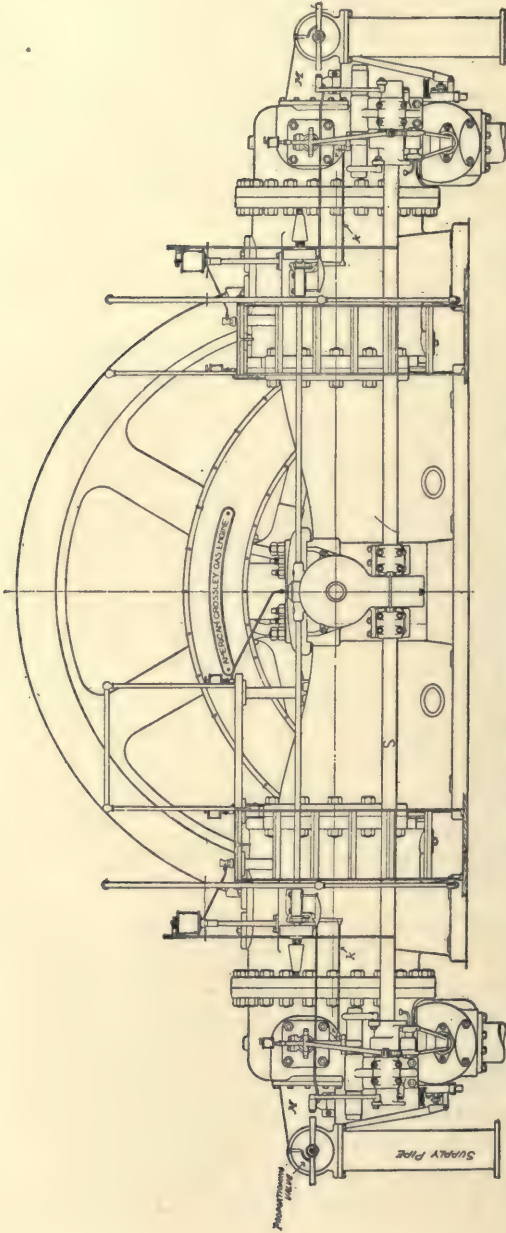


Fig. 12-66. — American Crossley Gas Engine.

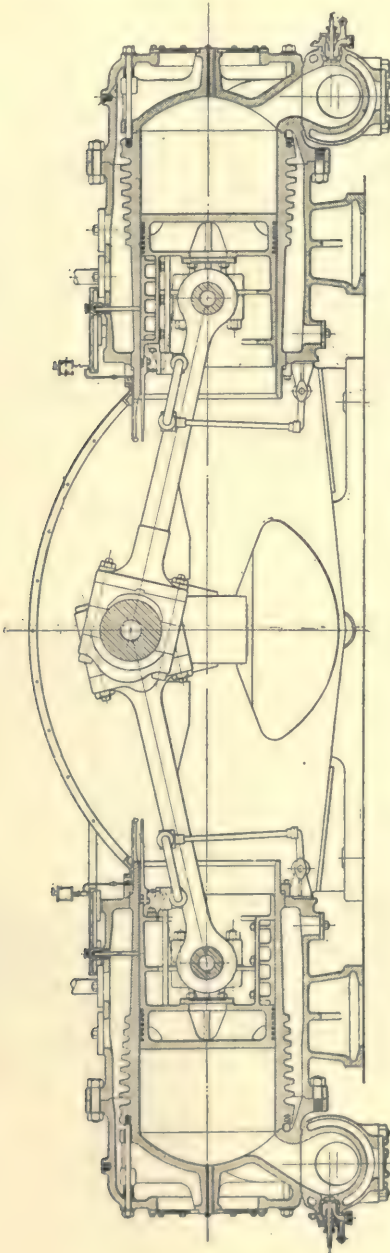


Fig. 12-67. — Cross-section American Crossley Gas Engine.

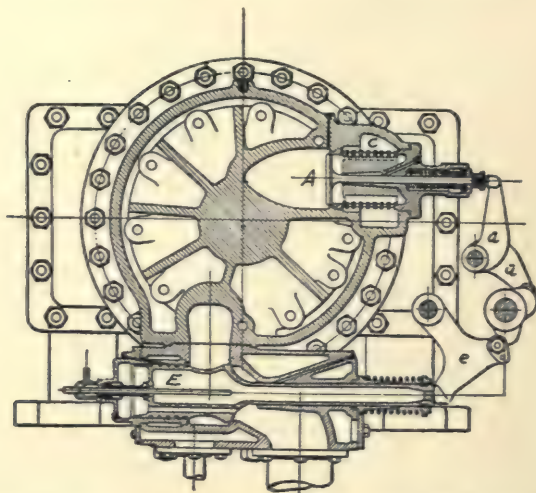


FIG. 12-68. — American Crossley Engine, Inlet Valve at A, Exhaust Valve at E.

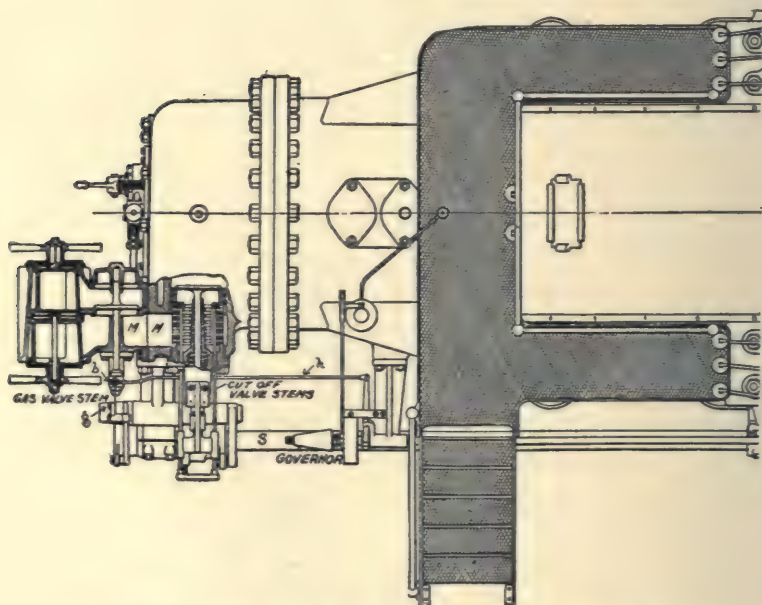


FIG. 12-69. — Details of Valve Gear, American Crossley Engine.

bustion becomes sluggish under very low loads, the engine automatically shifts over to the hit-and-miss governing by the governor withdrawing the block *b*, Fig. 12-69, thus keeping the gas valve closed altogether.

In multi-cylinder engines the point at which this occurs is so adjusted that one cylinder after another changes over to the latter system of regulation and not all of them at the same time.

The American company for some time adhered to hot tube ignition, but some of the later engines were fitted with make-and-break electric ignition.

The Snow Engine. — The Snow Steam Pump Company build

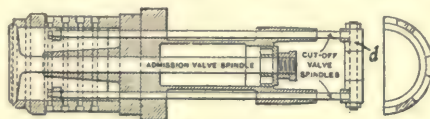


FIG. 12-70. — Inlet Valve, American Crossley Engine.

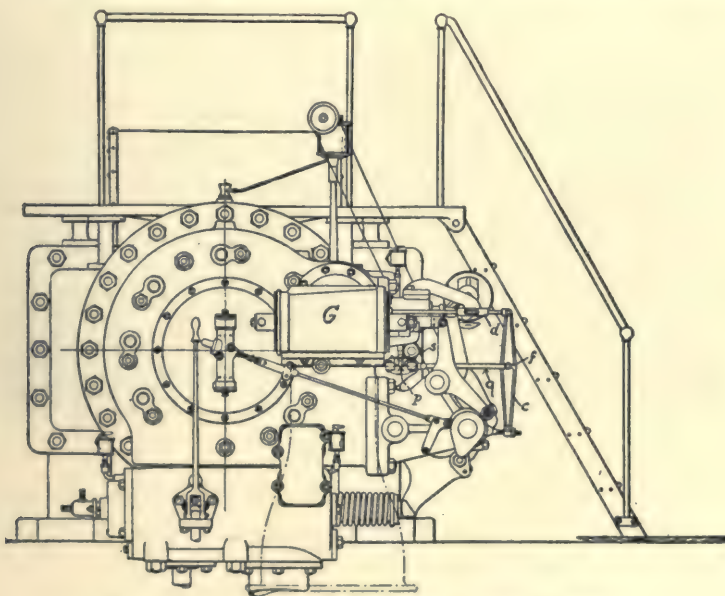


FIG. 12-71. — End View, American Crossley Engine.

two types of horizontal double-acting four-cycle machines, called respectively Type "A" and Type "B." Both of these designs differ radically from the construction of other large gas engines

in that the valves are placed in chambers at the side of the cylinders. There are reasons for and against this construction, the main disadvantage being perhaps the cut-up form of the combustion chamber. Some of the many advantages are outlined below.

Type B engines are built in single-cylinder units from 20 to 125 horse-power, and in tandem units from 80 to 500 horse-power. The general features of the design are shown in elevation in Fig. 12-72 and in cross-section in Fig. 12-73.



FIG. 12-72. — Snow Type B Gas Engine.

The most notable installations of Type A engines is found in the Martin station of the San Mateo Power Company in California. This station at present contains three of the twin-tandem units, a fourth is in course of erection, and the foundation is laid for a fifth. Fig. 12-74 shows a general view of the station, and also serves to give a general idea of the appearance of the engines. The engines of the Martin station were described in great detail by C. P. Poole in an article in *Power*, January 14 and

21, 1908, to which the writer is indebted for the following information:

Figure 12-75 shows in cross-section the main features of the design, while Fig. 12-76 is a transverse cross-section through one of the valve chambers to show the valve construction. Each cylinder of the twin tandem unit is 42 inches in diameter by 60-inch stroke. The engines are direct connected to Crocker-Wheeler generators rated at 4000 K.W. each. They are capable, however, of carrying momentarily an overload of 33 per cent, and have demonstrated their ability to carry 15 per cent overload continuously. These figures make these units the largest gas power

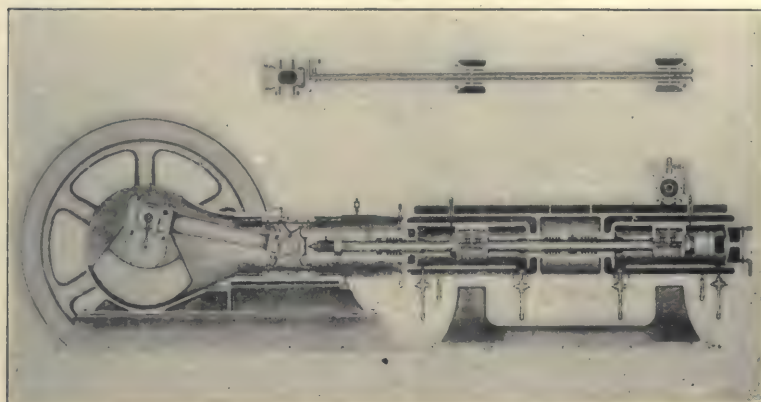


FIG. 12-73. — Cross-section of Snow Type B Gas Engine.

engines in the world. The fuel used is an oil-water gas made by the Lowe process.

The main frame is of the side crank type. The cylinders are cast in two parts, fastened together by flanges at the center, as shown in detail in Fig. 12-77. This construction makes the outer wall independent of the cylinder wall proper, and avoids temperature stresses. The valve chambers are cast integral with the cylinder casting. The cylinder heads are plain jacketed covers containing nothing but the stuffing-boxes. For the purpose of safety against leakage, however, each head has a double seat. The front and rear cylinders are connected by a distance piece of box-section, which has large openings in the side through which heads and pistons may be removed if required. The pistons are



FIG. 12 74. — Snow Type A Engines, Martin Station, San Mateo Power Co., Cal.

made in two parts bolted together. These pistons, together with their rods, are of course water-cooled, the water entering at the front cross-head and leaving at the tail cross-head.

The distinguishing feature of these engines, however, is the valve construction, shown in detail in Fig. 12-76. Mr. Poole, in the article mentioned, describes the gear as follows:

"The cam shafts which drive the valve gear are driven by steel gears, bevel gears being used on the main shaft, driving back through spur wheels to secure the proper reduction in speed of two to one. The igniters and lubricators are also driven from the cam shafts, as are also the starting valves, which admit compressed air on the cylinders for starting. The inlet and exhaust

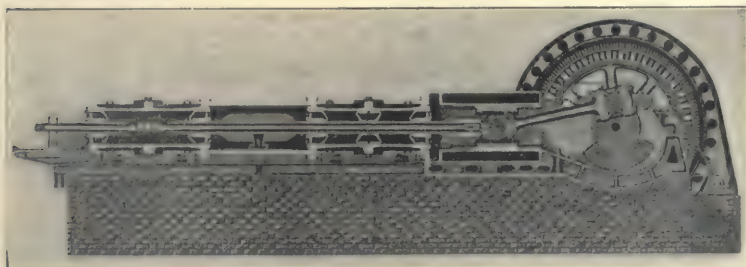


FIG. 12-75.

valves are driven by cams made of chilled cast iron, located on the cam shafts, which run in bearings bolted to the side of the valve chambers.

"The inlet and exhaust valves are of the unbalanced mushroom type, working in cages secured to the top and bottom of the valve chamber. Both valves and their cages are water-jacketed, in order to prevent back-firing or pre-ignitions on account of the treacherous nature of the gas used. Each inlet valve is combined with a combination mixing and throttling valve, of piston form, so designed that when the inlet valve opens gas and air ports in proper proportion are open for the passage of gas and air in the ratio desired, the amount of the opening of both being fixed by the governor. From this it will be evident that the engines operate with variable compression and constant mixture, the supply of air and gas to each end of each cylinder being throttled directly at each inlet valve for its end of its cylinder.

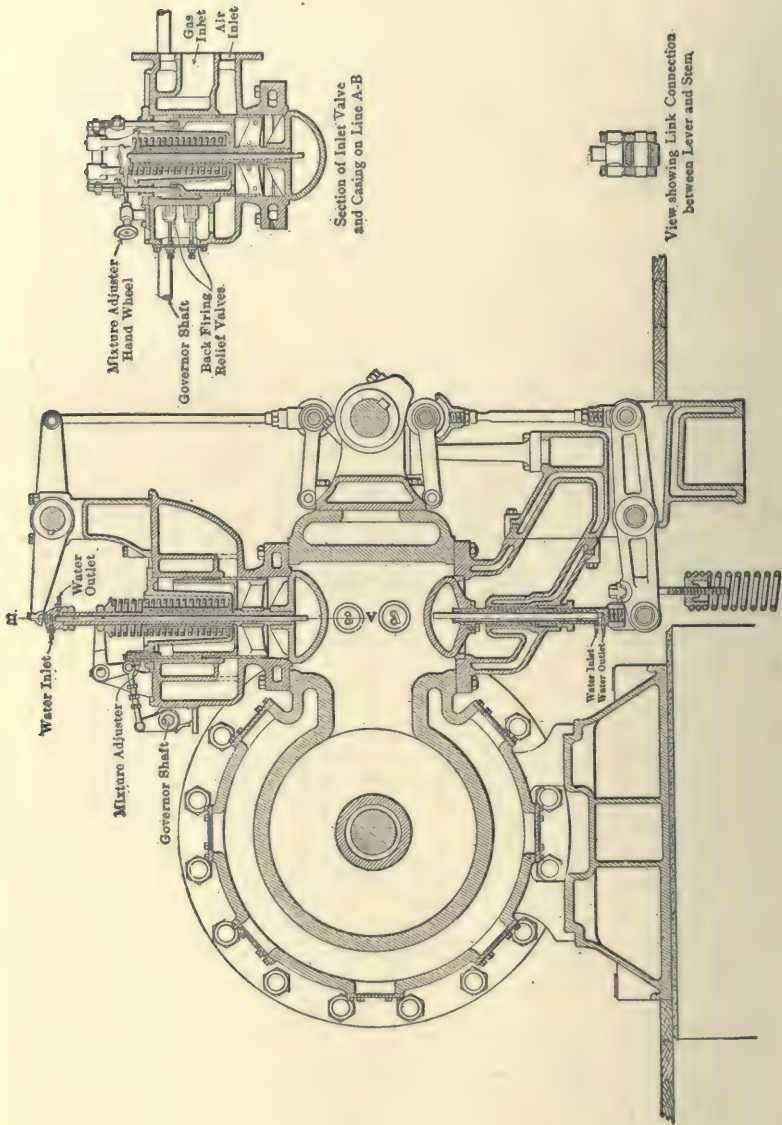


Fig. 12-76. — Transverse Section, Snow Type A Engine.

"The exhaust valves are of cast iron with nickel-steel stems and are thoroughly water-jacketed, the water being fed to and carried from the valve by positive circulation. The connection of the exhaust valve cages with the exhaust pipe is so made that the cages can be readily removed without disconnecting any other part of the engine."

In discussing the reasons for locating the valves at the side, Mr. Poole quotes the builders as follows:

"It permits of the use of an absolutely continuous bedplate under all cylinders, which is considered essential on engines as long as these for maintaining absolute alignment and permitting unrestricted movement to compensate for variations in temperature in cylinder walls and connecting parts.

"A solid, unbroken foundation from one end of the engine to the other is thus secured, and the builders consider that a solid, unbroken foundation is more essential for a gas engine than for any other prime mover on account of the enormous weight of the reciprocating parts and the inability to fully counterbalance.

"It enables all working parts of the engine, without exception, to be located above the engine-room floor and therefore to be in full view of the attendants at all times.

"Inlet- and exhaust-valve driving motions from the cam shaft are short and direct.

"Exhaust valves are much more accessible for removal when located in a valve chamber on the side, since the crane can be used throughout the entire operation and all work in connection with the removal and displacement of the exhaust valves is done from the engine-room floor.

"With valves located in a side valve chamber, broken inlet and exhaust valves cannot get into the interior of the cylinder and lodge between the piston and the cylinder-head, causing wrecks.

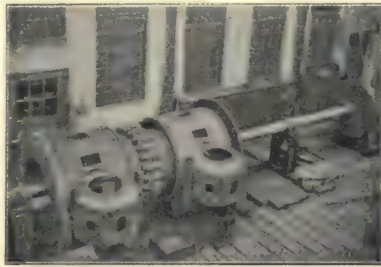


FIG. 12-77. — Cylinder Construction, Snow Type A Gas Engine.

"It has been very generally the opinion of gas-engine designers that the location of the valves in a side valve chamber of the kind used on the California engines entailed the certain disadvantage that foreign material entering the cylinder with the air and gas would deposit on the bottom of the cylinder counterbore, while if the exhaust valve be located on the bottom, such deposits will be carried out through that valve; furthermore, that lubricating oil collects in the bottom of the counterbore and is carbonized, causing back-firing and pre-ignitions. Experience with these engines thus far indicates that if lubrication is properly effected no carbonized oil is found in the cylinder, and that when oil is supplied excessively the resulting deposit of carbon is located not on the surface of the clearance space, but on the top of the piston barrel directly under the oil-inlet holes, on the piston rod where it wipes in from metallic packing, and on the face of the cylinder head directly under and close to the piston-rod hole in the head."

The Cockerill Engine. — This machine is built by the Soc. Anon. John Cockerill in Seraing, Belgium. This firm builds several types of engines, differing among themselves mainly in their valve constructions. Fig. 12-78 * shows a 1200 horsepower tandem gas engine, in which the inlet valve is on top, the exhaust valve on the bottom of the cylinder. Both are operated apparently from the same cam on the lay shaft. This type of machine is built either for quality or quantity governing, in which case the construction of the inlet valve differs. Fig. 12 79 shows another form, a single-cylinder double-acting engine direct connected to a blowing cylinder. The details of the valve gear of this machine are quite clearly shown in Fig. 12-80.† Both inlet and outlet valves are side by side at the bottom of the cylinder.

Figure 12-81 shows the latest form of the double-acting tandem Cockerill engine.‡ The distinctive features of this machine are that all valves are placed below the cylinder and that eccentrics only are used for operating these valves. The valve gear proper represents one of the most complicated constructions used

* H. Dubbel, Z. d. V. d. I., Sept., 1905.

† Güldner, p. 479.

‡ Güldner, p. 481.

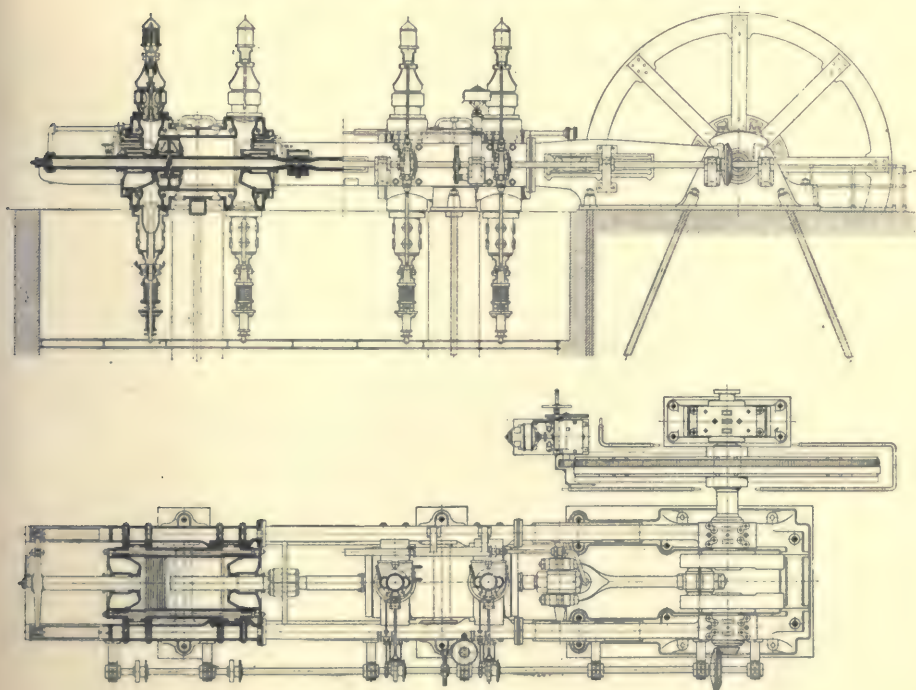


FIG. 12-78.



FIG. 12-79.

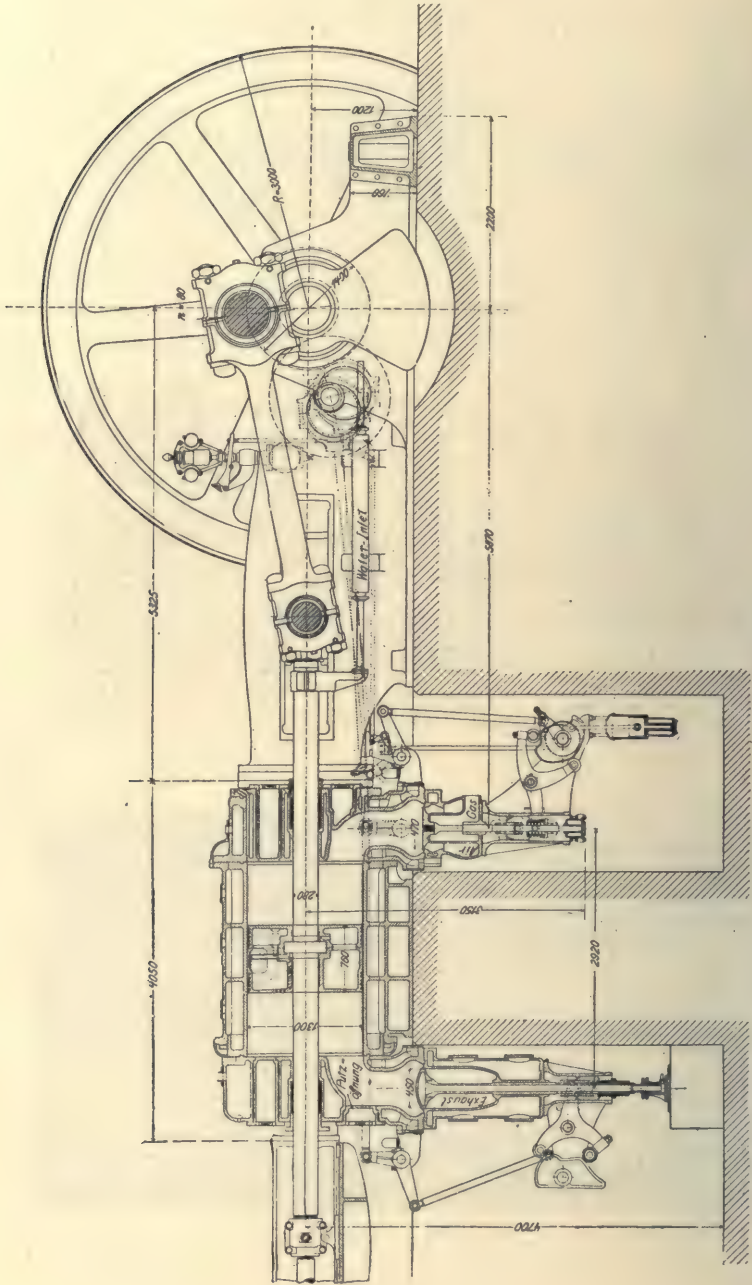


Fig. 12-80.

to-day and is shown in section in Fig. 12-82. In this figure at the left, the eccentric, through its rod *a* and the lever *b*, operates the cam *c* which positively opens and closes the exhaust valve through the triple lever *d*. The inlet valve eccentric, Fig. 12-82, at the right, in a similar manner operates the gas valve cam *c* and the inlet cam *c'*. The lever *b* actuating the gas valve cam is disengaged from the rod *a* when the trip arrangement *f-f'* is brought into play by the cam disc *e*. The position of this disc on its shaft is regulated by the governor, through the linkage shown, thus effecting speed regulation. The dash pot *h* allows the gas valve to seat noiselessly after its linkage is released.



FIG. 12-81. — Cockerill Double-acting Tandem Engine

The Cockerill engine has found considerable application in Europe, there being about 80,000 B. H. P. in operation in 121 engines, ranging from 200 to 3000 B. H. P. The fuel used is mainly blast furnace gas.

The Nürnberg Engine. — Although the Allis-Chalmers Company of Milwaukee have been the American licensees of the Maschinen-Gesellschaft Nürnberg, makers of the Nürnberg engine, the large gas engine now turned out by the American firm, differs in some of the important details from the original German design.

The Nürnberg engine is to-day perhaps the most important four-cycle gas engine built in Germany, and for that reason a description is first given of the German machine, to be followed by a few details of the Allis-Chalmers engine as far as they could be obtained.

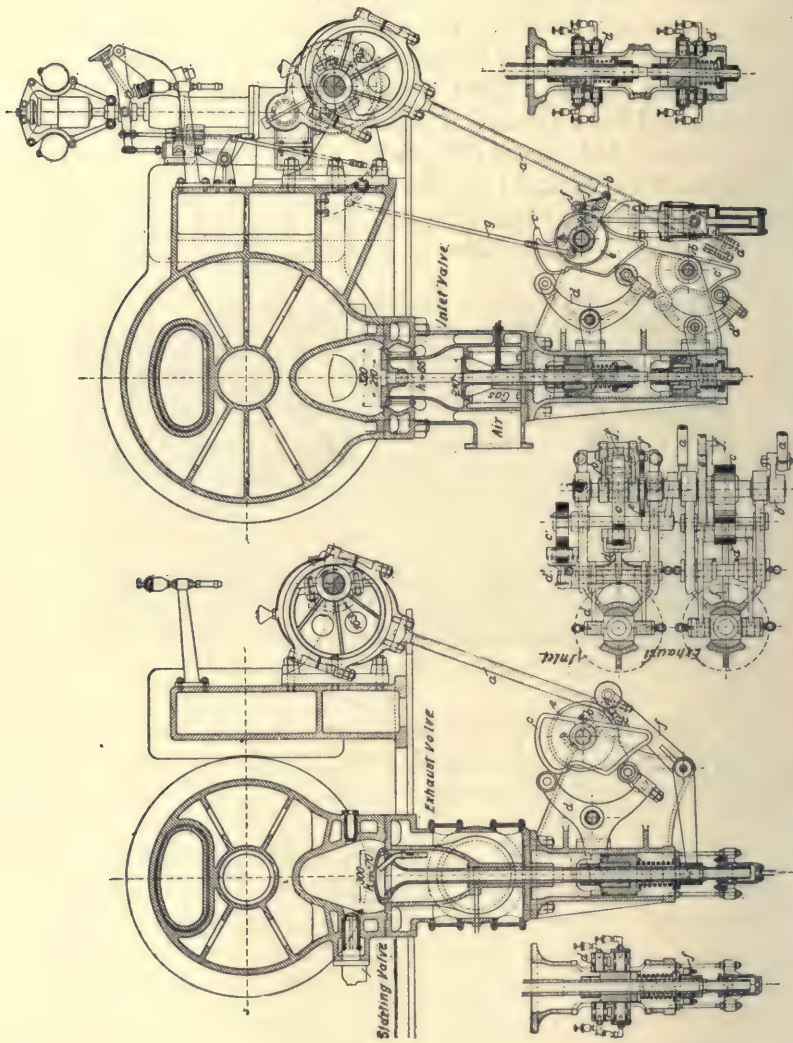


Fig. 12-82. — Valve Gear Details of Cockerill Double-acting Tandem Engine.

All of the medium sized and large Nürnberg engines are double-acting, either single-cylinder or tandem. They range in size from 250 to 6000 horse-power, the larger powers being the twin-tandem type. Probably the best description ever given of this machine is contained in Riedler's "*Gross Gasmaschinen*," from which the cross-section, Fig. 12-83, together with the two following figures, is taken. This cut shows frame, cylinder, and valve construction very clearly. The only part rigidly fastened to the foundation is the main frame, which is of the center crank type, as preferred by all European builders. The cylinders rest on supports such that they can freely expand and contract under temperature changes. The gas and inlet valves are placed on top and the exhaust valve at the bottom of the cylinder. The inlet and exhaust ports are cast in one part with the cylinder and jacket walls. This reduces the cylinder heads to simple water-jacketed covers, a point of great advantage as compared with the complicated cylinder heads of former days. All valve cages with their valves are easily removable for inspection. The exhaust valves are water-cooled. The valves are operated from a lay shaft running alongside, Fig. 12-84, by means of eccentrics and not by cams. How this motion is transmitted to the valve stems by roller levers to avoid shock and noise is very clearly shown in Fig. 12-85. The pistons are as simple as those of a steam engine. The method of fastening them on the shaft together with the water-cooling arrangements for rods and pistons are indicated in Fig. 18-83. The weight of piston and rod is carried by outside bearings, which relieves both cylinder and stuffing-boxes.

The greatest attention to accessibility has been paid in the design of this engine. As shown in Fig. 12-86, by disconnecting the piston rod between the cylinders, disconnecting the connecting rod and sliding the rod and cross-head forward, and by taking off the front and rear cylinder covers, the entire engine interior is at once open to inspection.

The Nürnberg engine regulates by pure quality regulation, that is, the amount of gas only is cut down as the load drops. To accomplish this there is a gas valve placed ahead of each main inlet valve on the top of the cylinder. Fig. 12-83 shows the construction of these valves in section and the method of operating them by eccentrics from the lay shaft may be seen in Fig. 12-84.

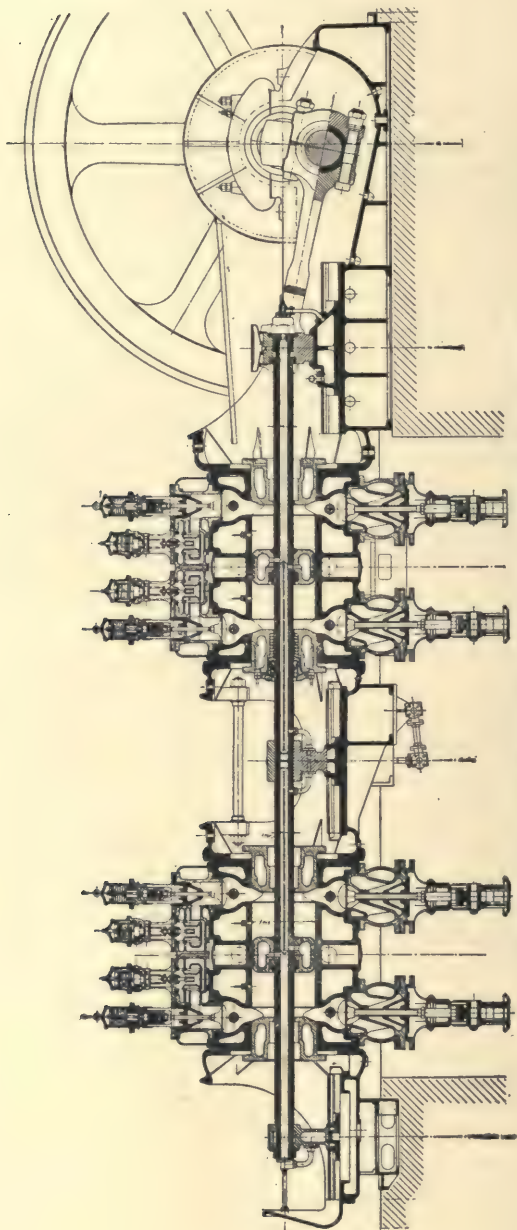


Fig. 12-83. — Nürnberg Double-acting Tandem Gas Engine.



FIG. 12-84. — Nürnberg Double-acting Tandem Engine.

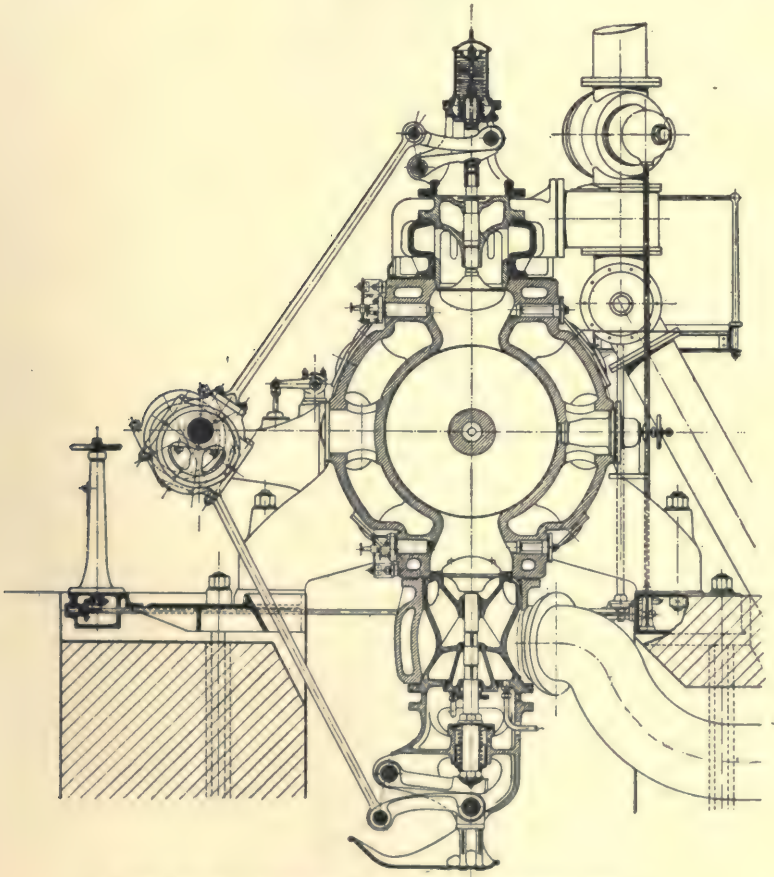


FIG. 12-85. — Details of Valve Gear, Nürnberg Engine.

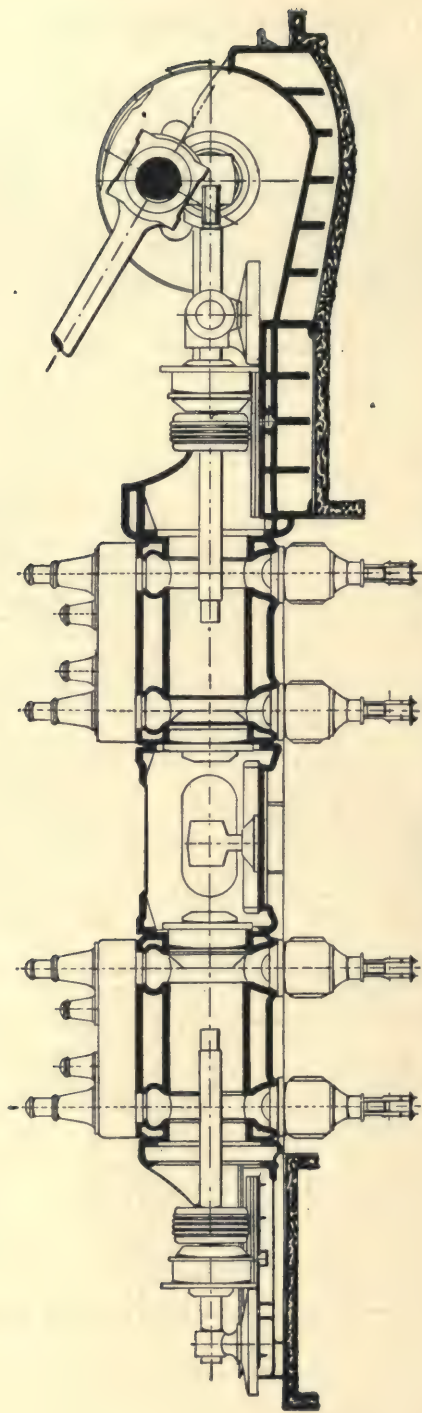


FIG. 12-86. — Showing Accessibility of Nurnberg Engine.

The latter illustration also shows the centrifugal governor and the governor shaft running alongside of the cylinders. From this governor shaft reach rods run to the gas valves and control the time of the opening of these valves in the manner explained in Chapter XIV. In some of the later engines the details of the governor mechanism are changed somewhat * but the principle of operation is the same in all, *i.e.*, to open the gas valve later in the stroke as the load drops and to keep the time of closure the same. The air is not throttled at any time, hence the compression remains about the same. It is interesting to trace out the sequence of events in a four-cycle tandem engine, for which purpose Fig. 12-87 published by the Allis-Chalmers Company is given.

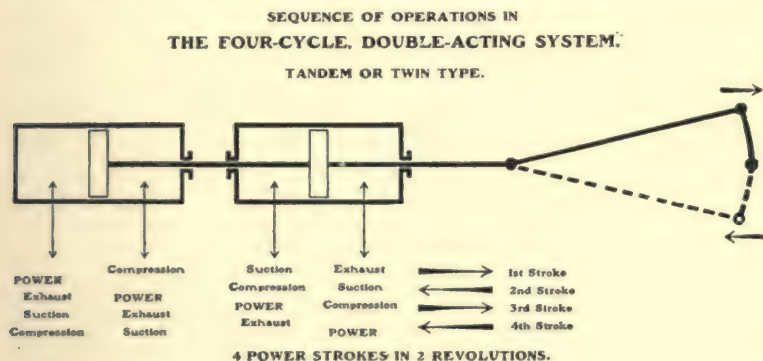


FIG. 12-87.

Most Nürnberg engines operate on blast furnace gas. The table on page 346, also from the catalogue of the Allis-Chalmers Company, will serve to give some idea of the cylinder sizes, speeds, floor-space, etc.

It has already been mentioned that the engine now built by the Allis-Chalmers Company is not quite like the Nürnberg machine. The following is a description of one of these engines, as given in *Power*, January 21, 1908. The engine, Fig. 12-88 is of the twin-tandem, double-acting type and direct connected to a 1040 K.W. Crocker-Wheeler generator:

"It is of the side-crank type so generally used in steam engine

* See *Zeitschrift des Vereins deutscher Ingenieure*, Aug. 11, 1906, and Sept. 22, 1906.

construction. The pistons are supported entirely by the piston rods, which are turned with sufficient camber to make them dead straight when the weight of the pistons is put on them. The rods are equipped with intermediate and tail shoes, as usual with large tandem construction, running on guides between the cylinders and behind the rear cylinder, in addition to the main cross-head.

NÜRNBERG GAS ENGINE

TABLE OF STANDARD SIZES

TANDEM						TWIN						TWIN-TANDEM					
Size of Cylinders		Speed. Revolutions per Min.	B. H. P.	Floor Space		Size of Cylinders		Speed. Revolutions per Min.	B. H. P.	Floor Space		Size of Cylinders		Speed. Revolutions per Min.	B. H. P.	Floor Space	
Diam. Inches	Stroke. Inches			Length Rear End to c. of Shaft. Feet	Width Overall. Feet	Diam. Inches	Stroke. Inches			Length Rear End to c. of Shaft. Feet	Width Overall. Feet	Diam. Inches	Stroke. Inches			Length Rear End to c. of Shaft. Feet	Width Overall. Feet
18	24	150	260	29	11	18	24	150	245	19	17	18	24	150	520	29	17
20	24	150	320	29	11	20	24	150	305	19	17	20	24	150	640	29	17
21	30	125	370	33	13	21	30	125	350	22	20	21	30	125	740	33	20
22	30	125	405	33	13	22	30	125	385	22	20	22	30	125	810	33	20
24	30	125	490	33	13	24	30	125	465	22	20	24	30	125	980	33	20
24	36	115	545	38	15	24	36	115	515	25	23	24	36	115	1090	38	23
26	36	115	630	38	15	26	36	115	600	25	23	26	36	115	1260	38	23
28	36	115	740	38	15	28	36	115	700	25	23	28	36	115	1480	38	23
30	42	100	855	44	17	30	42	100	810	29	27	30	42	100	1710	44	27
32	42	100	985	44	17	32	42	100	935	29	27	32	42	100	1970	44	27
34	42	100	1105	44	17	34	42	100	1050	29	27	34	42	100	2210	44	27
36	48	92	1300	50	21	36	48	92	1240	33	32	36	48	92	2600	50	32
38	48	92	1460	50	21	38	48	92	1400	33	32	38	48	92	2920	50	32
40	48	92	1630	50	21	40	48	92	1550	33	32	40	48	92	3260	50	32
42	54	86	1875	60	26	42	54	86	1780	40	38	42	54	86	3750	60	38
44	54	86	2080	60	26	44	54	86	1980	40	38	44	54	86	4160	60	38
46	54	86	2280	60	26	46	54	86	2170	40	38	46	54	86	4560	60	38
48	60	78	2475	70	30	48	60	78	2350	45	44	48	60	78	4950	70	44
50	60	78	2720	70	30	50	60	78	2580	45	44	50	60	78	5440	70	44
52	60	78	2950	70	30	52	60	78	2800	45	44	52	60	78	5900	70	44

NOTE — The overall widths given in the above tables allow for a plain fly-wheel; proper addition must be made if a band-wheel is substituted or an electric generator direct connected upon the crank-shaft.

“There are two inlet valves to each combustion chamber, one for air and one for gas, but both are mounted in a single cage. The air valve is of the piston type and the gas valve is of the poppet type, its axis being in line with that of the air valve. The latter is opened at the beginning of the suction stroke and

kept open throughout that stroke. The gas valve, however, is open during varying proportions of the suction stroke, according to the requirements of the load. The engine, therefore, operates with constant compression and varying mixture proportions. The compression pressure is about 180 pounds per square inch, absolute.

"The ignition is by make-and-break mechanism electrically operated; that is, the movable electrode is rocked by means of an electromagnet and the latter is energized by the ignition current controlled by a 'timer' or so-called commutator driven synchro-

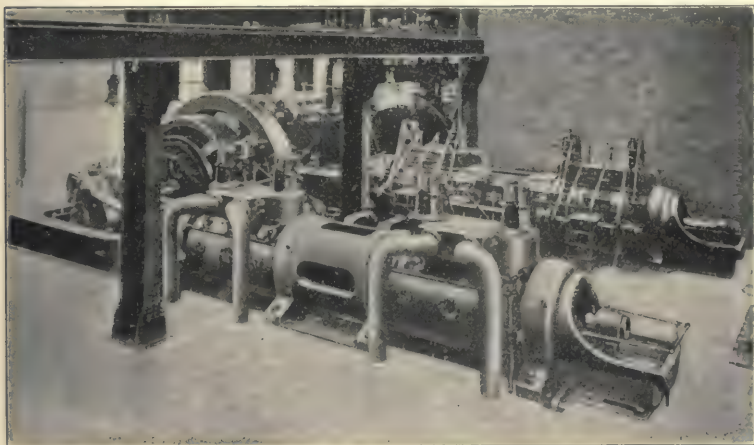


FIG. 12-88. — Allis-Chalmers Double-acting Twin Tandem Engine.

nously with the cam shaft. Tell-tale incandescent lamps are connected in circuit with the igniter magnets and indicate the performance or default."

The main differences between this and the Nürnberg engine then appear to be different cylinder supports, the combination of the gas and inlet valves in one housing, and the use of the side-crank frame.

Premier Engine. — Probably the best description of this engine is found in Robinson's "Gas and Petroleum Engines." It is of what is known as the positive scavenger type, *i.e.*, the combustion chamber is thoroughly washed out with air before a new charge is admitted. The cylinder is single-acting, and single-

cylinder and tandem units are built. The former go up to 250 horse-power, the latter up to 1200 horse-power. The pump serving to furnish the air for scavenging is usually placed ahead of the first power cylinder, but in some of the later designs the air pump is placed obliquely above the first cylinder.

Figures 12-89 and 12-90 are two illustrations from Robinson. The first shows the general appearance of the machine, the method of operating the inlet and exhaust valves from the lay shaft, the oblique rod to operate the air-pump valve, and the governor details. The second shows several sectional views from which the operation may be explained. The piston *D* of the single-acting air pump is rigidly connected to the piston *C* of the first power cylinder. The second power piston is connected by means of the yoke *K* and the side rods *R R* to the air pump piston. Thus the use of a stuffing-box in the combustion chamber of the forward power piston is avoided. *H H* are the combination air and gas inlet valves, and *G G* the exhaust valves, operated as shown in the transverse cross-section.

The operation is as follows: On the out stroke, air is admitted to the air pump *D* through the grid valve *F*, shown in the section *X X*. On the return stroke this air is compressed into the passage *D-E*, and serves to scavenge out the power cylinder just exhausting when the inlet valve *H* into that cylinder is opened about one-half exhaust stroke. On the next out stroke the air pump takes a new charge, but at the same time the valve *F* has also opened communication to the passage *E*, so that the cylinder just charging may draw air freely. Above the inlet valve *H* there is placed a cylindrical valve, which during the scavenging action opens the air ports completely and keeps the gas ports closed, but which, at the beginning of the charging stroke, shifts its position to give the proper relation between air and gas. While the exhaust and charging strokes above described take place in one, say the first, cylinder, the second has completed its compression and expansion strokes. On the third (the in stroke) of the pump, therefore, we shall have compression in the first cylinder and exhaust in the second. The pump then scavenges out the second cylinder during the last half of its exhaust stroke.

Speed regulation in this engine is effected by the governor cutting out the gas from the back cylinder altogether below a

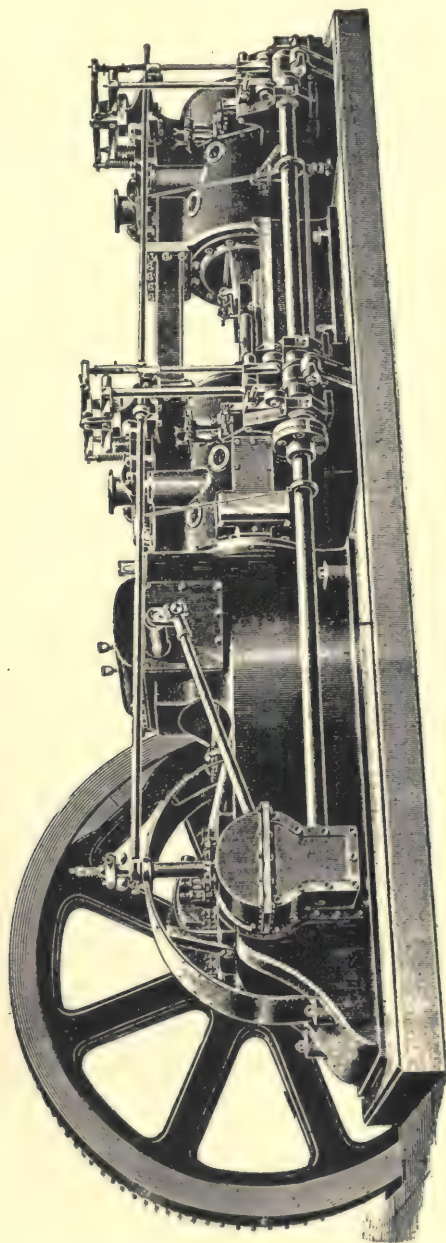


FIG. 12-89. — Premier Gas Engine.

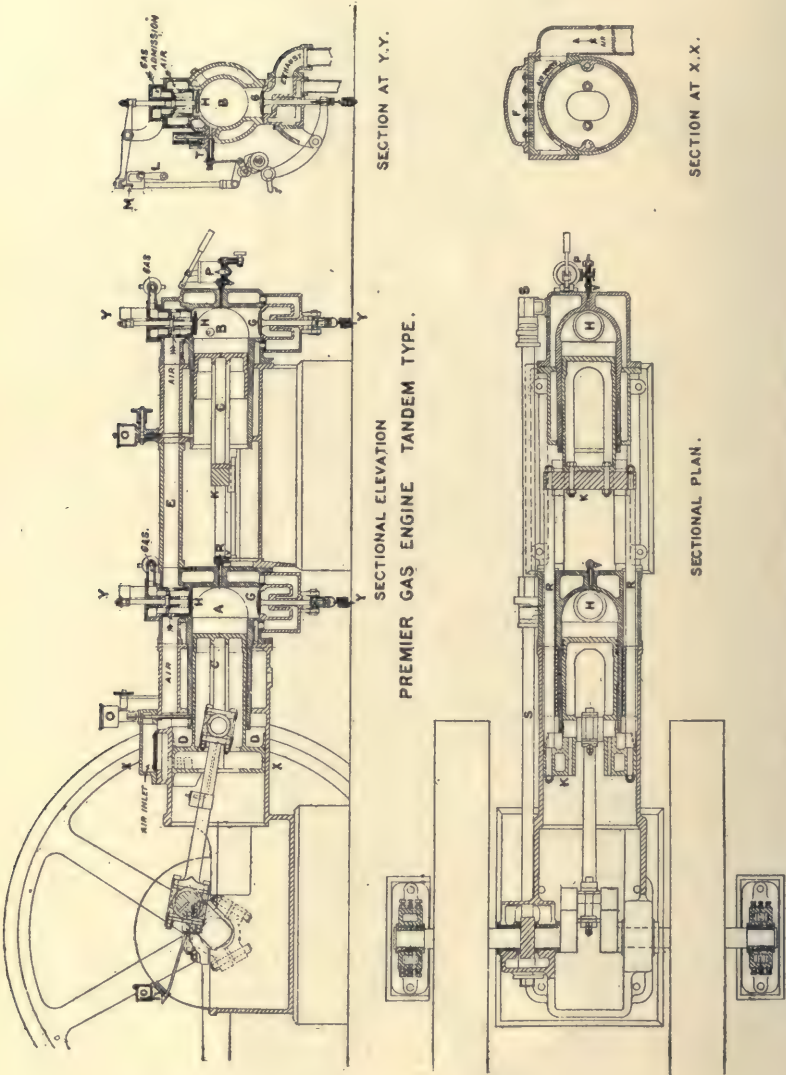


Fig. 12-90. — Details of Premier Gas Engine.

certain load. Above this a charge of gas is admitted occasionally, while above half power both cylinders work practically continuously.

Robinson states that the tandem design and the positive scavenging action make the Premier engine well adapted for the burning of cheap fuel gas. Güldner judges, from the high efficiencies obtained in conjunction with mean effective pressures exceeding 110 pounds per square inch, that the combustion process in this engine must be very perfect.

The Deutz Engine. — The Deutz Company of Deutz-Cologne were the first firm to build Otto engines and they have from the first been prominently identified with the development of this type of engine. Their present-day constructions embrace several designs of excellent form.

The large engines are all double-acting and are made either single-cylinder, twin or tandem. The general features of the design of a 600 B. H. P. twin engine are shown in longitudinal cross-section in Fig. 12-91 and in transverse section in Fig. 12-92.* The cylinder differs from that of the Nürnberg engine in that the jacket wall is not continuous. This is done, of course, to prevent temperature stresses. The central space is closed by a saddle casting as shown. Inlet and exhaust valves are placed in separate cages easily removable. The details of piston design and the water-cooling arrangements are clearly indicated. The manner of operating the valves from the lay shaft is shown in Fig. 12-92. All Deutz engines govern by throttling a mixture of constant composition. In the particular engine under discussion the throttle valve is a multi-ported cylinder surrounding the inlet valve stem. It is so designed as to keep the ratio of gas to air the same as that set by the hand-operated valves shown in the gas and air passages, but depending on the load, the mixture is throttled more or less. How the movement of the valve is controlled by varying the position of the fulcrum about which the throttle valve lever turns can be easily traced out by following the governor linkage.

The arrangement of the throttle valve is somewhat different in smaller engines. Thus in the 250 B. H. P. engine, a cross-section of which is shown in Fig. 12-93, the throttle valve is

* From H. Dubbel, *Zeitschrift d. V. d. I.*, Sept. 2, 1905.

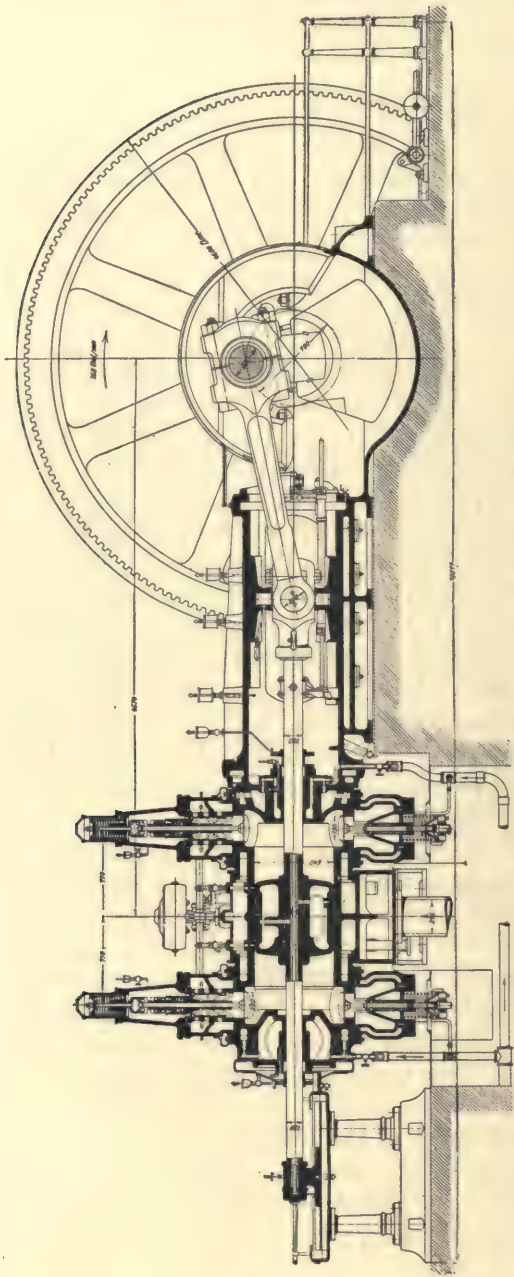


FIG. 12-91. — 600 B. H. P. Deutz Engine.

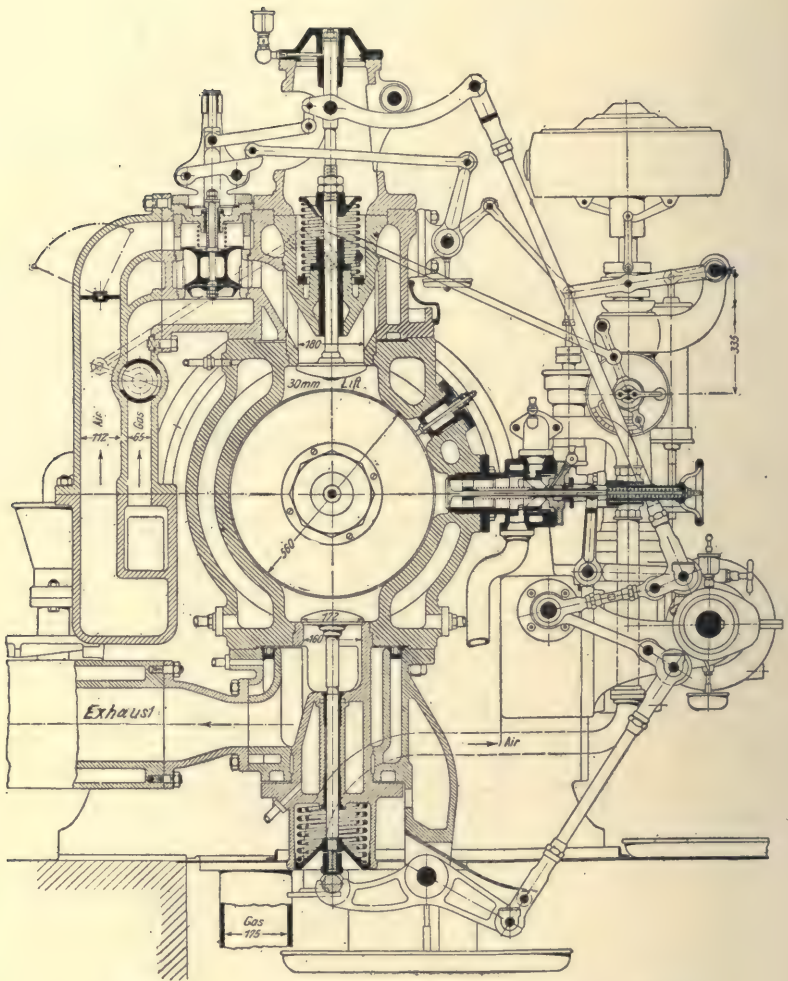


FIG. 12-93. — Valve Gear Details, 250 B. H. P. Deutz Engine.

independent of the main inlet valve. The governing features, however, are quite similar.

The Oechelhäuser Engine. — The Oechelhäuser Engine, built by several firms in Germany, is a two-cycle machine of distinctive design, as may be seen from the cross-sections, Figs. 12-94, which represents a 1000 horse-power machine built by A. Borsig.*

The power cylinder is open at both ends and contains two single-acting pistons. The front piston is connected to the middle crank of a three-throw crank shaft by piston and connecting rod in the ordinary manner. The rod of the back piston is fastened to a yoke which transmits the motion through rods on each side of the cylinder to cross-heads and connecting rods working on the two outside crank pins. This construction, while complex and probably costly, results in almost perfect balance. There are no valves as such. The exhaust gases escape through a ring of ports which is uncovered by the front piston near the end of the out stroke. Similarly the back piston near the end of its out stroke uncovers first a ring of ports admitting a charge of air for scavenging, and a moment later the gas or mixture ports. On the return stroke these rings of ports are covered one after the other and compression ensues between the two pistons. When in their inner dead center position, ignition is made to take place electrically, and the pistons are driven apart on their power strokes.

Gas and air under certain small pressures are furnished to the receivers surrounding the inlet ports by means of a combination air and gas pump which is usually operated by a tail rod. In blowing engines the blowing cylinder is usually so connected, and the air and gas pump is then placed under floor.

At full load the mixture follows the preliminary charge of pure air used for scavenging to about three-quarters or seven-eighths of the stroke. Regulation is effected by controlling the amount of mixture admitted to the cylinder. The means for doing this are discussed in Chapter XIV.

Oechelhäuser engines have given good satisfaction on blast-furnace and coke-oven gas. The general appearance of a twin engine of this type is shown in Fig. 12-95.

* Hoffman, Zeitschrift d. V. d. I., Sept. 15, 1906.

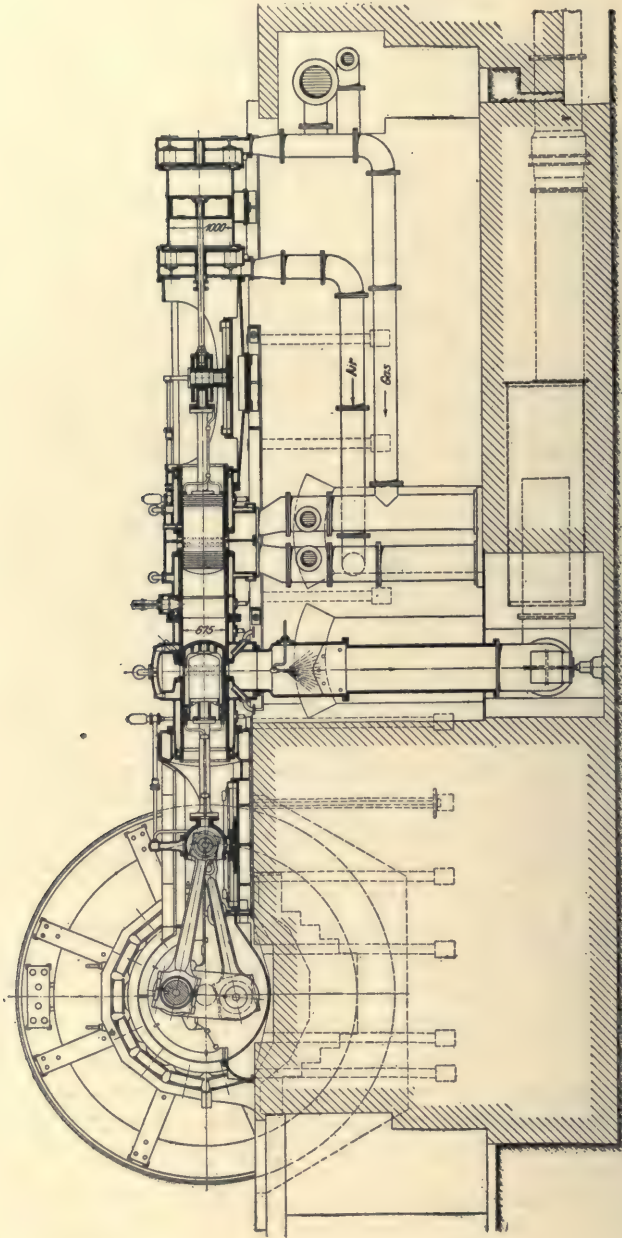


Fig. 12-94. — 1000 H. P. Borsig-Oechelhäuser Two-cycle Engine.

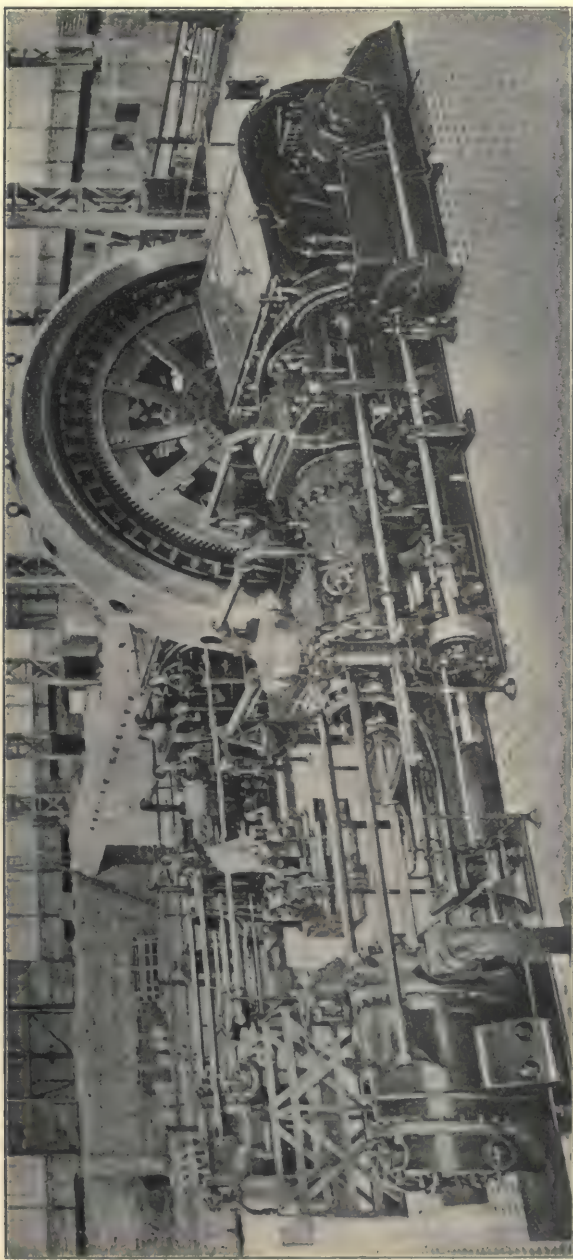


FIG. 12-95. — Twin Type Oechelhäuser Two-cycle Engines.

B. Liquid Fuel Engines

3. GASOLINE ENGINES. — The very great majority of all portable internal combustion engines are gasoline engines, and the same is true of a large percentage of stationary internal combustion engines for small powers. We may thus divide all gasoline engines into three classes — stationary engines, marine engines, and automobile engines. The number of firms engaged in the manufacture of these engines is very large. Usually the various makes differ only in minor detail, and for that reason only one or two *type examples* under each class will be considered.

Stationary Gasoline Engines. — The general type of this machine either vertical or horizontal does not differ much from that of the small-powered stationary gas engine, several makes of which have already been discussed. It is usually possible to convert any gas engine of this type into a gasoline engine by the simple addition of a carbureting device. A number of the latter have been described in Chapter VIII.

The Foos Gasoline Engine. — This machine is made by the Foos Gas Engine Company of Springfield, Ohio. The cylinder, Fig. 12-96, is partly supported by the frame, making an especially rigid construction. The cylinder head is a plain flat cover. Both valves, which are of the poppet type, work upward and are mechanically operated; they are not affected by any governor action. Thus if the governor keeps the fuel valve closed, pure air is worked through the engine, cooling the cylinder and clearing it thoroughly from burned gases. The valves are operated by bell cranks and rods as shown. These rods are in turn actuated by cams on the shaft of the secondary gear, *A*, Fig. 12-96. The valves have their seat castings separate from the cylinder, but in order to remove the valves for inspection or regrinding it is necessary only to remove the plugs in the top of the valve cages. In Fig. 12-96, *B* is the rod operating the fuel valve, *C* the fuel pump, and *D* the igniter rod. The fuel may be gasoline, naphtha, or distillate.

Foos engines are governed on the hit-and-miss principle. In Fig. 12-97, *E* is the igniter rod, *C* the fuel valve lever which is oscillated by a cam on the shaft of the secondary gear *G*. This gear, through a pinion, also drives the governor *D*. The latter is

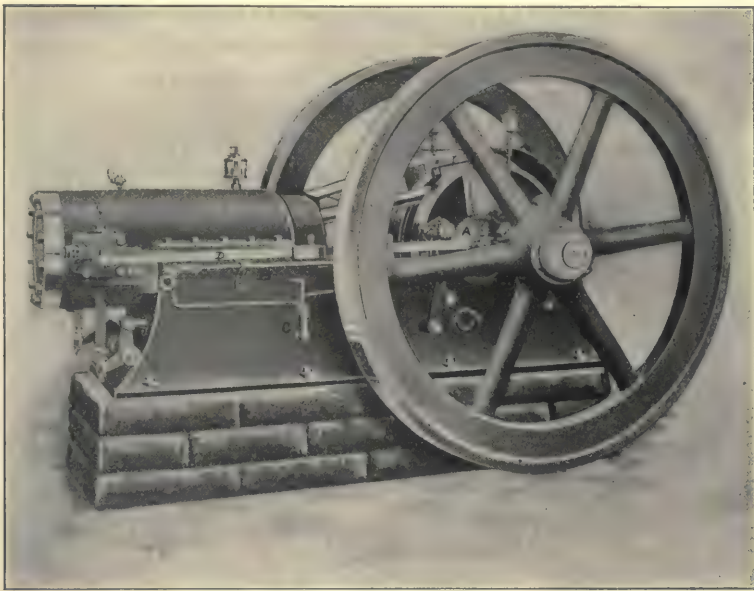


FIG. 12-96. — Foos Gasoline Engine.

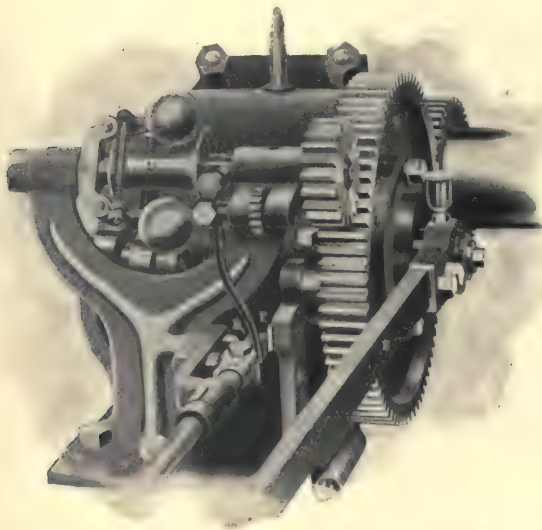


FIG. 12-97. — Governing Details, Foos Engine.

of the fly-ball type, and, when the speed becomes excessive, pulls the block *B*, on the lower end of the governor lever *A*, out of line with the blade *F*. Thus *F* misses the fuel valve rod and the en-

gine fails to receive a charge. The speed of the engine may be adjusted during operation by varying the position of the fulcrum *A* by turning the nut *H*.

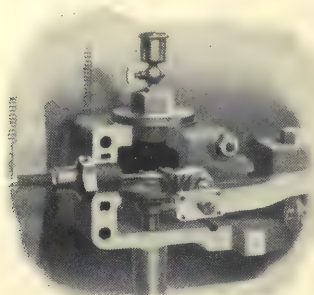


FIG. 12-98. — Wipe Spark Igniter, Foos Engine.

In place of the ordinary hammer break system, a wipe spark igniter is employed. In Fig. 12-98, the revolving electrode, every second turn of the engine, wipes over and snaps off the insulated electrode. Thus the points of contact are always

kept clean and bright. The igniter is placed directly over the inlet valve to insure a good combustible mixture.

The Olds Gasoline Engine. — Fig. 12-99 shows the carbureter

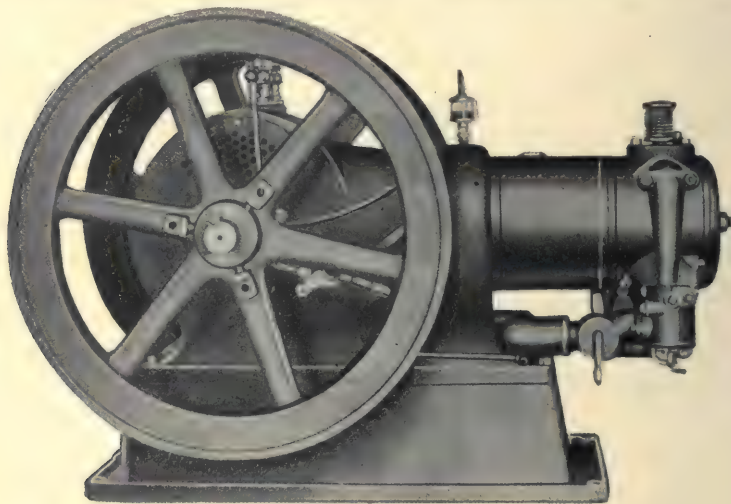


FIG. 12-99. — Olds Gasoline Engine.

side and Fig. 12-100 the valve construction of the Olds Type A gasoline engine. This is an engine of very simple design. Both

valves are of the poppet type, the upper, the inlet valve, being automatic while the exhaust valve is operated by bell crank and push rod. The latter is actuated by a cam. Fig. 12-99 shows the carbureter and its adjusting valve. Until recently the gasoline was fed to the carbureter from a small reservoir kept filled to a certain level by a small plunger pump driven from the shaft. In some of the recent designs this pump has been eliminated, the carbureter getting fuel by simple suction feed.

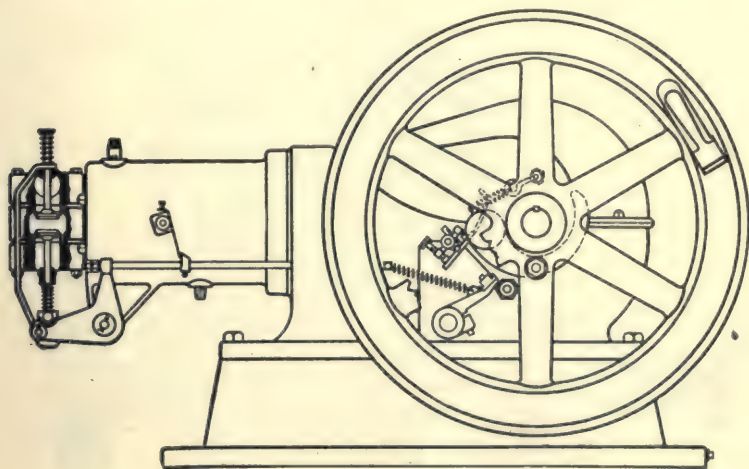


FIG. 12-100. — Olds Gasoline Engine.

The governor, which is of the fly-wheel type, is shown in Fig. 12-100. It operates to keep the exhaust valve open when the speed exceeds the normal, at the same time locking the inlet valve, so that no charge can enter the cylinder. The governor may be adjusted to give speeds varying from 200 to 600, and a change of about 50 turns per minute may be made while the engine is in operation.

The jump spark ignition system is used, which is unusual in small stationary engines. The governor serves also to throw the commutator of the system out of action should the engine fail to take a charge on a miss-stroke.

Type A Olds gasoline engines are built in six sizes from 3 to 18 horse-power.

Marine Gasoline Engines. — These engines are of either the

two- or four-cycle type, but in nearly all cases vertical. The maximum power developed in one cylinder, in the ordinary launch motor, is usually about 5-8 horse-power, higher power than this being obtained by the multiplication of cylinders.

Perhaps the majority of engines of this type, especially those of fairly high speed, 600 to 800, are equipped with the jump spark system; many builders, however, favor the hammer break ignition.

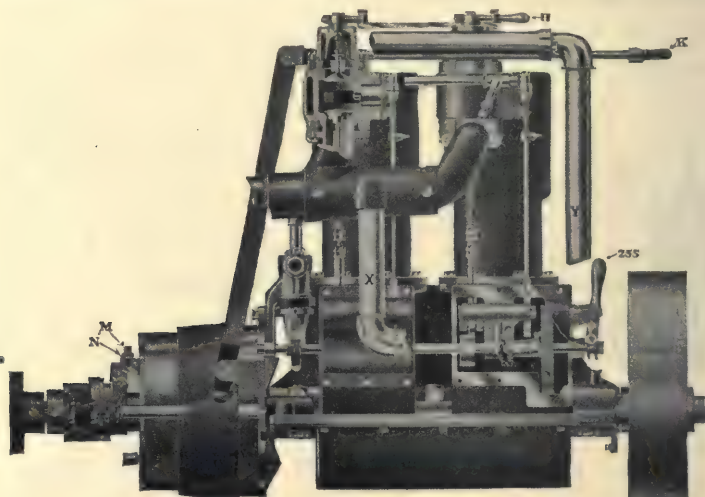


FIG. 12-101. — Strelinger Four-cycle Marine Engine.

Small gasoline boat engines are very rarely fitted with governor control. The speed is changed in most cases with the throttle or the spark, or both, as in automobile engines. A favorite way of checking the speed of small boats is by the use of a reversible propeller, in which case the speed of the engine need not be changed in any way.

The following two types of engines illustrate the general features of the four- and two-cycle marine engines.

The Strelinger Four-cycle Marine Gasoline Engine. — A 10 horse-power engine made by the C. A. Strelinger Company is illustrated in Fig. 12-101 and Fig. 12-102. In this design the heads are cast in one part with the cylinders. The latter are rigidly bolted to the crank case casting. The cam shaft and its drive are enclosed in the crank case. The cams on this shaft