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WORKS OF

PROFESSOR FORREST JONES

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THE GAS ENGINE

BY

FORREST R. JONES

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PREFACE.

The following discussion of gas and oil engines is presented in the manner which it is believed is the most suitable for a textbook for class instruction and for directing laboratory experimentation, as well as for meeting the needs of those who wish to learn to operate commercially and to test. The general consecutive order is: Descriptive, operative, testing for faults, theoretical, results of trials. The latter portion deals somewhat briefly with thermodynamics and theoretical cycles.

Gas producers are considered briefly from both the practical and theoretical viewpoints, the aim being only to give a clear insight of the principles and methods of manufacturing gas for power purposes.

The methods of locating and eliminating troubles have been given in considerable detail. The writer's experience in training something more than a hundred men in the commercial operation of gas and oil engines has been fully convincing as to the need of complete instruction in this particular.

The illustrations are, with one or two exceptions, representative of American practice, but the text is based on information gained by personal observation of motors in Germany, Belgium, France, and England, as well as operating experience in America.

The proof was kindly read by Mr. Charles E. Ferris, Professor of Mechanical Engineering, and the electrical portion also by Mr. Charles E. Perkins, Professor of Electrical Engineering, both in the University of Tennessee. The criticisms and suggestions of these gentlemen led to important modifications and additions.

F. R. J.

December 21, 1908.

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THE GAS ENGINE

CHAPTER I.

TYPES OF MOTORS, IMPULSE FREQUENCY, SCAVENGING, REVERSING.

1. **Introductory.** — In the operation of the internal-combustion motor of the reciprocating piston type, fuel is rapidly burned, or exploded, in an enclosed space, and the increase of pressure thus produced is utilized to drive out a piston which is connected more or less directly to a crank shaft, so that the energy of combustion is transmitted to the latter in such a manner as to cause it to rotate and have capacity to deliver power for the performance of useful work.

In nearly all of the smaller internal-combustion motors, a single piston reciprocates in the round bore of a cylindrical part, the cylinder, which is closed at one end, completely and permanently in some types, and in other types is pierced with ports for the admission of the charge and the expulsion of the gaseous products of combustion. These ports are intermittently closed by valves. The end of the cylinder next the crank shaft is left open. In such a construction the piston is long, of the type called a "trunk piston."

In modern designs the enclosed space at the end of the cylinder and into which the piston does not enter is called the **"combustion chamber."** The name **"compression space"** is also applied to it for the reason that, in modern practice, a cylinderful of combustible mixture is compressed into it before burning.

There are several modifications of and variations from this simple form of motor, the more important of which will be considered later.

The parts of the motor with which the hot gases come in contact receive considerable heat from the gases. Unless some means is provided for **cooling** these parts, they become too hot for satisfactory operation. This applies especially to the parts

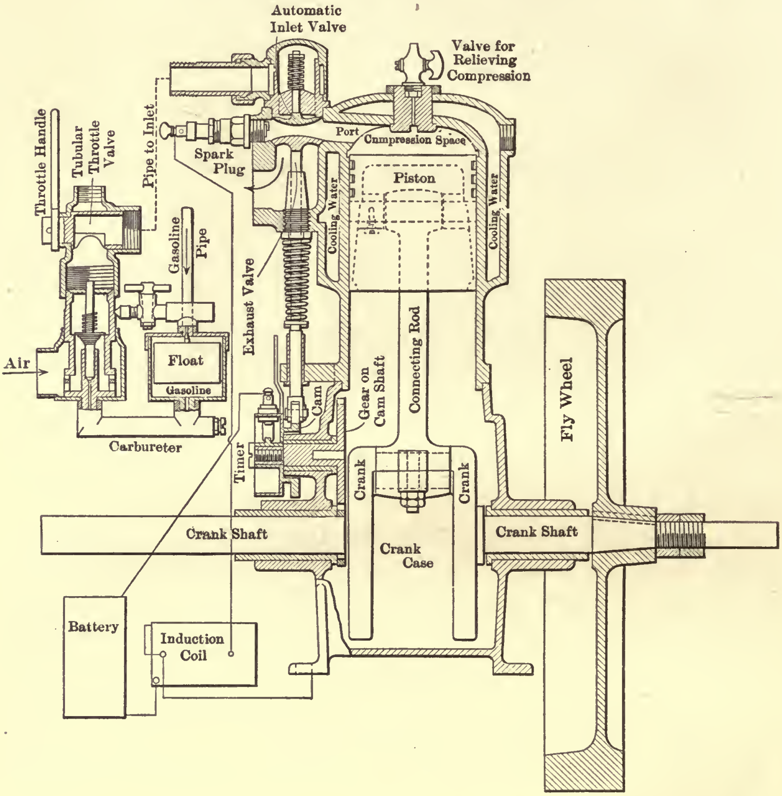


FIG. 1.

Section of Single-Cylinder, Single-Acting, Four-Cycle Motor with Diagrammatic Arrangement of Carbureter and Ignition System.

The float in the carbureter reservoir has a needle valve at the top which closes the opening of the gasoline supply pipe when the float rises and maintains a constant level of the gasoline lower than the spray nozzle in the air passage.

The gear on the cam shaft is twice the diameter of its mate on the crank shaft, so that the cam shaft rotates at half the speed of the crank shaft. The cam lifts the exhaust valve and holds it open during every second upstroke of the piston.

The rotor of the timer is on the cam shaft and closes the battery circuit every second revolution of the crank shaft.

enclosing the combustion chamber and the port through which the spent gases pass out from the motor cylinder.

In small motors, some are cooled by water, some by oil, and some, a minor number, by air. Large motors are always water or oil cooled.

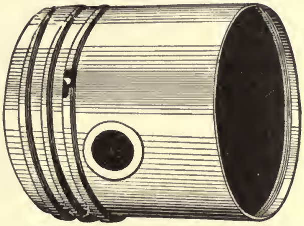


FIG. 2.
Piston. Trunk Type.

When water or oil is used for cooling, a jacket of the cooling liquid surrounds the combustion chamber more or less completely, and also part of the bore of the cylinder. The water or oil is circulated through the jacket space in most designs. In some it is not circulated. In very large motors the piston and exhaust valve are also water-cooled.

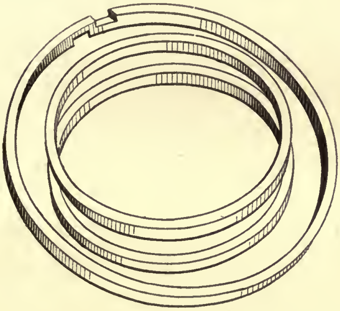


FIG. 3.
Piston Rings.

The larger ring shows a cut to allow the ring to expand against the cylinder wall to make a tight fit. The joint at the cut is made so that the surfaces parallel to the ends of the ring bear together to make the joint tight. The ring must be sprung together somewhat to fit the cylinder bore.

Air-cooled motors, always small in size, have projecting metallic lugs, fins, or other forms with which the air comes in contact. Some device, such as a fan, is generally used to circulate the air against the cooling parts, but sometimes only the motion of the motor through the atmosphere, as on an automobile, is depended on to bring fresh air in contact with the cooling parts. Sometimes the cylinder is encased, or air-jacketed, and a current of air forced through the jacket space.

Gas turbines have been constructed and tested in various forms, but none has yet proved successful. The efficiencies obtained have been extremely low. In some cases the motor, of the steam turbine type, would not develop enough power to drive the compressor for precompressing the air for combustion. Pulverized coal for fuel has been tested among others.

Combustion, as used in connection with internal-combustion motors, means the chemical union of hydrogen, carbon, and hydrocarbons of the fuel with the oxygen of the atmosphere, except in specific cases where pure oxygen, unmixed with any other chemical element, is taken as the supporter of combustion.

The fuel is the mechanical mixture, chemical compound, or element that combines more or less completely with the oxygen during combustion.

There is a certain, although quite wide, limit to the proportions of fuel and air in a mixture that can be ignited and burned in an internal-combustion motor; and there is a very limited range of the proportions of air and fuel that will give the maximum or nearly the maximum amount of power from the fuel and produce clean and complete combustion.

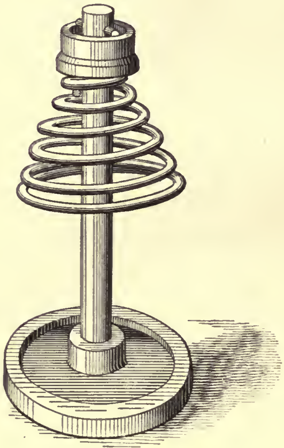


Fig. 4.

Valve and Closing Spring.

A saturated mixture of air and fuel cannot be burned in the cylinder of a motor. Air is saturated with the vapor of liquid fuel when it has assimilated all that it can, which is a definite amount. It is in a way analogous to the dissolving of salt in water. When the water has dissolved a certain amount, it becomes saturated and will not dissolve, or take into solution, any more of the salt.

Numerous methods of mixing the fuel with air and burning it have been tried commercially with more or less success. In some the mixture is made by bringing the fuel and air together, without burning, just before they enter the cylinder and while on their way to it. By this method there is never any dangerous amount of the combustible mixture on hand. In other methods the fuel is injected into the combustion chamber after the latter is filled with air. In still others the mixture is made in quantity outside the combustion space and then forced into it. In some of the early types of motors the air-and-gas or air-and-vapor mixture is drawn into the cylinder by suction and ignited at about atmospheric pressure. It was found later that greater economy of fuel and more power could be obtained from a given size of cylinder by compressing the charge before igniting it. All modern internal-combustion motors operate either by compressing the charge of combustible mixture before ignition or by compressing the air and then injecting the fuel, in this case liquid, into the compressed air.

The cycle on which the internal-combustion motor operates is the principal means of distinguishing one type from others. Cycle, in this use, means the series of changes through which each charge of combustible mixture passes from the time any process of change of volume, pressure, or chemical action begins on it until it passes, or is free to pass, out of the motor. The cycle of a single-acting, single-cylinder motor such as described above is not changed by the addition of cylinders that are duplicates of the first in their action on the charge. Neither is the cycle changed by making the motor double acting so that the piston receives an impulse to drive it first in one direction and then in the other, provided all the charges are acted on in the same manner.

2. Beau de Rochas- or Otto-Cycle Motors. — In motors approaching the theoretical Otto cycle most closely a charge of combustible mixture in the gaseous state and at a pressure somewhat less than atmospheric is taken into the cylinder, then compressed into the combustion chamber by the instroke of the piston and ignited at about the time the compression stroke is completed. (Ignition may occur slightly before, at, or slightly after the completion of the compression stroke.) Combustion takes place at nearly constant volume, accompanied by increase of temperature and pressure. The increased pressure forces the piston out, and the temperature and pressure drop on account

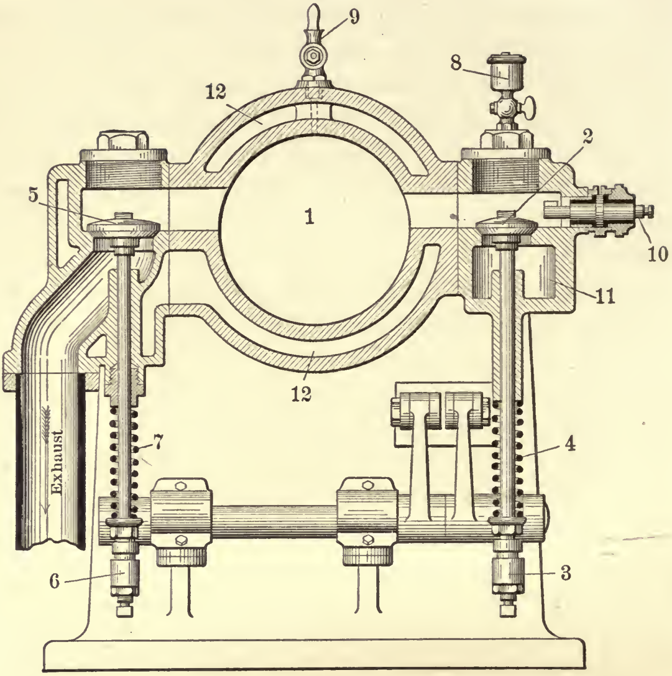


FIG. 5.

Section through Combustion Chamber and Ports of Single-Cylinder, Four-Cycle, Water-Cooled Gasoline Motor. Horizontal Stationary Type.

1. Cylinder bore.
2. Inlet valve.
3. End of lifting arm for inlet valve.
4. Closing spring for inlet valve.
5. Exhaust valve.
6. End of lifting arm for exhaust valve.
7. Closing spring for exhaust valve.
8. Priming valve with measuring cup for introducing gasoline into combustion space for starting motor when very cold.
9. Compression relief valve located part way down barrel of cylinder. For partially relieving compression when starting by hand.
10. Movable portion of contact (low tension) igniter surrounded by graphite bearing (not insulated).
11. Mixture passage.
12. Cooling-water space.

of the expansion. An exhaust port is opened just before the end of the stroke, and enough of the products of combustion escape in the gaseous state to allow the pressure in the cylinder to fall to or near atmospheric. This completes the cycle, although there are some of the hot gases still remaining in the cylinder. The remaining gases are useless in performing work, for they exert no appreciable pressure to drive the piston on account of having direct connection with the atmosphere.

The method of removing partly or completely the inert gas still remaining in the cylinder, and of introducing another charge of combustible mixture is not a part of the real cycle, but, since some work is done on the charge before its introduction into the cylinder, the removal of the products of combustion and the introduction of a fresh charge must be considered as auxiliary to the real cycle. The two usual methods of clearing out part of the inert gases of combustion (they are seldom completely cleared out) after they have fallen to atmospheric pressure, and introducing a new charge, have given to motors operating on the Otto cycle the names by which they are commercially known. The two types are designated as "four-cycle" and "two-cycle."

The "four-cycle" motor makes an exhaust stroke of the piston to expel part of the gases remaining after the real cycle is completed, and then a suction stroke to draw in a new charge, thus making four strokes in all from the beginning of one cycle to the beginning of the one that succeeds it.

In the "two-cycle" motor the elements that make up the combustible charge are compressed slightly, either together or separately, before entering the motor cylinder, then allowed to enter the cylinder and drive out most of the residual gases while the piston is at and near the out position. The inlet and exhaust ports are necessarily open simultaneously during this operation. There are two strokes for each cycle.

The terms "two-cycle" and "four-cycle" are indefinite in themselves, and also for the reason that they can be applied respectively to any motor making either two or four strokes per cycle. But by common usage they have a definite meaning in reference to the Otto-cycle motor.

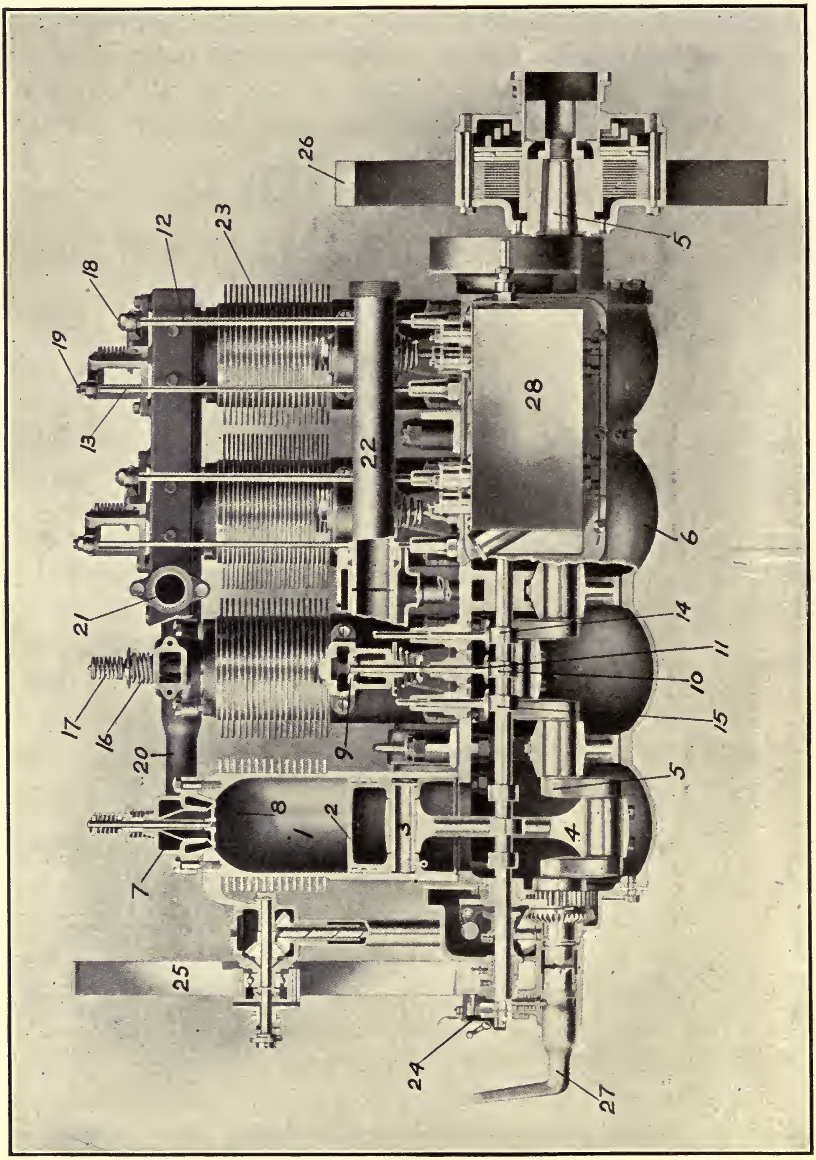


Fig. 6.

Fig. 6. (See also Figs. 7 and 8.)

Four-Cylinder, Four-Cycle, Air-Cooled Automobile Motor.
The H. H. Franklin Manufacturing Company, Syracuse, N.Y.

1. Cylinder.
2. Piston.
3. Piston pin (or wrist pin).
4. Connecting rod.
5. Crank shaft.
6. Crank case.
7. Inlet valve, hollow.
8. Exhaust valve, concentric with inlet valve.
9. Auxiliary exhaust valve, poppet type.
10. Cam for lifting auxiliary exhaust valve.
11. Cam follower for auxiliary exhaust valve.
12. Lifting rod for inlet valve.
13. Lifting rod for exhaust valve.
14. Cam for opening inlet valve.
15. Cam for opening exhaust valve.
16. Closing spring for inlet valve.
17. Closing spring for exhaust valve.
18. Adjusting screw for inlet valve.
19. Adjusting screw for exhaust valve.
20. Inlet pipe.
21. Exhaust pipe.
22. Auxiliary exhaust pipe.
23. Cooling flanges.
24. Timer. Only upper part shown.
25. Fan for cooling the cylinder.
26. Fly wheel.
27. Starting crank.
28. Oil reservoir for lubricating oil.

Gas- and Vapor-Burning Motors.

3. Four-Cycle Motors. — Motors operating approximately on the Otto or Beau de Rochas cycle and making four single strokes of the piston for each cycle are commonly known as "four-cycle" motors, as already stated. The four strokes of the piston correspond to two revolutions of the crank shaft and flywheel in motors resembling in general appearance the ordinary reciprocating steam engine.

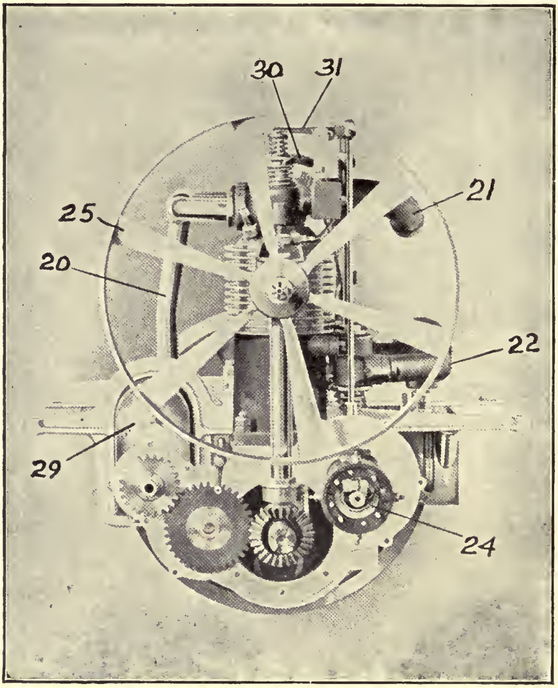


FIG. 7.

(See also Figs. 6 and 8.)

Four-Cylinder, Four-Cycle, Air-Cooled Automobile Motor.

20. Inlet pipe.
21. Exhaust pipe.
22. Auxiliary exhaust pipe.
24. Timer.
25. Fan for cooling the cylinder.
29. Magneto.
30. Rocker arm for inlet valve.
31. Rocker arm for exhaust valve.

The four-cycle motor of the usual type has two ports leading into the combustion chamber; one through which the combustible charge of mixed air and gas, or air and vapor, enters, and the other through which the inert gases remaining after combustion escape after expanding against the out-moving piston. Both ports have valves to close them. When permanent gas under pressure, as in gas mains for lighting, is used for fuel, a fuel valve is frequently used to prevent the flow of gas into the air passage or mixing chamber during the time the motor is not taking in a charge.

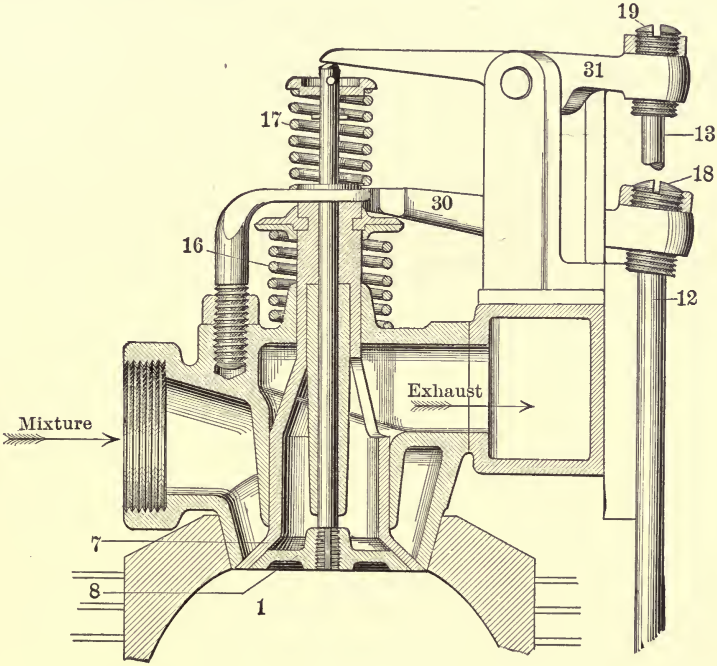


Fig. 8.

(See also Figs. 6 and 7.)

Concentric Inlet and Exhaust Valves for Air-Cooled Automobile Motor.

1. Cylinder.
7. Inlet valve, hollow.
8. Exhaust valve, poppet type, concentric with 7.
12. Lifting rod for inlet valve.
13. Lifting rod for exhaust valve.
16. Closing spring for inlet valve.
17. Closing spring for exhaust valve.
18. Adjusting screw for inlet valve.
19. Adjusting screw for exhaust valve.
30. Rocker arm for inlet valve.
31. Rocker arm for exhaust valve.

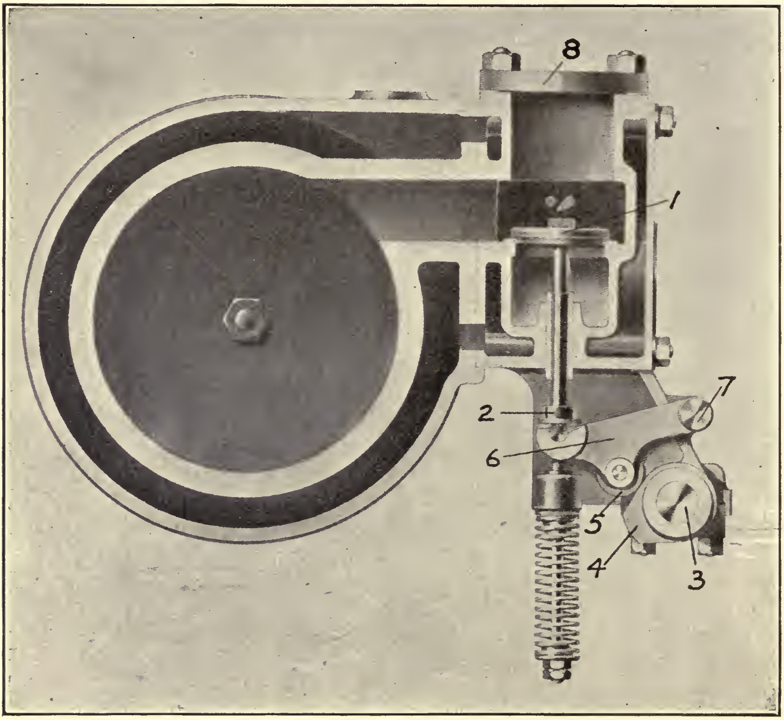


FIG. 9.

Cross-Section of Motor Cylinder and Valve Chest, showing Valve-Lifting Mechanism.

1. Valve.
2. Collar fastened to valve stem.
3. Cam shaft, lay shaft or half-speed shaft.
4. Lobe of cam.
5. Roller follower pressing against cam.
6. Rocker arm pivoted at 7 and lifted by cam 4 so as to open the valve 1.
7. Pivotal support for 6.
8. Cover for valve chest.

The low-tension ignition points (contact points) show just above the valve.

The intensity of compression is regulated by means of the valve chest cover 8. For natural gas, gasoline, etc., the almost flat-bottomed cover shown in place is used. But for higher compression, as for producer gas, or blast-furnace gas, a cover with a projection for filling the space between the cover and port is used. See Fig. 10.

The action of the moving parts of the motor in conjunction with the different steps of the heat cycle can be followed by starting with any of the events that occur. It is convenient to begin with the suction or charging stroke, which is not part of the heat cycle.

First Stroke. Four-Cycle Motor. — Charging, intake or suction. The piston, starting from its position nearest the combustion chamber, draws in a charge by suction during the outstroke. The inlet valve either opens by suction automatically against the resistance of a comparatively weak spring, or is opened mechanically against a fairly strong spring. The inlet valve closes at, or about, the completion of the suction stroke.

Second Stroke. Four-Cycle Motor. — Compression. The piston, returning during the instroke, compresses the charge into the combustion chamber. Both the inlet and exhaust valves remain closed during the compression stroke.

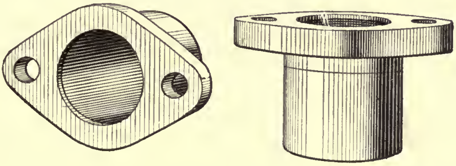


Fig. 10.

Covers for Valve Chest of Fig. 9. Covers are of different depths to give different degrees of compression according to the fuel used.

The compressed charge is ignited just before, at, or very slightly after the completion of the compression stroke. Ignition is accomplished by an electric spark, electric arc, a flame, or a hot piece of metal or other substance.

Third Stroke. Impulse Stroke. — Completion of combustion, expansion. Combustion, producing rise of both temperature and pressure, is generally well under way by the time the piston has made an appreciable part of the stroke following compression. Combustion is completed and the increased pressure drives the piston out, allowing expansion of the gases as the piston moves. When the piston is well toward the completion of the impulse stroke, the exhaust valve is mechanically opened against the

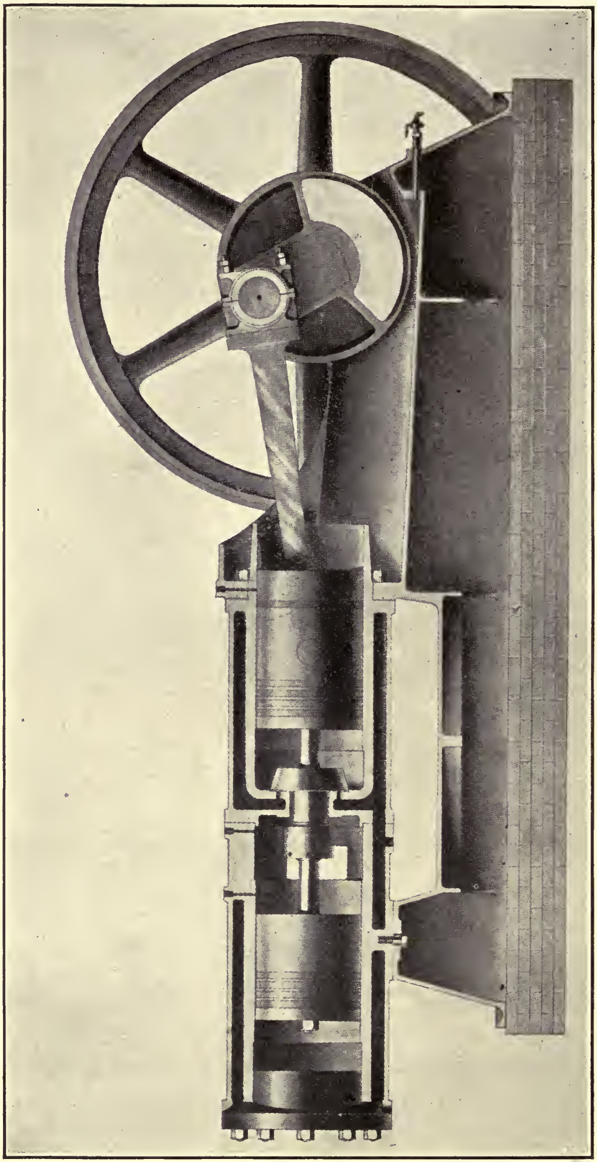


Fig. 11.

Two-Cylinder Tandem Single-Acting Gas Engine. Longitudinal section. The Alberger Company, Buffalo, N.Y.

pressure of the gases in the cylinder and of a stout spring. The hot, inert gases partly escape by expansion.

Fourth Stroke. Four-Cycle Motor. — Expulsion of inert gases. The exhaust valve is kept open, and the piston, moving toward the combustion chamber, expels part of the remaining gases. The exhaust valve then closes at, or more generally slightly after, the completion of the exhaust stroke.

In a single-acting, single-cylinder, four-cycle motor operating on the Otto cycle and having the piston joined directly to the crank by means of a connecting rod, the crank receives an impulse only once in two revolutions. This necessitates a very heavy or large-diameter fly wheel to secure reasonably steady running.

4. **Auxiliary Exhaust Port.** — In a small proportion of four-cycle motors, an auxiliary exhaust port is provided in the wall of the cylinder where it is uncovered by the motion of the piston just before the completion of the outstroke. When the auxiliary port is thus uncovered just before the completion of the impulse stroke, a considerable portion of the burned gases escapes through it on account of their expansion. By opening the valve of the customary exhaust port leading out from the combustion chamber at the usual time, two exhaust passages for the escape of the products of combustion are provided, and the release of the gases can be made so rapid that there is practically no back pressure remaining to resist the motion of the piston at the moment of beginning its exhaust stroke. The auxiliary port is again covered by the piston soon after the beginning of the exhaust stroke, and the remaining inert gases are partly expelled by the motion of the piston, the gases passing out through the port in the combustion chamber.

The auxiliary exhaust port has a valve in some designs, but none is used in others. The valve is sometimes of the automatic check-valve type and is either a ball resting on its seat by its own weight only, or a spring-closed valve similar to that used for an automatic inlet. In other designs a mechanically operated valve is used in the auxiliary exhaust port.

5. **Atkinson Four-Cycle Motor.** — Some years ago Mr. Atkinson, in England, constructed a single-cylinder, single-acting,

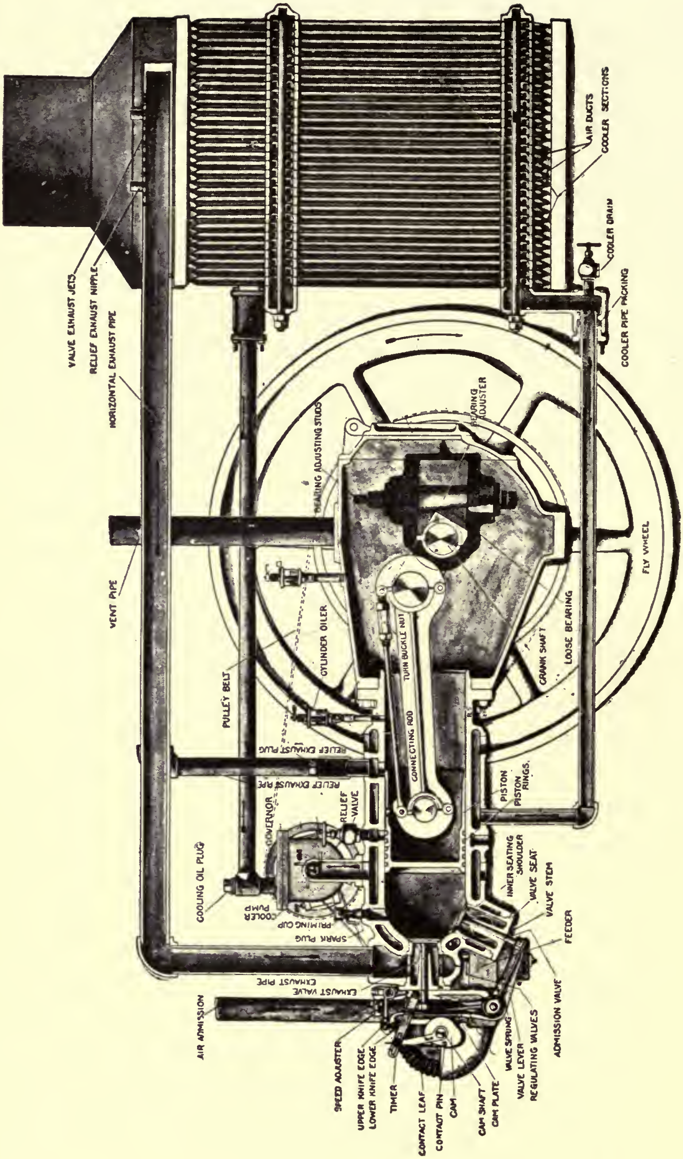

VALVE EXHAUST JETS
RELIEF EXHAUST NIPPLE
HORIZONTAL EXHAUST PIPE
VENT PIPE
PULLEY BELT
CYLINDER OILER
RELIEF EXHAUST PLUG
RELIEF EXHAUST PIPE
RELIEF VALVE
GOVERNOR
COOLING OIL PLUG
COOLER PUMP
PRIMING CUP
SPARK PLUG
EXHAUST PIPE
EXHAUST VALVE
AIR ADMISSION
SPEED ADJUSTER
UPPER KNIFE EDGE
LOWER KNIFE EDGE
TIMER
CONTACT LEAF
CONTACT PIN
CAM
CAM SHAFT
CAM PLATE
VALVE SPRING
VALVE LEVER
REGULATING VALVES
ADMISSION VALVE
FEEDER
VALVE STEM
VALVE SEAT
INNER SEATING SHOULDER
PISTON
PISTON RINGS
CONNECTING ROD
TURN BUCKLE NUT
CRANK SHAFT
LOOSE BEARING
FLY WHEEL
BEARING ADJUSTING STUDS
BEARING ADJUSTER
COOLER PIPE PACKING
COOLER DRAIN
COOLER SECTIONS
AIR DUCTS

FIG. 12.

FIG. 12. (See also Fig. 13.)

Two-Cylinder, Four-Cycle, Single-Acting, Oil-Cooled Motor for Traction Engine.
45 brake horsepower.
Adapted to burn gasoline or cheap grade kerosene. Electric ignition.
Hart-Parr Company, Charles City, Iowa.

Section through axis of one cylinder.

Oil-jacketed cylinder. Cooling oil circulated by rotary pump.

Exhaust jets create upward blast of air through cooler by ejector action. Horizontal pipe from relief (auxiliary) exhaust is hidden by exhaust pipe from compression end of cylinder.

One cam operates both the inlet and the exhaust valve of one cylinder. Cylinder barrel and breech cast in one piece.

Removable valve cages (with valve seats) ground to fit in cylinder casting.

During a five-hour continuous test of this motor under a nearly constant average load of 61.98 brake (delivered) horsepower the temperature of the cooling oil did not exceed 163° F., with a maximum atmospheric temperature of 77° F.

four-cycle motor operating on the Otto cycle, in which the crank made only one revolution for every four strokes of the piston. This was accomplished by means of a somewhat complicated system of links and other parts. The crank thus received an impulse every revolution. The piston moved farther in toward the combustion chamber on the exhaust stroke than on the compression stroke, in order to more completely free the cylinder from the inert gases of combustion.

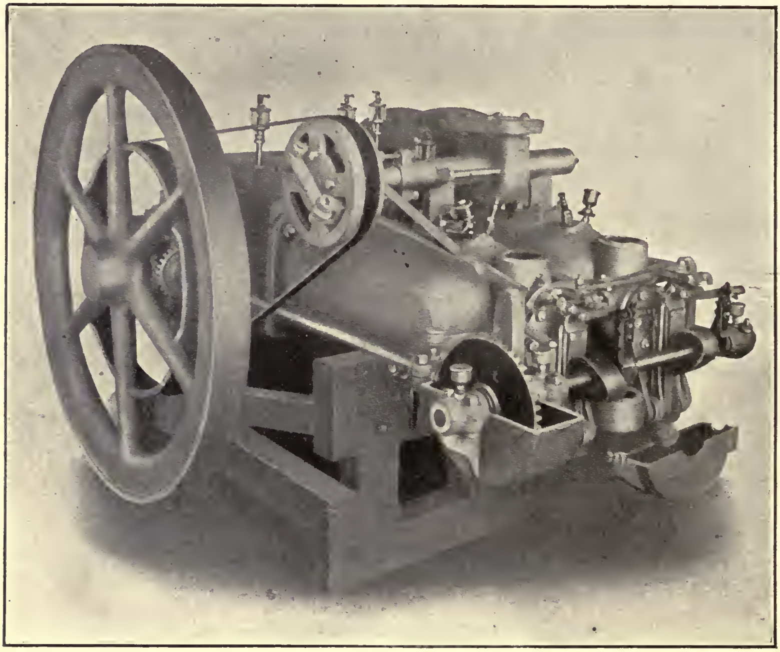


Fig. 13.

(See also Fig. 12.)

Two-Cylinder, Four-Cycle, Oil-Cooled Motor for Traction Engine, Unmounted. 45 horsepower. Adapted to burn gasoline or cheap grade kerosene. Hart-Parr Company, Charles City, Iowa.

The motor operated economically with regard to fuel consumption, and had good speed regulation, but the lack of mechanical balance of the moving parts was so serious a feature as to prevent its commercial adoption to any great extent.

6. "The Complete-Expansion Gas Engine." — Figs. 64a to 71. This is made as a four-cycle, double-acting tandem engine. It is the design of Mr. C. E. Sargent, and has several unique features.

When operating at any load less than its full capacity, air only is admitted during the early part of the charging stroke. Then gas also is admitted at a time determined by the governor, and continues entering until both air and gas are cut off before the completion of the charging stroke. At full load gas begins to enter at the same time as the air (at the beginning of the charging stroke) and both are cut off at the same instant. The instant of cutting off the mixture is invariable so far as automatic (governor) regulation is concerned, and is timed to suit the kind of gas used. The range of setting for the cut-off is from five-eighths to three-quarters of the stroke. After cutting off, the charge expands during the remainder of the charging stroke. The fixed point of cut-off determines the extent of compression, which is constant for all loads. Since producer gas can be compressed more without self-ignition than natural gas, the point of cut-off is set later for the former than for the latter. The heat value of the producer gas mixture is less than that of the natural gas, and this allows a higher compression without causing a higher terminal pressure at the end of the impulse (expansion) stroke. On account of cutting off the charge before the completion of the charging stroke, expansion is carried out further during the impulse stroke than in motors which admit the charge (air and mixture) during the entire intake stroke. The pressure at the time of opening the exhaust valve is well down toward atmospheric, hence the name "Complete-Expansion Gas Engine."

The cylinder volume is about twenty-five per cent greater than in the usual types of four-cycle motors of the same power, but it is claimed that the greater cost of construction on this account is more than balanced by the gain in economy on account of the more complete expansion.

Another feature of the engine is that there is only one port into each combustion chamber, which is unusual for either four-cycle or two-cycle motors. The charge enters and the burned gases escape through the same cylinder port. There is a small port with a by-pass valve for balancing the pressure on the poppet valve that closes the cylinder port, but its function does not include allowing the burned gases to escape. The by-pass valve is opened by cam action just before the exhaust is to take place.

On account of the extent to which the expansion is carried out, the burned gases are so cool at the time the exhaust valve opens that it is not necessary to water-cool the valve as in the usual types of large gas engines. The builders of the engine make the following statement regarding the temperatures of the burned gases:

"Aside from the greater economy of an engine which expands the charge to practically atmospheric pressure, the average temperature during the cycle is less and the engine is not subjected to the internal strains indigenous to the higher temperatures, — for example, the initial temperature in both types is about 3000° F., the terminal temperature in the ordinary engine is 1800° F., and in the complete-expansion engine 500° F., making the average temperature of the working stroke of the former 2400° F. and in the complete-expansion engine 1750° F."

The theoretical cycle which this motor approximates is shown in Fig. 135.

7. The Nuremberg motor in large sizes, and the **Gobron-Brillié motor** in small sizes for automobile and similar uses, both four-cycle, use an open-end cylinder, dispensing with cylinder heads. There are two pistons to one cylinder. The pistons are both connected to the same crank shaft so as to approach and recede from each other and the middle of the cylinder simultaneously. The one next the crank shaft has a connecting rod of the usual length and form. The rear piston has a crosshead at the end of the cylinder farthest from the crank shaft, and the crosshead is connected to the crank shaft by two connecting rods, one on each side of the cylinder (or cylinders). The cranks for the two pistons of one cylinder are at 180 degrees with each other, or, expressed otherwise, directly opposite each other. The ports are several small openings arranged circumferentially around the middle of the cylinder. The inlet and exhaust through these ports are controlled by valves in the usual manner.

This construction removes what is sometimes a source of serious trouble in large gas engines, that is, the fracture of the cylinder heads by heating and unequal expansion. There are no glands or stuffing boxes required for piston rods.

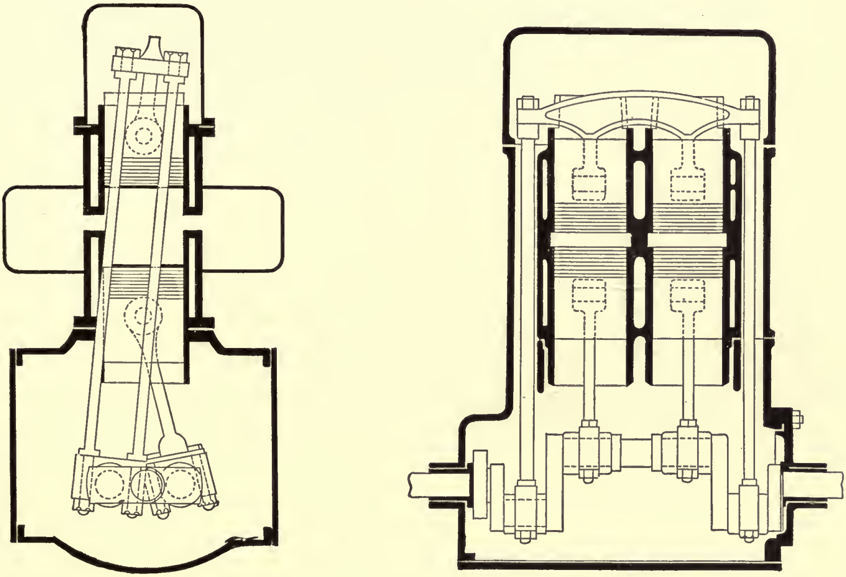


Fig. 14.

Open-End Cylinder Motor. Longitudinal sections at right angles to each other. Four-cycle. Two cylinders. Two pistons in each cylinder. Inlet and exhaust ports at middle of cylinder.

The two pistons in each cylinder approach each other during compression, and recede from each other during the impulse or expansion stroke. One impulse every revolution in the two-cylinder motor.

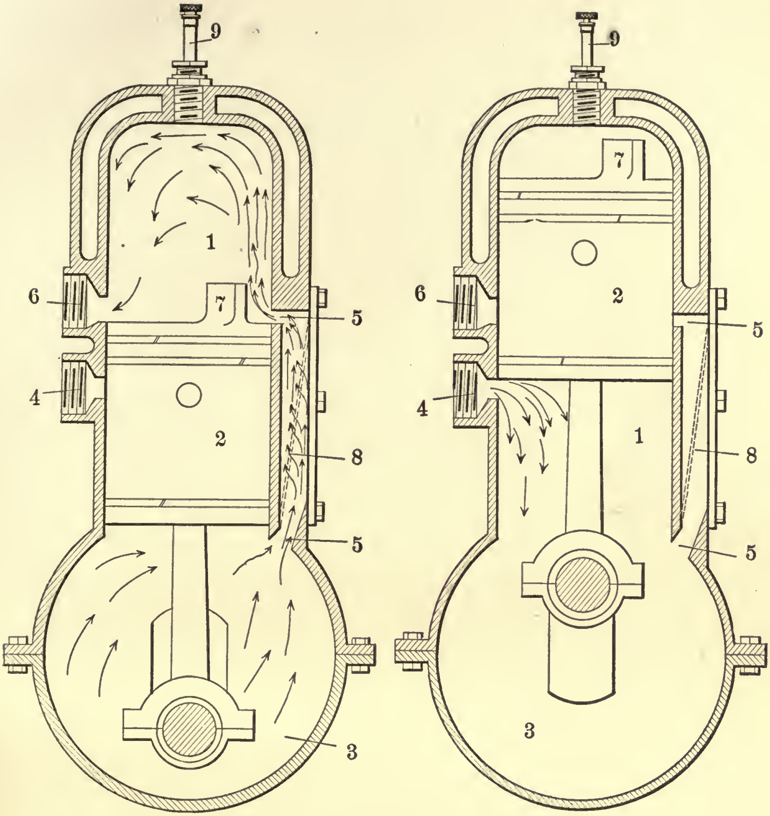
8. Two-Cycle Motors. — This name is generally applied to motors operating on the Otto cycle, and in which each piston makes only two strokes for each impulse it receives in a single-acting motor.

The two-cycle motor, in its simplest and most usual form, has its inlet and exhaust ports in the walls of the cylinder bore near the end farthest from the combustion chamber. Its action can be followed by starting with the piston in its position nearest the combustion chamber, and a compressed charge in the latter.

First Stroke. Two-Cycle Motor. — The compressed charge is ignited and burned, and the consequent increased pressure drives the piston outward as the charge expands. At the beginning of the outstroke the enclosed crank case is full of combustible mixture previously drawn in. The outstroke compresses this to some extent. When the piston is well toward the completion of the outstroke, it uncovers a row of small exhaust port-holes that pierce the cylinder walls and extend somewhat less than half way around it circumferentially. This allows part of the products of combustion to escape by expansion. The piston, continuing its outstroke, next uncovers a similar row of inlet port-holes that connect to the crank case. This allows a charge of the slightly compressed combustible mixture in the crank case to flow into the cylinder and drive out most of the remaining inert gases.

Second Stroke. Two-Cycle Motor.— The piston, now returning toward the combustion chamber, covers first the inlet port-holes, then the exhaust port-holes, and then compresses the charge till the end of the instroke is reached. During the instroke the piston also draws more mixture into the crank case by suction.

The mixture enters the crank case generally either through an automatic poppet valve in or near its walls or through a port in the bore of the cylinder that is uncovered when the piston has nearly completed its compression stroke (instroke). The latter port connects the crank case to the source of fuel and air supply. A motor constructed in the latter manner has no valves, and need have no moving parts but the piston, connecting rod, crank shaft, and the parts rigidly connected to them. This does not include the ignition system. This great simplicity makes this style of motor at once attractive on account of small cost of construction and absence of numerous parts to wear and get out of repair. There are certain features of its operation, however, that have prevented its adoption to as great an extent as the four-cycle motor. While it seems at first thought that the power developed per pound of weight of motor should be much more in the two-



Figs. 15 and 16.

Two-Cycle, Valveless, Three-Port Motor. Longitudinal sections.

1. Cylinder.
2. Piston.
3. Crank case.
4. Inlet to crank case.
5. Passage from crank case to inlet port of combustion chamber.
6. Exhaust port.
7. Baffle plate.
8. Fine-mesh wire screen to prevent back firing into the crank case.
9. Spark plug.

In Fig. 16 the piston has just completed the compression stroke (upstroke in this case) and uncovered the inlet port 4 to the crank case and mixture is flowing into the latter on account of the partial vacuum created in it by the upward movement of the piston.

Fig. 15 shows the piston after the charge has been burned and the piston moved down to the lower end of its stroke. The burned gases are passing out through the exhaust port 6 and the compressed mixture in the crank case is flowing into the combustion space. The baffle plate 7 deflects the entering charge upward so that it does not pass out of the exhaust port.

cycle than in the four-cycle motor, each, in fact, develops about the same amount of power per pound of weight.

When a two-cycle motor of the simple single-acting form just mentioned is changed to double-acting (with both ends of the cylinder closed as in most steam engines, and a combustion chamber at each end of the cylinder) it becomes impossible to initially compress in the crank case all the combustible mixture in order to force it into the combustion cylinder. The double-acting two-cycle motor therefore requires an additional cylinder for the initial compression of the charge. Numerous designs of double-acting two-cycle motors have been operated. In some the fuel and air are mixed on their way to the compression cylinder, as in the case of the single-acting motor, while in others the air is compressed in one auxiliary compression cylinder, and the gas, or a mixture of fuel vapor and air, too rich in combustible matter to burn, is compressed in another auxiliary cylinder, and the contents of the two auxiliary cylinders are mixed as they pass into the combustion cylinder. By this means there is no appreciable amount of combustible mixture ever on hand outside of the combustion cylinder. The liability to dangerous explosions outside of the combustion cylinder, which must be carefully considered for large motors, is thus eliminated.

9. **The Koerting Two-Cycle Motor** is of the double-acting type, with separate auxiliary compression cylinders for air and gas. Large motors of this type have been put into practical operation extensively both in this country and Europe. Many of them have been designed especially for using blast-furnace gas.

The Koerting motors, double-acting, are constructed with an inlet port leading into each combustion chamber and an exhaust port composed of a great number of small holes that pierce the cylinder wall circumferentially at the middle. The piston has a length but slightly less than that of the stroke. It covers the exhaust port except when near the end of its stroke in either direction. The same port is thus used for exhausting alternately from both ends of the cylinder. After the exhaust port has been uncovered and the inert gases have escaped till the pressure in the combustion cylinder has fallen to about that of the atmos-

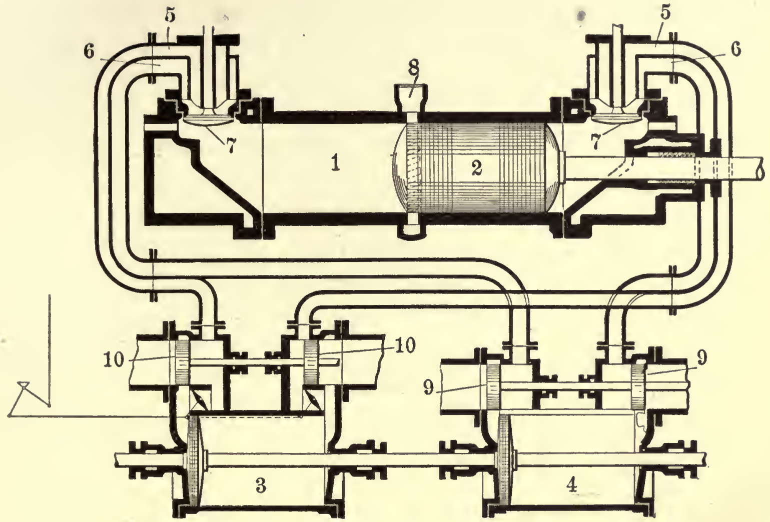


Fig. 17.

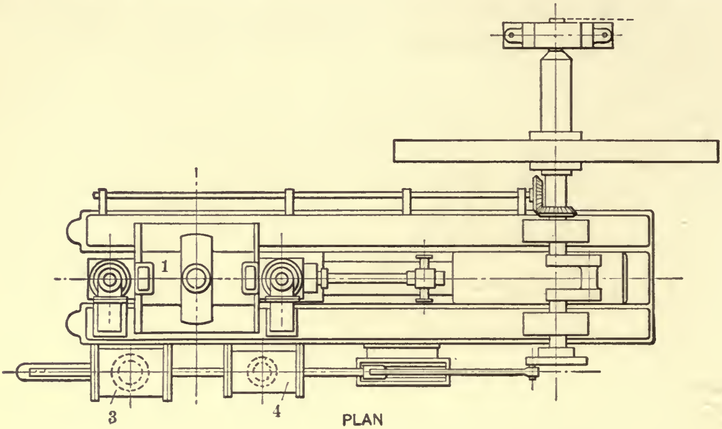
Koerting Two-Cycle, Double-Acting Gas Engine.

Diagram showing the arrangement of parts.

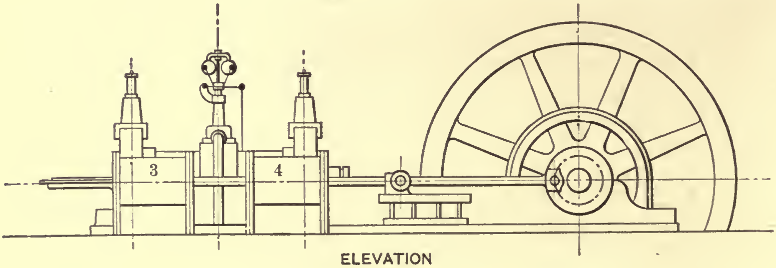
1. Combustion cylinder.
2. Piston, drum type.
3. Gas pump. Piston at left end.
4. Air pump. Piston at left end.
5. Air duct to inlet valve.
6. Gas duct to inlet valve.
7. Inlet valve.
8. Exhaust passage connecting to several small ports around the middle of the cylinder.
9. Air valve at pump.
10. Gas valve at pump.

The opening and closing of the inlet valves 7 do not vary either in time or extent. One of the inlet valves opens after the piston has moved away from it and uncovered the exhaust ports. The time and stroke of the air-pump piston and gas-pump piston do not vary. When the inlet valve of the combustion chamber opens, air, which has been compressed by the air pump, flows into the combustion cylinder. The piston of the air pump continues its compression stroke during this time. The governor controls the time at which gas, compressed by the gas pump, begins to flow into the combustion cylinder with the air. The gas and air mixture then continues to flow in till the inlet valve closes. The motor piston 2 is near the exhaust end of its stroke during the intake of charge. The process is then repeated for the opposite end of the combustion cylinder. The piston receives an impulse each stroke.

phere, the air inlet port is opened and air rushes in to scavenger the cylinder by driving out the remaining inert gases. If any of the air passes out of the exhaust port, there is no loss of fuel such as occurs if too much combustible mixture is brought in as in other types of two-cycle motors. After part of the compressed air has passed from the auxiliary cylinder into the combustion cylinder, the fuel inlet valve is opened, and the gas and remaining air mix as they pass into the combustion cylinder. Special forms



PLAN



ELEVATION

FIG. 18.

Koerting Two-Cycle, Double-Acting Gas Engine. Single cylinder. Plan and elevation. Made in units (single-cylinder) from 400 to 1500 horsepower.

1. Motor cylinder.
3. Gas-pump cylinder.
4. Air-pump cylinder.

The overhanging crank on the side opposite the flywheel is for driving the air pump and gas pump. The main connecting rod (for the motor piston) is not shown.

of port openings are adopted to cause the mixture to enter in such a way as to remain in and near the compression space, while the air that is not mixed with the fuel, but still remains in the combustion cylinder, stays next to the piston head. This stratification of the contents of the combustion cylinder is thought to give better economic results than other methods, and allows the use of very lean (low in capacity to produce heat) fuel, while, at the same time, the speed can be controlled by regulating the amount of fuel that enters for any stroke.

10. Brayton Motor and Cycle. — This cycle was invented by Mr. Brayton of Philadelphia, and a motor operating on it was constructed in 1873. The air and fuel were compressed by auxiliary compressors and delivered into separate tanks at a pressure somewhat greater than that of the maximum in the combustion cylinder. They were then allowed to flow toward the combustion cylinder and mix together just before entering it. The mixture then passed through a fine-mesh wire screen that guarded the port, and burned immediately after passing through the screen. The latter was to prevent the flame from backfiring into the port. The mixture was admitted to the combustion cylinder just as the piston was ready to start on the outstroke, and burned at a uniform pressure, practically the same as that in the tanks. The piston was forced out by the pressure, and the mixture was admitted during one-third of its stroke, more or less, and then the inlet valve closed and the highly heated contents of the cylinder expanded to drive the piston out to nearly the end of the stroke, when the exhaust valve opened and allowed them to escape till the pressure fell to about atmospheric. On the return stroke the residual gases in the combustion cylinder were compressed by the piston to nearly the same pressure as that of the fuel and air tanks. A small by-pass at the inlet valve allowed enough mixture to enter the combustion cylinder to keep a small pilot flame going constantly at the wire screen. This flame ignited the charge as soon as it began to enter the cylinder.

The cycle of the gases in the Brayton motor is accomplished partly in the air and fuel compression cylinders, and the remainder in the combustion cylinder.

Theoretically the Brayton cycle is of such a nature as to deserve careful consideration with a view to its commercial application. The chief difficulties that the inventor states he met in the motors constructed to operate on it were with the wire gauze screen and other devices used to prevent back firing, and from the extinguishing of the pilot flame and consequent stoppage of the motor. Many devices in addition to the wire gauze were tried without entire success in any case. The addition of air and gas compressors may seem a serious objection to this motor in comparison with the simpler ones for operating on the Otto cycle. Yet it is to be remembered that the larger Otto-cycle, two-cycle motors (Koerting motors) have auxiliary compressors for the air and the fuel. The absence of high pressures of explosion in the Brayton motor is well worthy of consideration, especially for very large motors. A central compressor plant for supplying compressed air and fuel to several motors would simplify the equipment of a power plant.

Oil-Burning Motors.

11. In the motors that have been discussed the combustible charge enters the cylinder either in the form of a mixture of gas and air or of vapor and air. There is another class of internal-combustion motors, in less general, but extensive, use, whose fuel is injected into the cylinder, combustion chamber, or an extension of the latter, in liquid form. Kerosene and other of the less volatile distillates of petroleum are used, and, in one or two designs, even the crude petroleum itself is used for fuel. The high cost of kerosene in comparison with the heavier or less refined oils is the chief objection to its use in large motors.

12. **The Hornsby-Akroyd Oil Motor** has a somewhat jug-shaped hollow metal vaporizer attached by the neck end to the end of the combustion cylinder so as to form an extension of the latter. The cylinder otherwise resembles that of an ordinary four-cycle, single-acting, Otto-cycle motor. The vaporizer space and cylinder space are joined only by the comparatively small opening of the neck connection. Inlet and exhaust ports

connect with the combustion chamber. The liquid fuel is injected into the vaporizer through one or more minute nozzles so that it enters as a spray.

The vaporizer, usually of cast iron, is kept at a dull-red heat. Before starting the motor, the vaporizer is heated by an external flame, but after the motor is running, the heat of combustion inside the cylinder and vaporizer keeps the latter hot enough.

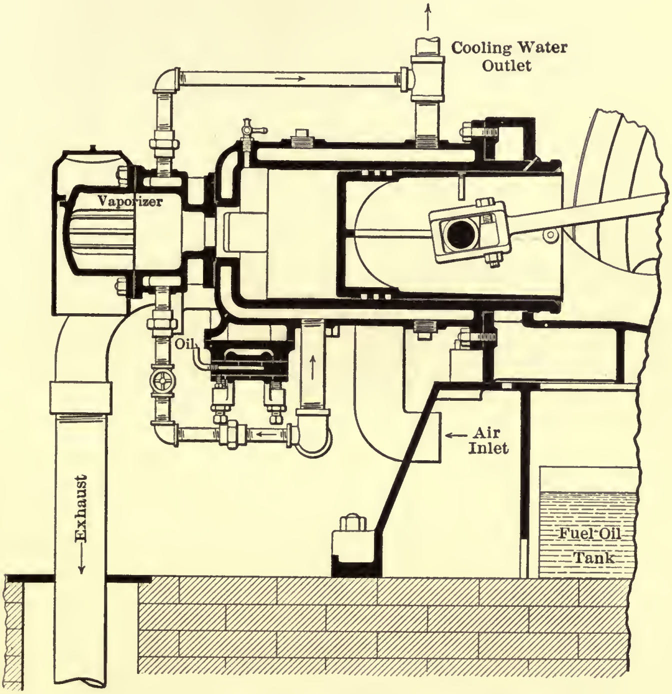


FIG. 19. (See also Figs. 20, 21, 22, 23, 24, 72.)

Hornsby-Akroyd Four-Cycle, Single-Acting Engine for Kerosene and Distillates. De La Vergne Machine Company, New York, N.Y. Longitudinal section through cylinder.

Oil is injected into the internally ribbed vaporizer during the suction stroke and vaporized by the heat of the vaporizer. The compression stroke forces the air into the vaporizer and the mixture is ignited at about the completion of the compression stroke by the heat of the vaporizer.

The amount of fuel oil injected is controlled by a governor acting on a by-pass valve connected to the outlet passage of a plunger pump.

The operation is almost exactly the same as that of a four-cycle, Otto-cycle gas or vapor motor. Taken step by step, it is, dealing with the strokes of the piston:

First Stroke. — Charging, intake or suction. The piston, starting from its position nearest the combustion chamber, draws in air to an amount practically equal to the volume of displacement of the piston during its outstroke. Oil is forced into the vaporizer during all or part of the outstroke, and vaporized

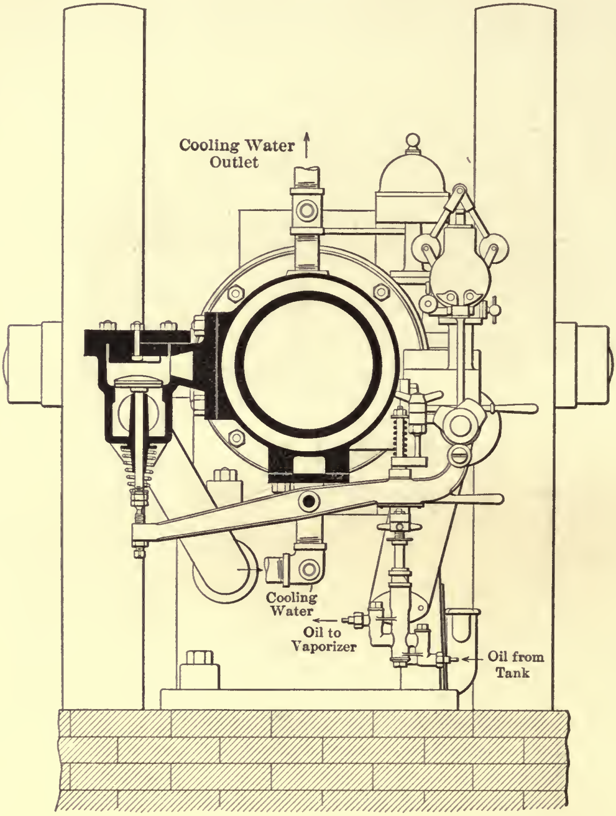


Fig. 20.

Transverse Section of Hornsby-Akroyd Oil Engine.

The fuel-oil pump is shown at the bottom of the figure, and the governor at the right-hand upper part.

more or less completely. The air inlet valve opens at about the time of beginning the stroke, and closes at or about the end of the stroke.

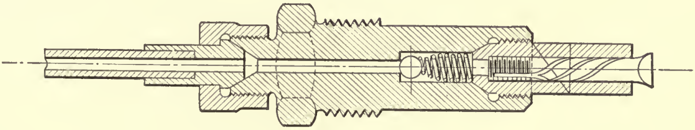


FIG. 21.

Injector Nozzle Used on Hornsby-Akroyd Oil Engine.

The oil enters through the pipe at the left end, passes through the ball check valve and around the helical grooves in the pin or plug at the right end, where it escapes into the vaporizer.

Second Stroke. — Compression and completion of vaporization. The piston, returning on the instroke to its first position, compresses the air and oil vapor. If any of the oil remains unvaporized at the beginning of this stroke, its vaporization is completed during the early part of compression. The compression of the air forces part of it in through the narrow neck into the vaporizer and mixes it with the vaporized fuel. The air is heated by the compression and by heat received from the hot parts of the motor. The heat of the vaporizer, together with that of compression, causes the mixture to ignite at about the time of completion of

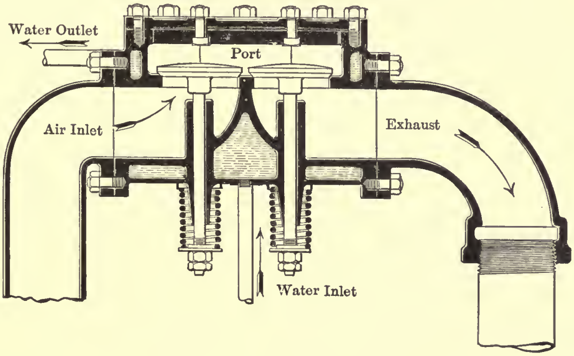


FIG. 22.

Air Inlet and Exhaust Valves of Hornsby-Akroyd Oil Motor.

Both valves are mechanically operated.

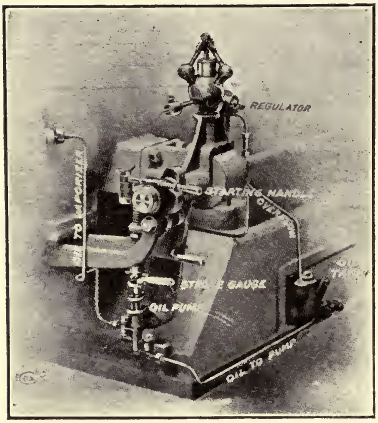


Fig. 23.

Oil-injecting System of Hornsby-Akroyd Oil Engine. The pump discharge is connected to both the injector nozzle in the vaporizer and the regulator.

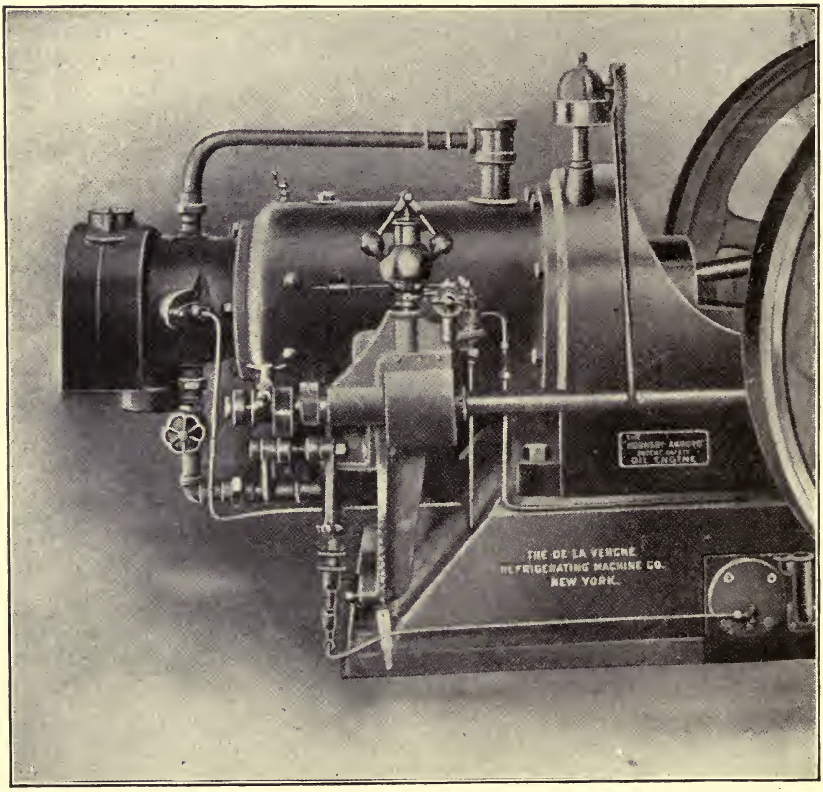


Fig. 24.

Full Side View of Cylinder End of Hornsby-Akroyd Oil Engine.

the compression stroke. The inlet and exhaust ports are both closed during most or all of the compression stroke.

Third Stroke. — Impulse stroke. Completion of combustion. Expansion. Opening of exhaust port. Combustion, accompanied by rise of both temperature and pressure, is generally well established at the beginning of the impulse stroke. It is completed during the early part of the impulse stroke, and the increased pressure drives the piston outward, allowing the gases to expand as the piston moves. When the piston has nearly reached the end of the impulse stroke, the exhaust valve is opened against the resistance of the gas pressure and a stout spring. The contents of the cylinder partly escape by expansion.

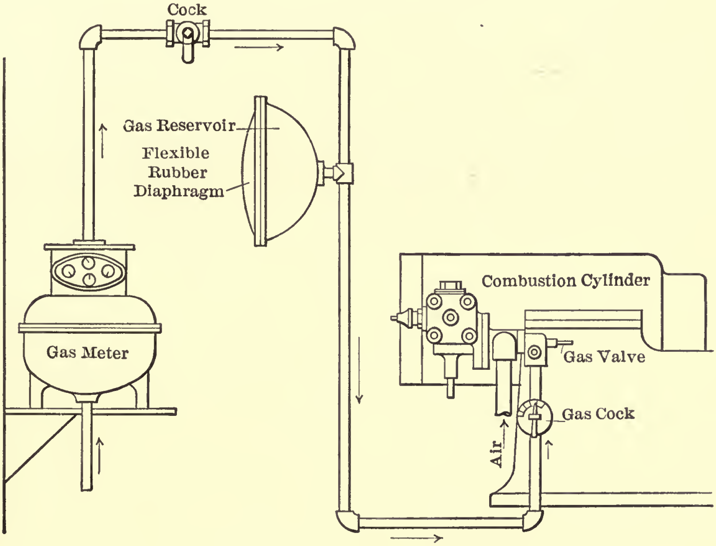


FIG. 25.

Gas Connections for Using Gas from Small Mains or through a Small Connecting Pipe. The gas reservoir fills between the suction or charging strokes of the piston, so that the flexible diaphragm is distended as shown. The suction stroke takes gas from the reservoir, so that the diaphragm is drawn in. A rubber bag is often used instead of the type of reservoir shown.

Fourth Stroke. — Expulsion of inert gases. The exhaust valve is kept open, and the piston, moving in toward the combustion chamber and vaporizer, expels a portion of the residual gases.

The exhaust valve is closed at, or slightly after, the end of the exhaust stroke. This completes the series of events.

In order that ignition shall occur at the proper instant in carrying out the cycle in the Hornsby-Akroyd motor, it is necessary to have the intensity of the compression made suitable to the purpose. Too high compression causes ignition too long before the completion of the compression stroke, and too low compression will not cause ignition soon enough, or, if very low, not at all. The usual method of adjusting the compression is by varying the effective length of the connecting rod so as to cause the piston to pass further, or not so far, as the case may be, into the combustion space end of the cylinder. Ordinarily this is done in preliminary trials before putting the motor into permanent service. The length of the connecting rod is fixed and a trial made to determine when ignition occurs and also the efficiency of the motor. If found unsatisfactory, the length of the connecting rod is changed and fixed at another length and another trial made, and so on.

The necessity of adjusting the length of the connecting rod for each motor arises from the fact that, since the vaporizer and cylinder are usually of cast metal, there is a variation in the size of those made from the same patterns; and similarly, in large motors, in other cast parts, as the piston and frame. In addition to this there may be other causes necessitating a slight difference in the compression pressures of two practically similar and equal size motors made from the same patterns. A slight difference in the form or composition of the metal in the two vaporizers or two motors made from the same patterns may make it necessary for one to have higher compression pressure than the other in order to produce ignition at the proper time. The compression also has to be regulated to suit the fuel used.

The compression of the air is carried to about the same pressure for this motor as is used in gasoline and naphtha motors with electric spark or arc ignition.

13. Oil-Burning Motor with Bulb Ignition. — In this motor a comparatively small hollow bulb of metal is attached to the closed end of the cylinder, and the space in the bulb is connected

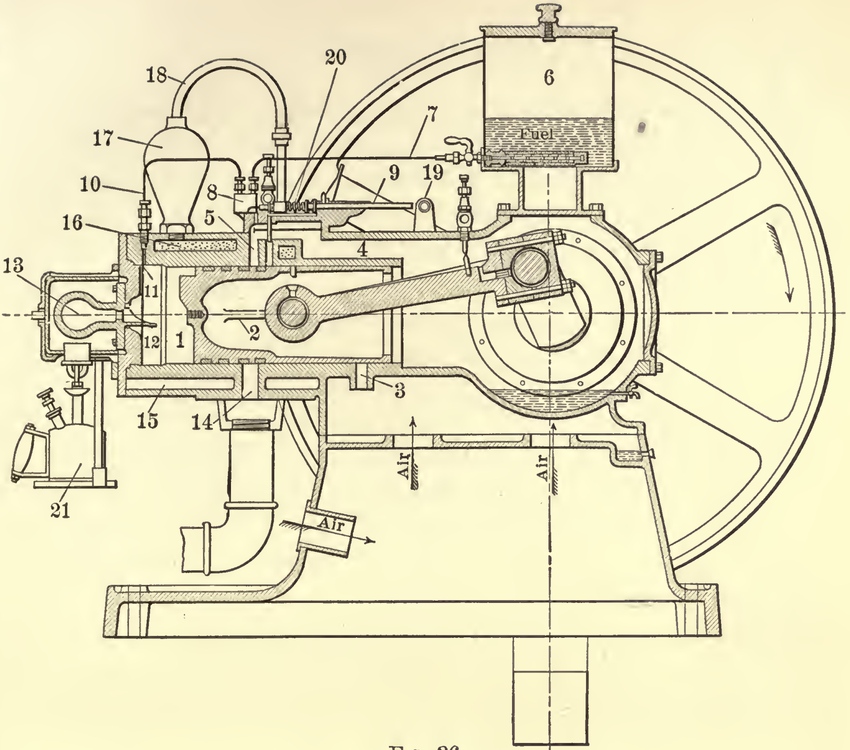


Fig. 26.

Mietz & Weiss Oil Engine. For kerosene oil and distillates. Two-cycle, single-acting. $2\frac{1}{2}$ to 75 horsepower per cylinder.

1. Combustion space of cylinder.
2. Piston.
3. Air port into crank case.
4. Air passage from crank case into combustion chamber.
5. Inlet port for air into combustion chamber.
6. Fuel-oil tank.
7. Oil pipe to plunger pump for injecting oil into the combustion chamber.
8. Pump for forcing oil into combustion chamber.
9. Pump plunger.
10. Oil pipe to injecting nozzle.
11. Nozzle for injecting fuel oil into combustion chamber.
12. Baffle plate opposite oil nozzle.
13. Hot bulb for ignition, cast iron.
14. Exhaust port.
15. Water in lower part of jacket for cooling cylinder.
16. Steam in upper part of jacket space.
17. Steam dome.
18. Steam pipe from steam dome to air inlet port 5.
19. Oscillating arm for forcing in the pump plunger at each revolution of the crank shaft.
20. Coil spring for forcing pump plunger outward.
21. Torch for heating the bulb 13 when starting cold.

The amount of fuel oil forced into the combustion chamber during each compression stroke of the piston is regulated by a governor (not shown). The governor varies the movement of the arm 19 toward the pump plunger 9 so as to give the plunger less motion when the speed of the motor increases. The amount of oil injected is thus reduced as speed increases. It is not necessary to time the injection of oil with any great accuracy.

The cooling water does not flow through and out of the jacket space, but is vaporized in it and the steam carried into the combustion chamber along with the air. See Fig. 27 for constant-level water tank that is attached to the side of the motor cylinder and connected to the jacket space.

to the combustion chamber by a short, small duct. The cylinder resembles that of an ordinary four-stroke, Otto-cycle motor, as do the other principal parts. The heat cycle is nearly the same as that of the usual types of gasoline and naphtha motors operating on the Otto cycle and making four strokes of the piston per cycle. The inlet and exhaust ports open into the combustion chamber.

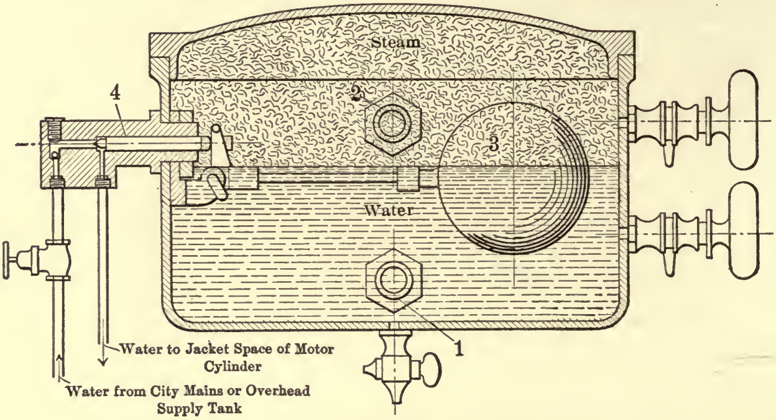


FIG. 27.

Constant-Level Water Tank for Mietz & Weiss Horizontal Oil Engine. This tank is connected to the side of the motor cylinder and communicates with the water-jacket space. The level of the water in the jacket space is the same as in the tank.

1. Connection to lower part of jacket space of motor cylinder.
2. Connection to upper part of jacket space above water level.
3. Float.
4. Valve.

The bulbous extension attached to the cylinder head must be heated by an external flame before starting the motor. When operating, the bulb, generally of cast iron, is kept at a full red heat. The liquid fuel is injected into the combustion chamber of the cylinder at about the time that the compression stroke is completed. The nozzle from which the oil is ejected is placed in the side of the combustion chamber, and points so that the jet of oil projected into the cylinder strikes a deflector plate extending out from the inner end of the piston, and part of it is deflected into the hot bulb, there mixing with the air forced into the latter during the compression stroke, vaporizing and igniting.

The steps of the operation, starting with the suction stroke, are:

First Stroke. Suction. — The outstroke of the piston draws in a cylinderful of air through the open inlet valve.

Second Stroke. Compression. — The inlet valve closes and the air is compressed by the instroke of the piston. Oil is injected just before, at, or very slightly after the completion of the compression stroke. The oil is vaporized and ignited by the heat of compression and of the hot parts of the motor, especially the hot bulb.

Third Stroke. Impulse Stroke. — Combustion and expansion against the piston are completed and the exhaust port opened to allow the inert gases to escape.

Fourth Stroke. — Most of the remaining inert gas is expelled by the instroke of the piston.

The compression of the air in this motor is about to the same intensity as for gas and gasoline motors equipped with electric spark or arc ignition apparatus.

14. **Diesel Oil Motor.** — This motor, the invention of Herr Rudolph Diesel, operates at a compression pressure of about 500 pounds per square inch, which is vastly higher than that used in any other internal-combustion motor, and utilizes the high temperature produced by compression to ignite the charge. It differs radically from other motors in these two characteristics of high pressure and of ignition.

In its operation a cylinderful of air is compressed by the instroke of the piston into a very small space that corresponds to the combustion chamber in an Otto-cycle motor. An oil inlet valve is then opened and oil is blown in by compressed air taken from tanks separate from the motor. The air pressure of the tanks is, of course, higher than that in the combustion cylinder. The first particles of oil are ignited and burned as soon as they enter the hot compressed air in the combustion cylinder, and so on with all the oil that follows. The burning is somewhat gradual, as compared with the explosion in other motors, since the oil is blown in slowly in comparison with the speed of the piston. The pressure is therefore not increased much, if any, above that of compression, but is kept up as the piston recedes, by the constant influx of fuel, until the oil inlet valve closes. The hot gases in the cylinder then continue to expand and drive out the piston until the exhaust port is opened. The cylinder is partly cleared of inert gases during the next stroke of the piston, and fresh air is drawn in by suction during the following stroke. Crude petroleum can be used for fuel.

The fuel is blown in through an atomizer of unusual construction which is made up of broad rings resembling washers, with grooved faces and small perforations. The rings are placed side by side on the oil-valve stem in sufficient number to form a column several times as long as their diameter. The compressed air from the auxiliary tanks passes through the nest of disks and becomes thoroughly impregnated with the oil, thus securing the best mechanical condition for rapid combustion.

On account of the extremely high compression pressure and the comparatively large size of the Diesel motors that have been put into operation, they cannot be conveniently started by hand power. Compressed air from a storage tank is used for starting. The motor is barred over by hand till the piston is just beginning the outstroke with the valves closed as for the impulse stroke. A hand valve from the compressed-air starting tank is then opened and the high pressure enters the cylinder and drives the piston outward. The motor starts quickly under the high pressure and the hand valve must be promptly closed.

The auxiliary air tanks are filled by a separately driven air compressor. These tanks are charged by means of power from the motor while it is running.

The speed of the motor is controlled by the action of a centrifugal governor that regulates the quantity of oil fuel forced into the nest of atomizing washers or disks, from which it is carried into the cylinder by the compressed air. The regulating devices that are used operate in various ways, generally on a pump, each stroke of which forces a charge of oil into the cylinder by varying the length of stroke of the pump, the extent of the opening of an oil by-pass valve, etc. The fuel valve closes early in the stroke, and the pressure in the combustion cylinder drops well toward atmospheric by the time the exhaust valve opens.

On account of the high compression and great expansion, the combustion cylinder (combustion chamber and cylinder together) and the stroke of the piston are longer, in comparison with their diameters, than is customary in other internal-combustion motors and in steam engines. This is on account of constructive principles, and is not otherwise necessary to secure the high compression and great expansion.

Pioneer Internal-Combustion Motors.

15. The earliest gas engine commercially used (still shown as a historical exhibit) has a vertical cylinder open at the top and with the inlet and exhaust ports at the bottom. The piston is connected to a horizontal shaft placed above the cylinder and carrying a flywheel. The connection between the piston and shaft is by means of a spur gear wheel on the shaft and a toothed rack on the piston. instead of the now customary smooth piston rod. The gear is connected to the shaft by a pawl and ratchet, so that it is free to turn around the shaft in one direction but not in the other. The piston is therefore free to move upward when a charge is exploded under it, but when descending it drives the shaft by means of the gear wheel and ratchet. The descent of the piston is due to its own weight only, unless the speed is very slow. Then the cooling and contraction of the gas after combustion may produce a partial vacuum.

In the operation of this free-piston motor the piston is lifted through part of its stroke from its lowest position by means of a connection, for this purpose, with the rotating flywheel shaft. The combustible charge is drawn in by suction during this early part of the piston's upward motion. When the piston has reached a certain height the charge is ignited at about atmospheric pressure, and the explosion projects the piston farther upward at a higher velocity than it had been traveling. It moves upward freely until stopped by gravity and friction, then descends by gravity and drags the flywheel shaft around, at the same time expelling the inert products of combustion through the exhaust port, which opens when the piston begins to descend. This is the cycle that is repeatedly performed while the motor is running.

Motors operating on the same cycle (heat cycle of the gases) as the free-piston motor just described, but having a cranked flywheel shaft and a fixed-length connecting rod between the piston and crank shaft, were constructed soon after the free-piston motor.

In comparison with motors in which the combustible charge is compressed before ignition, and which were brought out after the ones just mentioned, the free-piston motor and all other internal-combustion motors in which the charge is not compressed before ignition, are inefficient in transforming the heat of combustion into mechanical energy. They are uneconomical of fuel and heavy in weight in proportion to their power capacity. When motors operating on the Beau de Rochas or Otto cycle appeared, the earlier non-compressing types were discarded from commercial power generation use.

Scavenging.

16. In four-cycle motors following the Otto cycle approximately there is a considerable volume of the gaseous products of combustion left in the motor cylinder after the exhaust stroke of the piston is completed, unless some special provision is made for removing them. These inert residual gases mingle with the next charge that enters and dilute it. While this dilution affects the economy of the motor but little, if any, it reduces the power capacity by preventing a complete cylinderful of the combustible mixture from entering.

Some experiments were made in England on a small four-cycle motor to find what increase of power could be secured by removing the residual gaseous products of combustion before taking in a fresh charge. The method of scavenging the cylinder with pure air was very simple. A long, straight exhaust pipe was connected to the motor. The length of the exhaust pipe was so proportioned by experimentation that the inertia of the gases passing out rapidly when the exhaust valve opened, induced a partial vacuum at the motor end of the pipe at the instant of opening the inlet valve. When the inlet opened, the suction due to the inertia of the escaping portion of the exhaust gases drew the remaining portion out of the cylinder and fresh air into it. The fuel-gas valve was not opened till some air had passed into the motor cylinder. Some gain in the power capacity of the motor was thus secured.

The Atkinson four-cycle motor, already mentioned, can be classed as a scavenging motor, since its piston goes so far into the compression space on the exhaust stroke as to drive out nearly all of the inert gases.

Two-cycle motors that have air and gas compressors are scavenging motors when enough air is let in to drive out nearly all the products of combustion before the combustible mixture of air and gas is passed into the cylinder. The more simple form of two-cycle motor that precompresses the combustible mixture in the crank case can hardly be classed as a scavenging motor.

The advantages of scavenging in the four-cycle motor have not yet appeared great enough to warrant the more complicated construction necessary to secure it.

Compound Motors.

17. Motors in which the expansion of the gaseous products of combustion is carried out to a greater degree by the aid of a secondary low-pressure cylinder than in the usual types where all the expansion is in the combustion cylinder, are constructed to a small extent.

One of the most recent four-cycle compound motors, used for driving an automobile, has two vertical combustion cylinders of the same size, with a secondary low-pressure expansion cylinder between them. The pistons and all the cylinders are single-acting. The length of stroke of all three pistons is the same, but the low-pressure cylinder is of greater diameter than the others. The two high-pressure pistons (those in the combustion cylinders) move up and down in unison, while the low-pressure piston moves in the opposite direction. The crank angle between the low-pressure crank and the high-pressure cranks is 180 degrees or half a revolution. There is no angle between the two high-pressure cranks.

The high-pressure cylinders are each provided with an inlet and an outlet port, both opening into the combustion chamber in the usual manner.

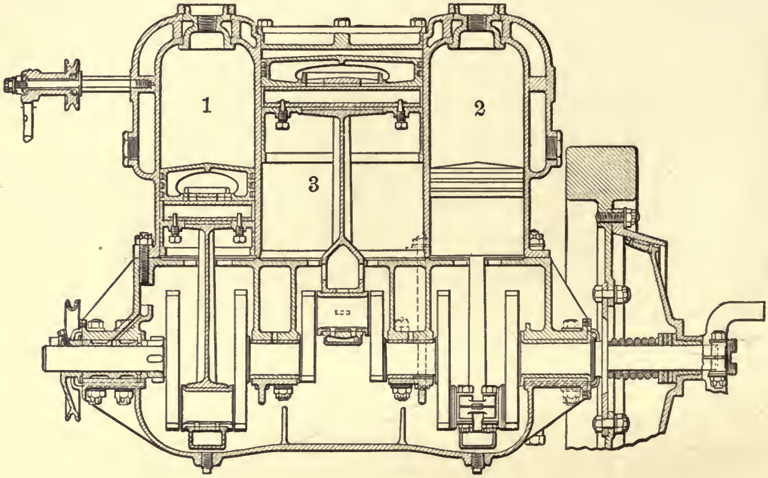


Fig. 28.

Compound Motor. Four-Cycle, Three-Cylinder Automobile Type. 12 to 15 horse-power. Section on plane of cylinder axes.

1 and 2 are the combustion or high-pressure cylinders.

3 is the intermediate low-pressure cylinder.

The upper end of the low-pressure cylinder is connected to each of the high-pressure cylinders by short passages with valves. The exhaust from the high-pressure cylinders passes into the low-pressure cylinder, so that its piston is given an impulse every downstroke.

The method of operating is as follows, dealing with the forward cylinder first for convenience: The exhaust gases from the forward high-pressure cylinder follow a short passage into the low-pressure cylinder and through one of the inlet valves of the latter. The exhaust valve of the forward high-pressure cylinder and the corresponding inlet valve of the low-pressure cylinder are opened and closed in unison. They open about the time of completion of the explosion stroke, and remain open about half a revolution of the crank, while the upstroke of the high-pressure piston in a vertical engine forces the chemically inert gases into the low-pressure cylinder, whose cylinder is descending on its impulse stroke. During this part of the operation the pressure of the gases on the two pistons is about the same per square inch for both, but is slightly lower in the low-pressure cylinder. Since the piston area of the latter is greater than for the high-pressure cylinder, the low-pressure piston delivers a turning moment to the crank which is greater than the resisting moment of the high-pressure piston. The net result is that the additional expansion of the gases develops mechanical power.

At about the completion of the downstroke of the low-pressure piston its inlet valve closes (together with the exhaust valve of the forward high-pressure cylinder) and its exhaust valve, at the upper end of the cylinder, is opened to allow the escape of the thoroughly expanded gases into the atmosphere as the low-pressure piston moves upward. A similar operation is then carried out by the rear combustion cylinder and the low-pressure cylinder. The latter has two inlet valves, one for each of the high-pressure cylinders.

The crank shaft receives an impulse at every half revolution to keep up its rotation. The impulses on the crank shaft come in the following order: forward piston, low-pressure piston, rear piston, low-pressure piston.

An earlier type of compound motor, an English production, has one high-pressure and one low-pressure cylinder. They are placed side by side close together, and the combustion chamber of the high-pressure one is connected by a large open passage to the closed end of the other. The low-pressure cylinder has, of course, the greater volume. The pistons are connected to separate crank shafts, which are parallel to each other and geared together so that the one for the high-pressure cylinder makes two revolutions to one of that for the low-pressure cylinder. The crank shafts are geared together in such a manner that the high-pressure piston makes nearly a complete stroke, immediately following combustion, by the time the low-pressure piston has moved a very small portion of its outstroke. Both pistons are single acting. The low-pressure piston then moves out rapidly while the high-pressure one is completing the small remaining part of its outstroke and moving back a short distance on its exhaust stroke, and so on.

A double-acting, four-cycle, compound motor of this type with two high-pressure and two low-pressure cylinders was recently constructed in this country with a view to using it for boat propulsion. There were some modifications, however, in the design which, while not changing the appearance of the motor, had a great effect on its operation. The most notable change was the placing of a large automatic valve in the passage between the high-pressure and low-pressure cylinders so that none of the gases could pass from the latter to the former. There may have been certain advantages to be gained by doing this. But, in addition to this, an igniting device was placed in the low-pressure cylinder as well as in the combustion cylinder. The result was as might well be expected. When the motor was started some of the combustible mixture entered the low-pressure cylinder on account of a missed explosion or some other cause. The igniter fired it in the low-pressure cylinder and the explosion closed the intermediate valve with such force as to shatter it. The same injury might have occurred without the ignition device in the low-pressure cylinder, after a misfire in the high-pressure one.

Impulse Frequency for Different Arrangements of Cylinders.

18. The following are the more customary methods of arranging the cylinders of motors, and the corresponding number of impulses delivered to the crank shaft:

Two revolutions of crank shaft for each impulse:

Four-cycle, single-acting, single-cylinder motor.

Four-cycle, single-cylinder motor with combustion chamber at middle of cylinder and two opposed pistons that recede from the middle of the cylinder at the same time toward the open ends of the cylinder during the impulse stroke, and then return at the same time during the compression stroke.

One revolution for each impulse:

Two-cycle, single-acting, single-cylinder motor.

Four-cycle, single-acting, two-cylinder motor with opposed cylinders on opposite sides of the crank shaft and cranks at 180 degrees.

Four-cycle, single-acting, two-cylinder motor with the cylinders on the same side of the crank shaft and the cranks at 0 degrees. (Twin cylinders in some designs.)

Two-thirds of a revolution for each impulse:

Four-cycle, single-acting, three-cylinder motor with all three cylinders on the same side of the crank shaft and the cranks at 120 degrees.

One-half revolution for each impulse:

Two-cycle, single-acting, two-cylinder motor with both cylinders on the same side of the crank shaft and the cranks at 180 degrees. (Twin cylinders in some designs.)

Compound motor, four-cycle, single-acting, three cylinders. Two high-pressure or combustion cylinders and one low-pressure or expansion cylinder, all three on same side of the crank shaft. Low-pressure crank at 180 degrees with the pair of high-pressure cranks. High-pressure pistons move in unison in one direction, while the low-pressure piston moves in the opposite direction.

Four-cycle, single-acting, four-cylinder motor with all cylinders on the same side of the crank shaft and one pair of crank shafts at 180 degrees with the other pair. One pair of pistons move in unison in one direction, while the other pair move in the opposite direction.

Four-cycle, double-acting pair of tandem cylinders with one crank.

One-third revolution for each impulse:

Two-cycle, single-acting, three-cylinder motor with all three cylinders on the same side of the crank shaft and the three cranks at 120 degrees.

Four-cycle, single-acting, six-cylinder motor with all six cylinders on the same side of the crank shaft and the cranks at 120 degrees in pairs.

Reversing the Rotation of the Motor.

19. The direction of rotation that the first impulse gives the motor shaft depends only on the position of the crank at the instant of ignition. This assumes that the motor is rotating at only a very slow speed, or not at all. The four-cycle motor, unless provided with mechanism for changing the time of valve action, will soon stop if the first impulse starts it in the wrong direction. Such reversing mechanism has not come into use for four-cycle motors.

The two-cycle motor will continue to rotate in the direction that the first impulse gives it when of the simple type that compresses its charge in the crank case, if the timer is adjusted so as to continue to give ignition at the proper time. The absence of mechanically operated valves, or of all valves, makes this possible.

The method of reversing small two-cycle motors of this class, such as launch motors, is to cut out the ignition and allow the motor to slow down. The timer is then set to give ignition before dead center is reached, as the motor is still rotating, provided the timer is not already in this position. The igniter is put into action again when the motor has nearly stopped, and the first impulse reverses the motor. The timer is then adjusted to the proper setting for the reversed rotation. The motor may be throttled during the reversing to prevent too strong an impulse at the instant of reversal.

CHAPTER II.

CARBURATION, CARBURETERS, PREHEATING THE CHARGE, FUEL SUPPLY.

Carburation of Air.

20. A motor that receives into its combustion cylinder a charge composed of a mixture of air and vapor of some volatile hydrocarbon which is normally a liquid at atmospheric temperature and pressure, must be provided with some kind of a carbureter for enriching the air with fuel on its way to the cylinder.

The spray carbureter has come into general use for naphtha and gasoline in this country. The characteristic of this type is that the liquid hydrocarbon is drawn out of a small nozzle, or group of nozzles, by the suction of the air going to the combustion cylinder, or, in the two-cycle motors, by the air going into the crank case of the primary compression cylinder. The suction that causes the flow of liquid fuel is aided by gravity in some types of the spray carbureter.

One carbureter will supply either one or more combustion chambers or cylinders. It is general practice to use only one carbureter for a multi-cylinder motor.

21. **Primer for Carbureter using Volatile Fuel.** — It frequently happens that a carbureter will not sufficiently enrich the air in the usual manner when starting the motor. In order to prime the carbureter, many are therefore provided with a means of causing more fuel than usual to flow from the spray nozzle just before starting the motor. The device for doing this is called a primer. It is a simple hand-operated arrangement that depresses the float of a float-feed carbureter, or opens the fuel valve otherwise in other types, so that some of the liquid can flow out into the mixing chamber or air passage without the aid of the suction of the motor.

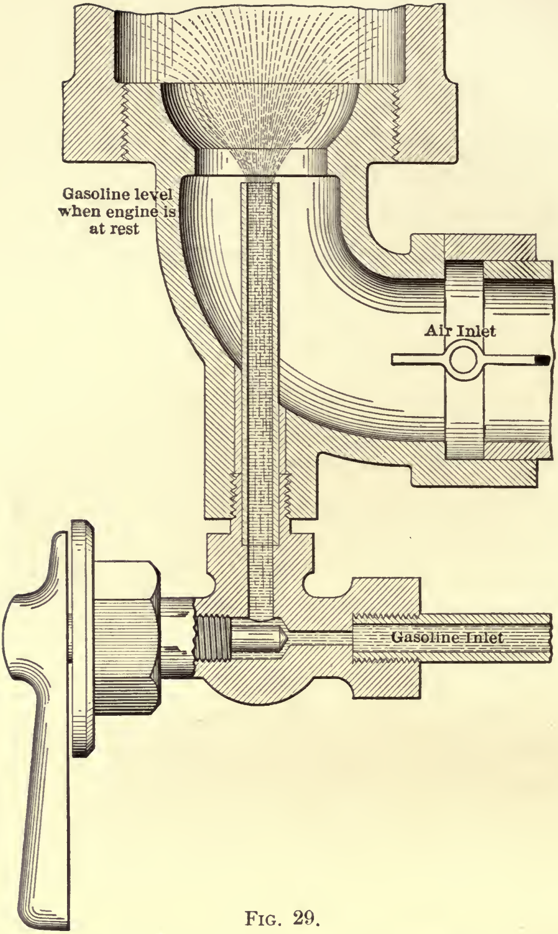


FIG. 29.

Spray Nozzle Carbureter. Sectional View.

The gasoline is supplied from some source that maintains a level somewhat lower than the open upper end (nozzle) of the vertical gasoline pipe. The air current passes up by the nozzle during the charging stroke of the motor. The partial vacuum due to the suction of the motor draws gasoline from the nozzle. The gasoline immediately vaporizes and mixes with the air. The amount of gasoline drawn out is regulated by the small valve at the elbow of the supply pipe. It can also be regulated by the butterfly valve in the horizontal part of the air pipe. When this air valve is turned from the horizontal position shown, so as to partially close the air inlet, a greater degree of vacuum is formed at the spray nozzle and more gasoline drawn out, thus making a richer mixture. The real use of the air valve, however, is generally for causing enough gasoline to be drawn out when starting the motor. The slow speed at starting, as by hand cranking, does not produce suction enough to draw out sufficient gasoline when the air valve is open as shown. But closing it will cause enough fuel to be drawn out to make a mixture rich enough for igniting. In such cases the air valve is opened completely after starting.

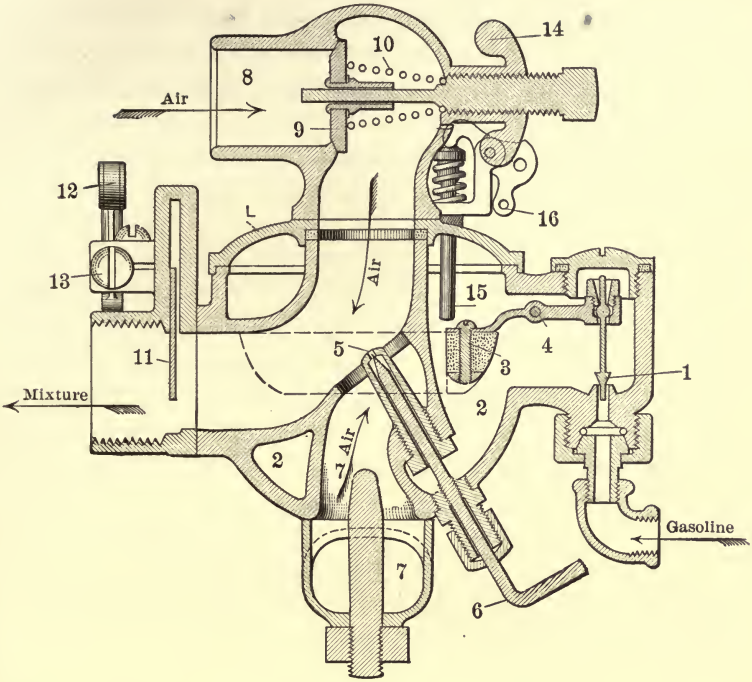


FIG. 30.

Float-Feed Spray Carbureter. Wheeler & Schebler, Indianapolis, Ind.

The gasoline flows up past the valve 1 into the reservoir (float chamber) 2. As the gasoline rises in the reservoir it lifts the cork float 3 (which is horseshoe shaped and extends around the sides of the main air passage). The float is fastened to an arm that is pivoted at 4 and engages with the upper end of the stem of valve 1. When the float rises to the proper height it closes the valve 1 and stops the inflow of gasoline at a level slightly lower than that of the spray nozzle 5. The needle valve 6 is for regulating the size of the passage to the spray nozzle.

When starting the motor the air all enters through the bottom air passage 7 whose orifice into the main air passage surrounds the spray nozzle. The passage 7 is always left full open. The mixture passes out as indicated. When the motor is running, air also enters at the upper inlet passage 8 by opening the valve 9 against the resistance of the coil spring 10. The gate valve 11, shown partly closed, acts as a throttle to the passage of the mixture from the carbureter. It is operated by the lever (or bell crank) 12. The throttle can be prevented from completely closing by the adjustable screw 13 against which a projection on the lever 13 strikes.

The force exerted by the spring 10 for holding the compensating air valve 9 closed is regulated by the wing nut 14.

For priming or flushing the carbureter, the vertical pin 15 is pressed down against the cork float. This can be done by pulling a wire or string attached to the bell crank 16.

Another method of priming the motor is to put the volatile fuel directly into the combustion chamber. A pet-cock (often with a cup-shaped end to be used as a measure) is generally provided for this purpose.

22. Float-Feed Spray Carbureter for Volatile Liquids. — The float-feed spray carbureter has a small reservoir in which a hollow metal or a cork float is buoyed up by the liquid fuel. The float is connected to a cone-point valve (float valve) which, when the float is lifted to a certain height, stops the opening through which the liquid enters from the main tank in which the bulk of the fuel is carried. The short duct that terminates as the orifice of the nozzle is led from the carbureter reservoir into the air passage through which air is drawn into the motor. This duct starts some distance below the level of the liquid, and the nozzle terminates a slight distance above the level of the liquid maintained by the float. The latter is adjusted to maintain this level at about one-sixteenth to one-eighth of an inch below the nozzle in most cases, but the nozzle is sometimes as much as an inch higher than the level of the fuel.

As the air is drawn through the air passage, its suction draws the liquid from the nozzle and it is vaporized almost instantly when the conditions are favorable. Drawing the liquid from the nozzle lowers its level in the small reservoir of the carbureter, and the float falls so as to open the float valve for letting in more liquid and maintaining the proper level.

The rate of flow of fuel from the nozzle in proportion to the rate of flow of air past it is adjusted by a needle valve that partially stops the nozzle orifice or the passage leading to it. This is the only adjustment in several makes of float-feed carbureters. Others, however, that are increasing in proportion of numbers used have an air valve that is used to regulate the intensity of suction at the fuel nozzle. In many modern designs a single air valve is placed so that the air passes through it before reaching the nozzle; the air valve is held to its seat by a weak spring except when lifted by suction. By adjusting both the needle valve and the air valve the mixture can be given correct proportions, within practical limits, for very greatly different rates of flow of the air. In other words, the carbureter can be adjusted to keep the mixture ratio of air and fuel practically constant for a motor that runs at greatly different speeds and whose power and speed are controlled by throttling the charge at a point between the carbureter and the motor. It is not unusual to find the spring-closed air valve in other parts of the carbureter.

In some types of carbureters in which no spring-seated air valve is used, two valves of the wing type that is common in stovepipes, etc., are used. One is placed between the fuel nozzle and the motor, and the other between the nozzle and the air intake of the carbureter. They are then both moved in conjunction to control the speed and power of the motor. By this means both the speed of flow of the air and the intensity of suction at the fuel nozzle are simultaneously regulated.

An adjustable stop to limit the lift of the air valve is provided in some designs, but this is unusual.

In carbureters for automobile motors the small liquid reservoir generally surrounds the air passage and the nozzle more or less completely. The chief reason for this form of construction is to provide a means to keep the level of the fuel in the nozzle constant when the carbureter is tipped by the car passing over hilly and uneven roads. The earlier types, and some still on the market, were made with the small reservoir at one side of the air passage and nozzle; this results, in some cases, in a lack of uniform carburation of the air when passing over uneven roads.

A throttle valve is often placed in the carbureter between the fuel nozzle and the motor. Wing and shutter type throttle valves are in common use, as are tubular forms.

While only one fuel nozzle is the rule in float-feed carbureters, some are made with several nozzles of the same size that act simultaneously. In more unusual designs, nozzles of different sizes are provided, all placed at the same level. This type of carbureter is intended for motor cars where the demand for mixture varies between wide limits. A large nozzle delivers the liquid fuel when the demand for power is great, as when climbing a hill, but when the throttle control is readjusted for light power on a good, level road, the large nozzle is cut out and a small one brought into action.

23. Pump-Feed Spray Carbureters for Volatile Fuel. — For stationary and other motors where the supply of fuel is carried below the level of the carbureter, and no air pressure is used to raise the liquid to the level of the carbureter, the open spray nozzle type, in which the constant level of the fluid fuel in the small reservoir of the carbureter is maintained by a pump, finds considerable use. The fuel pump generally forms part of the motor and is naturally very small. It pumps more fuel than the motor requires at any time, and the level is maintained by an overflow pipe or opening that takes the surplus fuel back to the main supply tank or its connections.

24. Pump-Feed Carbureter with Measuring Cup. — In this type a small pump lifts the liquid fuel from the main tank and discharges it into a small measuring cup or pipe end in the air inlet pipe of the motor. The capacity of the measuring cup is that for the amount of fuel required for one full charge of the motor. The pump supplies more fuel than sufficient to fill the cup, and the overflow returns to the main reservoir. The cup is filled by the pump during the strokes of the motor piston that come between impulse strokes. The suction of the air on its way to the motor combustion cylinder empties the cap of its complete charge of fuel. This type of carbureter is not suitable for use in connection with a throttle in the air passage.

25. Disk-Feed Spray Carbureter for Volatile Liquids. — In this type of carbureter the vertical fuel nozzle opens upward and is closed by a cone-point valve that points downward and rests in the orifice by gravity and prevents the flow of liquid when none is needed. The valve spindle is vertical and has a thin metal disk attached to it. The disk is placed in and partly closes the air passage leading to the motor combustion cylinder. When a charge is drawn into the motor, the air, flowing upward past the nozzle and disk, lifts the latter and the valve attached to it, and thus opens the orifice so that the liquid fuel can flow out into the passage for air, where it is vaporized and carried by the air to the motor.

The supply tank is placed higher than the nozzle, and the flow of the liquid is caused by both gravity and suction, except when a compression supply tank is used, in which case the compression pressure lifts the liquid to the nozzle.

In order to keep the valve and its seat free from dirt or deposit, the disk has a few tongue-shaped pieces cut out of it except at the part corresponding to the base of the tongue, and the point of each tongue bent up slightly to make an opening through which the air can pass. This tongue somewhat resembles the reed of a musical instrument. The length of each tongue is parallel to the periphery of the disk, and all are pointed in the same direction with regard to the rotation of the disk about the valve stem. As the air passes through the openings and strikes the tongues it causes the disk and valve stem to rotate somewhat in the manner of a wind motor, so that the valve spins slightly on its seat when it settles down.

The adjustment for securing the proper proportions of air and fuel in the mixture is made by regulating the height of the lift of the valve. This is ordinarily done by means of an adjusting screw that is placed above the valve and disk and is concentric with the valve stem.

A spring-closed and adjustable air valve can be used in this carbureter as well as in other types. The same is true of throttle valves. They are, in fact, both used.

26. Diaphragm-Feed Spray Carbureters for Volatile Liquids. — In this type the vertical fuel nozzle is closed by a cone-point valve whose stem is generally vertical. A circular diaphragm is attached to the valve stem, and its periphery rigidly held by an air-tight joint. Under the diaphragm is a small space that is nearly air-tight and is of the same diameter as the free part of the diaphragm. Above the diaphragm is another air space of the same diameter, but connected with the passage through which the air is drawn to the motor. When air is drawn into the motor the reduction of pressure above the diaphragm by suction allows the air confined in the space below the diaphragm to expand and lift the latter, together with the attached valve, so as to open the nozzle and allow the liquid fuel to run out by both suction and gravity, or by suction and pressure when a pressure fuel tank is used. The amount of fuel flowing out is adjusted by a regulating screw against which the valve stem strikes when it lifts.

Throttle control and a spring-seated air valve can be used in this type of carbureter.

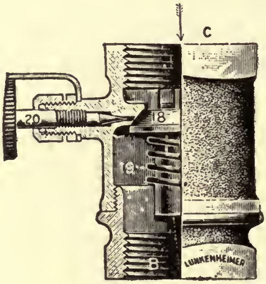


FIG. 31.

Carbureter Valve. The Lunkenheimer Company, Cincinnati, Ohio.

The gasoline is fed in by pressure to the passage around the needle valve 20 and passes through a small orifice to the conical seat of the main valve 18. The latter is pressed against its seat by the expansive action of the coil spring 19. The gasoline orifice is closed by the valve 18 when the latter is seated.

The suction of the motor at the lower end *B* of the carbureter draws the valve 18 down from its seat so that air enters at the top *C* and flows down past the valve. The suction and gravity (or pressure) both cause gasoline to flow from the open nozzle when the valve 18 is drawn from its seat by suction and air is passing through the carbureter. The flow of gasoline is regulated by the needle valve 20.

27. Spray Carbureters in General. — Numerous types of the spray carbureter other than those described above are in more or less general use. The nozzle is vertical in nearly all. In some cases it is slightly inclined from the vertical, as much as forty-five degrees in one or two designs. The air current passes in the direction that the nozzle points in the great majority of designs; in a smaller number it passes across the nozzle at right angles to the opening; and in a few isolated cases it comes down against the orifice of the nozzle.

In some a coil of wire is used to act as the spring air valve already mentioned and at the same time to break up the current of air so as to make the mechanical mixture of the air and vapor more complete than it is supposed to be without some mixing device. One, a recent design, has a cylindrical wire cage attached to one end of a propeller wheel and the whole mounted on a central spindle. The fuel and air pass through the propeller wheel and cage after coming together on their way to the motor. The current of air and vapor causes the propeller wheel and cage to rotate rapidly. The centrifugal action throws any liquid, such as water or unvaporized fuel, out against the walls surrounding the cage, and a dry mixture is thus secured.

Fig. 32.

Carbureter Valve. The Lunkenheimer Company.

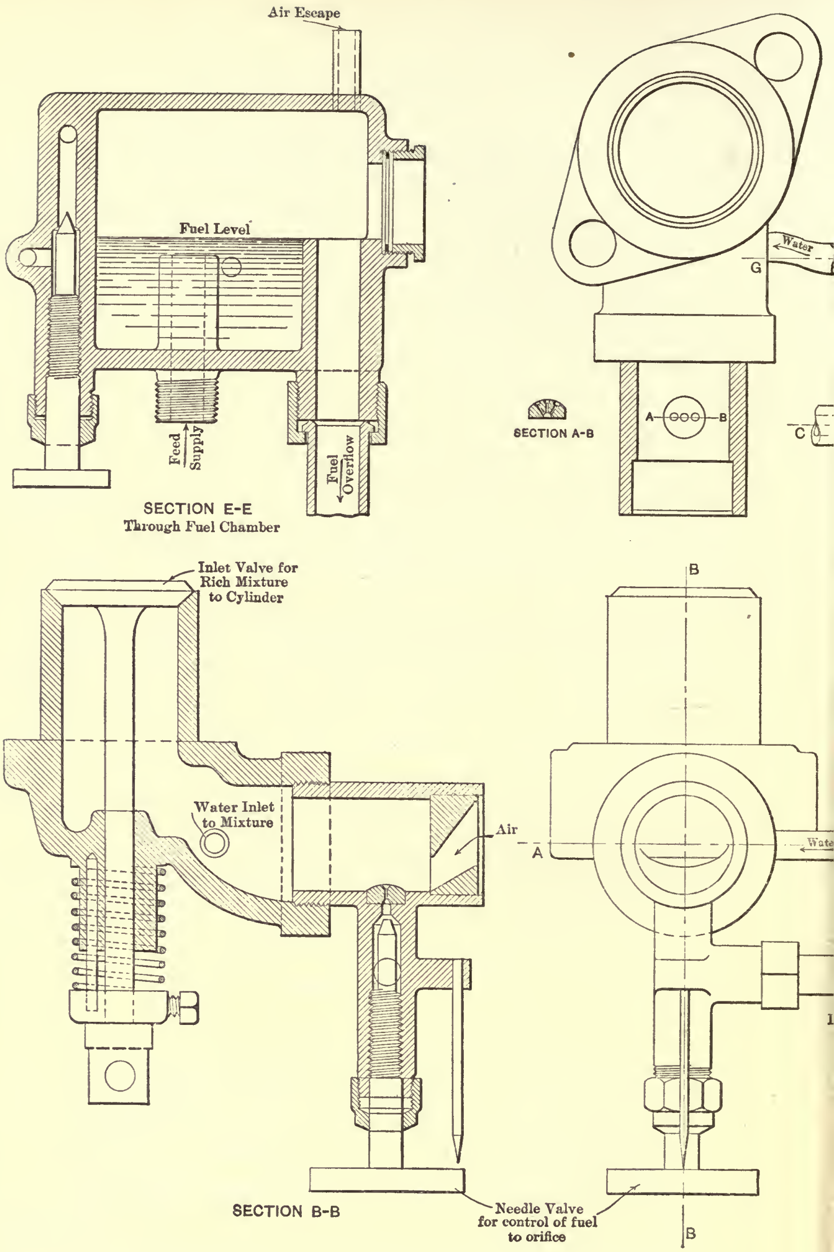
This is a modified form of Fig. 31. Air enters at the lower opening *C* and the mixture passes out at the upper opening *B*. Gasoline flows in at 5 and follows a duct to the pocket back of the needle-valve point. The lift or movement of the main valve *F* is regulated by the screw-threaded stem extending down from the wheel 3 at the top. The top of the valve strikes against and is stopped by the lower end of this stem.

One of the simplest carbureters, probably the simplest, constructed resembles an ordinary globe angle valve in general appearance. The valve is pressed against its seat by a weak spring that allows it to rise when the suction of the motor acts to draw air through. A liquid-fuel supply pipe terminates in a small orifice in the conical valve seat. When the valve rests on its seat the orifice is closed and no liquid can flow into the air passage, but when suction lifts the valve the orifice is uncovered and the liquid fuel is drawn out by the suction, with some aid from gravity or the pressure of a pressure system of fuel supply. The liquid is vaporized as in other types of spray carbureters. The lift of the valve is regulated by a screw above it that occupies the place of the valve stem that is used in the ordinary angle valve. The intensity of suction depends on the lift of the valve. The latter can be completely closed by screwing down the regulating screw. There is a needle valve in the fuel supply duct for the regulation of the amount of fuel delivered. This carbureter is intended for use only on motors that take a full charge for each impulse stroke. It has proved very satisfactory for such service.

28. **Other Types of Carbureters for Naphtha and Gasoline.** — One type of carbureter that was much used at one time but is becoming less common on account of its displacement by the spray class, has a considerable surface of metal on which the gasoline or naphtha is allowed to run and is then vaporized by air passing over it. The vaporizer is made in various forms. One is a cone of wire gauze. In its operation the liquid is dropped on the apex and runs down toward the base. The air is drawn up through the gauze and rapid vaporization occurs. Instead of the wire gauze a conically coiled wire or a piece of perforated metal is often used. Different shapes find application.

In the earlier forms the air was enriched with hydrocarbon vapor to the saturation point, which gave a practically definite amount of fuel per cubic foot of air, and then the saturated mixture was diluted by mixing it with pure air until the ratio of pure air and hydrocarbon vapor became suitable for complete combustion.

In most of the later types the liquid fuel is directly mixed with the air passing into the motor, and in such a proportion as gives a combustible mixture. The proportion of the liquid fuel is regulated by some device similar in its general action to those of the float-feed and disk-feed carbureters.



Fi

Spray Carbureter with Gasoline and Water Nozzles. C

This carbureter is provided with a reservoir for water as well as one for gasoline.
carbureting chamber or pipe. The carbureter is double, with a gasoline noz
one of the carbureting chambers and its nozzles are shown in the figures.

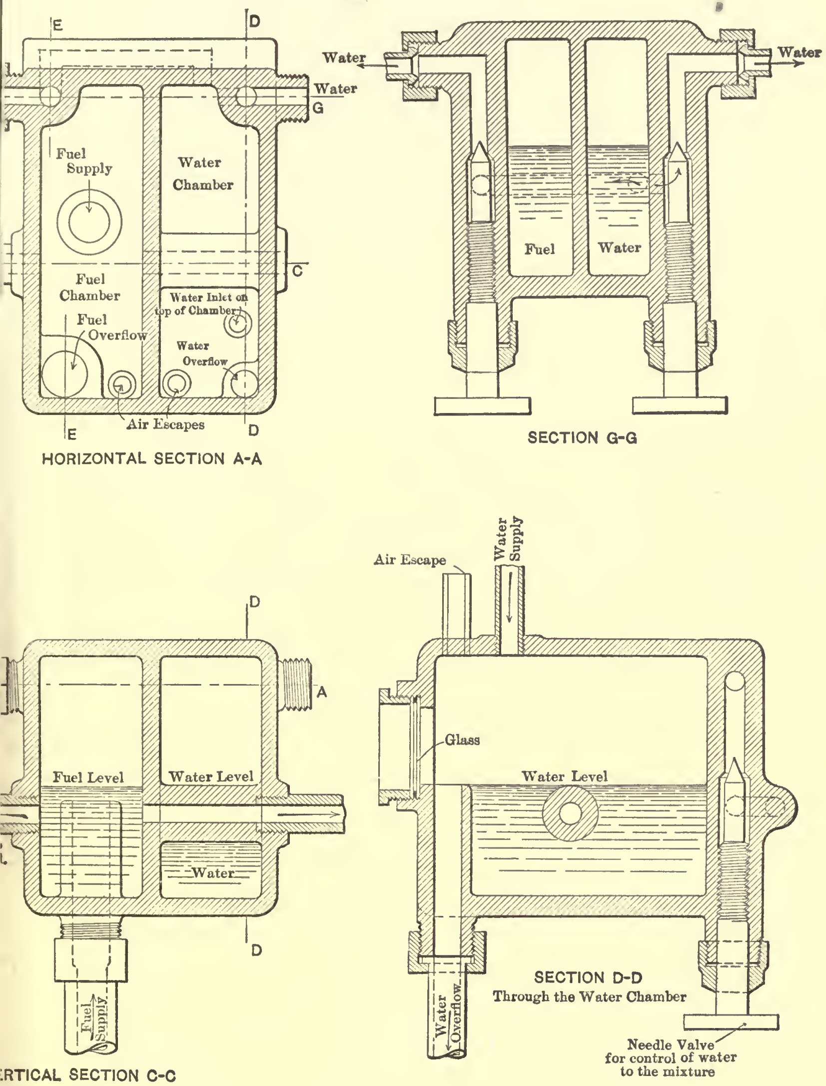
The water is mixed with the charge to cool down an overheated combustion ch

An excess of gasoline is pumped continuously into the gasoline reservoir of the carb
allows the excess gasoline to escape and maintains a nearly constant level in the
constant level in the water reservoir of the carbureter in a similar manner.

The needle valve for regulating the gasoline (for either combustion chamber) is set t
out past the spring-closed valve (which is opened by the suction of the motor) ar

The gasoline nozzle has three orifices.

This carbureter was used on a four-cycle, single-acting motor with two cylinders



HORIZONTAL SECTION A-A

SECTION G-G

RTICAL SECTION C-C

SECTION D-D
Through the Water Chamber

3.

ant Level of Gasoline and Water by Overflow Method.

as separate spray nozzles for water and for gasoline, both opening into the same
water nozzle, and a carbureting chamber for each combustion chamber. Only

er and prevent premature ignition.
r by a pump driven by the motor. An overflow opening in the carbureter reservoir
voir. The overflow runs back to the supply tank. The water is maintained at a

e a richer mixture than is to be used in the motor. This over-rich mixture flows
en mixes with more air on its way to the motor.

6½ inches diameter of bore, and with a piston stroke of 10 inches.

29. Cooling Effect of Vaporization. — The vaporization of a liquid requires heat. When the liquid fuel is vaporized in a spray carbureter the necessary heat is abstracted from the air with which the vapor mixes, and from the metal of the carbureter. Most of the vaporization takes place just beyond the fuel nozzle in the spray carbureter. As a result the metal in that neighborhood becomes very cold. It is not unusual to find it covered with frost even in hot, dry weather, but this occurs to a more marked extent in a cool, moist atmosphere. The heat conductivity of the metal causes the entire carbureter to become cold and chill the liquid fuel so that it will not vaporize so readily. With the better qualities, or more correctly, the more volatile fuels, this cooling by vaporization does not need much, if any, consideration so far as the vaporization is concerned.

But frost and ice not infrequently collect, in very humid or rainy weather, to such an extent that the inside of the air passage or mixture chamber where the vaporization occurs becomes coated with frost and ice. This is apt to interfere with the operation of the throttle valve, or even to obstruct the air passage to such an extent as to affect the working of the motor. When the poorer or less volatile grades of oil are used, they will not always vaporize at atmospheric temperature even before the carbureter has become cooled.

30. Heating the Carbureter or the Air. — In order to prevent the formation of ice in the carbureter, and to make it possible to use the lower and less volatile grades of naphtha and gasoline, either the air is heated before reaching the carbureter or the carbureter itself is heated by a hot-water or hot-oil jacket.

The hot-water jacket generally extends around the part of the air passage where the most vaporization occurs, and also around the carbureter reservoir when a float is used, or around the portion where the liquid fuel enters the carbureter when there is no float reservoir. The hot water or oil for jacketing is taken from that used to cool the motor cylinder when the latter is liquid-jacketed. The liquid-warmed carbureter is used only in connection with a water-cooled or oil-cooled motor.

Preheating the air before it passes into the carbureter is generally accomplished by causing it to pass over some of the heated surface of the motor cylinder or exhaust pipe. The intake pipe frequently has one branch that takes in preheated air, and another that receives air at atmospheric temperature. By the use of adjustable valves the air is taken in through either or both, as desired.

31. Carbureters for Kerosene and other Non-Volatile Liquids. — A temperature much higher than that of the atmosphere is necessary for vaporizing kerosene and others of the heavier distillates of petroleum. In the very numerous designs that have been used, the heat for raising the temperature to the vaporization point has generally been taken from the exhaust gases by passing them around or through the carbureter in passages provided for the exhaust gas. The chief difficulty met has been the keeping of the carbureter at a proper temperature at all loads on the motor. The tendency in a simple form of carbureter through which all or always the same proportion of the exhaust gases pass, is for the carbureter to become too cool on a light load if it is so constructed that it does not become too hot when the motor is working at about its full capacity. This type of carbureter has been made to work satisfactorily on launch and boat motors, where the rate of power generation is practically constant. An auxiliary flame is required for keeping the carbureter hot when the motor stops, and for heating it before starting after the parts have become cold.

When the temperature is kept high above the vaporization point while the motor works at full load, there is apt to be trouble from rapid deterioration of the metal of the carbureter, stoppage of its passages, oxidation of the metal and deposit of carbon from the fuel and exhaust and even from igniting the mixture while it is still in or near the carbureter.

Some of the kerosene carbureters make a saturated mixture of air and fuel vapor at a temperature well above the vaporization point of the kerosene, and afterward dilute it with air, thus securing a combustible mixture without an excessive temperature of the entering charge. The heat of compression and that received from the cylinder walls are relied upon to keep the kerosene in the vapor state until combustion occurs.

The adjustment and handling of a kerosene carbureter when in operation cannot be so readily and conveniently accomplished as with one for gasoline, naphtha, and alcohol, on account of the necessarily high temperature of the kerosene carbureter. Adjusting screws and minute parts are injured by the heat, which also opens joints and causes leakage. On the whole, the problem of making a successful kerosene carbureter is far more difficult than to make one for naphtha or alcohol. The result is that the general tendency is to eliminate the use of the kerosene carbureter by injecting the liquid fuel directly into the combustion space of the motor and to vaporize as well as burn it there.

32. **Early and Obsolete Forms of Carbureters.** — One of the early methods of carbureting the air for internal-combustion motors was to pass it more or less directly through the liquid fuel, as from the submerged opening of an air pipe partly immersed in the liquid. The bubbles of air, rising up through the liquid, became more or less completely saturated with the vapor of the liquid. Heat was added to the less volatile liquids to bring them up to the vaporization temperature.

Another method was to blow air down against the surface of the liquid so as to agitate it and absorb its vapor.

The above two methods are still applied to a small extent in the carbureters for kerosene and others of the less volatile liquids. It is difficult in them, almost impossible in fact, to secure the proportions of an economical combustible mixture in this manner. The usual method of using them, therefore, is to make a saturated or over-rich mixture and then dilute it with air to the desired proportions.

Still another early method was to drop or flow the liquid fuel on an absorbent piece of cloth or other textile fabric, cotton or woolen wicking, or the waste fiber from textile mills. The air was passed through the fabric or waste and thus became carbureted. The cloth or fibers gradually became fouled by dust carried in by the air, and in some cases by deposits from the liquid. The rate of carburation therefore changed, and the fabric had to be renewed.

The capillary action of wicks was also utilized by placing them partly in the liquid with one end extending into the air passage, so that the fluid that crept up the wick was vaporized and carried off by the air. The use of animal and vegetable fibers in any form for carburation seems to have been discontinued completely in connection with internal-combustion motors.

33. Effect of Preheating the Charge on the Power of the Motor. — The amount of power that is developed in the motor from a combustible charge of a given composition is almost directly proportional to the *weight* of the charge when the cylinder is always filled to the same pressure before compression begins. If a charge enters at a high temperature it will have less weight (for the same volume) than one that is cool when it enters. This assumes that both charges pass in through the same passages without any change in the area or form of the opening in any place. Under this condition the pressure in the motor cylinder at the completion of charging will be the same in both cases. The reduced weight of the hot charge means a corresponding reduction of the fuel to be transformed into heat, and consequently less power developed.

From the above it can be seen that, while preheating the air is in many cases advisable, or even necessary, to secure vaporization and prevent freezing of the carbureter on account of the vaporization, it should not be carried to a higher temperature than necessary if maximum power from the motor is desired. The reduction of power capacity of the motor is one of the objections to the kerosene carbureter with its highly preheated air.

The mixture from a gasoline or naphtha carbureter that is not jacketed by hot water, hot gases, etc., and takes its air at atmospheric temperature, is much cooler than the atmosphere when it enters the motor. This is one of the reasons why a motor running on naphtha fuel will develop more power than when on gas fuel, even though the heat value of a pound of the mixture is the same in both cases.

Fuel Supply for Carbureters.

34. **Gravity, Compression, and Pump Supply of Fuel.** — The liquid fuel for a carbureter is either placed in a tank at a level higher than that of the carbureter and flows down to the carbureter by gravity, or the supply tank is placed lower than the carbureter and the liquid forced up by compressed air, gas or vapor, or by a pump.

In the gravity system the tank should have a minute opening or vent at the top so that air can enter it as the fuel flows out. If this opening is not provided, the partial vacuum produced by the flowing out of the liquid will first retard and finally stop the flow. A very minute hole is sufficient for the vent, but it should be large enough not to be easily clogged. About one-thirty-second of an inch in diameter is the size generally used.

The pipe from the gravity supply tank to the carbureter should not, under any condition, have large vertical bends or any part much lower than the carbureter. Vertical bends or a low pipe is apt to cause an air lock that will prevent the liquid from flowing into the carbureter after it has been drained or otherwise emptied, or when the supply tank is filled after being completely empty.

In the compression system of fuel supply, air is forced into the supply tank after it has been nearly filled with fuel. After the motor is started the pressure is maintained in the tank by the exhaust from the motor. A common method of doing this in automobile practice is to make a pipe connection between the supply tank and the exhaust pipe of the motor. The connection to the exhaust pipe is made very close to the motor. A check valve is placed in the connecting pipe, generally near the motor, which is the proper location. The back pressure of the exhaust at the instant of its discharge is sufficient to force some of the exhaust gases past the check valve and into the fuel tank. The connecting pressure pipe must be of small diameter in order to prevent the passage of a flame through it from the motor to the tank in case the pipe should ever become filled with combustible mixture. It may at first seem that there is a probability of combustible mixture passing into the pipe when the motor misses an explosion in the cylinder to which the compression pipe is connected. But there is really little danger of this, since there is no pressure in the combustion cylinder at the time of opening the exhaust valve after a misfire.

The use of a pump to lift the fuel is confined chiefly to stationary motors, but a pump is used to some extent on portable and semi-portable motors. In stationary motors the fuel is very conveniently stored in the base of the motor. The plunger type of pump is generally used for this purpose, and is driven by the motor itself, of which it usually forms a part.

CHAPTER III.

IGNITION.

35. **General.** — The manner in which a charge is ignited in an oil motor whose charge of fuel is injected in the liquid form, has already been discussed in connection with the different types of oil-burning motors.

The electric spark or electric arc has come into almost universal use for igniting the combustible charge when it is necessary to have some source of heat for this purpose other than that necessary to vaporize an injected liquid fuel, as in the oil-burning motors. High-tension ignition, also called jump-spark ignition, systems use a spark passing across the gap between two permanently separated metallic points. In low-tension arc-ignition systems, an electric arc is drawn at the instant a break is made in the electric circuit by separating a pair of metallic contact points.

A hot piece of metal, porcelain, or other substance with which the combustible mixture is brought into contact, is still used to some extent, however. One of the early methods was to bring a flame into contact with the mixture at the moment it was to be ignited. This is practically obsolete. The constantly burning flame of the Brayton motor has already been discussed.

36. **Double Ignition.** — Two entirely separate ingition systems are used in many of the better small motors, and quite commonly in large ones. In automobile and launch motors both the high-tension (jump-spark) and the low-tension (arc) systems are installed. In large stationary motors the two systems are generally duplicates.

It is quite common practice to operate both ignition systems at once in large motors, but this is not usual in the smaller ones. In the latter case one system is generally held as a reserve.

37. **Low-Tension Electric-Arc Ignition.** — This is often called either the "make-and-break" or the "break-and-make" system, since the electric circuit is completed and broken each time an arc is formed.

A low-voltage electric current of a few amperes flows through an insulated metal rod that pierces the wall of the combustion chamber, in the arc system of ignition. A movable metal contact, electrically connected with the metal of the motor, presses periodically against the inner end of the insulated rod. The electric connection between the movable contact part and the metal of the motor is generally made by the very simple means of not insulating it from the cylinder where it pierces the latter's wall. The stationary and moving igniter rods both generally enter the cylinder through a removable plate or plug that forms part of the cylinder wall when in place. The insulated rod and

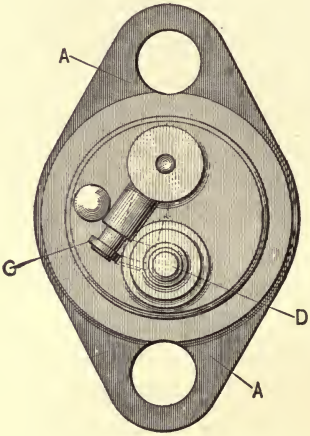


FIG. 34.

Ignition Points. Low-Tension Make-and-Break.

The stationary contact point (ring) *D* and the rod that supports it are insulated from the remainder of the complete igniter.

The contact ring *C* oscillates about the upper spindle and is brought into contact with *D* just before the time for ignition, and immediately separated from it to draw an arc. *C* and the parts attached to it are not insulated from the main part of the apparatus or from the metal of the motor when the igniter is in place.

the metal of the motor cylinder are respectively connected to the terminals of the source of electric supply. The separation of the contact points inside the combustion cylinder draws an electric arc that ignites the combustible gaseous mixture surrounding them.

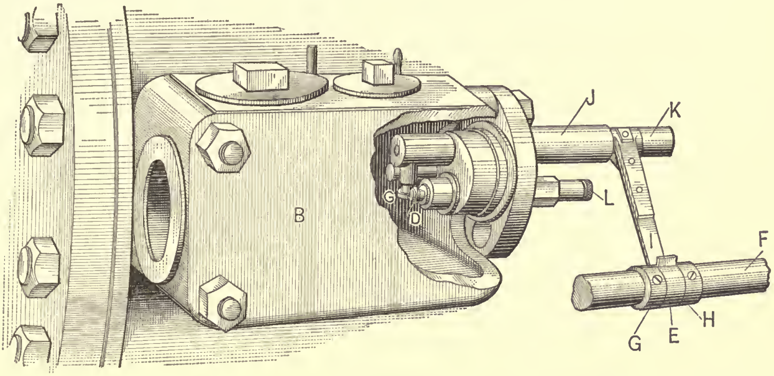


Fig. 35.

Make-and-Break Igniter in Place.

The igniter, Fig. 34, is here shown in place on the motor. The contact points are inside a chamber which forms part of the combustion space of the motor. *F* is the lay shaft (half-speed shaft) of the motor. The lay shaft rotates so that the top moves out from the paper on which the illustration is printed. The projection on *E* engages with the spring *I* as *F* rotates and thus brings the contact point *C* up against the stationary point *D*. Further rotary movement of *E* allows *I* to become disengaged from the projection on *E* and to snap back so as to quickly separate the contact points and draw an arc.

In the **"make-and-break"** system the contact points are brought together and immediately separated to draw the arc.

The **"break-and-make"** method is to keep the contact points together constantly except during the short interval that lies between their separation and almost immediate bringing into contact again.

A minimum amount of electric energy is consumed in the make-and-break system, and injurious heating of the contact points is hardly possible. There is a maximum opportunity for carbon and oil to collect on the contact points, however, and foul them so that they cannot come into electric contact when brought together mechanically.

There is less liability to failure of the formation of the arc in the break-and-make system on account of fouling of the contacts, but it requires more electric energy if the source of electric supply continuously delivers current at a uniform rate while the contacts are together, but not a larger current than is required by the make-and-break system. There is a greater tendency in the break-and-make system than in the other to heat the contacts when current flows during the entire time the circuit is closed at the contacts. Injurious heating by the current seldom occurs, however, in an electric arc ignition system that is properly designed and operated.

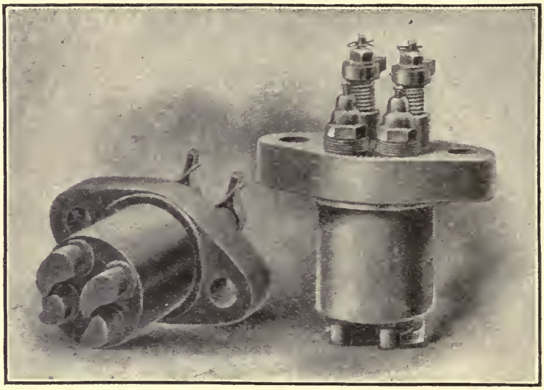


Fig. 36.
Double Make-and-Break Igniter.

To secure the advantage of the greater certainty of closing the circuit at the contact points than belongs to the break-and-make system, and at the same time keep the liability of heating as low as it is in the make-and-break system, special forms of electric generators are used. These generators produce current intermittently and during only a short period covering the instant that the contacts separate to draw the arc.

Metals and alloys having a high fusing point were thought necessary and were used exclusively in the early application of electric-arc ignition. Platinum, iridium, and platinum-iridium alloy were generally used. Platinum and iridium are so costly as to make it desirable to substitute less expensive materials for them. They have been almost completely displaced by steel alloy contacts, which give better service, under the modern methods of using them, than the more expensive metals previously used. It has been found that there is no necessity to form the contacts into a point or anything approaching a point in form. Blunt ends and flat or nearly flat surfaces are in common and entirely successful operation. One form that has given entire satisfaction has a broad steel ring, resembling a washer, attached securely to the end of the insulated rod, and another similar ring fastened to the moving part inside the cylinder. The axes of the rings are more or less perpendicular to each other, and their edges are brought together to close the circuit. If a ring-shaped contact piece becomes worn or pitted by fusing, it can be turned around slightly on its support so as to bring a new portion of its edge into action. Nickel steel alloy has been found good for contacts, along with other kinds of steel.

The insulating material for the stationary ignition rod that pierces the wall of the cylinder is subjected to a high temperature and must, therefore, be of a nature that will withstand the heat and retain its insulating properties. Mica, lava, porcelain, and asbestos are the materials generally used. The asbestos is more especially used as a packing for the other materials. The mica is used in thin pieces, stamped or cut to suitable form and laid against each other. The joints must be made with care, since the expansion and contraction due to heating and cooling of the cylinder tend to open them and allow the escape of gas, especially at the time when the pressure is high during and just after combustion.

The spindle carrying the movable contact point generally has an oscillatory motion in the cylinder wall, so as to give a rocker-arm motion to the arm that carries the contact piece. In some designs, however, the spindle has a rotary motion. There is ordinarily no difficulty met in keeping a tight joint at the place where the rocker arm pierces the cylinder wall. The pressure of the confined gases forces the shoulder or collar of the spindle against the inner surface of the cylinder wall, and thus keeps the joint tight if the bearing surfaces are true.

In one type the contact points are pressed together by the action of a spring connected to the external part of the rocker shaft, either directly or by means of an outside rocker arm. The contacts are separated at the proper instant by the action of a single-lobe cam on a shaft that rotates at the same speed as the crank shaft in a two-cycle motor and at half the speed of the crank shaft in a four-cycle motor. This refers to one cylinder of a single-acting motor. The cam acts through a system of rods and levers that transmit the motion of its follower to the movable arm of the igniter.

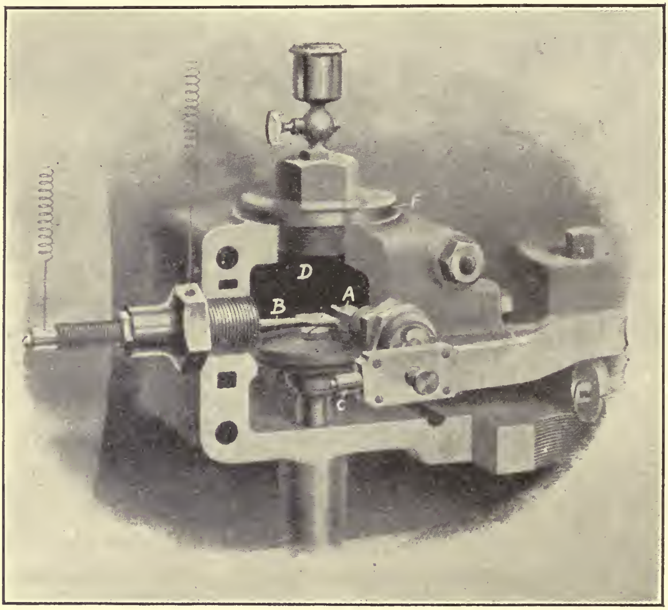


Fig. 37.

Make-and-Break Igniter with Rotary Contact Piece.

The stationary contact piece *B* is insulated from the frame of the motor and from the outer metallic bushing that surrounds the middle portion of *B*. The contact point *A* is rotated by the motor at half the speed of the crank shaft for a four-cycle motor, and makes contact with *B* at every revolution.

In order to secure a very rapid separation of the contact parts, a "hammer-blow" device is sometimes used. The rocker arm of the igniter supports a comparatively heavy part, the hammer, that is free to rotate on it. The parts that move the igniter press the hammer back against the resistance of a spring while the contact points remain together. The hammer is then released, and the spring throws it back quickly. It strikes an arm that is rigidly connected to the rocker shaft of the igniter point with a blow that forces the contacts apart almost instantly. The rapid separation reduces the fusing action of the arc, as compared with that of slow opening, by breaking the arc almost as soon as it is formed. Modern practice does not seem to show any necessity of breaking the circuit and the arc any more rapidly than can be done with the simpler, direct-acting arrangement more generally used.

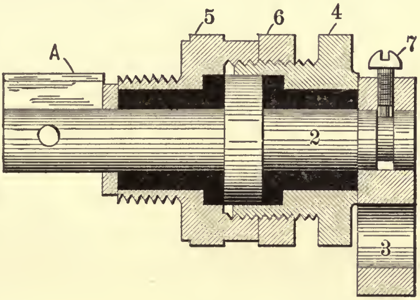


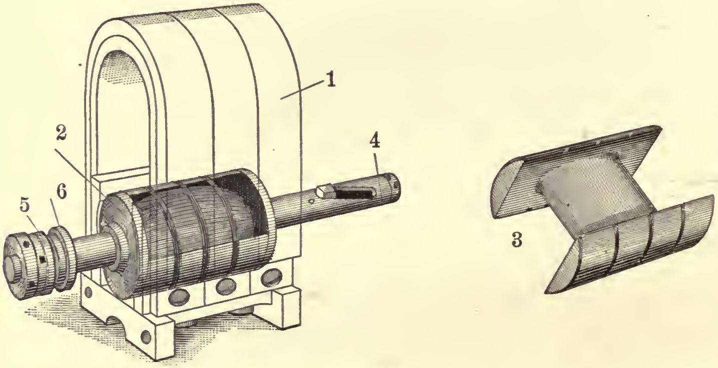
Fig. 38.

Rotor of Make-and-Break Igniter.

The rotary contact part of the igniter shown in the preceding figure has a graphite bearing, shown in black, for the rotating spindle 2. This eliminates the necessity of lubrication with oil, since the graphite is a solid lubricant. The graphite is not an insulator.

38. Sources of Electric Supply for Ignition. — **An electric generator** is the best source of supply for the low-tension arc system of ignition. The current provided must be flowing as a direct current at the instant of separating the contact points and drawing the arc at the igniter. The nature of the current at other times when the circuit is closed is immaterial (except that it must not be large enough to injure the apparatus).

It may be either direct continuous or pulsating, intermittent or alternating. Generators that are used solely for this purpose, and are practically a part of the motor accessories, are in common use. Both magneto-generators and those with electrically excited magnetic fields are suitable. The former has the advantage of being less complicated, but is more bulky and generally heavier than the electrically magnetized type. When the electric generator is suited to its work, one of its terminals is connected directly (electrically) to the insulated rod that carries the stationary contact point, and the other terminal of the generator is "grounded" by connecting it (electrically) to the metal of the motor at any convenient place. It will not give more current when thus short-circuited than it and the contacts in the cylinder can safely carry. In some cases the moving part of the generator rotates at a speed either constant or proportional to that of the motor; in others it is either



FIGS. 39 AND 40.

Magneto with Shuttle-Wound Armature. Alternating-current Type.

1. Permanent magnets.
2. Armature.
3. Armature core.
4. Armature shaft.
5, 6. Insulated slip rings to which the two terminals of the armature winding are connected and on which the brushes bear for carrying the current away from the magneto.

The armature wire is wound around the neck that connects the two convexed ends (or sides) of the core.

oscillated or moved intermittently and always in the same direction of rotation.

Direct continuous current generators and direct intermittent current generators are the types generally used for low-tension ignition. The direct continuous current generator is distinguished from others by its commutator of numerous (copper) segments.

The type of generator commonly known as alternating can be operated so as to give current which does not change its direction during the period for drawing the arc. This method of operating is described in sections 40 and 41.

In variable-speed motors, direct-current rotary electric generators for low-tension (arc) ignition are in a few cases driven at a speed proportional to that of the crank shaft. They are specially wound so as to give enough current for ignition at the lowest speed of the motor, and not to give excessive current, or to burn out on account of high voltage, at the highest speed of the motor. It is more usual, however, for the generator to be driven through a friction clutch which is thrown partly out of engagement at a certain speed that is the maximum predetermined for the generator. Friction-pulley drives are also used to limit the speed in a similar manner. The armature of the generator thus driven never exceeds a certain speed, but maintains it when the motor runs at its slowest speed. Generators of this class will give an arc hot enough to ignite the charge in the combustion chamber at the speed that a small motor can be cranked by hand. The generator is therefore all that is necessary to supply electric energy for ignition purposes.

An electric battery of dry cells, or a **storage battery,** can be used for low-tension arc ignition. The battery runs down rapidly, however, even when the make-and-break system is used, as distinguished from the break-and-make. A "kick coil," also called a "choke coil," should be used in the battery circuit to draw a longer and stronger arc by its inductive action than can be produced by the battery without it. The choke coil is made by winding a considerable number of turns of insulated copper wire around a soft-iron core. The core is usually made up of a number of small rods or short, straight pieces of soft iron wire gathered into a sheaf or bundle. The axis of the bundle coincides with that of the copper coil.

The chief use of the battery, in connection with low-tension ignition, is for starting the motor. The generator can be switched on for continued use.

When both a storage battery and a generator are thus used for igniting purposes they can be so connected together that the generator always keeps the battery charged and ready for use. The latter is thus always a reserve factor to be brought into use in case the generator fails. This method is known as "floating the battery on the line."

39. Low-Tension Arc Igniter with Solenoid Circuit Breaker. — This igniter differs from the ones of the type just described in that it does not require the motor to have as a part of its mechanism proper any device for separating the contact points. Their separation is accomplished by the magnetic action of a current passed through a solenoid coil that forms part of each spark plug. The igniter is compact in form and size. It screws into a hole in the cylinder wall. The hole is generally of the standard size for a half-inch gas pipe. A wire from the electric generator connects to its one binding post. The "grounding" of the outer casing of the plug is accomplished by screwing it into the metal of the cylinder. This completes the electric circuit, since the second terminal of the generator is also "grounded" to the metal of the motor. In general appearance the plug resembles the common form of high-tension spark plug to be described later.

When no current is passing through the solenoid the soft-iron movable core is forced out by a spring, so that its end presses against a metal bridge that spans the open end of the core space of the coil. The metal bridge is a part of the outer shell that is threaded to screw into the cylinder. When a current is passed through the solenoid its core is drawn in against the resistance of the spring and away from contact with the bridge. The path of the current is through the contact points before they are separated, so that their separation draws an arc between the end of the solenoid core and the bridge. The arc ignites the combustible gases in the cylinder.

An electric generator especially designed to supply current to the arcing plug is used with it. A timer on the generator closes the circuit to each plug in a multi-cylinder motor at the proper moment, and delivers current to it long enough to separate the contact points and draw the arc. A drop of heavy oil on the contact points does not prevent the formation of the arc when the contacts are separated, although the oil still connects the points. This system can be readily installed on a motor that has no mechanism for separating the contact points.

40. Oscillating Electric Generator for Low-Tension Ignition. — There are three features that are desirable in a low-tension arc-ignition system. They are:

1. Contact points kept pressed together except during the instant the arc is drawn;
2. Current supplied only when needed at the time that the contacts are separated to draw the arc;
3. An electric generator, operated entirely by the motor, that will supply the right amount of current whatever the speed of the motor, and also when the motor is moving very slowly, as when "cranking" a small motor by hand, or "barring" a heavy motor to start it.

By the use of an electric generator which produces an intermittent current a system embodying these desirable features has been evolved and is in general use.

In the oscillating generator the armature never makes a complete rotation, and the oscillations of the armature are intermittent. The armature is forced to one extremity of its oscillation by a spring.

When the motor is running, the armature, oscillator, or rotor is slightly rotated, through a fraction of a revolution, against the resistance of the spring, at a comparatively slow rate, by a cam, pin, or other device moving in unison with the motor shaft. Just before the time for separating the contact points the armature is released and snaps back by the action of the spring. This motion is rapid enough, and through a sufficient part of a revolution to generate enough current to make an electric arc hot enough to ignite the charge when the contacts inside the combustion chamber are separated. The separation of the contacts is generally done by mechanism connected to the armature or oscillator so as to move in unison with it. The separation is made when the current is at or near its maximum. The contacts come together again almost instantly, but no appreciable current passes through them till the armature is again snapped over. The motion of forcing the armature over against the resistance of the spring is so slow that no appreciable current is produced.

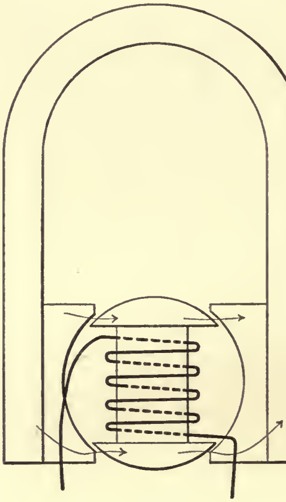


Fig. 41.

Position of the armature of the magneto at which no electromotive force and current are generated during its rotation or oscillation. The arrows indicate the direction of flow of magnetism, or magnetic flux.

The amount of current generated and the intensity of the arc do not in any manner depend on the speed of the motor. Even if the motor is not rotating, a charge can be ignited by this device by drawing over the armature and allowing it to snap back. The motor can be started from rest in this manner if the piston is in position for the impulse stroke and the cylinder charged with combustible mixture.

Generators of this type generally have permanent field magnets. Electromagnets can be used, but the necessity of maintaining a source of electric current supply is generally a sufficient reason for not using them. The armature may be made stationary outside the field magnet, which is then made small and mounted so as to oscillate in the manner already described.

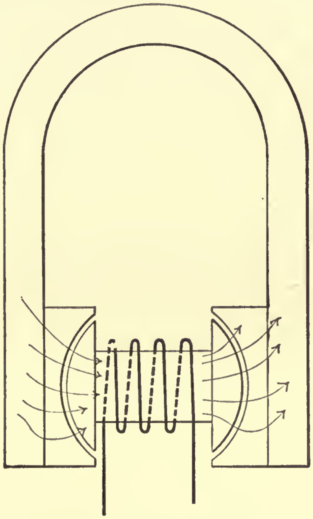


Fig. 42.

Position of magneto armature at about which the voltage and current generated by a uniform speed of rotation are a maximum. When the armature rotates at a uniform speed from the position of Fig. 41 to that of Fig. 42, the pressure (and current if the external circuit is kept closed) keep increasing till a maximum of each is reached at about the position of Fig. 42. The maximum value of the current lags somewhat behind that of maximum pressure when the external circuit is kept closed.

In a variable-speed motor, as one on an automobile, the separation of the contact points will not always occur when the piston is in the same position. This is because the time interval between the release of the armature and the separation of the contacts in the cylinder is always the same whatever the speed of rotation of the motor. If the release is made when the crank is on the dead center and the piston just ready to begin its impulse stroke, the contacts will not separate until the piston has moved out some on its stroke. The distance that the piston moves out will be greater the higher the speed.

Some means of readily adjusting the time of release of the armature while operating the motor is therefore desirable on a variable-speed motor, and is generally provided. Such a quick means of adjustment is not needed on a constant-speed motor, but some means of setting the release to the best position, where it is to remain permanently as long as the same fuel is used and the demands for power do not change greatly, is desirable.

41. Generator with Interrupted Magnetic Circuit, for Low-Tension Intermittent Current. — A very simple device for generating electric current intermittently as required for ignition in an internal-combustion motor finds application to some extent. It is a simple form of generator whose stationary armature consists of a permanent magnet, more or less horseshoe- or U-shaped, upon which is wound a single coil of insulated wire.

The gap between the ends of the magnet is alternately bridged by a keeper and opened by its removal. The nature of its construction and operation is illustrated by winding an insulated copper wire around the bar of an ordinary horseshoe- or U-shaped magnet and electrically connecting the ends of the wire so as to form a closed coil. When the keeper is removed from the magnet an electric current is induced in the coil. The same is true when the keeper is replaced. The quicker the removal and replacement of the keeper the greater the current generated.

If the magnet is of sufficient size and strength, and the movement of the keeper is rapid, an arc can be drawn by separating the ends of the wire at the same instant that the keeper is removed or replaced. It is not necessary that the keeper shall come into metallic contact with the magnet poles. The same effect can be produced by passing a bar of iron or soft steel between the poles of the magnet.

One form of apparatus used for ignition by a current generated in this manner has an air gap in the magnet core nearly closed most of the time by the edge of a rotating iron disk or the rim of a wheel that passes between the poles. The disk or wheel is attached to the crank shaft of the motor. A notch is cut in the disk edge or wheel rim. As the notch passes between the magnet poles the magnetic circuit is interrupted, as by removing the keeper from the poles, and a current is induced in the coils. The contact points are separated at the same instant in the combustion chamber and an arc is drawn. The contact points and the induction coil are, of course, electrically connected.

The notch in the disk or wheel rim is generally filled with some non-magnetic material, such as copper, brass, lead, wood, wood fiber, etc., so as to form continuous smooth surfaces.

42. High-Tension Jump-Spark Electric Ignition in General. — A single electric spark, or a series of sparks, jumping across a permanent gap or break in the metallic circuit, and passing through the combustible mixture in the cylinder of a motor, is the means adopted to a very considerable extent for igniting the charge in an internal-combustion motor. A high electromotive force or pressure is necessary to force the spark across the gap. This is secured by the use of an induction coil that transforms a current of an ampere or less and of only a few volts pressure into electric energy of enormously higher tension and correspondingly less volume. The low-tension current is supplied by a battery or a low-tension generator. A "timer" is used in connection with the battery. The function of the timer is to close the battery circuit so that a current can flow from the battery through the induction coil at the proper instant to produce a spark in the combustion chamber. A generator, instead of the battery, is very often used to supply the low-tension current.

The generator, the timer, the induction coil, and a distributer for directing the high-tension current to the different combustion chambers of a multi-cylinder motor, are all sometimes brought together and embodied in a single piece of apparatus. This combination is commonly known as a high-tension magneto, because a magneto generator has been used for this purpose up to the present time.

43. Jump-Spark Igniters for Electric Ignition. Spark Plugs.— The jump-spark igniter for high-tension ignition is, with few exceptions, made up of a central metal wire surrounded by a thick tube of insulating material which, in turn, fits into a hollow metal plug threaded on the outside so as to screw into a threaded hole in the wall of the cylinder of the motor or into some part that fits into the cylinder wall. The insulating material

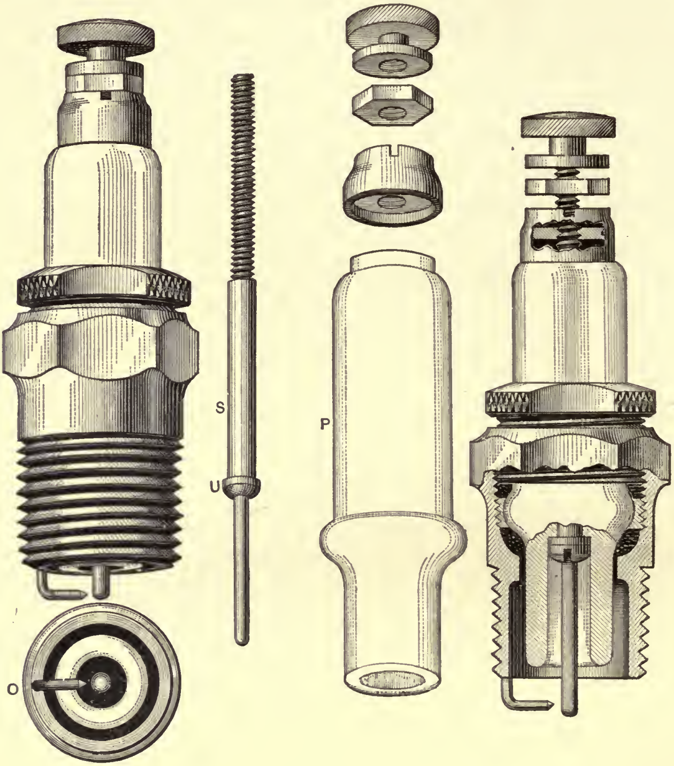


FIG. 43.

Spark Plug for High-Tension Jump-Spark Ignition. Porcelain Insulation.

The central rod or wire *S* is insulated from the outer metal parts by the porcelain *P*. Asbestos packing is used around the swell just below the middle of the porcelain. Copper or asbestos packing is used on the central wire at the shoulder *U*. The spark jumps across the gap between the lower end of the central wire and the curved wire set into the lower end of the outer metallic bushing.

is generally either porcelain or mica. The former is used in one tubular piece, and the latter is made up of numerous disks perforated for the central wire and placed side by side over it. Lava is also used for insulation to a limited extent. When porcelain is used, tight joints are made between the central wire and the porcelain, and between the porcelain and outer bushing, by the use of asbestos fiber packing or of soft copper washers. A fine copper wire wrapped with the asbestos fiber is especially convenient for this purpose. In general practice either the central wire of the spark plug terminates in an end of small diameter near some part of the outer shell, or a small wire is fastened to the outer shell and brought near the enlarged end of the central wire. The gap left between the end of the wire and the larger body of metal near which the wire terminates, is jumped by the spark when the igniter is in operation. This gap is called the "spark gap." Its width is about one-thirty-second of an inch. The insulation between the central wire and the outer shell is all the insulation that is between the two sides of the high-tension circuit at the spark plug. The standard size of the plug is that of a half-inch gas-pipe plug as made in this country. The French plug is smaller at the threaded part of the outer shell, but of nearly the same size elsewhere. Plugs intended for special motors are generally larger than the American standard. One special type has two insulated wires passing through a plate of considerable diameter. This secures double insulation between the two sides of the high-tension circuit. The ends of the wires are brought to within about one-thirty-second of an inch of each other. This type of plug is held in place by a yoke that spans it.

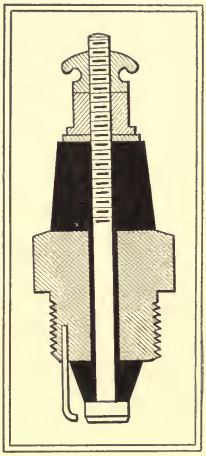


FIG. 44.

Spark Plug for Jump Spark. Mica Insulation.

The insulation is made up of disks or washers of sheet mica. The black portion indicates the mica.

44. Timers for High-Tension Electric Ignition. — When a battery is used to supply current for high-tension jump-spark ignition, a timer is placed in the battery circuit to close it at the moment a spark is required. The timer controls the time of flow of the low-tension current. Of the principal parts of the timer, one is stationary and the other rotates. They are electrically insulated from each other. As the rotor revolves, a metal contact piece on it comes against the metal of the stationary part at intervals and closes the electric circuit. There are as many metallic contact pieces on the stationary part as there are induction coils in use for operating the motor, in the more common and simpler device. (Other forms will be described later.) The contact pieces are placed around the circular path of the rotating contact piece so as to close the circuit at the time required for each cylinder of the motor. The stationary part is adjustable to a slight extent by rotary motion around the rotor shaft, so that the time of closing the circuit can be varied to meet the requirements of the motor.

In the better modern designs the stationary part generally consists of a ring of wood fiber supported on a metal part that is bored to receive the shaft of the rotor. The contact points in the stationary part are attached to the insulating ring so as to be insulated from each other and from the shaft of the rotor. The rotor has only one contact piece, and in some designs it has rigid metallic connection with the rotor shaft; in others it is insulated from the shaft, but permanently connected by a rubbing or rolling contact with the metal ring that is part of the stationary member of the timer and is electrically connected to the metal of the motor. The contacts are pressed together by the action of a spring. The moving parts are either packed with soft grease or copiously lubricated with oil.

In automobile practice the frequent movement of the adjustable (stationary) part of the timer breaks the wires that lead from its contact pieces to the other parts of the apparatus. In order to prevent this trouble the adjustable part is surrounded by a case that is truly stationary with regard to the motor frame, and the leading-out wires are connected to binding posts on the casing. The electrical connections between the case and the adjustable part are made by sliding contact.

The speed of rotation of the timer is half that of the crank shaft in the ordinary type of four-cycle motor. In the two-cycle motor the timer rotates at the same speed as the crank shaft.

45. Induction Coils for Electric Ignition. — The induction coil used for high-tension ignition in motor practice has a central core of very soft, small iron wires arranged in a circular bundle. Insulating material in the form of a tube covers the core. Comparatively coarse copper wire is wound around the insulating tube in the form of a solenoid coil of a few layers and several turns. This is the low-tension coil, primary coil, or battery coil. The turns of wire are insulated from each other either by using a wire with an insulating covering or by carefully winding bare wire over a thickness of sheet insulation for each layer, so that the turns of wire do not touch each other, and then filling the spaces between the wires with paraffine. One end of the primary-coil wire is attached to a binding post for receiving a battery wire, and the other end connects to a device for interrupting the current.

The interrupter has a thin, flat spring (vibrator, trembler) that is rigidly held at one end so that a metal contact point near the free end is pressed against a mating point. The metal parts to which the two contact points are attached are electrically insulated from each other when the points are separated. The second wire from the battery is connected to the part of the interrupter that is insulated from the side to which the primary-coil wire is connected. The free end of the spring has attached to it a disk of soft iron that is held just opposite one end of the soft-iron core of the coil and at a short distance from it. When a current of electricity is passed through the coil it magnetizes the iron core, which then attracts the metal disk and draws both it and the free end of the spring toward it. The contact points are thus separated and the current interrupted. The core then quickly loses its magnetism, and the elasticity of the spring brings the contact points together, so that current again passes through the coil. This operation is repeated and continued as long as the battery supplies sufficient current.

A second coil (secondary coil, high-tension coil, spark-plug coil) is wound over the first. It is of exceedingly thin wire and has an extremely great number of turns. The turns and layers of wire are insulated from each other in the same manner as in the inner coil. The outer coil is carefully insulated from the inner one that carries the low-tension battery current. One end of the outer coil is connected to the same binding post as the end of the inner coil of coarse wire (primary coil). The other end of the outer coil is terminated at a binding post of its own. The apparatus thus has three binding posts or terminals for receiving wires from outside.

One terminal is at the battery side of the interrupter; another, which may be called the intermediate terminal, is between the ends of the inner and outer coils; and the third terminal is at the remaining end of the outer coil.

The inner coil of coarse wire and few turns is designated, as has already been indicated, either as the primary winding or coil, the low-tension winding or coil, or the battery winding or coil.

The outer coil of thin wire and many turns is known as the secondary winding or coil or as the high-tension winding or coil.

When the battery current stops flowing through the primary winding it induces a current of extremely high pressure and very small volume, or amperage, in the secondary winding. For ignition purposes the tension of this secondary current should be at least great enough to give a spark across a one-quarter-inch air gap.

An electric condenser is used in connection with the parts of the induction coil that have just been described, and is a component part of the apparatus. Its function is to strengthen the action of the coil and protect the contact points at the interrupter from fusing. The condenser is made up of sheets of tin foil and paraffined paper laid together alternately, so that the paper insulates the sheets of foil from each other. Alternate sheets of the foil are connected together electrically to form one pole of the condenser, and the remaining sheets are likewise connected together to form the other pole of the condenser. One pole of the condenser is connected to the battery side of the interrupter, and the other pole to the primary-coil side.

When the contact points of the interrupter are separated there is a tendency for the battery current to keep flowing in an arc across the gap thus formed. The magnetic core, acting inductively on the primary coil, also has a tendency to maintain the arc.

The condenser counteracts this combined effort to maintain an arc at the interrupter contacts, by receiving and storing the electric energy and thus breaking down the arc quickly. The energy stored in the condenser is probably discharged back through the primary circuit immediately after the primary current is stopped, thus further increasing the inductive action and the strength of the spark.

The induction coil, when not constructed especially for ignition purposes, usually has four terminals instead of three. Each end of the two coils is provided with its own binding post. Such coils are still used, to a limited extent, for ignition purposes.

All parts of the induction-coil apparatus, except the interrupter and binding posts, are enclosed in a box or case and surrounded with paraffine poured in while melted.

American induction coils for ignition purposes are generally wound to operate on from six to seven volts. Most of the foreign coils require only about four volts.

A voltage much higher than that for which the induction coil is constructed should not be applied to the primary coil. It will injure the contact points by fusing and oxidizing them, and if very much in excess of the right amount, may destroy the coil by breaking down the insulation in the winding.

46. Batteries for Electric Ignition. — Storage batteries and those made up of dry primary cells are the only kinds used for ignition to any extent on automobiles and launches. They are the most suitable for the same use in connection with stationary motors, even though the spilling of the liquid of a wet cell does not have to be considered. The high internal resistance and the polarization of wet primary cells when in use are the main obstacles to their adoption for stationary motors.

47. Dry Batteries. — The primary dry cell that finds most use for ignition, has zinc and carbon for its elements; the electrolyte is a solution of sal ammoniac in water.

The sheet zinc used is made up into a round, cylindrical, open-top cell. A solid stick of carbon (coke) is placed in the middle of the cell and packed in with rather finely granulated coke. Absorbent paper, such as blotting paper, is placed at the bottom and top of the cell. The granulated coke is saturated with the sal-ammoniac solution. The top of the cell is sealed with a thick layer of pitch, poured in hot, and the end of the carbon stick protrudes through the pitch cap. A binding post is attached to the carbon and another to the edge of the sheet zinc.

The electromotive force of a carbon-zinc-sal ammoniac dry cell is about 1½ volts when the cell is not giving out current. The voltage drops while it is delivering current. From 1 to 1¼ volts is as much as a dry cell will ordinarily maintain when furnishing electricity to an induction coil used for ignition, even while the cell is still in good condition. Dry cells run down rapidly in both voltage and capacity when in use for ignition, and some even deteriorate rapidly while still new and not in use.

The carbon is called the positive element of the dry cell just described, and the zinc is called the negative element. They are indicated by the signs

(+) for the positive element;
(−) for the negative element.

48. Series and Multiple Batteries. — When dry cells are used for ignition they must be connected together in groups so as to give the required pressure and current.

For convenience the words *carbon* and *zinc* will often be used instead of *positive* and *negative*, in referring to the various battery connections.

In series battery connection the carbon of one cell is electrically connected to the zinc of another, from cell to cell. A positive element is left free at one end of the series of cells, and likewise a negative element at the other end. These two free elements are the terminals of the battery.

The connection of cells in series has the effect of adding their voltages together to produce a voltage equal to their sum. If all the cells have the same voltage, then the voltage obtained by connecting them in series is found by multiplying the voltage of one cell by the number that are connected in series. If five cells whose working pressure (when delivering current) is 1¼ volts each, are connected in series, the voltage between the terminals of the battery will be 5 × 1¼ = 6¼ volts. This is about the voltage for American induction coils for high-tension ignition purposes.

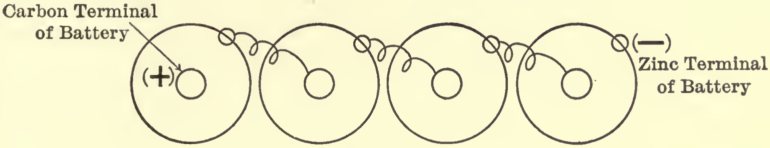


FIG. 45.

Battery of Four Series-Connected Cells.

1¼ volts per cell. 5 volts between (+) and (−).

The voltage, or electromotive force, of a battery is the measure of the pressure that forces electric current through the circuit to be traversed. All parts of the circuit, including the battery itself, offer resistance to the flow of current. The current must pass through the battery, therefore the internal resistance of the battery must be added to the resistance of the external circuit (external resistance) in order to obtain the value of the total resistance. The amount of current that a given voltage will send through a given circuit is inversely proportional to the total resistance of the circuit.

The elementary equation representing this is

$$\text{Current} = \frac{\text{Electromotive force}}{\text{Total resistance of circuit}}$$

$$= \frac{\text{Electromotive force}}{\text{Internal resistance} + \text{external resistance}}.$$

If the external resistance of the circuit is so great in comparison with the internal resistance of the battery as to make the latter insignificant in comparison, then the current that a battery will give is almost exactly proportional to the number of series-connected cells of equal voltage in the battery. But, on the other hand, if the external resistance of the circuit is very small in comparison with the internal resistance of the battery, as when the terminals of the battery are connected by a thick, short copper wire, the addition of cells of equal voltage and internal resistance, connected in series, will not appreciably affect the amount of current that will flow, for the total resistance of the circuit is increased in nearly the same proportion as the electromotive force.

Increasing the number of cells in a series-connected battery does not increase the current in the same proportion. But when the circuit includes an operating induction coil the proportionate increase of current is greater, and more nearly in proportion to the number of cells, than is indicated by an equation dealing only with current, electromotive force, and resistance when the latter is measured by a continuous, uniform flow of current. The reason for this is that the inductive resistance of the circuit on account of the rapid change in the rate of flow of current as the interrupter works greatly increases the external resistance above that which the external resistance offers to a steady flow of current.

Under the usual conditions of high-tension battery ignition, increasing the number of cells in a series-connected battery very materially increases the current that flows through the primary winding of the induction coil. The volume or hotness of the spark is also very materially increased as long as the magnetic core of the induction coil is not nearly or completely saturated. (Saturated = magnetized to its full capacity.)

In multiple battery connection all the carbons are connected together, as by a single wire, and all the zincs are similarly connected together. The two wires are the terminals of the battery. The voltage of the battery is the same as that of a single cell, when all the cells are of equal electromotive force. The current that the battery will give is but slightly more than that of a single cell when the external resistance is very high in proportion to the internal resistance of a cell. But when the resistance of the external circuit is very small in comparison with that of a cell, the current will be nearly proportional to the number of cells.

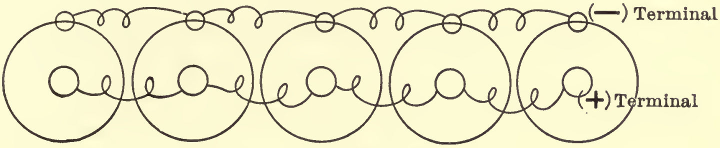


FIG. 46.

Battery of Multiple or Parallel-Connected Cells.

1¼ volts per cell; also 1¼ volts between (+) and (—).

The facts just pointed out go to show that if one cell is sending an electric current through a circuit, and it is desired to increase the current to the greatest value possible by the addition of another cell, they should be connected in series (carbon to zinc) if the external resistance of the circuit is large; but if it is small, they should be connected in multiple (zinc to zinc and carbon to carbon). The inductive resistance is to be included in the external resistance of the circuit. It is assumed that the cells are exactly alike.

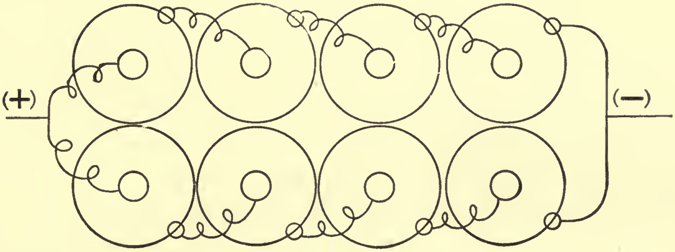


FIG. 47.

Two Sets of Four Series-Connected Cells in Multiple or Parallel.

1¼ volts per cell. 5 volts between (+) and (—).

49. **Multiple-Series Batteries.** — A group of series-connected cells can be considered as one of the units of which a battery is made up. In determining the pressure and current capacity of a

battery of such units, the work may be facilitated by imagining each series-connected group to be a single cell whose carbon and zinc correspond to the terminals of the group. The electromotive force of this imaginary cell is the same as that of the series. The effects on pressure and current obtained by connecting these groups either in series or multiple are similar to those already pointed out for series and multiple arrangement of single cells.

Thus, if five cells connected in series is the unit, whose electromotive force is $6\frac{1}{4}$ volts, then putting two of these units in series with each other will give $2 \times 6\frac{1}{4} = 12\frac{1}{2}$ volts; or putting the two units in multiple will leave the pressure $6\frac{1}{4}$ volts as before. And as for single cells, any number of the series-connected units when connected in multiple do not increase the pressure.

50. Arrangement of Batteries for Ignition. — It is advisable to have the batteries in duplicate for ignition purposes. Only one battery is used at a time. This leaves a reserve to be called on in case the one in use at the moment fails. If both batteries become too weak to supply enough current when either is used alone, they can both be used together. Simple and inexpensive switches for throwing either one or both batteries on are found in numerous designs. Such switches connect the two batteries

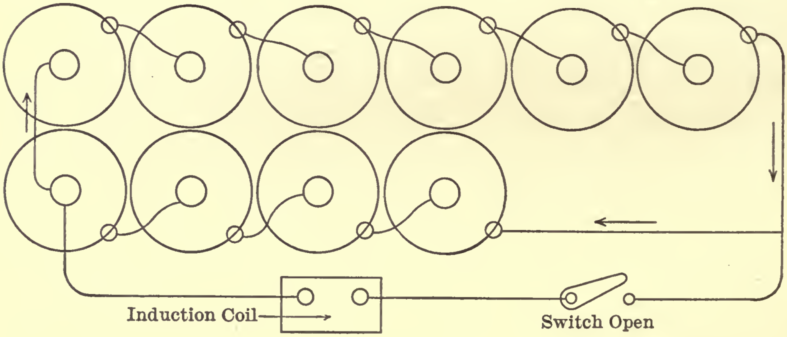


FIG. 48.

Incorrect Wiring for Two Batteries in Parallel.

Current flows as indicated by the arrows when the switch is open and exhausts the upper row of six cells. Current also flows in the same manner when the circuit is not closed by the timer of the ignition system.

in multiple when both are used at the same instant. The two batteries when thus connected really form a single multiple-series battery.

In jump-spark electric ignition for motors the resistance of the circuit that is external to the battery is generally of such an amount that the following method of arranging the cells can be used to advantage when there are originally two batteries.

After both batteries have become too weak to give sufficient current when used individually, they can first be connected in multiple, as already described, and used until still further weakened to such an extent as to fail to supply the necessary energy.

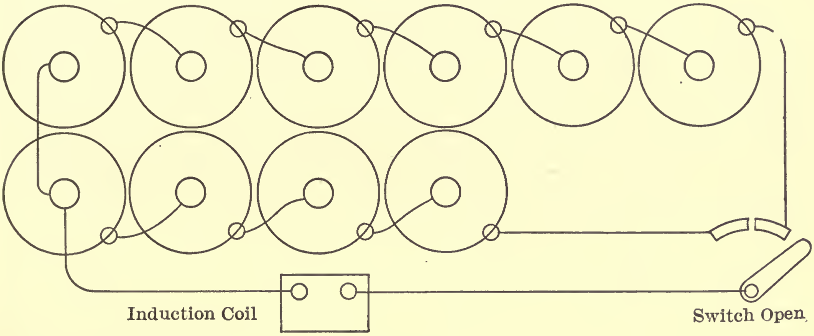


FIG. 49.

Correct Wiring for Two Batteries in Parallel.

No current flows when the switch is open. The switch when in mid-position puts the two batteries in parallel.

The two original batteries can then be connected in series and they will then generally give enough current for a while. Sometimes it is advisable not to change directly from multiple to series connection of all the cells, but instead to put only part of the cells of one battery in series with all those of the other and then add the remaining cells in series as they are needed.

When dry cells are used for low-tension arc ignition a gain of current can be obtained by putting two batteries in multiple after they have each run down so that neither alone will give enough current. There is no further gain by putting them in series, however, when the external resistance of the circuit is as low as in the usual practice for arc ignition.

51. Recuperation of Dry Cells. — Most carbon-zinc dry cells can be temporarily recuperated by making a hole in each and putting in a solution of sal ammoniac in water, or by putting in water alone. The rejuvenation thus secured is generally of short duration, however.

52. Storage Batteries, also called Accumulators and Secondary Batteries. — The storage battery for ignition purposes is ordinarily made up of two or three storage cells, all placed together in a single case, or in a large cell, so that the battery is a compact and inseparable unit in itself, which in many designs has but two external binding posts or terminals. In others the terminals of each cell are brought outside of the case and connected together to form the battery. Two of the cell terminals are left free, of course, to form the battery terminals.

The storage cells are made up of positive and negative plates. In one type the plates are of lead with numerous perforations or pockets which are filled with oxide of lead in the form of paste. Several of these plates, or grids, are connected to form the positive side of the cell, and another set for the negative side. The positive and negative grids are interposed between each other, and the intervening spaces are filled with a liquid electrolyte of dilute sulphuric acid.

When first made up the cell has no electric life, but must be charged by passing a current of electricity through it. When charged, the terminal of one set of plates becomes electro-positive and that of the other set electro-negative. When the cells are recharged, it must always be done so that each set of plates retains its initial polarity. The terminals of the battery are therefore marked in some manner to indicate which is positive and which negative. In ignition storage batteries the terminals are usually marked (+) and (−) to indicate positive and negative respectively.

The charging of the storage battery can be done from any source that will furnish direct current (not alternating) of sufficient pressure. The pressure of the charging current must be higher than that of the battery when it is fully charged. The current must not be allowed to exceed a certain maximum amperage that depends on the area of the surface of the grids. There are generally instructions with the battery which give the maximum allowable current for charging. The charging process is one of chemical change in the lead oxide. If done too rapidly, gases are formed too rapidly and the paste loosened in the pockets.

Before connecting the charging wires to the terminals of the battery, it is necessary to know which of the wires is positive and which negative, so that they can be connected accordingly. A very simple and convenient method of determining the polarity of the charging wires is to immerse their ends in water. Bubbles of gas will form on the immersed surface of the negative (−) wire more rapidly than on the positive (+). The wire on which the greater formation of bubbles occurs should be connected to the negative terminal of the storage battery, and the other wire to the positive terminal of the battery.

In testing for the positive and negative wires it is advisable to keep their ends well apart when they are first immersed in the water, and then bring them toward each other gradually till the bubbles show distinctly. An excessive flow of current will thus be prevented in cases where it would occur with the wire ends close together. Impure or slightly acidulated water will give bubbles more readily than pure water, on account of the lower electrical resistance of the former. In case the memory fails as to the pole at which the bubbles form most rapidly, wires can also be connected to the terminals of the storage battery to be charged and their free ends immersed in water. The formation of bubbles should be noted as for the charging wires. The two wire ends that give most bubbles in the two cases should be connected together for charging. Acidulated water is generally required to bring out the bubbles with the voltage of the ignition storage battery.

The case enclosing the ignition storage battery is tightly closed when the battery is in use. But when charging, each cell is opened to the atmosphere by the removal of a stopper to a hole in the cell, or by other means. This is necessary to allow the gas slowly formed during charging to escape. When the battery is completely charged, the formation of the gases by the continuance of the charging current is much more rapid than before. Charging should be discontinued as soon as gases begin to form rapidly.

Rectifiers for transforming alternating current into direct current are used for charging storage batteries when the source of electrical supply has an alternating current.

The electromotive force of the lead-grid storage cell is brought up to about 2.5 volts while charging. It quickly drops a tenth of a volt or so when it begins to discharge. When it has fallen to 2.1 volts per cell the battery should not be used till charged again. Three cells in series, giving an average of about 6.5 volts, are put together for the battery to be used in connection with American induction coils, according to the usual practice.

Storage cells with other elements than lead and its compounds are also in use for ignition purposes. In one, nickel and iron are the metals used for the elements. Another, a foreign production, is really a combination of a storage cell and a primary cell. It is charged by passing a current through it in the usual manner for a storage cell. But in order to obtain current from it a piece of metal, or alloy, is dropped into it. Current is then given out as in the ordinary case of a storage cell. This continues as long as any of the piece of metal dropped in remains. But as soon as the metal is consumed the cell becomes dead till more metal is dropped in. This makes it active again as long as the metal lasts. The number of pieces of metal that have been used in a battery after it has been fully charged is an index of its degree of discharge. The pieces of metal to be dropped in are made of uniform size. When a certain number have been used the cell must be recharged.

The electrical resistance of storage cells for ignition is much lower than that of dry cells, but not so low as that of the larger storage cells intended for power and lighting purposes where a vastly larger current is required. The ignition storage battery is, therefore, not so seriously injured by short-circuiting as are the larger ones, but is exhausted with great rapidity when the terminals are connected through a circuit of very low resistance.

53. Comparison of Dry Cells and Storage Batteries for Ignition Purposes. — The storage battery has a greater capacity than a battery of dry cells of equal bulk. It also provides a more uniform voltage. On account of these properties it is far more desirable than dry cells. The two features not so desirable are the necessity of recharging and the comparatively high cost of the storage battery. When used in connection with a generator that supplies it with current while both are connected in the working position with the motor, the objection to the necessity of recharging disappears.

Many makes of dry cells are notably unreliable in action. They sometimes have practically no energy in them when first put in place. This deficiency may be due either to an originally poor cell or to one that has been kept too long before putting it into use. It is believed that nothing more than care in selecting materials and in construction is necessary to produce a good, durable dry cell. When carelessly packed, the terminals of two cells may come together so as to make a short circuit and exhaust them both.

54. Testing Electric Batteries. — The test for the condition of a storage battery with regard to its capacity to deliver current is made by measuring the voltage. It will be remembered that the voltage drops as the battery is discharged. Since the drop is slight from the highest to the lowest working limits, a voltmeter reading to small fractions of a volt (milli-voltmeter) between these limits is necessary. A storage battery may be very much out of repair and still show a satisfactory pressure. In some cases of this kind a test of the current will disclose that it is faulty. The test for current can be made with an ammeter in a circuit that has from terminal to terminal of the battery about the same resistance as that on which the latter is intended to work. This is readily done by cutting the ammeter into the regular circuit. The current will decrease rapidly if the battery is seriously faulty.

The ammeter is sometimes applied directly to the terminals of the battery. This, if done at all, should be for only a small fraction of a second. The ammeter has a very low resistance, and applying it to the terminals without any other resistance in the circuit practically amounts to short-circuiting the battery. The only method of doing this that is at all safe for the battery is to connect one terminal of the ammeter to a terminal of the battery and then strike the other battery terminal a glancing blow with the free ammeter terminal. The kick of the ammeter needle is to be observed. The circuit should not be closed long enough for even a dead-beat needle to come to rest. This does not refer to storage batteries other than those constructed for ignition purposes.

Dry cells and dry batteries can be tested in the same manner as that just given for storage cells. The dry cell will not generally be so much injured by short-circuiting through the ammeter as the storage cell, but still it is never advisable to hold the instrument in contact with the terminals more than a second or two when there is a strong current. If the current is weak, the cell is poor and past injury in this manner. Tests of dry cells cannot be greatly relied on, however, for one that shows full voltage and a strong current after standing idle will not infrequently fail in a short time.

55. Wiring Scheme for Single-Acting, Single-Cylinder Motor with Jump-Spark Ignition. — A wire from one terminal of the battery connects to the induction coil at the binding post that forms part of, or is directly connected to, one side of the interrupter. A wire from the insulated stationary contact piece of the timer is connected to the induction coil at the intermediate binding post where one end of the primary and one end of the secondary coil terminate. The remaining terminal of the battery is "grounded" by connecting it to the metal of the motor or any part of the metal frame on which the motor rests. If the rotor of the timer is electrically insulated from the shaft to which it is mechanically attached, and thus from the frame of the motor, then a wire connects the insulated ground ring of the rotor to the metal of the motor or its supporting frame, or a slip ring and brush are used for the same or a similar purpose.

When the timer rotor is not insulated from the shaft, no special electric connection is used. This completes the wiring of the battery circuit.

When the timer closes the circuit, current passes from the battery to the interrupter, then through the primary winding and on through the timer to the metal of the motor or of the frame that supports the motor, and thence to the ground wire of the battery and through the ground wire back to the battery itself. A switch for opening and closing the primary circuit at will is placed somewhere in the circuit, generally between the battery and the induction coil.

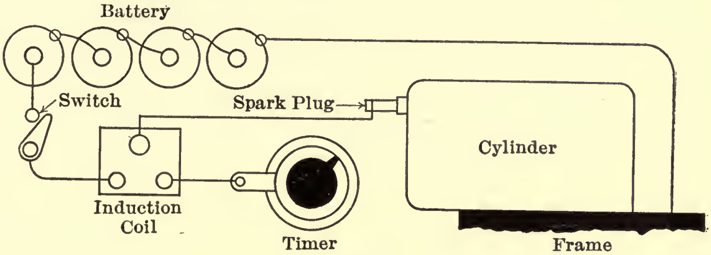


Fig. 50.

Ignition System for Single-Cylinder Motor. One Battery.
Heavy black indicates frame or "ground" connection.

Only one additional wire is required for the high-tension or spark-plug circuit. It connects the remaining terminal of the induction coil to the insulated part of the spark plug. The high-tension current passes along this wire from the induction coil to the spark plug, jumps across the spark gap to the metal of the motor, and then passes back to the induction coil by way of the timer and the wire connecting the timer to the terminal to which an end of each of the windings of the induction coil is attached.

It will be seen from the above that both the primary and secondary currents pass through the wire connecting the timer to the induction coil. This wire does not need heavy insulation, however, for the high-tension current passes through it only when the circuit is closed by the timer, thus making the potential of the wire practically the same as that of the motor. The insulation on the wire between the timer and induction coil needs to be only sufficient to prevent, when the timer is not closed, the primary current from passing between the wire and the motor or parts electrically connected to the motor.

While the method of wiring just given is the best, no serious injury is done if the timer wire is connected to the interrupter end of the primary coil. With this connection, however, the secondary current must either jump the open gap at the interrupter contacts immediately after the circuit is broken there, or pass from the motor frame back through the battery to the induction coil. There is apt to be more sparking at the interrupter with such connections than when they are made as first given.

A properly constructed induction coil is not injured by connecting the battery wires to the wrong terminals. When there is no way of determining, by an examination of the induction coil, how the connections should be made to it, it can be tested with perfect safety by connecting the battery wires to it till the interrupter vibrates, provided the interrupter is so adjusted that it will not allow a large current to flow through the coil without interrupting it. The current from a battery of the right capacity will do no harm unless it is allowed to flow for considerable time without interruption.

In testing for induction-coil connections, the vibrator spring should be set so that it presses the contact points together very lightly.

The substitution of a low-tension direct-current electric generator of constant voltage for the battery does not alter the wiring scheme. It is not usual, however, to find an electric generator used in connection with a current interrupter on the induction coil.

56. Wiring Scheme for Motor with More than One Combustion Chamber, Jump-Spark Ignition, and One Induction Coil for Each Combustion Chamber. — This differs from the wiring for a single combustion chamber, as just given, in the multiplication of the spark plugs, induction coils, number of contact points on the timer, and the number of wires connecting the induction coils to the timer and spark plugs.

A wire is led from one of the battery terminals to one of the terminals of a switch at the induction coils, which are grouped together, all of them generally being placed in one box. Each induction coil is complete in itself, including the interrupter.

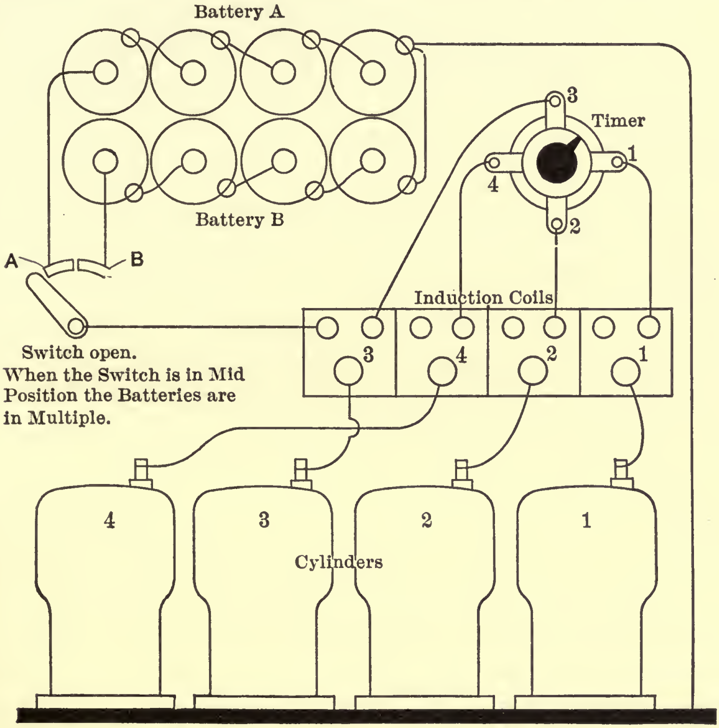


FIG. 51.

Ignition System for Four-Cylinder Motor. Two Batteries.

Heavy black indicates frame or "ground" connection.

When the switch is closed, one of the battery wires is electrically connected to the interrupter ends of all the induction coils. The timer has as many stationary contact points as there are spark plugs to be operated. There are as many wires between the timer and the group of induction coils as there are induction coils. Each induction coil has its own contact point at the timer, and is connected to the latter by a wire leading from the intermediate binding post of the coil. Each spark plug is connected to the remaining binding post of its own induction coil. The rotor of the timer and the remaining terminal of the battery are grounded to the metal of the motor as for a single-cylinder motor.

The timer, by its rotation, closes the primary circuit through each induction coil consecutively in the proper order and at about the instant the spark is to pass in the corresponding combustion chamber.

If the explosions are to occur with equal intervals of time between them, then the stationary contacts of the timer are placed at equal distances apart around the path traveled by the rotor's contact point. But if, as is the case of a double-acting, single-cylinder, four-cycle motor, the explosions occur first at one-half a revolution of the crank shaft apart, and then not until one and a half revolutions more have been made, then after another half revolution, and so on, the two stationary contacts of the timer must be placed at one-quarter of the circumference apart.

The low-tension direct-current generator can be used instead of the battery, but its application for this purpose is not common.

57. Jump-Spark Ignition with High-Tension Distributer and Battery Current. — In this system of ignition the timer and induction coils are replaced by a single piece of apparatus composed of one induction coil, a timer, and a distributer for directing the high-tension current to the proper spark plug.

The timer closes the battery circuit through the interrupter and the primary winding of the coil whenever a spark is wanted at any of the spark plugs. Since there is only one induction coil, a means of directing the high-tension current to where it is needed becomes necessary.

The distributer generally consists of an arm of some sort that is attached to and rotates with the same shaft that carries the timer rotor. As the distributer arm swings around it comes consecutively opposite the terminals to which the wires that lead out to the insulated parts of the different spark plugs are connected. The distributer has always come opposite one of these terminals when the timer closes the primary circuit.

In addition to the spark gap in the combustion chamber, the high-tension current must jump another small gap between the distributer arm and the terminal next to it.

By this condensing of the apparatus the wiring system is simplified to some extent. The wires necessary are: one wire from the battery to the induction coil; one from each of the spark plugs to the induction coil; and one from the battery to the metal of the motor, or to "ground." If the rotor of the timer is insulated from the metal of the motor, then another wire for grounding the rotor, or its ground-ring, is necessary.

58. Comparison of Multi-Induction-Coil and High-Tension-Distributer Ignition Systems. — The high-tension distribution system has the advantage of the absence of external wires between the timer and the induction coil and of more compact apparatus. It has the disadvantage of depending entirely on one induction coil for the current to all the spark plugs. In a four-cylinder motor the service is so arduous that the contact points of the interrupter become very warm, and fusing and oxidation are of frequent occurrence. It is not unusual for makers to construct the case for enclosing the apparatus with space for carrying an extra induction coil, and to supply the extra coil as a part of the apparatus.

When an individual induction coil is used for each spark plug, the failure of one coil to work does not necessarily stop the motor, for it can be run on the remaining coils and their corresponding motor cylinders and combustion chambers. A test can also be easily made to locate a faulty spark plug or a cylinder that is not acting properly, by holding down one or more of the vibrators and thus cutting out some of the spark plugs, at the same time noting the action of those left in operation. This cannot be done with the single induction coil combined with a high-tension distributer. The high-tension wires can be disconnected or short-circuited in either system, however, for locating a faulty plug or cylinder. This is far less convenient, and sometimes decidedly uncomfortable on account of the electric shock that may be received.

59. Jump-Spark Ignition in Two Cylinders with One Induction Coil and No Distributer. — In a two-cylinder, four-cycle, single-acting motor whose time interval between explosions is of uniform length (one revolution of the crank shaft apart) one induction coil can be used for ignition in both combustion chambers. The coil most suitable for this purpose has four terminal binding posts instead of three. This is the usual construction of the induction coil for general uses. Each wire end of the two windings is terminated in a binding post of its own, which gives the four binding posts or terminals.

The battery circuit is run as for a single spark plug, but the timer must either turn at the same speed as the crank shaft or have two stationary contacts at diametrically opposite points, and also have these two contacts electrically connected together so that the battery circuit is closed once every revolution of the crank shaft. The high-tension circuit has a wire from each of the two spark plugs to the corresponding terminal of the secondary winding of the induction coil. The path of the secondary current is from one terminal of the coil to the insulated part of the spark plug, when plugs having only one side of the spark gap insulated are used, then across the spark gap of the plug to the metal of the motor and thence to the threaded bushing of the other plug, then across its spark gap to its insulated part and back to the other binding post of the secondary winding of the induction coil. Spark plugs having both sides of the spark gap insulated from the motor metal require an additional wire between the plugs, or each must have one side grounded to the motor metal.

The spark is made in both cylinders simultaneously and twice as often as it is needed. It comes at about the beginning of the impulse stroke and at the corresponding time in the exhaust stroke or suction stroke, or between the last two. When the motor is operating properly there is nothing but inert gases in the cylinder whose piston is about beginning the suction stroke at the instant the spark passes in it, hence the spark in that cylinder produces no result.

But if a charge fails to ignite at the proper time there will be some of the combustible mixture still remaining in the cylinder when the spark passes at about the beginning of the suction stroke, and it may be ignited. The result generally is that it is still burning when the new charge begins to enter, and the latter is fired back into the inlet pipe and carbureter. This does no damage generally, but the motor does not get another charge of combustible mixture until after a stroke or two of the piston has been made to clear out the inert gases from the inlet pipes, and there is consequently loss of power.

This back firing into the carbureter occurs frequently when starting a motor by cranking, either on account of the failure to fire a charge at the proper time or by the incoming charge striking the spark plug at the instant the spark jumps.

This system of ignition can be extended to any even number of spark plugs by using one induction coil for each pair of plugs whose charges are to be fired one revolution apart.

The use of this system is decreasing. It has the objectionable features of depending on only one coil for two cylinders and the absence of a ready method of locating a defective spark plug or a cylinder that is not giving its full power.

60. Magneto Generators for Jump-Spark Ignition. — The primary current for jump-spark (high-tension) ignition is very often furnished by a magneto generator. Both the rotary-armature and the oscillating-armature types are used. The rotary type generates an alternating current. There are two forms of the apparatus found in general practice.

The armature of the magneto is usually of the simple shuttle-wound type with the customary I-shaped cross-section of armature core. In the better machines the armature core is built up of numerous thin stampings from sheets of soft iron or mild steel. The I-shaped stampings are placed side by side to build up the core.

The magneto is a separate piece of apparatus in one system of ignition. The low-tension current from the magneto is taken to a transformer for changing it into high-tension current for the spark-plug circuit. The transformer is an induction coil without an interrupter (trembler, vibrator).

In another system both the magneto and the induction coil, or transformer, are embodied in a single piece of apparatus, which is commonly called a "high-tension magneto."

61. Low-Tension Magneto and Separate Transformer System of Jump-Spark Ignition. — A magneto with either a rotary armature or an oscillating armature can be used in this system.

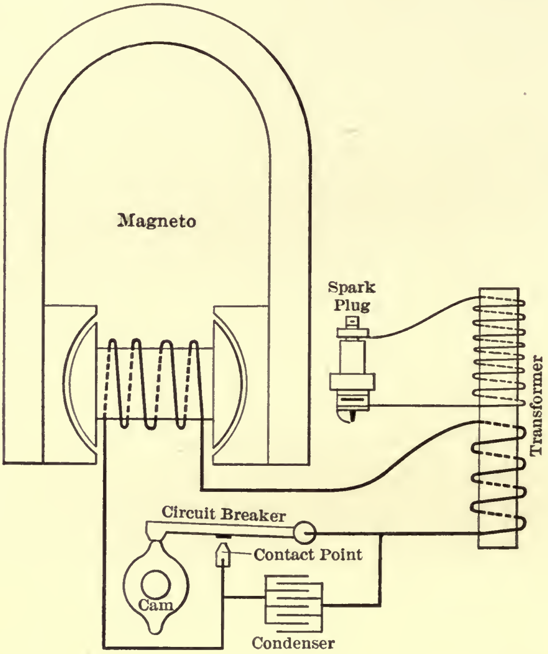


Fig. 52.

Magneto and Transformer for Jump-Spark Ignition. Interrupted Armature Current.

The cam is either placed on the armature shaft or driven at the same speed as the armature. The cam lifts the circuit breaker and breaks the armature circuit at the contact points when the current has reached about its maximum value. The sudden drop of current thus caused in the primary winding of the transformer induces a pressure in the secondary winding of sufficient intensity to make a spark at the ignition points of the spark plug.

The condenser has the same function as in an induction coil with a vibrator for interrupting the primary current.

The figure is an entirely diagrammatic representation of the system. A cylindrical timer with non-conducting segments for interrupting the current is generally used instead of a circuit breaker of the nature shown.

When a rotary armature is used, the more usual practice is to drive it at a high speed, and use a timer for closing the primary circuit through the transformer at the instant an ignition is wanted. The rapidly alternating current from the magneto passes through the primary (low-tension) coil of the transformer and induces a high-tension current in the secondary winding which connects to the spark plug. A series of sparks pass at the plug each time the primary circuit is closed by the timer.

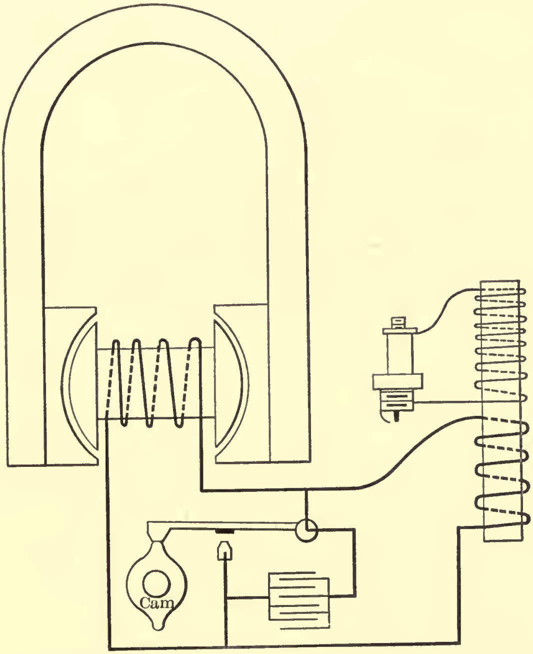


FIG. 53.

Magneto with Separate Transformer for Jump-Spark Ignition. Shunted or Short-Circuited Primary Current.

The armature current is short-circuited through the contact points till it has reached about its maximum. The circuit breaker is then opened and the consequent sudden increase of current in the primary of the transformer causes a spark at the spark plug. Immediate closing of the circuit breaker will induce another spark at the plug on account of sudden decrease of current in the primary of the transformer.

With this arrangement the armature can be driven by a belt, friction gears, or friction clutch, for it is not necessary that the speed of the armature shall bear a constant ratio to that of the crank shaft of the motor.

If a speed-limiting device is used in connection with the friction gears or clutch, then the armature can be given a high speed ratio in relation to the crank shaft, so that rotating the motor shaft slowly, as when cranking a small motor by hand, will generate current of sufficient volume and frequency to induce a spark in the combustion chamber. The speed-limiting device prevents the speed of the armature from becoming excessive when the motor rotates rapidly.

Some rotary magnetos for this system are so constructed that they can be connected by a positive drive to the motor crank shaft so as to have a constant speed ratio to the latter. The armature is wound so that it will give enough current to produce the ignition spark when the motor is cranked rapidly by hand, and will not be injured or deliver too much current or voltage to the transformer when the motor runs fast.

The oscillating-armature magneto always gives the same current and voltage, whatever the speed of the motor. A timer is not necessary in connection with it, but is often used. When the timer is used the transformer generally has a condenser. The oscillating magneto gives only one spark for each ignition. Its armature is moved partly around at a comparatively low rate against the resistance of a spring, and then allowed to snap back to generate the current for the spark at the plug. Or, in other designs, the armature is held stationary while the part to which the spring is attached rocks over, and then the armature is released and follows with a snap, first in one direction and then in the other. The oscillating magneto is used successfully on very high speed motors, such as those on motor cycles. In a four-cylinder, four-cycle, single-acting motor having only one magneto, the armature must snap over twice for every revolution of the crank shaft. This has been accomplished on the motor cycle.

62. "High-Tension Magneto." — This is the commercial name for a piece of apparatus which delivers high-tension current to the spark plug in jump-spark ignition when its armature is rotated at the requisite speed, or oscillated. It is really the embodiment, in one apparatus, of a magneto electric generator, a condenser, a transformer, a timer, and a high-tension current distributer. The latter is needed only when the motor has more than one combustion chamber.

In one type, designed for a four-cylinder, single-acting four-cycle motor, or for a two-cylinder, double-acting motor, the

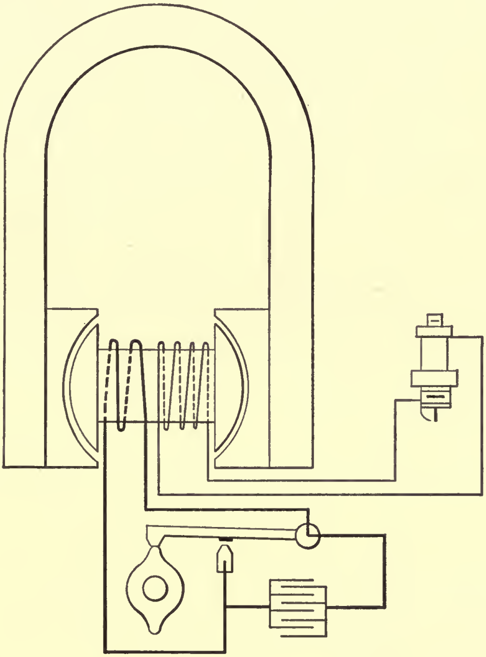


FIG. 54.

Magneto without Separate Transformer for Jump-Spark Ignition.

Magneto Armature used on Transformer. Interrupted Primary Current.

The secondary coil is wound on the armature core of the magneto outside of the primary coil. The primary current is interrupted by the circuit breaker when at about its maximum value. The sudden drop of current in the primary coil of the armature, together with the action of the magnetic field, induces pressure in the secondary coil great enough to produce a spark at the spark plug. The condenser may be embodied in the magneto, thus forming a "high-tension magneto."

shuttle-wound armature is driven at the same speed of rotation as the crank shaft of the motor. The armature delivers low-tension current to a condenser of the usual tin-foil construction; a timer closes the circuit between the condenser and the primary winding of the transformer at the time the condenser is fully charged, which corresponds to the instant the spark is required for ignition. One end of the secondary winding of the transformer is connected to a rotating high-tension current distributer arm that comes, at the proper instant, opposite the terminal of a wire leading to the spark plug where the spark is wanted. The other terminal of the secondary winding is grounded to the metal of the motor. The high-tension current jumps both the slight gap at the distributer arm and that at the spark plug at the same instant. The rotation of the distributer arm brings it in turn opposite the end of each wire that leads to a spark plug, so that a spark is produced in each combustion chamber as desired.

The apparatus resembles an ordinary magneto in general appearance. It can be constructed for any number of cylinders, and the speed or rotation of its armature and distributer arm varied accordingly in relation to the crank shaft.

When an oscillating armature is used the timer can be dispensed with, especially if the speed of the motor is not high. When there is no timer the condenser can also be eliminated.

An induction coil with an interrupted magnetic circuit and a single winding of many turns of wire can be used for producing high-tension current for the spark plug. The coil can be used with or without a timer and condenser. Without the condenser it differs from the similar induction coil already described for low-tension ignition only in having a greater number of turns in the winding.

63. Dynamo-Battery Ignition and Lighting System. — Storage battery "floated on the line." Direct-current shunt-wound dynamo. Fig. 55 illustrates a method of using a dynamo and storage battery simultaneously for supplying current for ignition purposes, and for small lights also when desired. The scheme is a simplification, to some extent, of the same method as applied to power and lighting purposes on a large scale.

The voltage of the system is determined by the battery within slight variations.

When the voltage of the dynamo is higher than that of the battery, the direction of flow of current is as indicated by the full arrows. The current from the lower (+) brush of the dynamo divides, most of it flowing out through the lower line. The other (very small) portion of the current flows first through the field coil of the generator and then through the thin-wire coil of the armature cut-out and back to the dynamo. The main part of the current, in the lower line, divides and the different portions flow through the storage battery and lamps, each portion in its own course. The induction-coil circuit is shown open, and will not be considered at present.

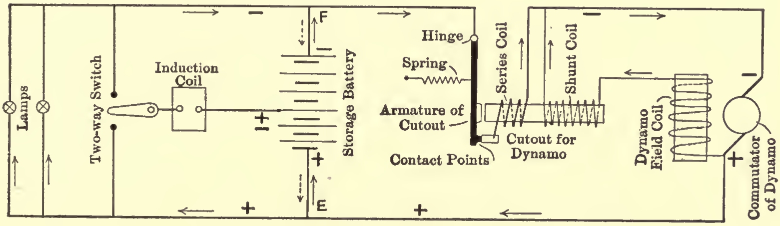


FIG. 55.

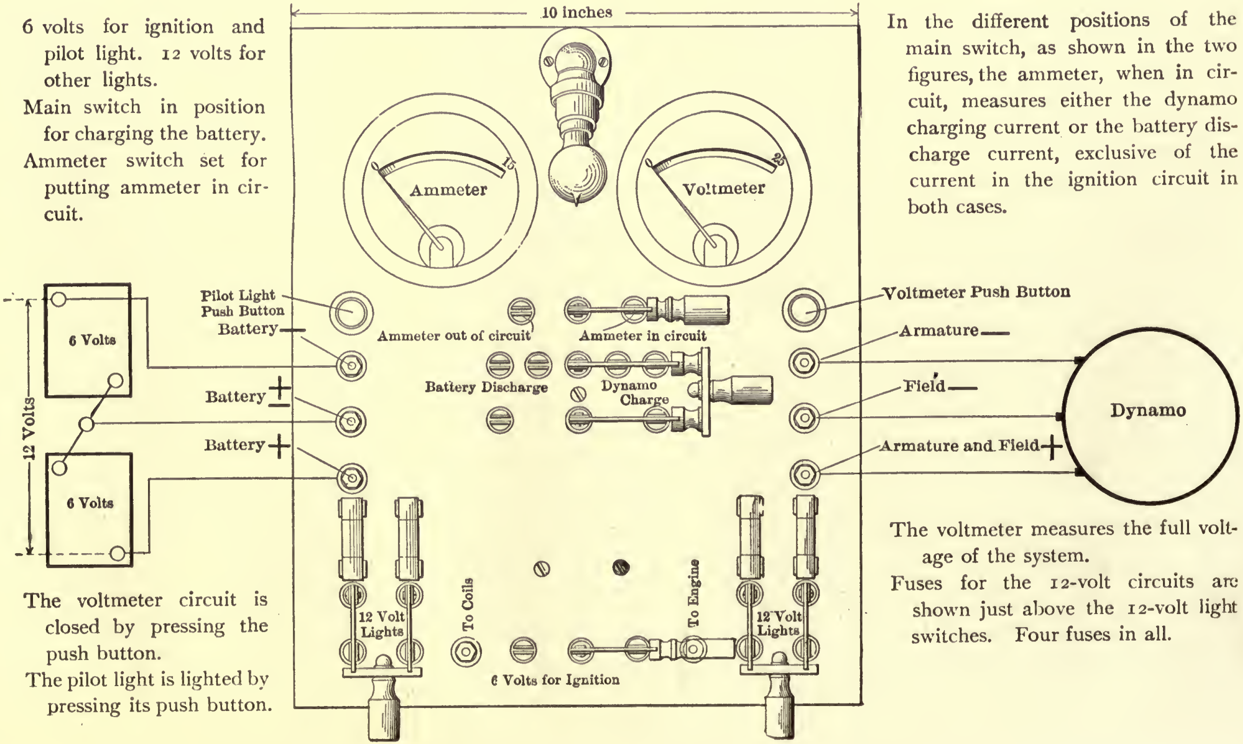
Dynamo-Battery Ignition and Lighting System. Battery "floated on the line."

The current returning along the upper line passes down through the armature of the dynamo cut-out, through the contact points and around the series coil of the cut-out, then back to the dynamo. The currents in both coils on the cut-out act in unison to draw the armature of the cut-out toward the core of the magnet and thus to keep the contact points together. The current flowing through the battery as indicated by the full arrows charges it.

If the dynamo furnishes between the junction points, *E* and *F*, of the battery wires with the main lines a voltage that is just equal to the voltage of the battery, then no current will flow through the battery, but all the current delivered by the dynamo

Fig. 56. (See also Fig. 57.)

Dynamo-Battery Ignition and Lighting Switchboard. Storage battery "floated on the line." Direct-current shunt-wound dynamo. Dayton Electric Manufacturing Company, Dayton, Ohio.



6 volts for ignition and pilot light. 12 volts for other lights.

Main switch in position for charging the battery.

Ammeter switch set for putting ammeter in circuit.

The voltmeter circuit is closed by pressing the push button.

The pilot light is lighted by pressing its push button.

In the different positions of the main switch, as shown in the two figures, the ammeter, when in circuit, measures either the dynamo charging current or the battery discharge current, exclusive of the current in the ignition circuit in both cases.

The voltmeter measures the full voltage of the system.

Fuses for the 12-volt circuits are shown just above the 12-volt light switches. Four fuses in all.

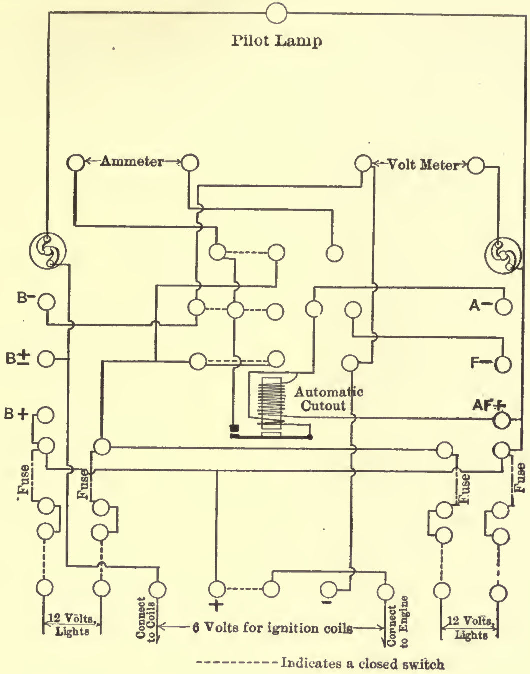


Fig. 57.

Wiring Plan for Switchboard shown in Fig. 56.

The main switch, ammeter switch, and ignition switch are all shown here in the alternate positions of the preceding figure. The dynamo circuits (both the main circuit and the field circuit) are open. The ammeter is out of circuit. The ignition is connected to the + side of the battery.

to the lower main line will pass through the lights (induction-coil circuit open).

When the pressure between *E* and *F* falls slightly below that of the battery terminals, but with the pressure at the dynamo still higher than that of the battery, which condition may occur on account of the resistance of the circuit from *E* through the dynamo to *F*, then current will flow from the battery, as indicated by the broken arrow, and through the lamps, as well as from the dynamo through the lamps. The battery thus aids the dynamo.

If the pressure of the dynamo falls below that of the battery, or more correctly, below that between *E* and *F*, then current will flow from the battery to *E*, divide there and pass in parallel through the dynamo and the lamps back to the battery. The current flowing back through the dynamo circuit in this manner acts in opposition to the shunt coil of the automatic cut-out. Before this back-flowing current becomes great enough to injure the dynamo, it weakens the cut-out magnet to such an extent that the spring draws the cut-out armature away from the magnet and separates the contact points, thus breaking the circuit that leads through the dynamo and battery. The battery continues to supply current to the lamps.

By now increasing the voltage of the dynamo, as by speeding it up, the current through the field coil of the generator and the shunt coil of the cut-out can be increased to magnetize the core of the cut-out enough to draw its armature in and again bring the contacts together to close the dynamo circuit. This is the same process as when starting the dynamo from rest.

The induction coil is connected to the middle of the battery, so that only half of the total voltage acts on it when its two-way switch is closed on either contact. If the dynamo circuit is open and the two-way switch is closed on the lower contact, then the lower half of the battery furnishes current to the induction coil; if the switch is closed on the upper contact, the upper half of the battery furnishes the current to the induction coil. If with the latter position of the switch the dynamo is put on with enough pressure to send current through the battery, the current from *E* will pass up to the middle of the battery and divide there, so that part will pass to the upper line through the induction coil and part to the same line through the upper part of the battery.

Small dynamos for this method of ignition are made with the automatic cut-out as a part of the dynamo. When intended to operate in connection with a variable-speed motor, a governor is used on the dynamo shaft to limit its speed to that which gives sufficient voltage to charge the battery.

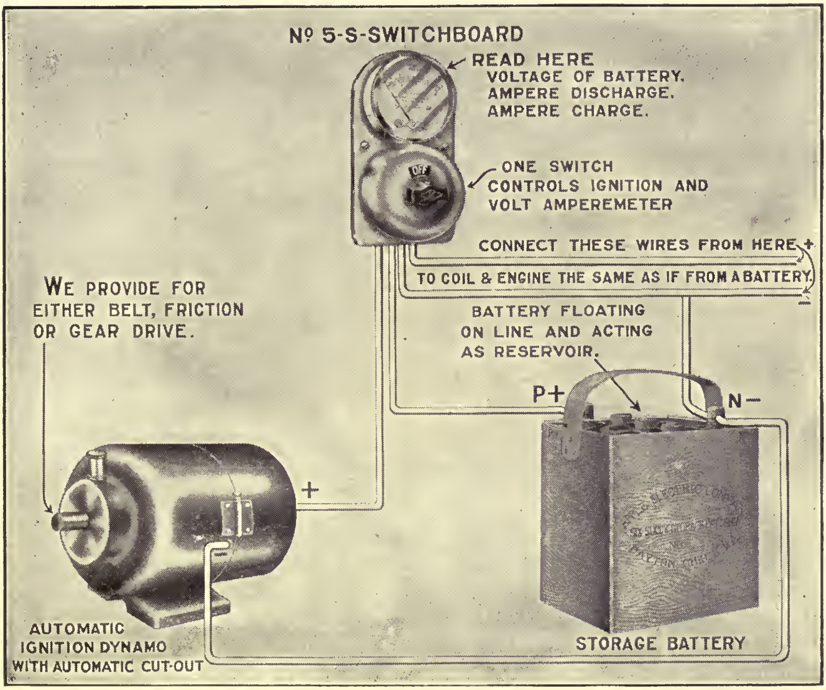


FIG. 58. Dynamo-Battery Ignition System. Apple Electric Company, Dayton, Ohio.

With suitably constructed batteries and a kick-coil in the ignition circuit, the above method of supplying current can be used for low-tension arc (make-and-break) ignition.*

* There are several other conditions and refinements which might be considered in connection with this method of supplying current, but is

64. Hot-Tube Ignition. — This method of ignition was extensively used until recent years, and is still in some use on constant-speed motors.

A tube of metal or some such material as porcelain or lava is attached to the cylinder of the motor so that one end opens into the combustion chamber; the outer end of the tube is permanently closed. An external flame keeps the tube at a red heat. When a charge is compressed into the combustion chamber some of it is forced into the open end of the tube on account of the diminution of volume of the inert gases contained in the tube at the beginning of compression. The combustible mixture thus forced into the tube is ignited by coming into contact with the red-hot inner surface, and the sudden expansion of the gases in the tube, due chiefly to combustion, projects a flame into the body of the charge. The length of the tube is so proportioned, and it is so heated, that ignition occurs at about the completion of the compression stroke. The principal application of hot-tube ignition is to motors running at constant or approximately constant speed.

A timing valve was used in connection with the hot-tube igniter in English practice. The valve closed the opening from the combustion chamber into the tube until time for ignition. The valve, of the poppet type, was then lifted from its seat and some of the compressed charge in the combustion chamber allowed to pass into the tube and become ignited. The timing valve was lifted by the action of a cam or some corresponding mechanism. With the timing valve, the hot tube can be used on a variable-speed motor.

The tubes were made of various metals in their earlier appli-

believed that the cases considered will make the method clear enough for the purpose at hand.

It may be noted, however, that there is no provision shown for automatically cutting out the battery when it becomes fully charged, in order to prevent its injury by overcharging. Such a device, common to all larger work, is not generally considered necessary for gas-engine ignition outfits. Fuses to prevent excessive current can of course be installed in the usual manner. Automatic circuit breakers for opening by the action of excessive current are hardly necessary above that shown.

cation. Platinum and other precious metals were tried, but their cost was objectionable. The friable tubes of porcelain and lava cracked, often without warning, and were therefore unsatisfactory on account of stopping the motor when power was needed. Nickel-steel hot tubes have finally proved the most satisfactory for this method of ignition. They are not particularly expensive, last well, and give ample warning when approaching the age limit.

The objections to the hot tube are the open flame, the deterioration of the tube, and, when the timing valve is used, the difficulty of keeping it tight. When the timing valve is omitted the ignition cannot always be brought about at just the instant desired, especially if the motor is exposed to wind and cold. Throttling the charge so as to reduce it in quantity also affects the time of ignition, especially if there is no timing valve.

65. Hot-Metal Igniter Heated by Internal Combustion. — This igniter for motors receiving a gaseous charge is, in one form, a piece of steel resembling a short section of tube with a deeply corrugated or ribbed interior. The corrugations are very deep, and the open space between them is narrower near the center of the tube than at a slight distance further out toward the circumference. The igniter is heated by a flame before starting the motor. The compression of the charge in the cylinder forces some of the combustible mixture back into the tube and against the hot metal, which ignites it. The heat of the combustion of the gases thus ignited is sufficient to keep the igniter red hot. An adjustment makes it possible to bring the mixture against the igniter at the proper instant if the amount of the charge is always the same so that the compression pressure is practically constant.

In connection with this method of igniting may be mentioned the very simple expedient of having a piece of metal project into the combustion chamber so as to become hot. After becoming heated it serves as an igniter, but the time of ignition cannot be well regulated with it. A bolt screwed into the piston has been used in this manner. The overheating of a water-cooled motor when its water circulation fails is another example.

66. Hot-Wire and Platinum-Sponge Igniters. — Ignition by means of a hot wire or a platinum sponge has been accomplished, but neither method was found serviceable enough to warrant its continuance.

In the hot-wire igniter, a short piece of very thin wire, generally of platinum, was placed in the combustion chamber and heated to incandescence momentarily by passing an electric current through it at the time a charge was to be ignited.

The platinum-sponge method depends on the property, peculiar to platinum, of becoming incandescent when placed in a current of combustible gas. This property is called "catalysis." The sponge, or a number of very thin platinum wires, was placed inside the cylinder where the current of incoming gas would strike it and quickly heat it to a temperature that would ignite the charge. The fouling of the sponge was a serious objection to its use. This method is analogous to igniting the gas escaping from an ordinary illuminating jet by holding a platinum sponge or a number of pieces of very thin platinum wire in the current of the escaping gas.

CHAPTER IV.

CONTROL OF POWER AND SPEED.

67. General Methods of Control. — There are two fundamental methods of controlling the power and speed of an internal-combustion motor whose fuel enters the combustion chamber in the form of gas or vapor, that find general application in general engineering practice. They are:

Variation of the amount of fuel supplied;
Variation in the instant of ignition.

There are several other methods of regulating the speed and power, but they are wasteful of fuel and otherwise undesirable in comparison with the two methods just cited.

It may be said that control by variation of the instant of ignition is also wasteful of fuel, and otherwise usually undesirable, yet, under certain conditions in connection with the operation of variable-speed motors, as those of automobiles, hoisting machinery, and, to some extent, of boats, the control of speed by this method is most convenient and desirable when used in connection with variation in the rate of fuel supply.

68. Fuel Control. General. — Variation in the amount of fuel is accomplished by two distinct methods in motors using gas or vapor fuel.

In one method the motor takes in either a complete charge, or no charge at all, of the combustible mixture during the normal charging period. This method is probably entirely limited in practice to four-cycle stationary motors operating at as nearly a constant speed as can be maintained, although it can also be applied to two-cycle motors.

On account of the form and the method of operation of the mechanism generally used to accomplish the cutting out of a charge, it is commonly known as the "hit-or-miss" method.

The other method is to vary the amount of the charge while always allowing enough mixture to enter the combustion cylinder to ignite and produce an impulse.

69. Fuel Control in Four-Cycle Gas or Vapor Motor. — Both the intermittent cutting out of a charge method and the reduction in the amount of the charge method, cited in the preceding section, find general application according to the conditions to be fulfilled.

The four customary ways of completely cutting out a charge, all of them **hit-or-miss** methods, are:

1. Keeping the mixture inlet valve closed during the suction stroke and also keeping the exhaust valve closed as usual;
2. Keeping the exhaust open and holding the inlet valve closed during the suction stroke;
3. Leaving the exhaust closed during the regular exhaust period so as to retain the inert products of combustion;
4. Keeping the gas valve closed while the mixture valve is kept open to admit air during the suction stroke.

The three usual ways of diminishing the quantity of fuel in a charge are:

A. Throttling the mixture;
B. Varying the length of time that the mixture inlet valve is kept open;
C. Varying the length of time that the gas valve is kept open, but opening and closing the mixture valve at fixed times.

By combinations of the above methods control for exceedingly variable demands for power is accomplished by first diminishing the quantity of fuel admitted for each charge till a certain condition is reached, and then cutting out charges as by the hit-or-miss method.

70. Governing and Hand Control. — The power and speed may be controlled either by a governor or by the hand of the operator, according to the requirements.

The governor is used when the speed is to be kept as nearly constant as possible with the degree of sensitiveness that the apparatus can attain.

Hand control is used on variable-speed motors, as those for automobiles, hoisting machines, launches, etc. It is generally accomplished by throttling the mixture and, to some extent, by varying the time of ignition.

Both governing and hand control are used in conjunction on variable-speed motors. In this application the mechanical governor limits the speed to a predetermined maximum and maintains that speed as long as the demand on the motor for power does not exceed its capacity at the speed limit of rotation to which the governor is then set. When the hand control (or foot control) is brought into use the governor is put out of action, either partly or completely, as desired. Usually the movement of the hand control changes the speed limit maintained by the governor. Such a governor is generally constructed so as to hold the speed fairly constant at the speed to which it is temporarily adjusted, within the speed limits of the motor. Throttling the mixture is the method generally adopted.

Methods of Governing by Cutting out Full Charges of Fuel or of Combustible Mixture.

71. Hit-or-Miss Governing in General. — This method was applied to the early motors operating on the Otto cycle, and still finds extensive application especially in small and medium sized motors. The speed cannot be as closely regulated as by reducing the amount of the charge to keep down the speed when the demand for power is low, but is sufficiently accurate for a large range of service.

This method of governing gives the highest theoretical efficiency of any, since each charge admitted is a full one, and the compression is therefore always to practically the same pressure, which is the maximum pressure suitable for the fuel. It may be remembered that the efficiency is higher the higher the compression pressure.

The usual means of securing the hit-or-miss effect is by the use of a part (called a "trigger" or "pick-piece" in certain forms) whose position is controlled by the governor in such a manner that, when the speed is not in excess of the normal, it engages with other parts (or does not engage) in such a manner as to cause the valves to perform their functions regularly. But when the speed exceeds the normal this part takes a position such as either to cause the omission of the movement of a valve or to modify its movement so that no charge is drawn in during the suction stroke of the piston.

The device generally has a pair of sharp, beveled edges (knife-edges) where the hit-or-miss occurs, so that when brought together by a very slight movement of the governor the beveled edges catch together and slip over each other so as to bring more substantial parts into full engagement for operating the valve. There are numerous modifications of the hit-or-miss apparatus.

A pendulum governor was used on the early thrust-rod valve lifters, and still finds application on account of its great simplicity and consequent small cost. It is used in its simplest form in connection with a valve whose stem is horizontal. The lift rod, or the trigger attached to its end, is hinged and supports a weight that hangs below the hinge. The reciprocating push rod has a tendency to carry the suspended weight with it, but the inertia of the weight causes it to lag behind the rod and thus deflect the trigger from its horizontal position. The lag and deflection are increased as the speed increases until, at the maximum speed of the motor, the deflection is sufficient to cause the rod or trigger to miss the valve stem so that the valve is not lifted, and thus a charge of fuel is cut out.

In later mechanisms for hit-or-miss governing the centrifugal governor with weights rotating about a shaft is also used for moving the trigger, the cam, the cam roller, etc.

One mechanism has a rotary cam with a roller follower. Both the cam and the follower have knife-edge projections which engage and bring their lifting parts together when the speed is below normal, but clear each other when it reaches the maximum, or vice versa.

72. Hit-or-Miss Governing by Omitted Openings of the Mixture Inlet Valve. Four-Cycle Motor. — This method finds its application generally in motors with mechanically operated inlet valves. The action of the governor prevents the opening of the mixture inlet valve when the motor speed exceeds the normal. The exhaust valve opens as usual both before and after the omission of the charge.

Either the springs of the inlet and exhaust valves must be strong enough to hold the valves to their seats during the suction stroke when the inlet is left closed, or additional means of holding the valves to their seats must be provided. The degree of the partial vacuum in the cylinder is greater at this time than at any other, and the tendency of the suction to open the valves is, of course, correspondingly great.

Since there is no admission at the time of a cut-out during the suction stroke, there is a partial vacuum induced in the cylinder at the end of the impulse stroke (without the impulse) when the exhaust valve opens in its regular operation. This causes a rush of inert gases from the exhaust port into the cylinder by which foreign matter is apt to be carried from the exhaust passages into the cylinder.

The speed at or about the time of the beginning of the suction stroke determines how the governor shall act regarding the opening or closing of the inlet valve. There are about two inertia strokes between the action of the governor and the beginning of the following impulse.

73. Hit-or-Miss Governing by Keeping the Exhaust Valve Open during the Suction Stroke. Four-Cycle Motor. — This method is used in connection with an automatic inlet valve. Very little suction can be produced by the action of the piston when the exhaust is open, therefore there is little tendency to lift the inlet valve.

It should be remembered, however, that if there is a long, straight pipe for carrying off the exhaust the inertia of the rapidly expelled gases may reduce the pressure in the cylinder enough to open an inlet valve with a weak spring and draw in a small amount of the mixture, but not enough to be ignited. In such a case the fuel drawn in is simply passed through the motor and wasted. The springs of automatic inlet valves are apt to become weak in service.

As a precaution against the untimely opening of the inlet a device for holding the inlet valve to its seat when the exhaust is open is generally used. The simplicity of the valve mechanism for this method of governing is the chief feature that recommends it. The closeness of regulation is practically the same as with the hit-or-miss mechanically operated inlet valve. There is a possibility of drawing foreign matter into the cylinder during the suction stroke when the exhaust valve is open.

74. Hit-or-Miss Governing by Keeping the Exhaust Valve Closed during the Exhaust Stroke. Four-Cycle Motor. — This is simpler than either of the two methods just discussed, since there is no need of any locking device for the inlet valve. It has the objection, however, that the retained hot gases of combustion heat the motor and destroy the lubricant in the cylinder more rapidly than when they are allowed to escape at the end of the impulse stroke.

75. Hit-or-Miss Governing by Keeping the Fuel Valve Closed, but Opening the Mixture Inlet Valve to Admit Air during the Suction Stroke. Four-Cycle Motor. — The use of this method is confined almost entirely to motors using permanent gas for fuel. It can, however, be used by those in which air carbureted far beyond the ignition point is mixed with pure air to form a combustible mixture as has been stated. But very few motors that first carburate the air nearly to saturation and then dilute it are found in use.

An additional valve for the fuel is required. It generally opens into the air passage, or mixing chamber, near the mixture inlet valve, and in such a manner as to cause the gas and air to mix quite thoroughly before entering the cylinder. The mixture valve is opened for every suction stroke.

This method of governing has an undesirable property that is peculiar to it and is most marked when the mixture is somewhat too rich in fuel and the load changes suddenly from heavy to light. Under these conditions the passage of cool air through the cylinder during the several consecutive cut-outs that follow the consecutive explosions of the heavy load, cools the cylinder to some extent and clears out the inert gases that remain after the exhaust stroke immediately following the last explosion. This allows a greater weight of the mixture to enter when the fuel valve is opened after several cut-outs, and the air in the cylinder at the beginning of the suction stroke mixes with the incoming overrich mixture so that a more perfect mixture is formed in the cylinder. The greater weight of fuel, the more perfectly proportioned mixture, and the absence of dilution by inert gases all act to produce a greater impulse on the piston than is obtained when there has been no cut-out. A greater increase of speed during the first impulse after several cut-outs is the natural result. Even with a single cut-out the energy of the following explosion is greater than that of one following an immediately preceding explosion.

76. Modern Modified Method of Cutting out Charges. Four-Cycle Motor. — At least one modern gas-engine builder has introduced a cut-out device that reduces the objectionable speed variation of this method to a considerable extent and completely eliminates the drawing in of exhaust gases. In this method the mechanical inlet valve is opened by a rotating cam with one lobe, and the exhaust valve by an exhaust cam in the same manner. They are both attached to a shaft that rotates at half the speed of the crank shaft as long as explosions are needed regularly. An increase of speed throws the cam shaft out of engagement with its driver, and it remains at rest till the speed falls below normal. It is then brought into engagement with its driver again and opens the valves as usual. The device for driving the cam shaft is of such a nature that the parts can be disengaged and brought into engagement again during one revolution of the crank shaft of the motor, corresponding to half a revolution of the cam shaft. Therefore, when the motor is working at almost its full capacity and a charge is cut out, the cam shaft will be picked up again after one revolution of the crank shaft, the mixture valve opened and a charge admitted so as to be exploded after only six strokes of the piston instead of eight as with other cut-out valve mechanisms.

The cam shaft is disengaged so as to come to rest just after the exhaust valve closes. The latter remains closed until the time to open for discharging exhaust gases again, so there is no possibility of drawing foreign matter into the cylinder from the exhaust port and pipe, as with some of the other devices for governing.

Governing by Varying the Amount of Fuel Admitted for an Explosion.

77. **General.** — The power that is developed by an explosion in the cylinder of a motor is proportional, at least in a measure, to the amount of fuel that is admitted and burned during the impulse stroke of the piston. Since the impulses occur regularly and are graduated to the amount required to keep the speed constant in this method of governing, it is therefore the method that gives the closest speed regulation.

There are three methods by which the amount of fuel admitted per charge can be varied so as to still give a combustible mixture in the cylinder when the charge has been reduced within certain limits. The three methods are:

a. Throttling by partly closing the passage through which the mixture enters the cylinder, or by partly closing both the air and the gas passages;

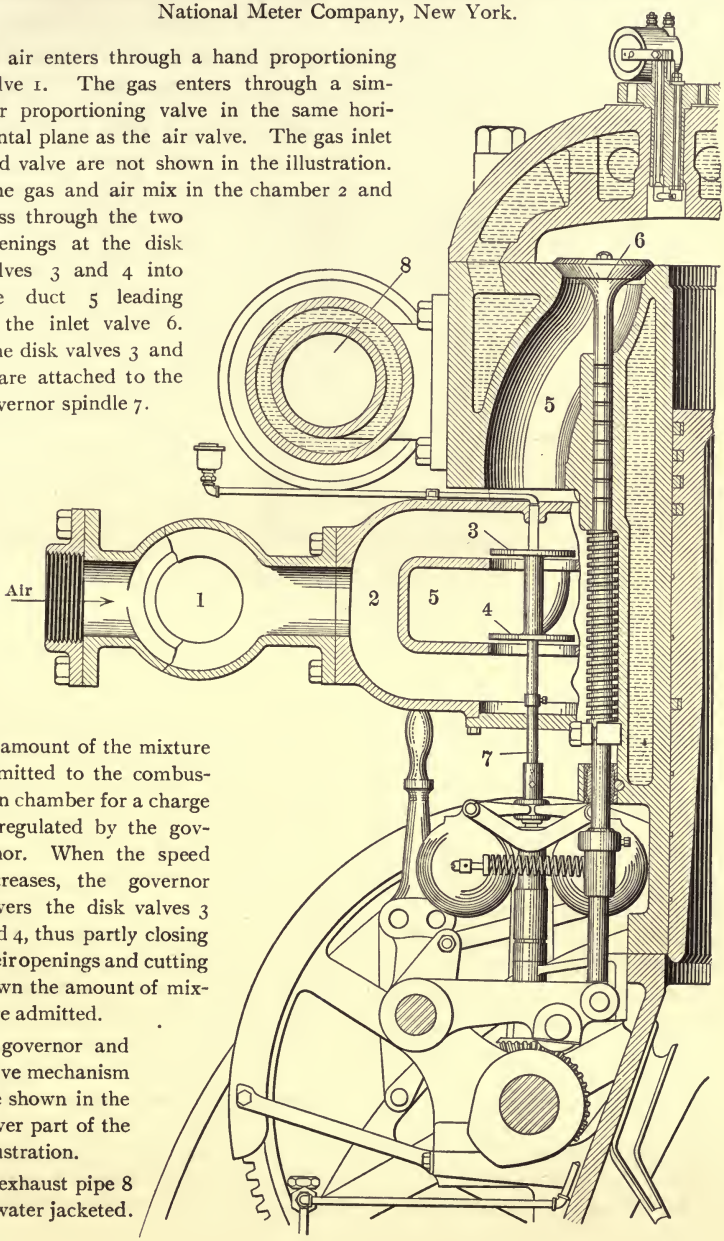
b. Varying the length of time during which the mixture inlet valve is kept open;

c. Varying the length of time during which the fuel valve is kept open, and opening and closing the air valve at regular times.

78. **Governing by Throttling.** — This method finds more general application than any other. It is adapted to both two-cycle and four-cycle motors using either permanent gas or carbureted air for fuel. The largest as well as the smallest motors can be successfully governed by throttling. The valves for throttling vary in form from the simple wing type or butterfly type to somewhat complicated ones that have separate and adjustable passages for air and gas. The simpler ones naturally find most application to the smaller sizes of motors, which,

FIG. 59.

Balanced Throttling Governor and Valve Mechanism of Nash Gas Engine.
National Meter Company, New York.



The air enters through a hand proportioning valve 1. The gas enters through a similar proportioning valve in the same horizontal plane as the air valve. The gas inlet and valve are not shown in the illustration. The gas and air mix in the chamber 2 and pass through the two openings at the disk valves 3 and 4 into the duct 5 leading to the inlet valve 6. The disk valves 3 and 4 are attached to the governor spindle 7.

The amount of the mixture admitted to the combustion chamber for a charge is regulated by the governor. When the speed increases, the governor lowers the disk valves 3 and 4, thus partly closing their openings and cutting down the amount of mixture admitted.

The governor and valve mechanism are shown in the lower part of the illustration.

The exhaust pipe 8 is water jacketed.

however, are not necessarily those of the cheapest form of construction. The double valve arrangement with one valve for fuel and one for air is found only on motors using permanent gas and the very limited number using air carbureted to nearly the saturation point. A centrifugal governor is generally used to move the throttle valve so as to give the required amount of charge.

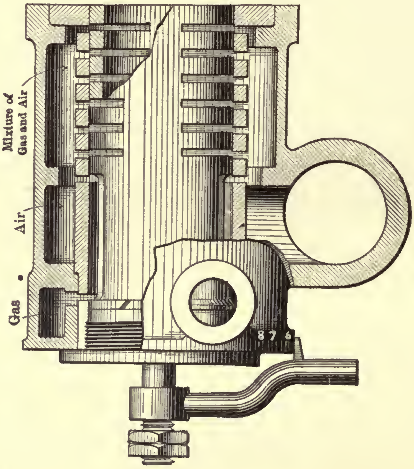


FIG. 60.

Proportioning, Mixing, and Throttle Governing Device for Gas Engine. The Bruce-Merriam-Abbott Company, Cleveland, Ohio.

The principal parts of the device are:

An outer casing with provisions for gas and air connections;

A ported bushing fitting in the casing;

A cylindrical hollow valve with ports for gas and mixture.

The gas passes from the gas space at the bottom of the casing through the port in the bushing and up between the bushing and valve to the top of the air space. The gas then passes out through the bushing and mixes with the air flowing up to the annular chamber marked "Mixture of Gas and Air" in the illustration. From there the mixture goes through the numerous ports in the upper halves of the bushing and valve to the inside of the valve and then out at the top.

The governor is connected to the valve spindle which extends downward from the bottom of the device. Increase of speed causes the governor to lift the valve and thus reduce the area of the port openings.

The gas and air are proportioned by moving the bent handle shown at the bottom of the illustration. This rotates the valve and changes the area of the gas ports.

The reduction of the charge causes a corresponding reduction in the compression pressure. Since the efficiency of the transformation of the heat energy of the gas into mechanical energy increases with increased compression pressure, there is a decrease of this efficiency caused by throttling on account of the reduced compression pressure that accompanies it. This decrease of efficiency is not so great, however, as to counterbalance the advantage of the close regulation of speed that can be secured by reducing the amount of the charge, as compared with other methods, when close regulation is desired.

There is always some suction resistance to the motion of the piston during the charging stroke in a four-cycle motor. This resistance is increased throughout the stroke by throttling. The suctional resistance abstracts mechanical energy from the motor. The amount of energy thus abstracted is not entirely lost, however, for some of it is returned during the early part of the compression stroke while the pressure in the cylinder is still below atmospheric.

79. Governing by the Mixture Inlet Valve to Reduce the Charge. Four-Cycle Motor. — By the use of suitable valve mechanism the inlet valve can be opened at the same time for each charging stroke of the piston, and its closure timed later or earlier so as to let in more or less mixture as the speed of the motor decreases or increases. As compared with throttling, practically the same delicacy of speed regulation can be secured by this automatic cutting off of the admission of mixture. The loss of efficiency in the heat transformation into mechanical energy, due to the reduction of the compression pressure, is practically the same as for throttling, but there is not quite so great a waste of mechanical energy during the suction stroke, for with the cut-off governor the mean value of the resistance to the motion of the piston during the suction stroke is not so great as by throttling. This is because in cut-off governing the inflow of the mixture is not restricted during the early part of the suction stroke. There is free flow until the inlet valve closes. Up to this point the suction resistance is only that due to the passage of the gases through the unobstructed port. This

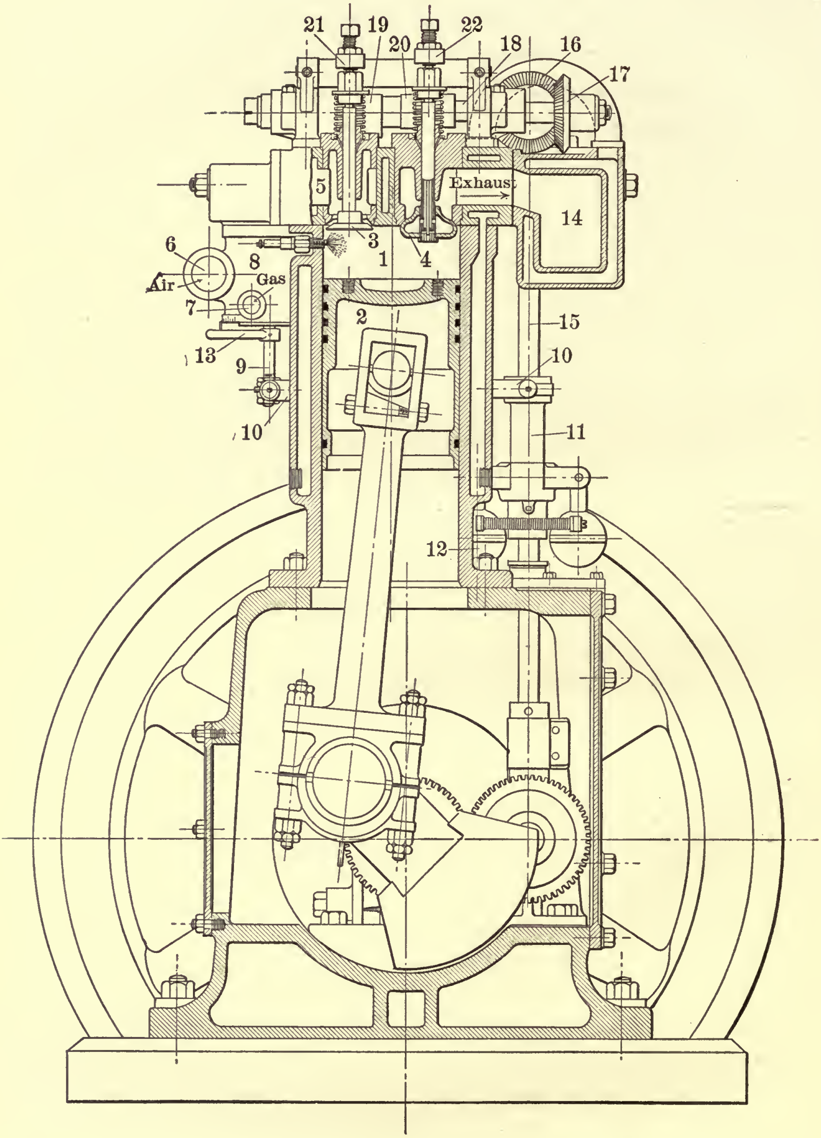

21
19
20
22
18
16
17
5
Exhaust
14
3
1
4
6
8
Air
Gas
7
2
15
13
9
10
11
10
12

FIG. 61.

FIG. 61. (See also Figs. 62 and 60.)

Four-Cylinder, Four-Cycle, Single-Acting Gas Engine. 115 to 200 Horsepower.
The Bruce-Merriam-Abbott Company, Cleveland, Ohio.

1. Cylinder.
2. Piston.
3. Inlet valve.
4. Exhaust valve, water cooled.
5. Mixture port.
6. Air intake.
7. Gas intake.
8. Mixer and throttle.
9. Throttle valve stem.
10. Lever arm between throttle valve stem and governor.
11. Governor sleeve or quill.
12. Governor fly-balls.
13. Hand handle for proportioning mixture.
14. Exhaust gas main.
15. Vertical shaft for transmitting power to valve mechanism.
16. Gear on shaft driven by 15.
17. Gear on cam shaft.
18. Cam shaft.
19. Cam.
20. Cam.
21. Rocker arm for opening inlet valve.
22. Rocker arm for opening exhaust valve.

As the speed increases the governor lifts the throttle valve by means of the stem 9 and cuts down the flow of mixture into the motor cylinder, while keeping the proportions of the mixture constant (constant quality mixture).

The cooling water for the exhaust valve flows down through the small pipe in the hollow valve stem and enters the valve at the bottom of the hollow space, then flows through the openings into the hollow valve stem near the top of the water space in the valve and passes up and out through the annular space between the inflow pipe and the walls of the hollow stem.

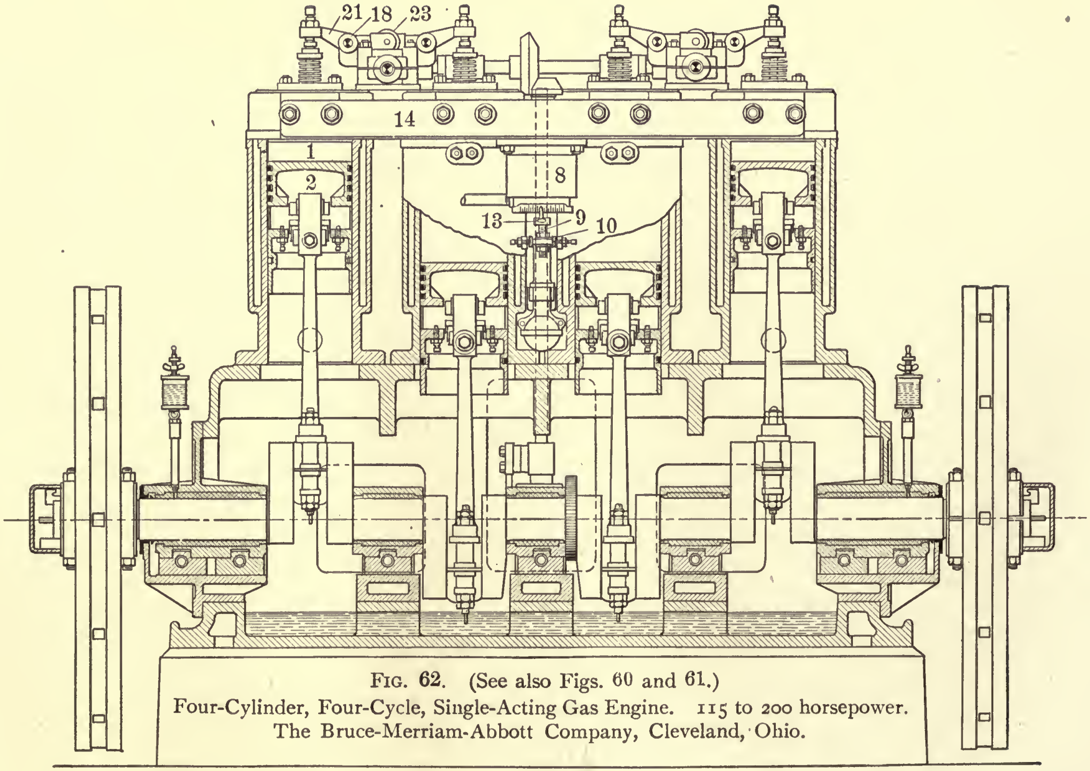


Fig. 62. (See also Figs. 60 and 61.)
Four-Cylinder, Four-Cycle, Single-Acting Gas Engine. 115 to 200 horsepower.
The Bruce-Merriam-Abbott Company, Cleveland, Ohio.

1. Cylinder.
2. Piston.
8. Mixer and throttle.
9. Throttle valve stem.
10. Lever between throttle valve stem and governor.
13. Hand handle for proportioning mixture.
14. Exhaust gas main.
18. Trunnions for rocker arm.
21. Rocker arm for opening inlet valve.
23. Roller follower resting on cam.

suction resistance, up to the corresponding position of the piston, is much less than when the inlet passage is throttled. After the inlet valve is closed, the suction resistance increases to the end of the stroke, where it has the same pressure as at the end of the throttled stroke, if the weight of the charge is the same in both cases. Here again the resistance during the completion of the suction stroke after cut-off is less than by throttling during the corresponding latter part of the stroke. The mechanical energy returned to the motor by suction during the early part of the compression stroke is the same by both methods.

There is a possibility that the temperature of the mixture at the end of the charging stroke is higher by cut-off than by throttle governing, since in the former the complete charge is in the cylinder some time before the completion of the stroke, and is therefore heated more than when drawn in gradually as by throttling. The principal effect of heating the mixture during the charging stroke is to reduce the weight of the charge and the power of the motor. The difference of this effect in the two cases is hardly great enough to need attention.

80. Governing by the Fuel Valve to Reduce the Charge. — This method is applicable to both two-cycle and four-cycle motors using gas or vapor fuel.

Its especial field is the two-cycle motor of the type in which the air and fuel are separately precompressed in auxiliary compressors to a slight extent, sufficient to force them into the motor cylinder when the exhaust port is opened, but it is equally applicable to four-cycle motors. It has already been said of this type of motor that when the piston is at and near the out position the exhaust port is open and the charge enters while the piston is at and in the neighborhood of the extreme out position and while the exhaust port is open. Air is admitted first to scavenger the cylinder, and then gas is also admitted to mix with the entering air in proportion to form a combustible mixture just before they enter the combustion cylinder. The time at which the fuel valve opens is regulated in accordance with the need of fuel to maintain the speed of the motor. The air and fuel valves, or the air and mixture valves, close at the same time,

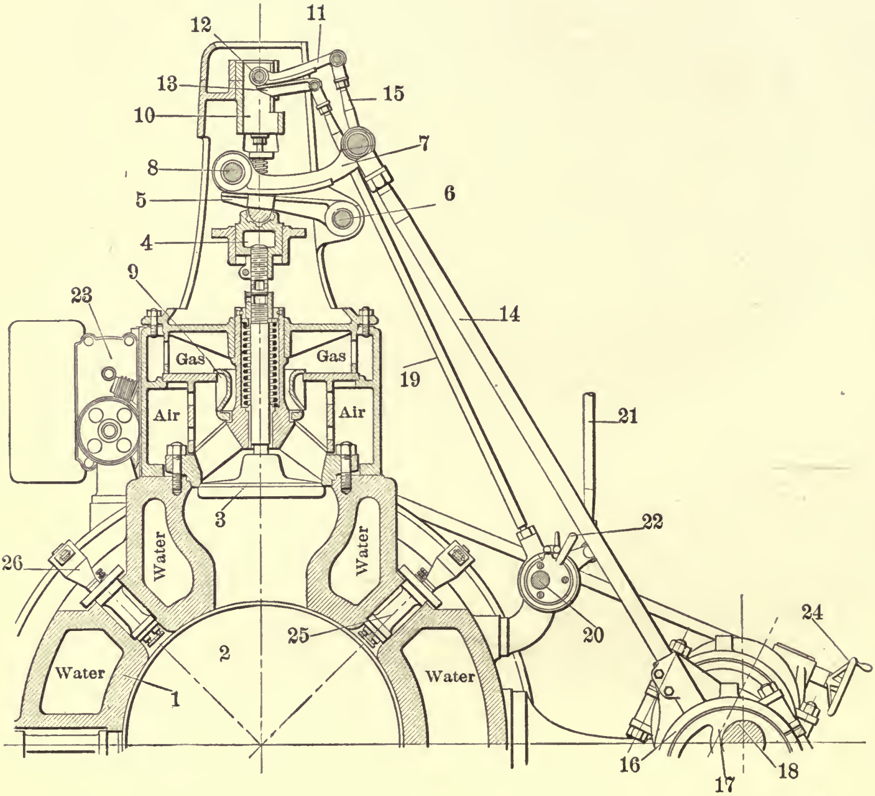


FIG. 63.

FIGS. 63 AND 64.

Valve Mechanism of Gas Engine. Governing by fuel valve. 2000 kilowatts capacity in double-acting twin tandem engine. (Four cylinders, eight combustion chambers.) The Allis-Chalmers Company, West Allis, Wisconsin.

1. Cylinder.
2. Piston.
3. Inlet poppet valve for mixture. Closed by spring.
4. Head on upper end of inlet poppet valve stem.
5. Rocker arm pivoted at 6 and resting (through a small sliding block) on 5. Operated by cam rocker 7.

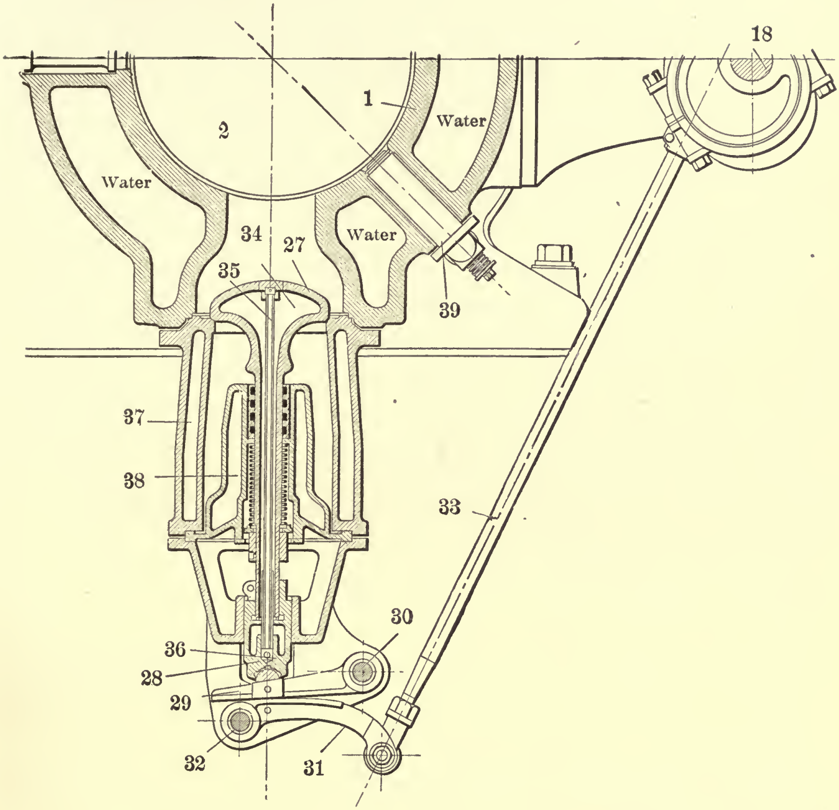


Fig. 64.

6. Pin connection between 5 and stationary part of engine.
7. Cam-shaped rocker pivoted at 8 and bearing on its follower 5.
8. Pin connection between 7 and stationary frame of engine.
9. Double-seated hollow gas valve. Concentric with 3. Spring closed.
10. Head on gas valve stems.
11. Cam-shaped rocker resting on 13 and pivotally connected to 10.
12. Pin connection between 10 and 11.
13. Movable rest for cam rocker 11. Partly supported by the stationary frame of the engine.

14. Eccentric rod between rocker 7 and eccentric on 18.
15. Rod connection between 7 and 11.
16. Eccentric strap on 14 and on eccentric 17.
17. Eccentric on 18.
18. Lay shaft or half-speed shaft.
19. Rod connection between rest 13 and an eccentric on the governor-actuated shaft 20.
20. Regulating shaft or governor shaft.
21. Governor rod.
22. Hand grip for dropping 13 so that the gas valve will not lift (open).
23. Valves for proportioning gas and air by hand.
24. Hand wheel for setting proportioning valves.
25, 26. Electric igniters.
27. Exhaust poppet valve. Water cooled.
28. Head on lower end of exhaust valve stem.
29. Rocker arm cam follower for lifting exhaust valve 27. Pivoted to stationary frame of engine at 30.
30. Pin connection between stationary frame of engine and 29.
31. Rocker cam for lifting 29 and the exhaust valve 27. Pivoted to the stationary engine frame at 32.
32. Pin connection between 31 and the engine frame.
33. Eccentric rod between the rocker cam 31 and an eccentric on lay shaft 18.
34. Water space in exhaust valve.
35. Water pipe for exhaust valve 27.
36. Water inlet to exhaust valve.
37, 38. Cooling-water spaces.
39. Check valve for starting with compressed air.

The governor regulates the amount of gas admitted for each charge by raising and lowering the rest 13 on which the cam-shaped lifting arm 11 rocks, and thus varying the extent of opening of the gas valve.

When the exhaust valve begins to open against the pressure in the cylinder, the line of contact between the eccentric-driven rocker 31 and its follower 29 is near the pivot (fulcrum) 32 where the rocking cam is supported by the stationary frame of the engine. This gives a long lever arm for the eccentric rod 33 to act on when first lifting the valve from its seat, and a slow initial motion to the valve. As 31 rises, the line of contact between it and 29 moves out toward the pivot 30 of the rocker 29, thus giving an increasing speed of lift to the valve relative to the motion of 31 and a decreasing leverage for 33. The reverse occurs during the closing of the valve, so that it seats gently. Since the force required to move the valve after it leaves its seat is much less than at the instant of lifting it from its seat, the decreasing leverage as the valve rises is of no disadvantage in the application of the lifting force, and is advantageous in giving the valve a rapid movement after it leaves its seat.

The action of the mixture inlet valve is the same as that of the exhaust valve, and that of the gas valve mechanism is similar in a general way.

The gas enters around the outside and through the inside of the shell gas valve.

which is invariable in relation to the movement of the piston. If the air and combustible mixture stratify in the combustion cylinder as desired, the part next the piston is filled with air and possibly some of the inert gases of combustion, and the combustion chamber is filled with perfect mixture, all at about atmospheric pressure before compression begins.

The igniter is located so as to be surrounded by combustible mixture at the instant for ignition.

Since the mixture arranges itself in a stratum in the cylinder at less than full loads, the fuel can be cut down to a much smaller amount than when the combustible charge is distributed throughout the cylinder. Therefore close speed regulation can be accomplished satisfactorily for all loads including very light loads and the friction load of the motor alone.

By this method of regulation the pressure of compression is always kept the same, hence there is no reduction in the efficiency of heat transformation into mechanical energy on account of a reduced compression pressure corresponding to a light load, as there is when mixture alone is admitted to the cylinder in amounts varying according to the demands for power. This is true theoretically, because the efficiency of the cycle remains always the same in a motor when the initial and final pressures of the compression stroke do not change.

There is no power loss on account of suction resistance in this case, but its counterpart appears in the energy expended to compress the air and gas for forcing them into the motor cylinder.

As applied to the four-cycle motor, this method of governing can be used without any auxiliary compression cylinders or pumps. The suction of the charging stroke is effective here as in other methods of governing. The mixture valve opens and closes at invariable times, and the fuel valve is opened early or late, as the speed is slow or fast within the limits of the sensitiveness of governing, and closes at an invariable time. The same advantage of close governing on very light loads, and on motor friction load, obtains here as in the two-cycle motor.

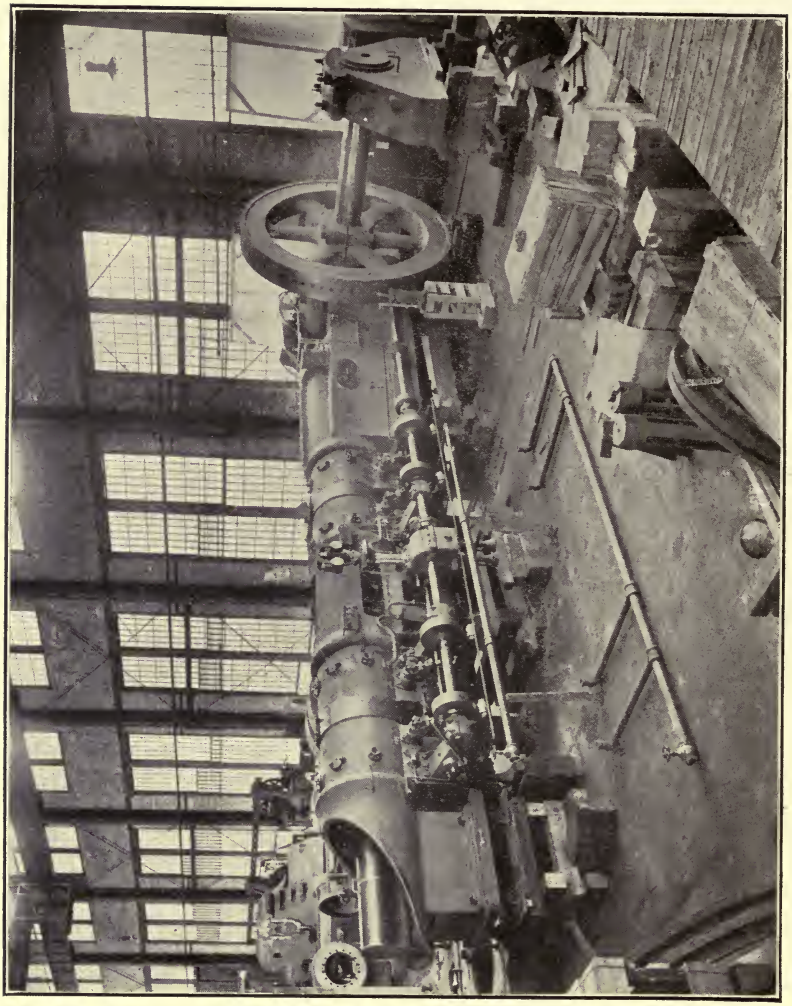


FIG. 64a.

“Complete Expansion” Gas Engine, 600 Horsepower. Pneumatic device for moving the engine to starting position is shown at the flywheel.

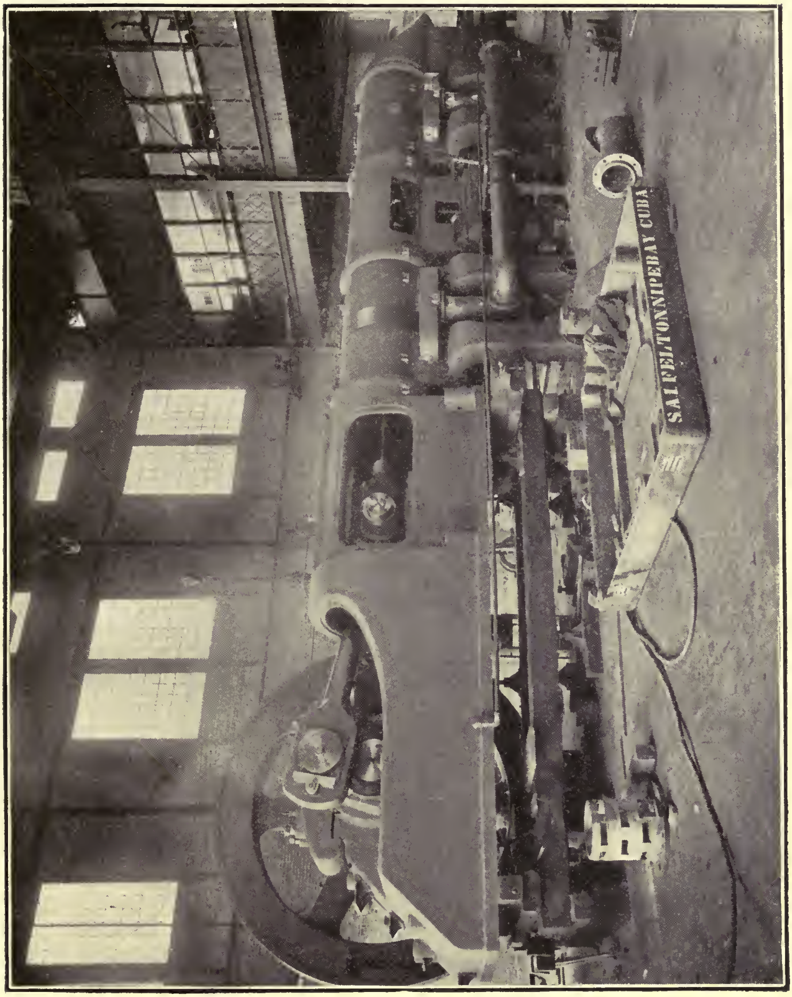


FIG. 64b.

"Complete Expansion" Gas Engine, 600 Horsepower.

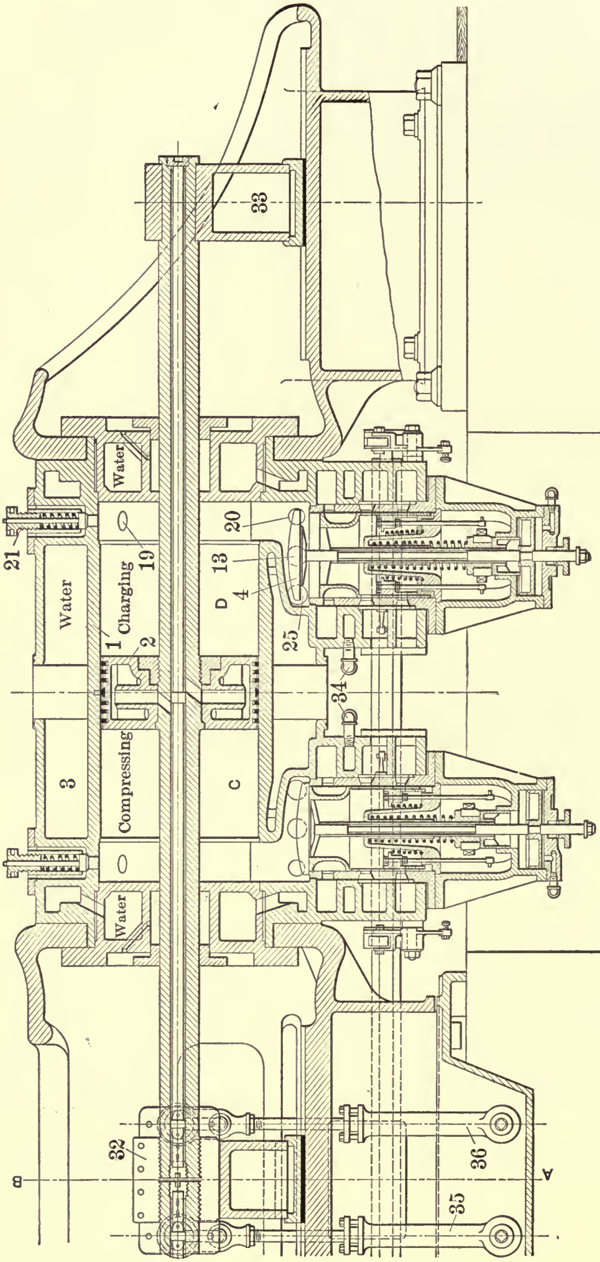


Fig. 65.

"Complete Expansion" Gas Engine. Section through one cylinder and adjacent parts.

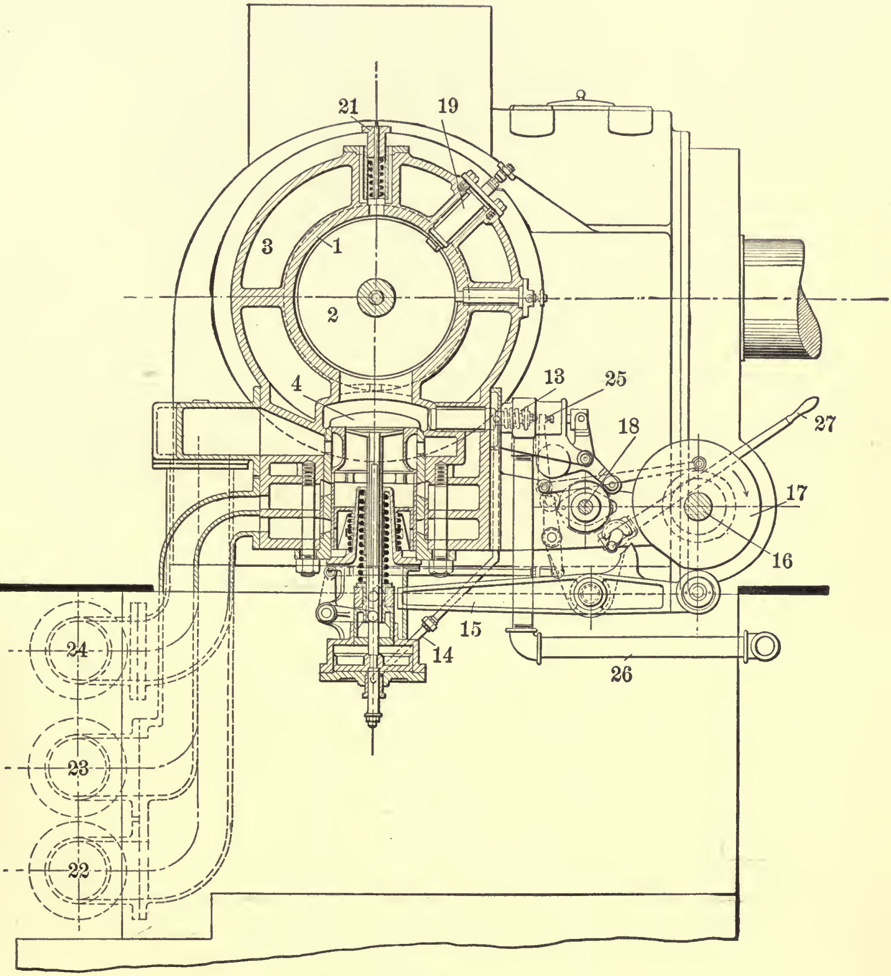


Fig. 66.
Section through Cylinder and Valve.

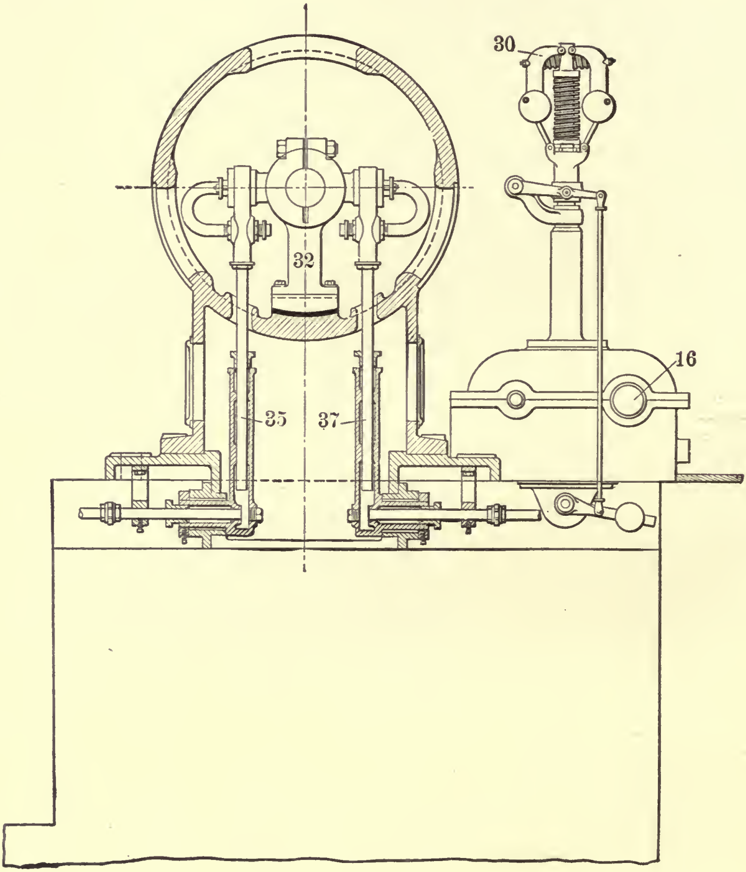


Fig. 67.
Section on A–B, Fig. 65.

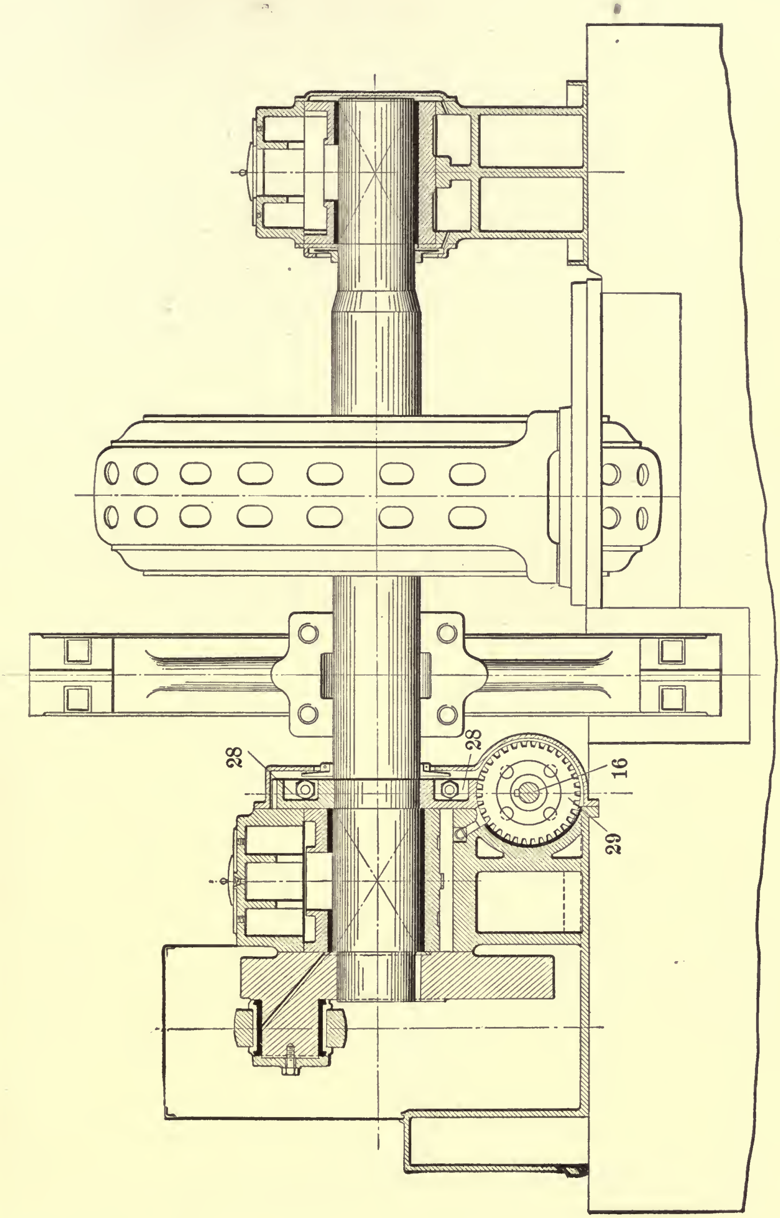


FIG. 68.

Section through Main Bearings. Gear 29 acts as an Oil Pump.

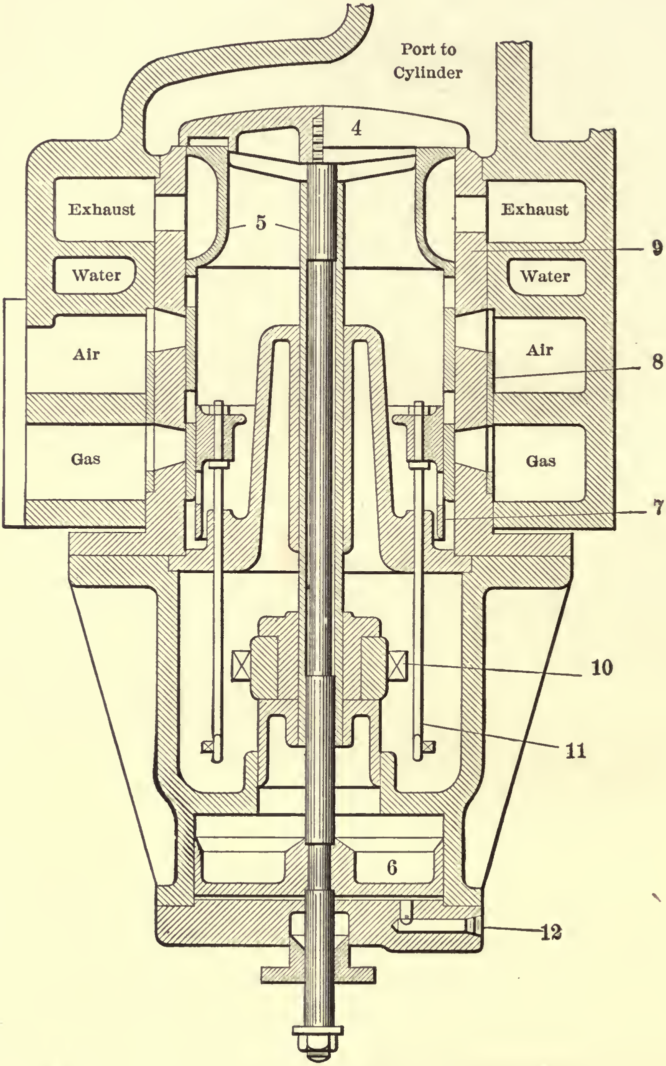


Fig. 69.
Valve closed for Compression and Impulse Stroke.

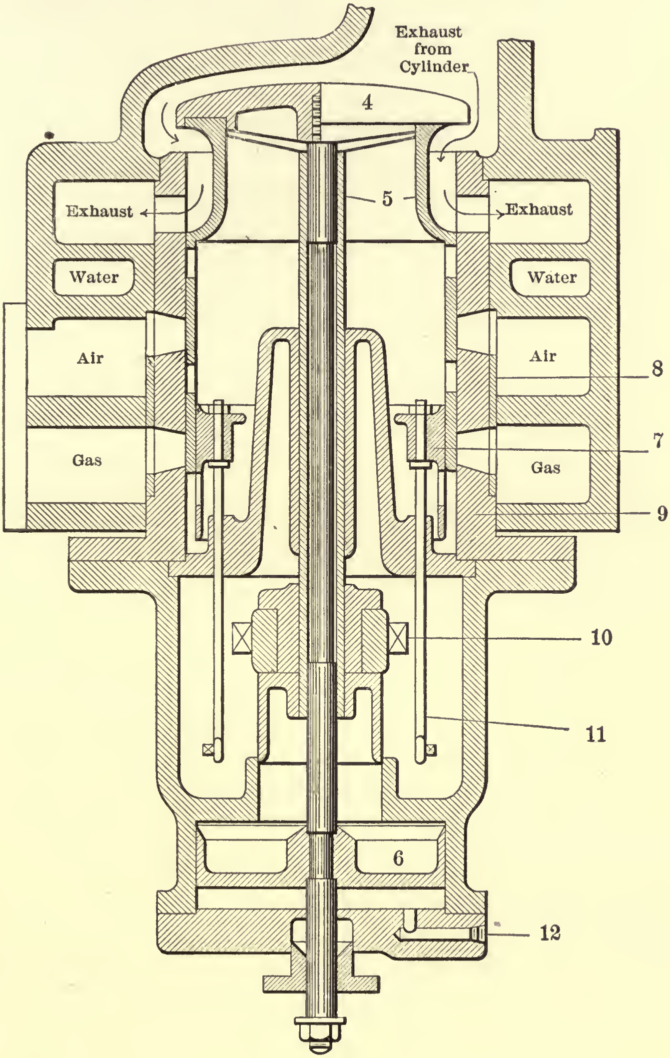


FIG. 70.
Valve in Exhaust Position.

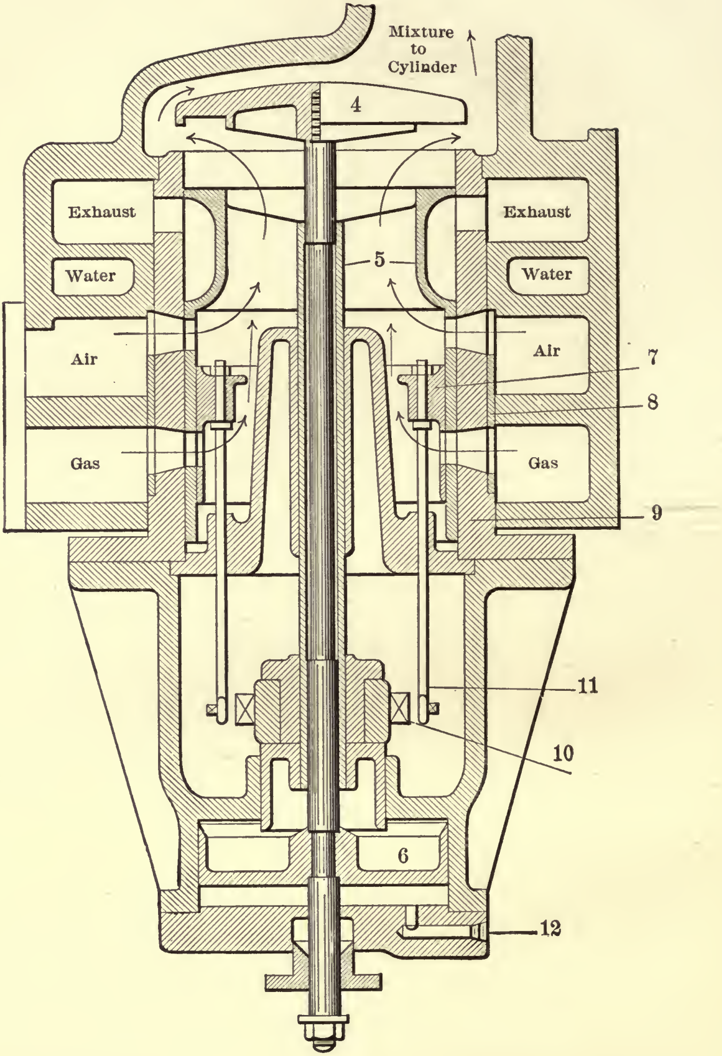


Fig. 71.
Valve in Charging Position.

FIGS. 64a, 64b, AND 65 TO 71.

"Complete Expansion" Gas Engine. Four-Cycle, Double-Acting Tandem 600 Horsepower. The Wisconsin Engine Company, Corliss, Wis.

1. Cylinder.
2. Piston.
3. Water-jacket space.
4. Poppet valve for inlet and exhaust. Stem extends down through the bottom of the valve cage.
5. Cylindrical valve with air, power gas, and exhaust ports. Hollow stem down nearly to bottom of valve cage. Concentric with 4.
6. Piston on bottom of poppet valve stem.
7. Automatic fuel cut-off valve. Cylindrical. Concentric with 4 and 5. Motion regulated by governor.
8. Ported tubular valve for proportioning air and gas by hand.
9. Stationary bushing and poppet valve seat.
10. Bearings for arm that lifts 5 and 4.
11. Rods for moving cut-off valve 7. Operated by cam on shaft 18.
12. Connection for pipe leading to 13 and the combustion chamber.
13. By-pass valve. Operated from shaft 18.
14. Pipe connection between by-pass valve 13 and cylinder space under poppet valve piston 6.
15. Rocker arm for lifting valves 4 and 5. Cam driven.
16. Cam shaft, lay shaft, or half-speed shaft.
17. Cam for operating valves 4 and 5.
18. Small cam shaft. Controlled by governor.
19. Igniter.
20. Igniter. (Shown only in longitudinal section.)
21. Relief valve or snifter valve.
22. Gas supply pipe.
23. Air supply pipe.
24. Exhaust pipe.
25. Compressed air valve for starting engine.
26. Compressed air supply pipe.
27. Starting handle.
28. Screw gear on main shaft (crank shaft) for driving cam shaft or lay shaft at half speed of main shaft.
29. Screw gear on cam shaft or lay shaft. Driven by 28. 29 also acts as an oil pump for supplying lubricating oil to the main bearing of the crank shaft, the main crosshead, and the crank pin.
30. Governor.
31. Main crosshead. Not shown in line illustrations.
32. Intermediate crosshead.
33. Rear crosshead.
34. Cooling water supply pipes to valve case, cylinder, and cylinder heads.

35, 36, 37. Water connections to intermediate crosshead. Swinging telescopic connections. For water-cooling the pistons and piston rod.

In the longitudinal section, Fig. 65, the valves of two combustion chambers are shown in the positions for movement of the pistons toward the crank shaft (toward the left). Combustion chamber *B* (not shown) is on the impulse (expansion) stroke; *A* (not shown) is exhausting; *C* is compressing; and *D* is charging.

Enlarged sectional views of the valves are shown in Figs. 69, 70, and 71 for the three positions during the different steps of the cycle. The coil compression springs are omitted.

Fig. 69 shows the position of the valves for one combustion chamber during the charging and impulse strokes. The poppet valve 4 is closed and the others have no action or function during this time.

Just before the completion of the impulse stroke the by-pass valve, 13, Figs. 65 and 66, is opened by cam action and the pressure in the combustion chamber is transmitted through the pipe 14 to 9 and to the under side of the balancing piston 6 on the lower end of the stem of the poppet valve 4. The pressure under the piston 6 almost balances that on the top of the poppet valve. The cylindrical, double-ported valve 5 is then mechanically lifted by cam action at an invariable position of the motor piston, by a rocker arm bearing against the trunnions 10. As the cylindrical valve 5 rises it carries the poppet valve 4 with it, thus opening the port for exhausting.

Fig. 70 shows the position of the valves of one cylinder for exhausting. The air and gas ports are of course closed during the exhaust stroke.

At about the end of the exhaust stroke the cylindrical valve 5 descends under the combined action of the expansion coil spring (see longitudinal section) and the cam, so that its ports register with those of the air and gas ducts around the valves just after the beginning of the charging stroke. This position of 5 is shown in Fig. 71. If the engine is on only part load, the gas cut-off valve 7 still retains the position shown in Fig. 70, so that the gas port is closed and air only is allowed to enter the cylinder. Later in the charging stroke, at a time determined by the governor, cam action allows the cut-off valve 7 to be lifted by the expansive force of the coil compression spring (see longitudinal section) bearing against it, so that the port in the cut-off valve registers with the gas port in the cylindrical valve 5 and in the bushing 9.

Fig. 71 shows the position of the valves for admitting both gas and air to the cylinder. At the fixed time for cutting off the admission of mixture to the cylinder, the double-ported valve 5 is lifted by cam action to the position shown in Fig. 69, thus closing both the air and gas ports.

Up to this time since opening for exhausting, the poppet valve is held up by the exhaust gases under the balancing piston 6 on account of throttling which prevents rapid escape of the gases from under 6. After the mixture is cut off, the poppet valve 4 settles to its seat so as to be closed at the beginning of the compression stroke.

The gas cut-off valve 7 is drawn down by cam action at about the same time that the cylindrical valve 5 is lifted to cut off air and gas.

At full load the gas cut-off valve 7 rises early, so that the admission of gas begins at the same time as that of the air.

Summary of the Valve Motions. — The cylindrical, double-ported valve 5 moves at invariable times relative to the motion of the motor piston. The poppet valve 4 is lifted (opened) at a fixed instant and closes between the cut-off of the mixture and the completion of the charging stroke. The gas cut-off valve moves to admit the fuel gas at variable times controlled by the governor. For full loads it opens so that gas is admitted as early as the air, but it opens later for light loads. It does not act to stop the flow of gas, which is done by 5.

Cutting Out Combustion Chambers. — When the load falls below one-fifth full load, the governor automatically cuts out two of the combustion chambers by leaving their gas valves closed. The engine then runs on only two combustion chambers.

When the engine is run for some time on light loads, one or more of the combustion chambers can be permanently cut out by hand. This is done by locking the exhaust valve open.

Proportioning Gas and Air. — The tubular shell 8, outside of the stationary bushing 9 that surrounds the valves, is rotatable to a limited extent by hand mechanism. The rotary adjustment of 8 changes the relative areas of the air and gas ports leading from the outer ducts to the cylindrical valve 5 and regulates the proportions of gas and air in the mixture.

Relief or Snifter Valves. — In order to prevent abnormally high pressures in the cylinder, each combustion chamber is provided with a spring-closed relief valve of the same nature as those used on steam engines for allowing the escape of water from the cylinder, or of the nature of a safety valve on a steam boiler.

The relief valves come into action in case of premature ignition during the compression stroke.

Igniters. — Each combustion chamber has two igniters of the low-tension make-and-break type. One is placed in the port at 20 and the other well up toward the top of the combustion chamber at 19. This disposition insures dry contact points on the upper igniter when starting with cold cylinders, and also the ignition of the charge by the lower igniter when the engine is running on a light load with a correspondingly small amount of gas admitted at the latter part of the charging period.

The igniters can be removed and replaced in any combustion chamber while the engine is running, by locking the open exhaust valve of that chamber.

Cooling Water. — The cooling water for the cylinders and the exhaust valves enter below the exhaust valves and passes up to the top of the cylinder to the open top of an overflow pipe. This pipe pierces the jacket casing of the cylinder near the bottom and close to the end near the intermediate crosshead. The portion of the pipe between the open overflow end at the top of the jacket space and the point where it pierces the jacket wall is inside the water space.

The pistons and piston rods are cooled by water that flows to the intermediate crosshead through oscillating telescopic pipe connections. A pipe in the center of the hollow piston rod leads the water from the intermediate crosshead to the rear crosshead 33. The water flows back through the space between the central pipe and the wall of the hollow piston rod to the piston, then through the piston and back to the outflow connection at the intermediate crosshead. The other piston and its portion of the rod are cooled similarly.

Lubrication. — The screw gear 29 on the cam shaft (lay shaft) 16 and under the main shaft (crank shaft) acts as an oil pump for forcing streams of lubricating oil to the main bearing of the crank shaft, the crank pin, and the main crosshead. The gear is enclosed in a case that fits a portion of the periphery closely, so that, when there is sufficient oil in the casing, the gears act much as an ordinary gear pump whose spaces between the teeth are the pockets that carry the oil around in pump action. The other bearings have self-oiling devices or run in an oil bath.

The pistons and metallically packed stuffing boxes are lubricated with gas engine cylinder oil by mechanically driven sight-feed pressure lubricators.

Starting the Engine. — The engine is started by compressed air at about 125 pounds pressure. A cam on the governor shaft acts to admit the air during the impulse stroke until the pressure from combustion during this stroke is sufficiently great to hold the air-admission check valve closed when the compressed air is cut off by shutting the main air valve.

Governors.

81. The work to be performed by the governor of a gas or oil motor is generally very light. The governor can therefore be small. Its sensitiveness naturally depends on the desired closeness of speed regulation. The centrifugal type is generally used in forms analogous to those used on throttling steam engines and on those with Corliss or analogous valve gears for cutting off steam at part stroke. An exception to this practice is the hydraulic governor.

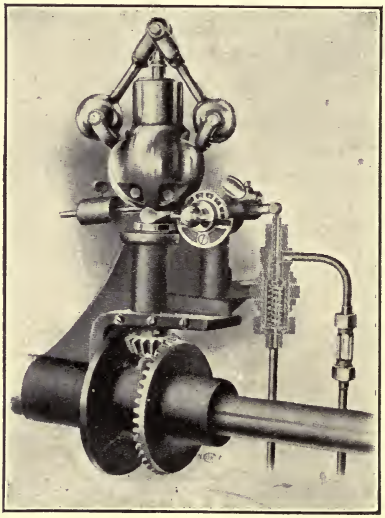


Fig. 72.

Governor and By-Pass Oil Valves for Hornsby-Akroyd Oil Engine.

The vertical pipe at the right of the bevel gears is connected to the discharge of the fuel oil pump. The curved pipe with the glass sight (at the extreme right) leads to the fuel oil tank.

When the speed of the motor increases, the governor acts through the horizontal lever arm so that the end of the latter forces down a small valve above the end of the vertical pipe. The opening of this by-pass valve allows a portion of the oil delivered by the pump to return to the tank and thus reduces the quantity of oil that is forced into the vaporizer. The pump discharge is also connected to the vaporizer. If the speed of the motor exceeds a certain limit, the governor acts in the same manner as before to open a larger by-pass valve that is concentric with the smaller one already mentioned. The opening of the larger valve completely (or nearly completely) cuts off the injection of oil into the vaporizer.

The speed to which the motor is governed can be changed by moving the small cylindrical weight along the left-hand extension of the horizontal arm.

82. **Hydraulic governors** are used to some extent on automobile motors that have a pump for circulating the cooling water. When the speed of the pump is proportional to that of the motor, the pressure of the water at points near the pump varies in nearly the same proportion as the speed of the motor. This variation of pressure with variation of speed is utilized to open or close the throttle as the speed of the motor falls or rises.

In the more general forms of hydraulic governor, the water acts against one side of a corrugated diaphragm to the center of which is attached the mechanism that connects to the throttle. The variation of the water pressure moves the central part of the diaphragm, and the motion of the latter is transferred to the throttle.

The accuracy of governing in this manner is not great, but this is not important for variable-speed motors operating under the usual conditions.

The simplicity of the governor and the absence of wearing parts are strong points in its favor in automobile use, where the dust and grit that invariably reach bearings that are not thoroughly protected cause rapid wear.

Hand Control of Speed and Power.

83. **General.** — The nature of the requirements for variable speed and power that the motor must fulfil needs to be understood before the control can be studied comprehensively. These requirements cover a wider range in the automobile than in any other service.

In the automobile the motor is called upon to run at any speed from the highest permissible on account of danger of its flying to pieces, to the lowest at which the inertia of the moving parts will keep it going between impulses. It is also expected to deliver power of varying amount up to its full capacity for the speed at which it is rotating. When the clutch is thrown into engagement to start the car, the motor should, when desired, change quickly from its friction load to its full capacity corresponding to the speed at which it is rotating. When running idly with the driving gear disconnected, it works against its own friction resistance only. It must drop from full load to friction load quickly, almost instantly, when the friction clutch for transmitting the power is suddenly disengaged, as in an emergency at the time the car is climbing a steep hill or rapidly gaining speed on a level road. The motor is often used as a brake for retarding the speed of the car, either when stopping the car or descending a hill.

As has already been pointed out, the speed and power of a motor can be regulated either by varying the amount of fuel supplied during each charging stroke or by varying the time, relative to the position of the piston, at which the charge is ignited and burned. Except in one or two isolated cases, variable-speed motors are so constructed that both methods can be applied simultaneously.

Hand control of the fuel can be effected by any of the methods that have been given for governing. The only change necessary is the replacement of the governor by a hand or foot device for regulating the supply of fuel.

Governor and hand control can both be applied by connecting to the governor, or the parts closely related to it, a hand mechanism by which the speed at which the governor acts can be varied at will.

Throttling the fuel supply is, with few exceptions, the method adopted for its control in variable-speed motors.

84. Early and Late Ignition. Definitions. — The instant at which the charge in the cylinder of a motor is ignited can be determined accurately in relation to the position of the piston and crank when the igniter is of the make-and-break or break-and-make type and has the contact points separated by the action of rigid mechanism between it and the crank shaft or piston. In an igniter of this type the contact points separate, for a given setting, at the same position of the piston and crank shaft whether the speed is high or low.

When a variable-speed motor is running at moderate speed, the ignition apparatus is so timed that the igniting arc will be formed at about the time the piston has completed the compression stroke and is ready to start on the impulse stroke, in other words, at about the dead-center position of the crank. The dead-center position in the usual types of motors is that at which the axes of the crank shaft, crank pin, and of the piston pin or wrist pin all lie in the same plane and the piston is at one end of its path of travel.

Under certain conditions of speed and power the arc is timed to come earlier in the rotation of the crank, and under other conditions later.

The terms "**early spark**" and "**late spark,**" or "**early ignition**" and "**late ignition,**" are used to designate the different times of ignition. They are only relative terms used in a general way. There is no fixed boundary between early and late ignition. The act of adjusting the ignition apparatus to make earlier ignition is called "**advancing the spark,**" and adjusting for later ignition "**retarding the spark.**"

The exact time of separation of the contact points of an igniter varies in relation to the position of the piston in its travel when the force that separates the contacts is transmitted through a spring and the speed of the motor varies. This is due to the inertia of the parts that are actuated by the spring to cause the separation of the contacts. The lag due to inertia may be of appreciable magnitude in comparison with the movement of the piston at high speeds.

In a similar manner, when an induction coil or transformer is used as a part of the ignition apparatus its use makes it impossible to determine at just what position of the piston and crank the spark passes. This refers to the usual outfit of a motor in service.

When glowing hot surfaces are used to ignite the charge, there is no means of telling the exact instant of ignition.

85. **Early and Late Ignition Effects on Power and Speed.** — If a variable-speed internal-combustion motor is running at moderate speed under any constant load with ignition at dead center, and the ignition is changed to come later in relation to the movement of the parts of the motor, the speed and power will immediately drop if there is no governor to regulate the fuel supply. Under certain conditions the motor will take the new speed and hold it approximately, while the torque resistance to the rotation of the motor remains constant at the same value as before the ignition

was retarded. The power developed is decreased in about the same proportion as the speed of rotation. The energy given to the piston at each impulse is the same as it was at the higher speed. It is assumed that the strength, or hotness, of the igniting arc or spark remains constant.

The reason that the retarded spark or arc causes a decrease of speed is that, with the later ignition, the charge does not burn early enough in the stroke of the piston at the higher speed to give it as great an impulse as before retarding the ignition, and the contents of the cylinder escape at a higher pressure and temperature than with the earlier ignition. But when the speed falls, inflammation and combustion are both completed earlier in the stroke, so that the resulting mean pressure is higher and the gases expand through a greater portion of the stroke after the charge has completely burned.

By retarding the ignition still more, the speed and torque will both be decreased. With late ignition and a greatly reduced speed, the charge will still be burning when the exhaust port is opened. When the ignition is extremely late, even though the speed is rather high, the exhaust will come out as a flame. In extreme cases the flame will be carried through and out of the opening of an exhaust pipe several feet long.

If the ignition is now advanced, the speed and power will be increased until they return to the initial values when the ignition reaches the dead center again. By advancing the ignition still further, the speed and power will generally be still further increased for a slight advance; they will always be increased in a high-speed motor. But still further advance will cause a decrease of power, and if the torque is still kept constant, as has been assumed, the speed will drop. If the ignition is advanced to come very much before dead center, the motor will slow down suddenly and stop quickly, sometimes with a sudden reversal of rotation due to the explosion of a charge before the completion of the compression stroke and the consequent driving back of the piston from the combustion chamber before dead center is reached.

The increase of power and speed caused by advancing the ignition from the dead-center position to a slight degree earlier, in motors other than slow-speed ones, is due to the fact that the early ignition gives the charge time to become well inflamed by the time compression is complete, so that combustion is finished early in the impulse stroke and the mean pressure on the piston is increased. But when the advance becomes so great that the pressure attained before the completion of the compression stroke comes so early and is of such intensity as to seriously check the motion of the piston and to detract from the energy that should be transmitted to the piston during the impulse stroke, the motor of course loses power. And not only does it lose power, but heavy stresses are thrown on the parts, and if there is the slightest looseness, or lost motion, in any of the connections between moving parts, it will be indicated by knocking, hammering, or pounding.

86. Time of Ignition as Affected by Degree of Compression. — If a throttle-regulated motor is running on a light load with the ignition so timed as to give the maximum power per pound of fuel, and the throttle is then opened either for speeding up or to meet the demands of a rapidly increasing load, there will be immediate knocking in a motor that has some lost motion, as evidence that the ignition is too early for the higher compression that accompanies the opening of the throttle and consequent taking in of larger charges. The ignition must be retarded to give satisfactory running. And, on the other hand, when the motor is again throttled for a light load, the power can be increased by advancing the spark when the speed of rotation is the same as before.

The rates of inflammation and combustion are more rapid the higher the compression pressure. They both act to suddenly check the motion of the piston when ignition takes place before the completion of the compression stroke, and thus cause hammering or pounding. When the compression is high, knocking will sometimes occur before the ignition is advanced to the time that gives the maximum power for the speed and setting of the throttle. This is seldom true, however, when the load is light and the throttle well closed.

87. Lag in Jump-Spark Ignition Apparatus. — In all the various systems of jump-spark ignition there is a time interval of greater or less length between the instant the timer closes the primary circuit and the passing of the spark across the spark gap inside the cylinder in the secondary circuit. This time interval of delay in the passing of the spark will be called the "**lag**" of the electrical apparatus.

When the battery circuit is closed by the timer in the battery system of ignition, the current is retarded, in gaining its maximum value, by the inductive resistance of the induction coil. This induction resistance is due chiefly to the magnetic lag of the soft-iron core and the reactionary effect of the current in the secondary winding. This causes a lag in the formation of the first spark at the spark plug, even if a spark jumps before the primary current is broken by the interrupter. In most induction coils no high-tension spark is formed until the interrupter breaks the primary circuit. When the spark does not come till the battery circuit is broken, there is an additional lag caused by the inertia of the vibrator or interrupter. The total lag has a time value that is equal to that of a very considerable part of a piston stroke in a small, high-speed motor. Therefore, if the timer is set to give a spark at the dead center when the motor is cranked by hand, the spark will not jump till long after the dead center has been passed when the motor speeds up. In order to keep the spark at dead center at the higher speed, the timer must be advanced accordingly. Advancing the timer to keep the spark at the same place in the motion of the piston is generally, and incorrectly, called **advancing the spark.**

The difference in the amount of advance of the timer necessary in the make-and-break low-tension system, as compared with the jump-spark system with battery and induction coil, is due to the lag of the latter apparatus. It is not because the ignition must take place earlier in the cycle by one method of ignition than by the other. The necessary advance of the spark itself (not the timer) or of the arc is practically the same in both cases when their hotness does not vary with the speed.

Jump-spark systems with a transformer for raising the electric tension all have some lag, which is generally less than for those having an interrupter induction coil.

88. Hand Control by Throttle and Spark. — In order to bring out as clearly as possible the nature of the work that must be done by the motor and the methods of manipulating the controls, the operation of the automobile will be taken up in some of its phases. It will first be assumed that the control is entirely by hand, there being no governor or safety device for regulating the speed of the motor. Jump-spark ignition with a battery will be considered first.

When the motor is to be started by hand cranking, the spark is set at or later than the dead center, otherwise the motor will kick backward, with danger to the operator. The throttle is opened partly. After starting, if the motor is to rotate while the car remains still for a while, the throttle is then nearly closed and the spark is set late to give a slow speed. The throttle should be closed as far as possible with still enough opening to keep the motor turning over slowly. Just before throwing the friction clutch into engagement to start the car, the throttle is opened to produce a more powerful torque and power to give the car momentum. As the speed of rotation increases, the timer is advanced to keep the spark at least as early as at the time of throwing in the clutch. The timer is generally moved up to give a spark at least as early as the dead-center position of the crank. When the motor gets well up toward its maximum speed and the transmission gears are to be shifted so as to give the car more travel per revolution of the motor, the timer is retarded and the change of gears quickly made. The throttle need not be closed any when the gear shift is made so quickly that the motor has not time to race.

When the car is running along a good, level road, the throttle and spark are adjusted in conjunction till the throttle is open the least amount possible, and the timer is advanced to the point that gives the best result. When approaching an up grade or a piece of heavy road that is to be passed over without decrease of speed the timer is gradually retarded and the throttle opened to give the requisite power. The more the throttle is opened, the more the timer must be retarded; but the timer is always kept as far advanced as possible in order to get the maximum power for the setting of the throttle without pounding in the motor. When the motor is new and all the parts snugly fitted, the timer is set up to the position that gives maximum driving effort. If it is desired to pull the car slowly for a short time without changing from the high-speed gear, it can be done best by retarding the timer till the spark comes late, and opening the throttle well to secure a large torque. This method is very satisfactory so far as handling the car is concerned, but it is wasteful of fuel and heats the motor rapidly. The exhaust pipe will become glowing hot after driving in this manner for some time, and the cooling water will soon boil except in very cold weather. If the slow speed of travel is to be continued for some time, the transmission gears should be shifted so as to let the motor turn over more rapidly with the throttle well closed and the timer far advanced. A late spark makes the motor work smoothly and the car easy to handle on slightly varying grades, but the effects of heating the motor and destroying the exhaust valves are too seriously objectionable to admit of operating the motor in this manner for a very long time, even if the large consumption of fuel is not a consideration.

When the ignition is by a low-tension current from a constant-speed generator, so that the intensity of the arc is always the same, and there are no springs that will allow lag in the separation of the contact points, the advancing and retarding of the arc are exactly the same as for the jump spark (not the timer). It will be remembered that the larger part of the advance and retard with the jump-spark system is in the position of the timer, and not in the instant of the spark itself.

In one automobile motor no provision is made for changing the time of ignition, but the arc is made stronger as the speed of the motor increases. This is accomplished by increasing the speed of the generator as the speed of the motor increases. The ratio of the two speeds is kept constant, or nearly so. With this arrangement, the advantage of slow speed and strong pull cannot be secured by retarding the spark and opening the throttle. A slow speed of rotation and a strong pull are often extremely desirable for a short time.

89. Combined Hand Control and Governing. — When a motor is entirely controlled by hand (and foot) there are times when it is impossible for the operator to perform all the operations quick enough to prevent the motor from racing, as in the case of suddenly disengaging the clutch and applying both hand and foot brakes to avoid an accident, or when it is necessary to release the brakes, throw on the power and steer the car quick enough to get away from a dangerous position. For this reason, especially to avoid racing of the motor, and in order to provide means by which a uniform speed can be easily maintained on a clear road, a governor is connected to the throttle or other fuel-regulating device. The governor is found on many automobile motors, to a less degree on launch motors, and sometimes on stationary motors for hoisting, etc. Some motors are provided with a connection between the clutch and throttle such that the act of disengaging the clutch also partly closes the throttle. This, however, does not keep down the speed of the motor when the transmission gears are in neutral position and the clutch in engagement.

A governor has, to a small extent, been applied to the timer to adjust it in relation to the speed, but without very satisfactory results. The governor for a timer should advance and retard it in relation to both the speed and the amount of fuel supplied for a charge or the degree of compression, instead of for the speed alone.

The fuel governor is set, in the usual practice, to keep the speed at the lowest at which the motor will run well, and to maintain that speed from friction load up to the maximum torque capacity of the motor at that speed. When a higher speed is wanted, the hand control is set for that speed, and the governor maintains it as before. In other designs the governor ceases to act as soon as the hand control is brought into action. This latter method is hardly desirable for an automobile. An accelerator foot lever for opening the throttle wide and throwing the governor out of action quickly is generally provided for sudden speeding up of the motor, or for working it at its full torque capacity and the highest speed it will take under the load.

Comparative Accuracy of Methods of Governing.

90. Speed Variation in Cut-Out-of-Charge Governing. — By the use of the cut-out mechanisms of the forms generally adopted, and which have been described, the piston of a four-cycle, one-cylinder, single-acting motor of the simpler type must make eight strokes, corresponding to four revolutions of the crank shaft, between the beginning of impulses when one charge only is cut out of a series.

If the motor is working at nearly its full capacity, and consequently cutting out an impulse only after several have occurred in regular consecutive order, there will be a considerable drop of speed following the missed explosion. And, on the other hand, if the motor is running with little or nothing more than its own frictional resistance to overcome, there will be several consecutive cut-outs, with a slowly decreasing rotative speed and then a considerable rapid increase of speed when an explosion occurs.

The total variation of speed is not as great when working against only the friction load as when delivering power up to nearly the full capacity of the motor. The maximum speed of the motor is reached shortly before the completion of the last impulse stroke preceding a cut-out, and the minimum speed just after the beginning of the first impulse stroke following the cut-out.

The relative extent of the speed variation under light and heavy loads can be shown mathematically with a close degree of accuracy. In doing this it will be assumed, for convenience, that the maximum speed is reached at the completion of the last impulse stroke preceding a cut-out, and that the minimum speed occurs just at the beginning of the next impulse stroke. These assumptions do not vary from the true conditions enough or in such a manner as to affect the result appreciably. The same motor will be considered under both light and heavy loads.

It should be remembered that, in this method of governing, every impulse acting on the piston is produced by the combustion of a full charge. It will be assumed that all charges contain the same amount of fuel; also that the resistance opposing the crank shaft is constant. The assumption is also made that the speed decreases uniformly during the time there are no impulses. This is not strictly true, since the inertia effects of the reciprocating parts and the variation of pressure against the piston cause a variable rate of drop. The truth of the results is not affected by this assumption.

The discussion refers to a single-cylinder, single-acting, four-cycle motor governed in such a manner that the time interval between explosions when there is a cut-out is never less than the time corresponding to four revolutions of the crank, and is always a multiple of four.

The following notation will be used:

N = any number of strokes of the piston not less than 12 and a multiple of 4;

H = the heat transformed into mechanical energy and delivered to the piston each time a charge is burned in the motor cylinder. A constant;

W = the sum of the external work done plus the friction loss in the motor, both during one stroke of the piston;

K.E = the kinetic energy given up by the flywheel and other moving parts during the longest series of consecutive inertia strokes of the piston.

When the motor is running on light load and there is only one impulse stroke during N strokes of the piston, then

$$W_0 = \frac{H}{N},$$

and since there are $N - 1$ inertia strokes during the N strokes of the piston,

$$\text{K.E}_0 = (N - 1)\,W_0 = (N - 1)\,\frac{H}{N}. \qquad \text{(Light load.)}$$

Again, when the motor is carrying a heavy load and there is only one cut-out during N strokes of the piston, there are $\frac{N}{4} - 1$ impulses during the N strokes. Therefore

$$W_h = \left(\frac{N}{4} - 1\right)\frac{H}{N},$$

and since the maximum number of inertia strokes is 7 when there is only one cut-out during N strokes,

$$\text{K.E}_h = 7\,W_h = 7\left(\frac{N}{4} - 1\right)\frac{H}{N}\cdot \qquad \text{(Heavy load.)}$$

The decrease of speed is nearly proportional to the amount of kinetic energy given up for the amount of speed variation that occurs in a governed motor. The ratio of the kinetic energy given up in the first case (light load) to that given up in the second case (heavy load) is

$$\frac{\text{K.E}_0}{\text{K.E}_h} = \frac{N-1}{7\left(\frac{N}{4} - 1\right)}\cdot$$

When N is given its minimum value of 12, corresponding to one impulse and two cut-outs for K.E._0 and to two impulses and one cut-out for K.E_h, this ratio becomes $\frac{11}{14} = .786$.

And since the speed variation in each case is practically proportional to the kinetic energy given up, the speed variation at the light load is only about 79 per cent of that at heavy load, or the variation at heavy load is about 1.27 times that at light load.

If $N = 40$, corresponding to one impulse and nine cut-outs for K.E_0 and to nine impulses and one cut-out for K.E_h, then the ratio of the kinetic energy given up during the 39 inertia strokes with the light load to that given up during the 7 inertia strokes with the heavy load is $\frac{39}{63} = .619$.

In this case the speed variation at light load is only about 62 per cent as great as at heavy load, or the heavy load variation of speed is about 1.62 times that at light load.

The nature of the speed variations for consecutive strokes of the piston is shown in the diagrams, Figs. 73 and 74, for $N = 40$. The diagrams are drawn to the same scale. The diagrams do not show the minor effects of compression, expansion, reciprocating parts, etc.

Beginning at the left-hand side of Fig. 73, which is for the light load, the straight line inclined downward toward the right indicates a uniform decrease of speed. The time for the governor to act is at the completion of the 2d, 6th, 10th, . . . 34th, 38th, etc., strokes (suction or charging strokes). The speed has fallen below that at which the governor cuts out when the inclined line crosses the vertical line that represents the beginning of the 38th stroke to the left of the zero. A charge is therefore taken in and compressed during the two strokes preceding the impulse stroke that begins at the zero division. The speed is increased from *A* to *B* during the impulse stroke, and then falls uniformly during the following 39 inertia strokes and reaches a minimum at the end of the 40th stroke. The speed has fallen below the cut-out line at the end of the 38th stroke, so that the inlet valve is opened for this charging stroke. The impulse given during the 41st stroke brings the speed up to the maximum again.

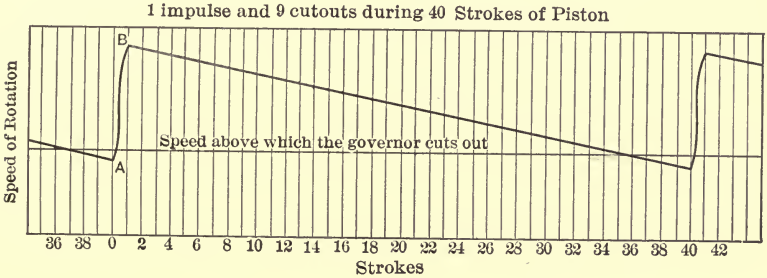


FIG. 73.

Now taking up Fig. 74 for a heavy load, the last impulse of a consecutive series of impulses increases the speed from *N* to *P* during stroke 1 according to the numbering on the diagram. The speed then falls off uniformly, as indicated by the inclined straight line, but at the beginning of the third stroke, as represented by vertical line 2, it is still above that at which the governor cuts out. The charge is therefore cut out, and the piston must make, in all, seven inertia strokes during which the speed falls to *R* before another impulse begins. Impulses are then given during every fourth stroke, beginning with the 9th and ending with the 41st. The speed has now again reached the same value as at *P*, and the cut-out is repeated. The speed change from *A* to *B*, Fig. 74, and that from *P* to *R*, have a ratio of $\frac{39}{63}$ as has been calculated.

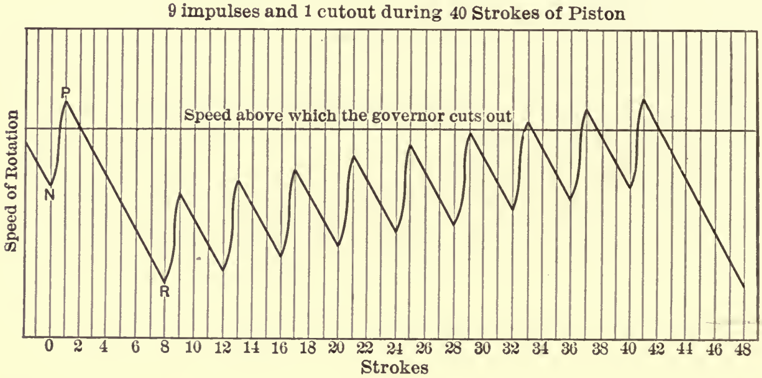


FIG. 74.

While the greatest total speed variation comes with the heavy load, the highest *rate* of variation occurs with the light load. The highest rate of variation takes place during the impulse stroke with both the light and heavy load. The energy stored in the moving parts during each impulse stroke is the difference between that given to the piston by each explosion and that abstracted for external work and friction in the motor. It is represented by the expression

$$\left.\begin{array}{c}\text{Heat energy stored in moving parts}\\ \text{of motor by each explosion}\end{array}\right\} = H - W.$$

The values of *W* for the two cases already considered are

$$W_0 = \frac{H}{N} \quad \text{and} \quad W_h = \left(\frac{N}{4} - 1\right)\frac{H}{N}.$$

Since N is never less than 12, the value of W_0 is always less than that of W_h. Therefore $H - W_0$ is always greater than $H - W_h$, which indicates that there is more energy stored in the moving parts during the impulse with the light load than with the heavy load.

Applying this to the concrete case in which $N = 40$ gives:

$$\left.\begin{array}{l}\text{Energy stored in moving parts during one}\\ \quad\text{impulse when there is but one impulse}\\ \quad\text{during the 40 strokes}\end{array}\right\} = H - \frac{H}{40} = \frac{39}{40} H.$$

$$\left.\begin{array}{l}\text{Energy stored in moving parts}\\ \quad\text{during one explosion when}\\ \quad\text{there is but one cut-out dur-}\\ \quad\text{ing 40 strokes}\end{array}\right\} = H - \left(\frac{N}{4} - 1\right)\frac{H}{N} = H - \left(\frac{40}{4} - 1\right)\frac{H}{40} = \frac{31}{40} H.$$

These results show that the increase of speed during one impulse stroke with the light load is $\frac{39}{31}$, or about 1.25 times that of the corresponding increase with the heavy load.

91. Speed Variation with Throttling Governor. — In this case the speed variation is very much less than by cutting out whole charges. The piston receives its impulses at regular intervals, so there is no long period of inertia strokes. The speed curves for both light and heavy loads are of the same nature. The accuracy of speed depends on the inertia of the rotating parts.

92. Uniformity of Speed in Two-Cycle Governed Motor. — Since the impulses come twice as often in a two-cycle motor as in a four-cycle one when both have the same speed of rotation, the governing is naturally more accurate. This is most marked in motors with only one combustion chamber and one piston.

CHAPTER V.

COOLING THE MOTOR.

93. **General.** — It has already been stated that some means of cooling the parts of the motor with which the hot gases come in contact is necessary to prevent their overheating.

The three methods adopted are water cooling, oil cooling, and air cooling.

When a charge is burned in a motor, part of the heat is abstracted by the enclosing walls, part is transformed into mechanical energy by driving out the piston, and the remainder passes out with exhaust gases. The only useful part as far as the motor is concerned, is that transformed into mechanical energy.

The cooler the confining walls, the greater the amount of heat abstracted from the gases by them. The transformation of the heat of the fuel into mechanical energy is therefore the more efficient the hotter the walls. From this viewpoint it is therefore desirable to have hot walls.

On the other hand, the cooler the walls the higher the pressure to which the compression of the charge can be carried before ignition occurs by the heat due to compression when the air and fuel are mixed before compressing, as is the practice in all modern motors using gas or vapor fuel and in most oil motors. The Diesel oil motor is a decided exception to the general practice. The efficiency of heat transformation is higher the higher the compression. On this basis cool walls are desirable.

There have been many tests on water-cooled motors reported in which it is pointed out that when the cooling water is kept at or near the boiling point, the efficiency is higher than when a bountiful supply of cold water is circulated through the water jacket. But these tests all seem to have been made without changing the compression pressure in any of the motors during the test when the change was made from hot to cold water. If the compression pressure had been carried higher for the cold water than for the hot, as can be done by lengthening the connecting rod so as to decrease the ratio of the volume of the compression space to that of the displacement by the piston per stroke, the results would have been different. How far different would depend on how much higher the compression pressure could be carried with the cold-water jacket without producing ignition before the completion of the compression stroke.

The capacity of the motor is lower the hotter the cylinder and combustion chamber. The hot metal of the walls heats the charge and expands it before the compression stroke begins and while the inlet port is still open. This is especially true when the inlet port is located so that the cool incoming charge will strike the hot exhaust valve and cool it. The expansion of the mixture by heat reduces the weight of the charge and therefore also reduces the power that is developed from it. The result is that motors working with hot cylinders develop less power per cubic foot of piston displacement per minute than those with cooler cylinders. In other words, of two motors having the same diameter of piston and length of stroke, and running at the same speed of rotation, but one having a hot cylinder and the other a cool one, the latter will develop more power.

The distortion and deterioration of the parts in the neighborhood of the combustion chamber by heat, and the difficulty of sufficiently lubricating the hot parts, both limit the degree of hotness at which the motor will operate satisfactorily.

94. **Air Cooling.** — Air cooling has been found entirely satisfactory for small motors such as are used on motor cycles and air ships. The movement of the vehicle generally brings enough air in contact with the external portions of the heated parts to keep them cool enough to operate. But when a motor cycle is moving in the same direction as a strong wind on a hot day up a long grade, the motor is apt to become rather hot.

Air-cooled automobile motors up to ten-horsepower capacity per cylinder in four- and six-cylinder designs have been operated successfully for several years. In the multi-cylinder motor a fan is provided to create a draft against the radiating protuberances of the heated part. In some designs the fan merely causes a circulation of air through the space enclosed by the hood that covers the motor. In others the heated parts and their protuberances are surrounded by a casing which encloses a comparatively small space so as to form an air jacket between the casing and cylinder, etc. A current of air is forced through the jacket by a blower or fan.

When the circulation of air is poor around the cylinder of an air-cooled motor, the metal becomes hot enough to glow distinctly in moderate darkness. The motor runs successfully at this temperature, but the continuation of such heating injures the valves, etc., and very copious lubrication of the cylinder is necessary with an oil that will stand high temperatures before burning or evaporating.

95. Water Cooling. — By far the greater proportion of automobile motors, practically all small stationary motors and all large ones, launch motors, etc., are cooled by water or some other liquid.

In the more usual practice of cooling the cylinder, water is passed through the water jacket and then out through a waste pipe or to a cooler from which it returns to the motor again. In at least one motor, however, the method is different. In it the water is kept at a constant level in the jacket space of the horizontal cylinder, so as to surround about three-quarters of the cylinder, and there is no water outlet from the water jacket. As the water is gradually vaporized, the vapor passes out of the jacket through a pipe that leads it to the inlet of the motor. The water vapor mingles with the air that is entering the cylinder and is carried in with it.

In the true circulating system of cooling, the water passes repeatedly from the motor to the cooler and back to the motor, and so on.

Whether the circulating system or the waste system of the cooling water shall be adopted for a motor naturally depends on conditions separate from the motor itself. On a launch the water is allowed to flow overboard, while on an automobile it is carefully retained and cooled.

It is quite common practice to pass the waste water into the exhaust pipe on stationary and launch motors. This serves the triple purpose of cooling the pipe, silencing the exhaust to some extent, and of preventing serious explosions in the exhaust pipe and its connections, in case some of the combustible mixture is passed unburned through the motor into them.

Thermal circulation, in which the heat from the cylinder walls is utilized to move the water in the circulating system, is the simplest and most economical method. In the thermal system, the top level of the water in the cooling apparatus is higher than the top of the jacket space of the motor, and the lower level of the water in the cooler is above the bottom of the jacket space. A pipe, or passage, carries the water from the top of the jacket space to the upper part of the water in the cooler. The opening of this pipe into the cooler must be below the surface of the water, at least the lower part of the opening must be lower than the water level, and the pipe, should have an upward incline, or be vertical, from the motor to the cooler, so that the water always rises as it passes through it from the former to the latter. There should be no downward bends in the pipe. The pipe from the lower part of the cooler to the lower part of the jacket space should either be inclined downward from the cooler or descend vertically, so that the water will always descend on its way from the cooler to the motor.

The operation of the thermal system depends on the fact that hot water has less density, or weighs less per cubic foot, than cold water, and therefore always tends to rise to the surface. The hot water rises to the top of the jacket space and flows up through the pipe to the cooler, while the cold water from the bottom part of the cooler flows through the pipe to the bottom of the jacket space, thus maintaining circulation.

If the water in the cooler falls below the opening of the pipe from the motor jacket space to an appreciable extent, the circulation will stop.

In stationary-motor practice the cooler can be a tank, a barrel, a reservoir, or any simple form of vessel that will retain the water.

since it can be made large enough to have ample exposed water surface and enough of its own outer part exposed to the air to cool it. This is also generally true of portable and, to a considerable extent, of semi-portable motors.

A radiator is used for cooling the circulating jacket water in automobiles. It is placed at the extreme front of the car in usual practice. Numerous designs of radiators are used. The object sought in all the correctly designed ones is to present as large an exterior cooling surface to the air and as large an interior contact surface to the water as possible for the amount of water carried, and at the same time to have rapid passage of air over the radiating or exterior surface of the cooler. It is also extremely desirable to keep the weight of the radiator as low as possible.

Copper, brass, and bronze are the materials almost universally used for automobile radiators. Copper, or its alloys, is most suitable on account of its combined high capacity for conducting heat, ease of working to form and of soldering, and toughness.

A fan is generally used for drawing air over and between the external surfaces of the radiator. When the fan is a separate piece of the apparatus, it is generally placed just back of the radiator. The tendency of modern practice is to utilize the arms of the flywheel of the motor for a fan by making them vane-shaped. In such cases the motor is completely enclosed by a tight hood and a bottom pan, so that the suction of the flywheel at the rear of the motor draws air in through the radiator at the front, allows it to circulate around the motor, and then discharges it under the body of the car.

The aid of a fan is not generally required in freezing weather, but it becomes an absolute necessity in hot weather. Without it an automobile traveling up a long grade together with a breeze in the same direction and at the same speed, and in a hot sun, will have the cooling water boiling in a short time.

A circulating pump for forcing the water to circulate rapidly through the cooling system is generally used in automobile practice, especially in the larger, high-powered cars. The small quantity of cooling water carried (often not more than three or four gallons for a forty-horsepower motor) makes it necessary to circulate the water rapidly. This is largely due to the fact that the water space in the radiator is so limited that but a very small part of the water is contained in its very narrow passages, hence the circulation must be more rapid than thermal action will produce.

The pump for circulating the water is interposed in some part of the circuit, generally in the pipe between the bottom of the radiator and the bottom of the jacket space. The pump is generally of the rotary type, since this form will deliver a large quantity of water when of small size and light weight. Two types are used, centrifugal and positive action. The **centrifugal pump** creates a pressure in a measure proportional to its speed of rotation, and the amount of water that flows depends on the freedom of its passage through the circuit. The **positive-action** pump is of the nature of a force pump. At every revolution it delivers a fixed and constant volume of water, and the pressure is proportional to the resistance of the flow through the circuit. This is true provided the pump has no leakage between the parts that work together and give the impulse to the water. There generally is considerable leakage in this class of pumps as used on automobiles. The centrifugal type has come to be used more generally in automobile practice. It is the simpler form, and does not depend on the absence of leakage for its satisfactory operation.

In launches, the reciprocating plunger type of circulating pump for the cooling water is more commonly used than the rotary. The reason for this selection does not seem plain when the pump is placed below the level of the water in which the boat floats. It is, of course, a simple and inexpensive form of pump, and can be driven by a crank or an eccentric instead of gear wheels.

96. Water-Cooled Pistons and Valves. — In the smaller sizes of motors the heat is conducted away from the piston and valves by the parts of the cylinder with which they come in contact. In single-acting motors, the piston is also cooled by the external air when the piston is exposed to the air, as in the usual forms of single-acting stationary motors.

In large, or even in medium-sized motors, the heat is not carried away with sufficient rapidity in this manner to keep the parts cool enough for operation. The head of a 20 inch diameter piston will glow with heat after the motor has been on a heavy load for some time, and the exhaust valve becomes hot and distorted so as to leak. The hot gases passing by it also destroy the smoothness of the bearing surface that comes against the seat when the valve is closed.

Water-cooling the piston becomes especially necessary in double-acting motors, since the piston receives heat on both faces and none of it is exposed to the external air.

The usual method of cooling the piston of a double-acting motor is to pass water in through a pipe in the hole of a hollow piston rod. The piston is also made hollow, and the space so divided that the water upon entering it flows around so as to cool its entire surface and then flows out through the hollow piston rod in the space not occupied by the pipe that carries the water in. A pump or a head of water is necessary to force the water through the piston and piston rod.

The cooling of the exhaust valve with water is done in a manner similar to that for the piston.

97. Oil-Cooling the Motor. — Oil can be used in the same manner as water for cooling the motor by circulating it through the jacket space. This has been demonstrated in regular service on a considerable number of motors for several years.

For motors that are exposed to the cold when not in operation the use of oil for cooling has great advantages over water. Freezing of the water will burst the jacket shell and other parts. Any failure to drain it off completely may be the indirect cause of broken pipes and radiator. If there are any pockets that do not drain easily, this failure is apt to occur.

When oil is used for cooling, the value of the oil makes a circulating system necessary. A radiator and circulating pump can be used as for water.

"Oil-cooled" is often erroneously applied to air-cooled motors under the supposition that so much cylinder oil is required to lubricate the cylinder and piston that it has an appreciable cooling effect.

98. Gaskets and Packing Materials. — A gasket is a piece of comparatively soft material, generally thin and flat, placed between two harder surfaces, generally metallic, for making a tight joint.

Where the temperature is high, as where the parts are heated by exhaust gases, the gasket must be of a material that will not burn, and should also be soft and thick enough to allow for warping of the connected parts. Asbestos woven into a sheet, together with a net of small copper wires for strengthening, is much used. The material can be easily cut to the form needed. Asbestos covered with sheet copper and made up into forms to be used (rings, ovals) is convenient and good.

When gasoline or naphtha comes in contact with the gasket, as in an inlet pipe, some material that is not affected by the naphtha or gasoline should be used. Rubber will not do on account of the softening action of the gasoline or naphtha, but leather, wood fiber, paper, lead, and soft copper are suitable.

For joints in the cooling-water connections, any of the last mentioned materials, or any good steam gasket material, will answer if there is no oil or other substance in the water that will attack them. Rubber and rubber composition should not be used when oil is present, as in a non-freezing mixture, or when oil alone is used as in oil-cooled motors.

The pipe for the liquid fuel is generally very small. Lead or soft-copper rings serve well in it for packing, but the lead ring should be quite thin so that there is not enough material to be squeezed out so as to close the passage. Vulcanized wood fiber does well here. The small joints are generally ground to a fit. If a ground fit in the fuel-pipe connection cannot be made tight without packing or some other filling material, a thin coating of cake soap or some rubber cement put between the ground surfaces will generally stop a leak.

When the joint remains dry, and especially if it is highly heated in service, it can be prepared for easy separation by coating one side of a non-metallic gasket with powdered or flake graphite (plumbago, black lead) and the other side with varnish. The varnished side will adhere so as to hold the gasket in place, but the graphite-coated side will separate readily from the surface that was pressed against it.

99. Pump Packing. — Some fibrous material is generally used for packing the circulating pump. Flax (tow) is probably best for a water pump, but cotton wicking covered with graphite grease is good. The latter, or prepared steam packing (without any rubber), does well for the circulating pump of an oil-cooled motor.

CHAPTER VI.

LUBRICATION OF MOTOR.

100. Oils and Methods of Applying. — Copious lubrication of the piston of an internal-combustion motor is an absolute necessity. In the absence of lubrication, the rubbing surfaces of the piston and the bore of the cylinder become dry and abrade each other, and may even seize together. As a result the motor loses power and finally stops. Oil is used for lubricating.

The oil to be most suitable must withstand a high temperature without decomposition or rapid vaporization, and when finally evaporated and burned must leave a minimum deposit on the walls of the cylinder and piston, valve stems, and ignition apparatus. It must also be free from acids that act on the metal of the motor. Most of the oils used are thin (not viscous) and flow readily, especially those for small motors. In the latter it is often desirable to use the same oil for the bearings on the crank shaft as for the piston.

One of the simplest methods of lubricating the piston and crank-shaft bearings of a vertical motor is the splash system. In it the enclosed crank case is kept partly filled with oil to such a level that the rotating parts strike it and splash it up into the bore of the cylinder and against the piston. The latter is amply lubricated by this method.

In order to prevent too copious lubrication of the piston by splashing in this manner, a splash plate is sometimes placed across the lower end of the cylinder between it and the crank case. The splash plate has a slot in it only large enough to allow the movement of the connecting rod. No oil is fed in through the cylinder walls in the best practice when the splash system is used. The lowest piston ring is sometimes beveled on the lower part of the periphery so that the oil will pass up by it on the downstroke of the piston. The upper side is left with a

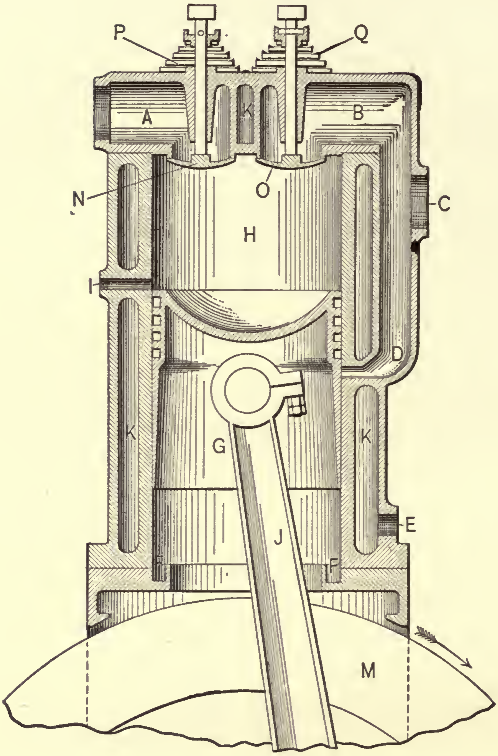


Fig. 75.

Axial Section of Cylinder of Vertical Gas Engine. Four-cycle, Single-Acting, Water-Cooled. Oil Well at Bottom of Cylinder. Auxiliary Exhaust Port.

A. Mixture inlet.
B. Exhaust passage.
C. Exhaust pipe connection.
D. Auxiliary automatic exhaust port.
E. Jacket-water inlet. Outlet at top of jacket space not shown.
F. Annular oil well into which piston dips.
G. Piston.
H. Combustion part of cylinder.
I. Opening for relieving compression during first part of compression stroke when starting. Ordinarily closed by valve.
J. Connecting rod.
K. Water-jacket space.
M. Flywheel.
N. Inlet valve.
O. Exhaust valve.
P. Closing spring for inlet valve.
Q. Closing spring for exhaust valve.

sharp corner so that the oil will be carried up on the upstroke. This practice does not seem necessary, however. It is not found in very many motors.

Forced lubrication is a still more certain way of securing positive lubrication of the parts. In this system a small pump is used to take the oil from the bottom of the crank case and force it through pipes or passages in the case leading to the bearings and thence through the hollow crank shaft and passages in the cranks to the crank pins and then through the hollow connecting rod up to the piston pin or wrist pin. The oil escapes through the various bearings and runs back to the crank case to be pumped through the system again. Both reciprocating plunger and rotary pumps are used for circulating the oil. Positive-acting rotary pumps are more suitable here than for water circulation, since the copious lubrication prevents rapid wear and consequent leakage.

Ring oiling of the crank-case bearings that support the crank shaft is frequently adopted. The usual method is to make the bearing with an oil reservoir beneath it, and to cut away part of the top of the bearing in order to hang a ring over the shaft so that its lower part dips into the oil in the reservoir. The weight of the ring resting on the top of the shaft causes the ring to turn when the shaft is rotating, but at a slower rate. The rotation of the ring carries oil up to the shaft, so that the bearing is lubricated as long as there is enough oil in the reservoir for the ring to touch it.

In horizontal motors oil is fed in at the top of the cylinder. This is the only way the oil is supplied in open-frame motors. But when the crank case is enclosed there is some lubrication of the piston by the oil that flies from the crank and connecting rod.

When there is no pump, as for forced lubrication, the oil must be supplied by some sort of a lubricator which gradually delivers oil to the motor.

The amount of oil required per stroke of the piston of a motor is in a measure proportional to the rate at which the motor is working. More oil is required for a heavy load than for a light one when the speed of the motor is constant. The oil required for variable-speed motors is approximately proportional to both the speed and the load. The refinement of lubricating in proportion to the work per stroke does not seem to have been attempted. It is doubtful as to its being worth while. But practically all the lubricators for variable-speed motors, except the simplest gravity types, supply the oil more or less nearly in proportion to the speed of rotation. When the splash system is used, it is not so important that the rate of feed of the oil shall be proportional to the speed. But when the motor works steadily on a heavy load for a long time, the rate of gravity feed that is suitable for a light load is not rapid enough for a heavy one.

101. Lubricators. — There are four distinct types of lubricators used on internal-combustion motors, as classified according to the method of delivering the oil. They are:

Gravity feed;
Mechanical oil supply and gravity delivery;
Compression feed;
Positive mechanical feed.

The gravity-feed lubricators that are used on gas and oil motors are principally of the adjustable sight-feed type. The rate of flow of the oil is adjusted by a needle or cone-point regulator, and is observed through the glass sight below the point from which the oil drops. The gravity lubricator can be used where there is no compression resistance to feed against. It can be used for the crank shaft of an enclosed crank case, four-cylinder vertical motor of the usual type in which two of the pistons move upward in unison while the other two move downward, since neither compression nor partial vacuum is produced in this form of motor.

The mechanical-supply and gravity-delivery lubricator was used on the early horizontal motors of the Otto type for lubricating the piston. It still finds considerable application to this style of motor. In it a mechanically driven part, generally rotary, dips into a reservoir of oil and carries some of it up over the open end of a tube which extends down through the cylinder wall to the bore of the cylinder. Some of the oil either drops or is scraped off the rotating part as it passes over the top of the tube, and flows down through it to the piston. If the pressure due to a leaky piston blows the oil up out of the tube, it is caught in the cup or reservoir and again carried up by the rotating part.

In several forms of motor with an enclosed crank case the air or mixture in the case is alternately compressed and expanded. The gravity-feed lubricator will not deliver oil into the compressed air.

The compression-feed lubricator is applicable to such motors. In some of its forms a pipe connects the crank case with the air space above the oil in the lubricator reservoir. The pipe terminates in a check valve in the lubricator. When the air is compressed in the crank case, some of it is forced into the air space of the lubricator and retained there under pressure by the check valve. When the pressure in the crank case falls as the pistons recede, the compressed air in the lubricator forces the oil out through the openings for that purpose. The oil is fed out and regulated as in a sight-feed gravity lubricator, except that the orifice can be at or above the level of the oil provided it is connected with the body of the oil by a passage that opens below its surface. If the compressed air is not released from the lubricator when the motor stops, it will continue to feed oil out till the pressure falls. A release valve is generally provided. It is opened by a pressure of the finger when the motor is stopped.

Some of the types of single-acting motors in which the air is alternately compressed and expanded in the enclosed crank case are: single-cylinder motor; two-cylinder opposed motor, with the cylinders on opposite sides of the crank shaft and the cranks 180 degrees apart, so that the pistons alternately approach and recede from each other; two-cylinder, twin-cylinder motors, in which the cylinders are side by side and the pistons move in unison toward and away from the crank shaft.

The positive-feed lubricator in one of its forms has a number of small plungers and corresponding cylinders or pipe ends, one for each outlet of the lubricator. The lower ends of the plungers and the cylinders are submerged in the reservoir of oil. The plungers are consecutively lifted by a rotating part, and oil flows into the cylinder beneath the plunger through a small hole in the side of the oil cylinder. The plunger is then released and a spring snaps it down suddenly. The side orifice of the cylinder is closed as the plunger passes it. The descent of the plunger forces the oil into a tube which carries it to the part to be lubricated. There are no valves in the device for forcing the oil out. The plunger-lifting part of the lubricator is driven by the motor at a speed proportional to that of the motor. The amount of oil fed to the motor is therefore approximately proportional to the speed of rotation of the motor.

Practically all mechanically driven lubricators deliver oil at a rate approximately proportional to the speed of the motor.

Slow-moving mechanically driven plunger pumps with valves are used in some of the other positive-feed lubricators.

CHAPTER VII.

DISPOSAL OF EXHAUST GASES.

102. Precautions. — Since the exhaust gases from an internal-combustion motor are hot, and since combustible mixture may be mingled with them at times, the pipes or passages through which the exhaust is carried to the atmosphere must be so located and protected as not to injure anything by their heat, and must be strong enough to resist the pressure of explosions in them. It is often desirable to carry the exhaust from a small stationary motor out through a chimney or flue of a building in which the motor is located. In such a case the exhaust pipe must be extended the full length of the flue so that the gases will be discharged directly into the atmosphere. If the exhaust is discharged into the masonry flue and an explosion occurs in it, the flue is apt to be wrecked.

The discharge of a spray of water, as cooling-jacket water, into the exhaust pipe reduces its temperature and lessens the liability of explosions. This is not generally practiced for stationary motors of small size, however. If there is much sulphur dioxide (SO_2) in the exhaust gases, cooling with water causes destruction of metal pipes by chemical action.

The exhaust should never be discharged into a room even for a short time. A small quantity of the gases will cause headache, and a large quantity asphyxiation. There is no warning odor, and fainting is apt to occur before the danger is realized.

When too rich a mixture is used in a gasoline motor, the exhaust gases will also cause the eyes to suffer by smarting and pain.

The danger is greatest in heavy, damp weather.

103. Silencing the Exhaust. — The pressure of the gases in the cylinder of an internal-combustion motor is still high enough when the exhaust valve opens to cause them to escape with a loud explosive sound, except in compound motors or others of unusual design in which the expansion is carried out to almost atmospheric pressure. Some provision is generally made for deadening or silencing the sound of the exhaust. The apparatus for this purpose is generally known as a silencer or muffler.

An efficient muffler not only deadens the noise of the exhaust, but also offers a minimum resistance to the escape of the gases. Any resistance to the escape of these gases causes a back pressure against the piston of the motor during the exhaust stroke, or against the piston of the pump that forces in the new charge in two-cycle motors, and thus reduces the efficiency of the motor and decreases the amount of power that it will develop.

104. Subterranean Mufflers or Silencers. — For stationary motors, the exhaust is generally discharged into a buried tank or a pit when ground space is available. The gas expands to a low pressure in the receptacle and then escapes to the atmosphere through a comparatively small pipe or opening.

For very large motors a pit or well is generally excavated and used in the manner just described.

The noise is more completely deadened by filling the well with loose broken stone, coarse cinders, slag, etc.

Since some of the combustible mixture is apt to pass through the motor at times and on into the muffler, and may be exploded there by the hot gases of a subsequent discharge, the muffler should be provided with means of relieving the pressure of the explosion instantly, so that it may not be blown to pieces. A hinged trap door of planks answers this purpose well for large pits, and a large short pipe extending from the barrel or tank to the atmosphere and closed by a relief valve at the top is suitable for smaller sizes. The pipe from the motor to the muffler should be strong enough to resist the pressure of these explosions.

105. Exposed Muffler. —When the muffler is not buried, it is made of metal strong enough to resist the pressure of explosions in it. If the exhaust pipe from the motor to the muffler is long, there should be a relief valve either on the muffler or very near it.

The exposed metal muffler has either a comparatively large chamber, or a number of chambers, into which the exhaust gas is discharged and expanded and then passes out to the atmosphere. When the volume of the muffler is large in proportion to the size of the exhaust pipe, the escape from the muffler is often made through a single large pipe into the atmosphere. But if the muffler is small, the discharge is made through a great number of small orifices direct into the atmosphere.

One simple form of muffler consists of two comparatively small enlargements of the exhaust pipe in series and a short distance apart in the pipe. The gas expands in the first one and then passes through the pipe between them into the second for further expansion and then escapes through a length of pipe to the atmosphere.

Another form of muffler has two or more pipes of different diameter concentrically arranged in a nest, and the ends of all the pipes are closed by one pair of heads. The exhaust is received inside the smallest pipe and passes from it through a number of small holes into the next larger pipe, and so on to the outer tube or casing, and thence to the atmosphere direct or through a pipe extension.

Still another form is made up of a number of thin metal disks slightly concaved and placed on a pipe so that the convex side of the first disk forms one end of the muffler and the concave side of the second disk is placed toward that of the first one so that the outer edges of the two press together. The convex side of the third disk is placed next to that of the second one and presses against it at the edge of the central hole, and so on for all the disks. The pipe through the disk is stopped at one end and has holes communicating with the spaces between the concave sides of the disks. The exhaust gases pass from the pipe through the holes into the enclosed spaces between the disks and escape through the cracks between their outer edges.

106. Submerged Exhaust Pipe. — On launches it is quite common practice to submerge the end of the exhaust pipe in the sea water. When this is done, the precaution should be taken to give the pipe sufficient fall to prevent drawing the water up into the motor by the contraction of the hot gases in the pipe when the motor is stopped, or after an explosion in the exhaust pipe. A check valve is often used to meet this and other contingencies tending toward the same result.

107. Muffler Cut-Out. — A cut-out or relief valve is commonly used on automobiles. It is controlled by the driver, and is opened when the maximum power that the motor will develop is desired, as when climbing a grade or speeding up quickly.

108. Momentary Back Pressure. — In a four-cylinder, four-cycle motor whose impulses occur at equal time intervals and whose valves have the usual setting, the exhaust valve of one combustion chamber opens before the completion of the exhaust stroke of the piston of one of the other cylinders. If the exhaust pipes from the two combustion chambers (or from all of them) are brought together into a single main passage near the motor, this action of the exhaust will produce a momentary increase of pressure in the latter combustion chamber unless the connections between the single exhaust pipes and the main pipe are correctly made. This increase of pressure usually occurs during the early part of the suction stroke of the piston and before the inlet valve of the combustion chamber affected is opened. While the action of the momentary back pressure on the piston is not directly harmful in affecting the power of the motor, it does act to reduce the amount of charge that is drawn into the cylinder. This is because the exhaust valve closes while there is momentary back pressure in the cylinder and thus retains more inert gases of combustion than would be retained at atmospheric pressure in the cylinder.

The proper method of connecting the individual exhaust pipes to the main is to bring them nearly parallel with the latter where they are connected, so that the Y formed will have a very sharp angle between the branches. The discharge from one combustion chamber will then have a tendency to draw the exhaust gases from the others by ejector action instead of producing a back pressure as when the passages are at right angles to each other at their connection.

CHAPTER VIII.

STARTING AND ADJUSTING THE MOTOR.

109. Methods of Starting the Motor. — There are three methods in general use for starting an internal-combustion motor. They are:

1. Rotating the motor by external power till a charge is exploded in the usual manner and the motor then runs itself. Small motors are "cranked" or otherwise turned by hand, and large ones are driven from some source of mechanical power.

2. Starting the motor from rest by its own impulse. This is generally done by exploding a charge of the combustible mixture in the cylinder. An impulse is thus given the piston in much the same manner as when the motor is running, so that it starts. A less common method, although probably older, is to fire a charge of gunpowder in the cylinder.

3. Driving by compressed air passed into the cylinder to act on the piston in a manner similar to that of steam in steam engines.

110. Relieving the Compression while Starting. — The larger sizes of motors intended to be started by hand are often constructed so that the compression can be cut down to a much lower pressure for starting than is used during the regular operation of the motor. A very common method of doing this is to have the regular cams move aside so as to bring the starting cams into position for actuating the motor valves. The starting cams hold either the inlet valve or the exhaust valve of each cylinder open during a portion of the compression stroke, so that part of the charge that was drawn in during the preceding suction stroke, in a four-cycle motor, is either forced back through the inlet port or out through the exhaust port. When the inlet valve is mechanically operated, the starting cam is applied to it, but with an automatic inlet valve the starting cam can act only on the exhaust valve. The latter has the seriously objectionable feature of passing combustible mixture through the motor into the exhaust pipe, and of the resulting danger of explosions in the exhaust pipe and muffler.

In automobile motors the cam shaft is shifted to the starting position by putting on the starting crank. The throwing of the hand crank out of engagement when the motor starts on its own impulses allows the cam shaft to come back to the running position. Some of the large motors that are started by external mechanical power are provided with means for relieving the compression in the same general way as the small ones.

111. **The preparations for starting** a motor are practically the same to a certain extent, whatever the method of starting. The general preparations which are given immediately below do not all apply to any one motor, but such of them as do apply to any particular case should be made. It should be seen that:

Fuel is in the tank for motors that use liquid fuel;
The vent of the gravity fuel tank is not clogged;
The compression fuel tank is tightly closed;
Gas is in the supply pipe for motors using permanent gas. This can be done by lighting a jet or burner connected to the pipe at a point near the motor;
Lubricating oil is in all the lubricators;
The reservoir of a compression lubricator is tightly closed;
Grease cups are filled;
Cooling water is provided. If a stationary motor is located in a warm room and the cooling water is very cold, as when it flows from mains or an exposed tank in winter, it may be advisable to start the motor before turning on the cooling water. This applies especially to gasoline, naphtha, and alcohol motors.

Then:

Give the grease cups a turn to force grease into the bearings;
Turn on the lubricating oil;
Disengage the clutch when one is used between the motor and a load having considerable inertia or a load that must be started slowly.

The operations following these depend so much on the kind of motor and the method of starting that they must be differentiated.

Starting by External Power.

112. Starting a Small Electrically Ignited Gas Motor by Cranking. — After such of the above preparations as apply to the motor have been made:

Set the igniter in the late or retard position;
Set the relief cam mechanism so that the compression will be cut down when starting;
Turn on the gas, but only part way if there is no fuel valve to prevent its flow from pressure pipes into the air passage or mixing chamber;
Crank the motor. Always pull up on the crank. The cranking should be done immediately after the gas is turned on if there is no provision to prevent flow of the gas into the air passage or mixture chamber;

As soon as the motor begins to run itself:

Turn on the cooling water if it has not been done before (see preparations). This is not necessary in a circulating system;
Close the throttle enough to prevent racing if the motor is hand controlled;
Open the gas valve to its proper setting (see below);
Advance the ignition (see below).

There is no provision for retarding the time of ignition in many small stationary motors. Under such conditions it is safer to open a switch in the primary circuit of the ignition system before cranking the motor. Then crank up to a fair speed and close the switch. If this precaution is not taken, the motor may start backward (kick) if the ignition comes as early as it should for economical operation at fairly high speed. When provision is made for retarding the ignition in a small stationary motor, there are often only two positions in which the timer or igniter can be set — a starting and a running position.

If an electric generator that does not give enough pressure or current to cause ignition until the motor has been cranked up to high speed, is used, there is no necessity for the precaution of breaking the ignition circuit when starting.

The amount of opening to be given the hand-opened gas valve depends on the pressure of the gas and its richness or heat value. The opening that gives maximum power can be determined by noting the load that the motor will pull. The setting for maximum power does not generally correspond to that for maximum economy of fuel, however. The economy of fuel is generally better with slightly less gas than is required for maximum power.

The hand crank for starting the motor should be made so as to free itself and cease to rotate with the motor as soon as the latter starts on its own power.

For the greatest safety to the operator, the hand crank should be made, when possible, so that it can be pulled only upward at the time of ignition. Then, if the motor kicks, the crank may be snapped or jerked out of one's hand with less danger than when pressing down on it.

113. Starting an Electrically Ignited Stationary Gasoline Motor by Cranking. — (See preparations.)

Turn on the gasoline and lubricating oil;
Set the timer or igniter for late ignition;
Close the throttle well toward shut so that the motor will not race if hand controlled;
Prime the carbureter (this is not generally necessary);
Crank the motor; pull up on the crank;
Turn on the cooling water if it has not been done before (see preparations);
Advance the timer and close the throttle still further if the motor is to run light for a while.

See preceding section regarding timer and crank.

It sometimes happens that the slow speed of cranking does not cause enough gasoline to mix with the air while cranking to form a combustible mixture. The priming of the carbureter is intended to remove this difficulty. If there is no way of priming the carbureter, its air intake may be partly closed with one's hand or anything else that is convenient, while cranking. This causes enough suction to draw out sufficient gasoline.

When the motor is very cold, as one that has been exposed to freezing weather, it is sometimes very difficult to get the fuel, especially if it is of a poor grade for the purpose, to vaporize. Most motors are provided with a small valve or pet-cock at the top of the cylinder, through which gasoline can be poured into the cylinder. If a small quantity of gasoline is poured in and left for a minute or two, it will generally vaporize and diffuse enough to produce a mixture that will ignite.

A still further expedient with a cold motor is to pour hot water into the jacket space, or into the circulating system at a convenient place. In the latter case, a motor with a circulating pump should be rotated by hand to force the water into the jacket.

Still another expedient, which should be that of last resort, is to heat the cylinder and inlet pipe with a torch, or by putting a little gasoline on them and burning it off. Very little gasoline should be put on at first, and then more can be squirted on from an oil can with a small opening in the nozzle. The gasoline will not ignite in the can, for the flame cannot pass in through the small opening.

114. Starting a Large, Electrically Ignited Gas Motor by External Mechanical Power. — The method is practically the same as for the small gas motor, except the substitution of mechanical power for muscular effort.

The gas motor to be started may be driven by friction gears pressing against the flywheel. In such a device the driving gear should be movable so as to be withdrawn from engagement with the flywheel when the motor starts on its own power.

Starting the Motor by Its Own Impulse.

115. A single-cylinder, single-acting gas motor with electric ignition can be started by its own impulse in the following manner after it has been stopped by cutting off the fuel supply: Set the crank past its dead-center position with the piston a short distance out on its impulse stroke. The crank may be set as much as 30 degrees or even more past dead center.

Open the hand valve and allow gas to flow into the combustion space through a small auxiliary pipe or opening for this purpose. The gas mixes with the air in the cylinder that was drawn in after the fuel was cut off. After enough gas has passed in to make a combustible mixture, as determined by judgment or a small gas meter, its flow is to be cut off. Then after the suitable preparations (see preparations) have been made, the charge is to be ignited. This will give the piston an impulse sufficient to drive the motor till a charge is drawn in and ignited.

When a battery is used in connection with an induction coil for ignition, the first ignition can be made by leaving the battery circuit open till the time to ignite and then closing it. The jump spark thus produced will ignite the charge.

If an oscillating-armature magneto is used, the electric spark or arc can be produced by snapping the armature over by hand.

In the absence of an ignition system suitable to cause ignition when the motor is at rest, one manufacturer has adopted the expedient of striking a match inside the combustion chamber to ignite the charge. The end of a match is fastened in the plunger point of a holder and the latter screwed into a threaded hole in the combustion chamber wall. The plunger is then forced in and the match ignited by rubbing against a surface provided for the purpose. The flame of the match ignites the charge.

116. Starting the Motor on " Compression." — If the ignition is cut out to stop a four-cycle, single-acting, four-cylinder motor, and the throttle is opened during the last revolutions before stopping, at least two of the cylinders will contain a combustible charge when the motor stops. The piston of one of the charged cylinders will stop on the impulse-stroke position. The motor can be started again by exploding the charge in this cylinder. In a hand-controlled motor the ignition can be effected by moving the timer to the position that will give a spark in the cylinder whose impulse will start the crank in the right direction, that is, in the cylinder whose piston is part way out on the impulse stroke.

Two-cylinder, single-acting, four-cycle motors will sometimes stop in position to be started on compression, but this is unusual and in the nature of an accident. Motors with more than two cylinders generally stop so as to start on compression, provided the fuel has free access and is not exploded while stopping.

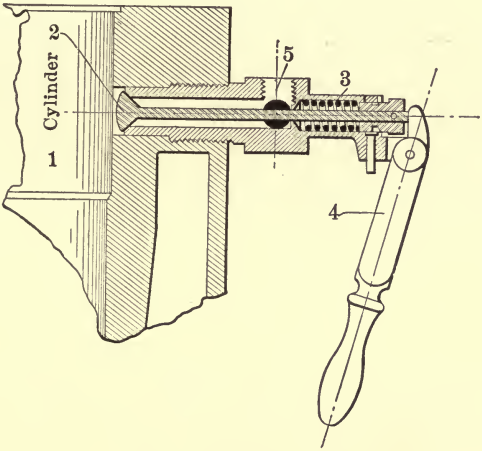


Fig. 76.

Starting Valve for Starting Motor with Compressed Air.

1. Motor cylinder.
2. Valve.
3. Coil spring to hold valve closed.
4. Lever for opening valve.
5. Connection to compressed air supply.

The motor is put into position with the piston a short distance out on the impulse stroke and then the compressed air is admitted by opening the valve 2 by means of the hand lever 4.

The length of time that a motor will retain a charge in the cylinder so as to start on compression depends on the tightness of the cylinder, piston, valves, etc. The writer has frequently seen motors that have been in considerable service started in this manner after standing for a week.

117. Starting by Firing a Blank Cartridge in the Cylinder. — Motors are not infrequently, and with entire success, started in this manner. The powder should be comparatively slow burning, as black gunpowder. A blank cartridge, such as is used in a gun, is suitable. The amount of powder necessary depends on the size of the motor, of course. About four drams, or 120 grains, should start a motor with a cylinder bore six inches in diameter.

It is advisable to begin with small charges of powder and gradually increase the amount until it is great enough.

Suitable means of holding the cartridge, as a breech block, must of course be provided. The piston of the cylinder in which the cartridge is fired should be placed a short distance out on its impulse stroke, with the crank for that cylinder some distance past the dead-center position.

118. Stresses Due to Starting a Motor by Its Own Impulse. — The explosion of a charge of combustible gas or a cartridge in the cylinder when the motor is at rest produces a higher pressure in the cylinder than if the piston were moving out on its impulse stroke. The force transmitted to the crank shaft is greater in proportion to the pressure against the face of the piston than when the speed of the piston is accelerating rapidly at the time of explosion, as is the case when the motor is running and the charge is fired at the usual time at about the beginning of the impulse stroke. It is therefore not advisable to explode a full charge in the cylinder when the motor is at rest, on account of the great stresses that such an explosion would produce, unless the motor is constructed with a view to starting it with full charges. The practice of starting in this manner is mostly confined to motors below medium size.

Starting on compression does not produce higher pressure in the cylinder than the explosions during regular running, for the piston stops in such a position that the charge is but slightly compressed when ignited. The pressure of explosion is higher, the higher the compression pressure at the time of igniting.

*Starting the Motor with Compressed Air.**

119. The use of compressed air in the cylinder for starting the motor is a certain and gentle way. It is much used on large-size motors. The cost of the equipment for compressing the air is an objection to this method for small and medium size motors, but when the compressed air is to be used for other purposes also, this objection disappears.

120. **In starting a single-cylinder, single-acting motor by compressed air,** the usual practice is to use a hand valve to admit the compressed air to the cylinder after the crank shaft has been rotated (barred over) to bring the piston to a position a little way out on the impulse stroke. The compressed air is turned on and quickly shut off again before the completion of the impulse stroke. The momentum given the moving parts in this manner is sufficient to keep them moving until a charge is drawn in and exploded immediately after the first suction stroke.

The air is generally compressed by a compressor driven by the motor long enough to store up a sufficient amount of the compressed air in storage tanks. Some attempts were made in the earlier single-acting, single-cylinder motors to have them act as air compressors while stopping after the fuel was cut off. This practice has not come into much use.

121. **Starting a Motor with More than One Combustion Chamber by Compressed Air.** — When the motor has more than one combustion chamber, compressed air can be used in one of them for driving the motor till the explosion impulses in the other combustion chamber (or chambers) come into effect to drive the motor. The compressed air is then shut off and the motor operates in the usual manner.

A starting valve-mechanism must be brought into operation on the valves of the combustion chamber to which the compressed air is admitted, so as to cause the admission valve to open during the early part of each outstroke of the piston and the exhaust valve to open during each return or instroke of the same piston.

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* See also Diesel motor.

The starting cams or other starting mechanisms are usually made so as to be readily moved into position for starting and promptly withdrawn when the motor has gained speed.

An automatic device for cutting off the compressed air is used in general practice.

Adjusting the Lubricator and Cooling Water.

122. Lubricator Adjustment. — The lubrication of the piston requires more care than that of the other parts of the motor, although it is very important that all of the bearings shall have plenty of oil or grease. It is practically impossible to give the bearings of the crank shaft, connecting rod, cam shaft, and other similar parts too much oil, but an excess of oil for the piston is accompanied with undesirable results, which are not so serious, however, as those of too little oil.

The piston (or cylinder) lubricator can be well opened at first, so that blue smoke is discharged with the exhaust gases, and then gradually closed just enough to prevent the appearance of the blue smoke. The oil should be cut down slightly and the motor allowed to run at least several minutes before making further adjustment of the piston lubricator. The black smoke of too rich a mixture should not be mistaken for the blue smoke of too much oil. The actual amount of piston-lubricating oil cannot be well specified for motors in general, but it is safe to start with twenty small drops a minute for a piston 5 inches in diameter and running at high speed. The condition of the exhaust gases can be observed by opening a small hole in the pipe near the motor, or by partly disconnecting a pipe joint, when the motor discharges into the atmosphere at a considerable, or unobservable, distance from the motor, as is frequently the case with stationary motors.

For the bearings of small motors from which the oil is allowed to run to waste, three or four drops a minute on crank-shaft bearings 2 inches in diameter and running at 400 to 500 revolutions per minute are generally sufficient. The smaller and slower speed cam shaft requires but very little oil.

123. **Cooling-Water Adjustment.** — When the cooling water is taken from water mains and allowed to flow to waste the water valve should be set so as to give the escaping water a temperature as near the boiling point as possible. The amount of water depends on the rate at which the motor is developing power. It requires more water at full load than at light load. Care should be taken to give it enough water for the heaviest load that comes on it.

In circulating systems of cooling there is seldom any means of adjusting the rate of flow. In thermal systems the water in the cooler must be kept above the opening of the upper pipe from the motor, as has been previously stated.

Adjusting Spray Carbureters and the Ignition.

124. **The air-valve stop,** not generally used, is not referred to in the following direction for adjusting carbureters. This stop is used in some carbureters for constant-speed motors, where its function is to positively limit the lift of the automatic air valve of the carbureter.

It should be remembered that the more the lift of the carbureter air valve is restricted by the stop, the richer will be the mixture when the motor is working at full load. The introduction of the action of this device into the general discussion would make it complicated to an extent hardly warrantable on account of the small use that is made of the stop.

125. **Rich and Lean Fuel Mixtures.** — The amount of power developed by a motor falls off from the maximum with either an increase or a decrease in the proportion of the fuel in the mixture, and the charge fails to ignite when it becomes either too rich or very lean. If the mixture is very rich, but still ignites, black smoke will be discharged with the exhaust. The exhaust from an over-rich gasoline mixture has a strong characteristic odor and is painful to the eyes, even if it is not so rich as to produce black smoke. The black smoke should not be confused with the blue smoke that comes from too much lubricating oil in the cylinder or from oil of the wrong quality.

A very rich combustible mixture burns so slowly that the flame continues long enough to pass out into the exhaust pipe when the exhaust valve (or port) is opened. This heats both the cylinder and the exhaust valve and pipe unduly, as well as wasting the fuel. The ignition of an over-rich mixture is uncertain. An unfired charge is therefore apt to pass out into the exhaust pipe, where it is subject to ignition by the flame of a succeeding burning charge or by hot particles of soot in the exhaust pipe or muffler. The after explosion, or muffler explosion, thus produced is extremely undesirable.

Premature ignition is apt to occur with the continued use of too rich a mixture, on account of the carbon or soot that is deposited on the walls of the combustion chamber while the charge is burning. This deposit becomes ignited and burns like the soot in a fireplace in a house. The glowing soot ignites the charge prematurely, generally during the compression stroke of the piston. It may, however, ignite the entering mixture during the suction stroke, thus causing back firing into the intake pipe.

A very lean mixture is also slow burning and uncertain of ignition. This is especially true when the charge is also rarefied by a nearly closed throttle. The characteristic result of a lean mixture is back firing into the inlet pipe and carbureter, or into the crank case of a two-cycle motor of the type in which the mixture is compressed in the crank case. The back firing is caused by the slow burning of the charge till the fuel port is opened and the mixture in the inlet passage is ignited by the flame in the combustion chamber. The explosion thus produced in the intake passage and carbureter is sharp and light in sound. It compares with an exhaust explosion as the snapping of a percussion cap does with the report of a gun using black powder.

Misfires of a lean mixture are also conducive to explosions in the exhaust.

When the fuel mixture is too rich there will generally be combustible gas carried out with the exhaust in the form of carbon monoxide, CO. Carbon monoxide is not only suffocating but also poisonous.

The following method of detecting CO in the exhaust gases from an internal-combustion motor is given by Mr. R. E. Mathot.* "A small glass flask, about two inches in diameter and four inches high, closed with a cork, through which pass two vertical tubes, is used for collecting some of the exhaust gas. One of the tubes is connected to the exhaust pipe of the engine, while the other end is plunged in mercury about one inch deep in the flask. As soon as the connection between the exhaust pipe and flask is established, some of the exhaust gas will be blown into the flask at each stroke, and the mercury, operating as a check valve, will prevent it from being withdrawn. The air contained in the flask, and afterward the exhaust gas, will be expelled through the second pipe open to the atmosphere and ending inside, at the top of the flask.

"To detect CO, which is contained in the exhaust gas continuously rushing through the flask, a small piece of white blotting paper is hung in the flask, the paper being previously prepared by dipping five or six times in a solution of double chlorid of palladium and sodium of such concentration as to give a dark brown color, and drying after each immersion.

"If there is more than 1 per cent of CO in the exhaust gases, the paper will, in two or three minutes, lose its bright brown color and become gray. This shows insufficient air in the mixture for combustion, which can be corrected at the mixing valve."

126. Rough Adjustments for Black Smoke and Back-firing. — If black smoke (not blue, see adjustment of lubricator) is discharged from the exhaust after the motor has been running a minute or so after starting, the fuel mixture is too rich. The fuel valve of the carbureter should be closed some, or the air valve (of the carbureter) opened more.

If the motor back-fires with a sharp explosion in the intake pipe and carbureter, it may be due to having the throttle nearly closed and the ignition set late in a hand-controlled motor, or the fuel mixture may be too lean. Open the throttle slightly and advance the ignition a little. If this does not stop the back firing, then,

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* Trans. Amer. Soc. Mechanical Engineers, April, 1908, Vol. 30, p. 401.

if the carbureter has been previously adjusted, close and open the needle fuel valve quickly, so as not to stop the motor, bringing the valve back to the same setting that it had. This will generally remove or crush foreign matter that may have lodged under the valve. If the back firing still continues, open the fuel valve still more, or close the air valve some. Continue this till black smoke appears at the exhaust if the back firing does not stop before. If this does not stop the back firing, it is probably due to some other cause than those just mentioned. (See back firing).

Closing the air valve enriches the mixture in greater proportion with a closed setting of the throttle and slow speed of the motor than with an open throttle and high motor speed, in the usual forms of carbureters. The same effects generally obtain when the spring is adjusted to press the air valve harder on its seat in a carbureter with a spring-closed air valve. Adjusting the spring to press the air valve harder on its seat is commonly referred to as closing the air valve.

The above adjustments are only rough ones, and should be followed by the more accurate ones described later.

127. Adjusting the Carbureter and Ignition on a Cut-Out-Governed Motor. — (See preceding section for rough initial adjustments.)

Run the motor on a constant load and adjust the fuel valve and the air valve to obtain the maximum number of cut-outs.

Set the timer to give earlier and later ignition till the position of the timer that gives the greatest number of cut-outs is determined. Leave the timer in this position, and

Adjust the carbureter again as at first.

Continue the adjustments of the carbureter and timer in this manner till the final settings for the greatest number of cut-outs are found.

128. Adjusting the Carbureter and Ignition of a Throttle-Governed Motor. — (See rough adjustments.) To make the best adjustment for regular service, the motor should be run part of the time on a nearly full load of constant value and the remainder of the time on a small constant load of about the same amount as the average small load on which the motor is to operate. These loads can be obtained by the use of an absorption dynamometer if not otherwise.

The object in each case is to secure the least opening of the throttle for the load applied.

Put on the full load:
  Set the air valve of the carbureter at about mid-position;
  Adjust the fuel valve and the ignition to find the settings that let the throttle close farthest.
Put on the small load:
  Adjust the air valve to give the least opening of the throttle;
  Set the air valve about midway between its first and second settings.
Put on the full load again and adjust the fuel valve and the air valve in the same manner as before with both the full and the small load. Repeat until very slight adjustments are required when changing from one load to the other.
Put on the small load and adjust the ignition for the least opening of the throttle.

If the throttle continues to close as the air valve is adjusted up to its limit either way at any time during the test, then the air valve should be set nearly to its other limit and the process of adjustment begun again.

When the limit of the decrease of the throttle opening is not reached by adjusting the spring-closed air valve from one extreme setting to the other, then the spring is either too weak or too strong, provided the carbureter is otherwise correctly constructed.

If the initial setting of the spring gave the lightest pressure of the air valve on its seat, and the adjustments increased the seating pressure up to the heaviest, then the spring is too weak. The remedy is to remove the spring and stretch it, if it is a compression spring, so as to close the valve harder. The stretching must give the spring a permanent elongation when it is free. A tension spring (seldom used) must be shortened under similar conditions.

The reverse of the above applies to the spring when its initial setting gives the heaviest pressure of the valve on its seat.

The fuel valve may be slightly closed from the adjustment determined as above in order to secure the best economy of fuel.

The ignition should finally be set to correspond with the prevailing load, using at least two of the settings just determined as a guide, but it should not be set so early as to cause thumping of the motor on full load.

129. Adjustment of a Variable-Speed Motor with Hand Control by Throttle. — (See rough adjustments.) In a hand-controlled variable-speed motor the throttle and the ignition are both operated by hand when controlling the motor, except in infrequent designs where the time of ignition is not changed.

The following method of adjusting the carbureter applies to motors in which both the throttle and the ignition are manipulated for controlling.

The adjustment requires the load to be rapidly varied at will, as by an absorption dynamometer.

After each adjustment or set of adjustments is made, the throttle may be quickly operated between the open and the nearly closed positions (not completely closed). If this causes either back firing or smoky exhaust, further adjustment of the carbureter should be made before testing any more. If there is black smoke, the air valve generally should be opened more; if there is back firing, the air valve should generally be closed some. Adjustments the reverse of these are sometimes required, however, this depending on the form of the carbureter. If misfiring occurs with neither black smoke nor back firing while the throttle is quickly operated, the fuel valve can be adjusted, but whether more or less fuel is needed cannot be determined before making an adjustment.

1. Adjust the air valve to about mid-position; set the ignition late and the throttle to give nearly maximum speed with no load or a very small load. Put on a small load and open the throttle till the speed is well up to the maximum. Increase the load and open the throttle still more till the speed is nearly up to the

maximum again. Continue the increase of the load and the opening of the throttle till the latter is full open. Then advance the timer and increase the load till the setting of the ignition that pulls the greatest load at somewhat less than maximum speed is determined. Now adjust the fuel valve and timer to increase the speed till the maximum is reached. Retard the timer slightly, put on more load, and adjust the fuel valve and timer again till the maximum speed is reached. Continue till the settings that give the greatest load at full speed are found.

2. Retard the timer and increase the load till the motor is brought down to a slow speed. Adjust the air valve and ignition, and increase the load till the greatest load that the motor will pull at slow speed is determined.

3. Set the air valve about midway between its last two positions and repeat the operations and adjustments of (1).

4. Repeat the operations of (2).

5. Continue the adjustments as above till there is not much change of setting for the maximum and slow speeds with heavy loads. Make the last adjustment of the air valve as in (2).

6. Set the throttle about one-quarter open and adjust the air valve to the setting that gives the most satisfactory operation at all speeds with light load. The ignition must also be adjusted during this test, of course. Just what is the most satisfactory operation of the motor depends on the nature of the service required.

7. Set the air valve about two-thirds of the way back toward the last setting. Give the throttle full opening and adjust the fuel valve to give the best results at maximum speed. If these fall much below what was obtained in (1), the test should be started over again with a different setting of the air valve from that in (1).

If the power continues to increase as the air valve is adjusted up to its limit either way at any time during the test, then the air valve should be set to its other limit and the series of tests begun again. (See latter half of preceding section.)

130. Adjustment of the Carbureter on an Automobile. — The following is such an adjustment as can be made on the road without any apparatus other than the automobile itself.

1. Set the air valve at about mid-position.
2. Open the throttle half way or less.
3. Set the timer for late ignition.
4. Disengage the clutch.
5. Start the motor.
6. Advance the timer part way.
7. Open and close the throttle quickly several times to determine how rapidly the motor speeds up, and whether there is either black smoke in the exhaust or back firing. Set the timer in different positions while doing this.
8. If back firing occurred, open the fuel valve more, or close the air valve some;

If black smoke (not blue) was discharged, close the fuel valve some, or open the air valve more;

Test after each adjustment by opening and closing the throttle at different settings of the timer until the motor operates satisfactorily.

9. Test the motor by climbing a hill or by noting the rate of speed acceleration on a level road.
10. Adjust the fuel valve (without changing the air-valve setting) till the best running of the car is obtained.
11. Change the air-valve setting and repeat (10).
12. Change the air-valve settings again and repeat (10). Continue in this manner till the settings of the air valve and the fuel valve that give the most satisfactory operation are determined.

131. Adjusting the Carbureter and Ignition on a Launch Motor. — The requirements for power in this case are much like those for an automobile motor, but simpler. There is no demand for maximum torque, or turning effort, at slow speed of the motor in a launch.

Apply such of the steps for the automobile as are necessary. The object is to secure maximum speed of rotation.

Adjusting the Fuel Mixture in Gas and Oil Motors.

132. The securing of a suitable proportion of gas and air for a combustible mixture is a much simpler operation for the gas motor than when the air is carbureted by the vaporization of a volatile liquid.

In the simpler designs only the gas valve is set by trial to the position that gives the greatest power, speed, etc., as is desired.

The more complicated designs of gas-and-air mixers have adjustments for both the gas and the air in some cases. Since the process of adjusting is so simple, it seems hardly necessary to give the steps in detail.

It is generally more economical of fuel to close the gas valve slightly after the adjustment for maximum power has been found.

In some designs of gas motors, the securing of the proper mixture proportions is largely a matter of selecting the proper proportions in designing. Designing is not under consideration in this part of the discussion.

The above statements also apply in a general way to oil motors in which the oil is injected into the combustion space. The regulation of the fuel is generally by varying the stroke of the piston of the oil pump, by opening a by-pass valve, etc.

CHAPTER IX.

SETTING OR TIMING THE VALVES AND IGNITER.

133. **Marks for Valve Setting.** — A large number of motors, especially those on automobiles, have marks on the flywheel to indicate its positions when the valves should begin to open and complete their closing. One of the marks on the flywheel registers with a reference mark, that is stationary with regard to the frame of the motor, at the instant that the corresponding valve should just begin to open, and another mark on the flywheel registers with the same reference point at the time the valve should just come in contact with its seat.

Since the mark on the flywheel is often a line drawn across its face in a direction parallel to the shaft, or radially across the side of the rim, and since the stationary part is often a pointed piece of metal, they will be referred to as the **flywheel mark** and the **reference point,** or, more briefly, as the **mark** and the **point,** for convenience.

134. **Testing the Valve Timing when the Flywheel is Marked.** — The simplest case is a single-cylinder, single-acting motor with an automatic inlet valve and one exhaust valve (which must be mechanically opened). (There are sometimes two mechanically opened exhaust valves when an auxiliary exhaust port is used.)

To test the valve setting: Insert a piece of very thin tissue paper (thick paper will not do) between the end of the valve stem and the part that lifts it. Rotate the motor by hand or any other suitable means till the piston and other parts are in the position of about three-quarters of the impulse stroke. Then turn the shaft very slowly in the direction that it runs and keep the paper moving at the same time till it is pinched tight by the movement of the valve-lifting mechanism toward the valve stem. Stop in this position. If the valve setting is correct, the mark on the flywheel will register with the reference point.

If the mark has not yet reached the point when the paper is first pinched, then the valve opens too early according to the marking. But if the mark has passed the point, then the valve does not open soon enough.

For the closing of the valve, rotate the crank shaft quickly through about half a revolution in the direction that the motor runs without paying any attention to the paper under the valve stem. Then turn the crank shaft very slowly while pulling on the paper till it begins to loosen on account of the seating of the valve and the reduction of pressure against the valve stem. If the second flywheel mark and the reference point register at the instant the paper begins to loosen, then the time of valve closing is correct according to the marking. If the mark has not yet reached the point, the valve closes too early, but if the mark has passed the point the valve closes too late.

When the inlet valve is mechanically operated, its setting can be tested in the same manner as that for the exhaust valve. The exhaust valve should always be closed before the inlet valve begins to open, in motors of the usual construction without provision for scavenging. This can be determined without any markings on the flywheel.

In a two-cylinder motor with either opposed or twin cylinders, whose explosions occur every revolution, the same marking of the flywheel serves for both cylinders.

In a four-cylinder motor, either with all the cylinders on one side of the crank shaft or with two on each side, whose explosions come every half revolution, there must be two sets of markings. One set is the same as the other, but half way round the flywheel from it.

In a six-cylinder motor with the cranks in pairs at 120 degrees apart and the cylinders all on the same side of the crank shaft, there are three sets of markings, one third of a revolution apart.

The gears that connect the cam shaft to the crank shaft should be marked so that they can be placed together again with the same teeth mating as before, in case of their being taken apart. Some manufacturers mark the gears for this purpose.

135. Locating Dead Centers when there are no Marks for Valve Setting. — If there is no marking for the valve setting or for the dead-center positions of the crank, then the latter should be determined.

To determine the dead centers, some means of locating the position of the piston is necessary. When there is a pet-cock with a straight passage in the cylinder head, and the length of the passage is parallel to the bore of the cylinder, this can be done by inserting a straight wire through the pet-cock till the end touches the piston. The wire should be of about the same size as the hole. If the head of the piston is flat, the wire will always enter the same distance for the same position of the piston. But if the piston head is not flat, care must be taken to insert the wire so that it will always enter the same distance for a given position of the piston. Any opening through the cylinder head, as that for the ignition plug of the pet-cock, can be used for inserting the wire after the part is removed. If there is no opening in the cylinder head, then the position of the piston can be determined from the crank end of the cylinder. The crank case may have to be opened for this purpose. The general method of procedure is the same in all cases when the cylinder is not offset (set to one side so that the center line of the bore does not intersect the axis of the crank shaft).

Offset cylinders are unusual. The method of determining the dead centers will therefore be given only for those whose crank shaft crosses in front of the center of the cylinder bore. It will be assumed that there is a suitable pet-cock for inserting the wire.

Put the wire into the cylinder through the pet-cock till its end rests against the piston and rotate the crank shaft through about one revolution. Note roughly the positions of the wire while resting against the piston at each end of its stroke. Make a notch in the wire at a position that will coincide with the end of the pet-cock when the piston is about one-third of the way out from its position nearest the head of the cylinder. This notch can be located by judgment without measuring. Place the wire against the piston as before and turn the crank shaft till the notch on the wire registers with the end of the pet-cock. Make a temporary mark on the face of the flywheel to coincide with a stationary reference point. Rotate the crank again through part of a revolution till the notch on the wire again registers with the end of the pet-cock. Mark the flywheel again as before to coincide with the reference point. Divide the shortest length of the periphery of the flywheel between the two marks just made on it into halves and make a third mark midway between the other two. When the last mark registers with the stationary reference point, the crank will be in its dead-center position with the piston at the head end of its stroke.

The dead-center position with the piston at the crank end of its stroke can be determined in a similar manner by placing another notch on the wire where it will coincide with the end of the pet-cock when the piston is about one-third of the way from the crank end of the cylinder. The two dead-center marks will be 180 degrees, or half the circumference of the flywheel, apart, if correctly located.

When there is no flywheel, or it is difficult of access, some other rotary part can be used in the same manner. In small motors, the starting crank can be used as the hand (as of a clock) and a board or piece of cardboard provided for a dial.

136. Time at which a Valve should Open and Close. — In a four-cycle motor, the exhaust valve should open long enough before the piston reaches the end of its impulse stroke to allow the pressure in the cylinder to drop nearly to atmospheric by the time the piston has moved an appreciable distance on the exhaust stroke, and should not close before the end of the exhaust stroke. The smaller the port and the less the lift of the valve, the earlier must it open and the later it must close.

A mechanically operated inlet valve should not open before the exhaust valve has closed, and should remain open at least until the suction stroke is completed.

The time at which a valve must open and close in relation to the position of the piston in its movement in order to develop the most power depends principally on the following three items:

Speed of rotation of the motor;
Area of the ports in relation to the volume of the cylinder, or of the piston displacement per stroke;
Lift of the valve.

Among other features (which should all be minor ones) affecting the valve timing are the back-pressure resistance to the exhaust and the suction resistance to the intake due to causes outside of the motor proper.

In high-speed, single-acting, four-cycle automobile motors the exhaust valve is sometimes set to open as much as 40 degrees (one-ninth of a revolution) of rotation of the crank before the piston has reached the end of its impulse stroke, and does not close until as late as 10 degrees (one-thirty-sixth of a revolution) after the completion of the exhaust stroke. In such a case the inlet valve does not generally open earlier than 15 degrees (one-twenty-fourth of a revolution) of rotation on the suction stroke. It sometimes closes the same amount later on the compression stroke.

The proportion of the stroke of the piston represented by these angles of rotation is not as great as it might at first seem, especially at the crank or exhaust end of the stroke, where the angularity of the connecting rod brings the piston nearer the end of its stroke than it is from the completion of its stroke at the head end when the crank is the same part of a revolution from the head dead center.

When the length of the connecting rod is twice that of the stroke of the piston (connecting-rod length = four times the crank radius), which does not differ much from automobile motor practice, and the crank is 40 degrees from the dead-center position between the impulse and exhaust strokes (crank dead center), the piston has only .091 (less than one-tenth) of its stroke remaining to complete the impulse stroke. When the exhaust valve closes 10 degrees after the completion of the exhaust stroke, the piston has moved out only .0095 (less than one-hundredth) of the suction stroke from the head end When the inlet valve opens at 15 degrees of the crank past dead center, the piston has moved out .021 (a little more than one-fiftieth) of its stroke from the head end. And if it closes at the same angle of the crank past the crank dead center, then the piston has moved out .013 (a little more than one-eightieth) of its stroke from the crank end.

The writer's experience in increasing the power development of motors by changing the timing of the valves on a number of automobile motors of different makes in which the exhaust and inlet valves, as originally timed, closed at or near the dead-center positions of the crank, or the exhaust valve opened only slightly before the dead-center position, or in which all three of these conditions existed, has been thoroughly convincing in favor of early openings and late closings to conform more or less nearly with those just mentioned, according to speed, area of ports, lift of valves, etc. In some cases the only change was to set the cam shaft a little earlier in relation to the crank shaft, while in others new cams were made.

In moderate- and slow-speed motors on which an indicator can be used without the inertia effects of its moving parts causing serious modification of the true indicator card, the card can be used to determine the correctness of the valve action. This will be discussed later (see Indicator diagrams). In very high-speed motors the power test is all that can be applied for this purpose. The power test is the crucial one in all cases.

137. Marking the Flywheel for Valve Setting. — After the times of opening and closing of the valves have been decided upon, the flywheel can be marked accordingly.

If the exhaust valve is to begin opening at one-ninth of a revolution before the completion of the exhaust stroke, measure from the crank dead-center mark on the flywheel (see locating dead centers) one-ninth of the circumference around in the direction of its rotation and mark the flywheel accordingly (see below for lettering). If the exhaust valve is to close one-thirty-sixth of a revolution after the completion of the exhaust stroke, measure one-thirty-sixth of the circumference of the flywheel from the head dead-center mark in the direction opposite that of the rotation. For the inlet valve to open one-twenty-fourth of a revolution after dead center, measure from the same (head) dead-center mark one-twenty-fourth of the circumference in the same direction (opposite the rotation). And for the inlet valve to close 15 degrees after the dead center, measure one-twenty-fourth of the circumference from the crank dead-center mark in the direction opposite the rotation.

The marks on the flywheel should be lettered to avoid confusion, especially in multi-cylinder motors. The following lettering is suggested. A numeral can be placed after the letters of each marking to indicate to which cylinder or combustion chamber it refers. If the same mark is for more than one valve, the corresponding numerals can be placed after the letters.

HC = head center.
CC = crank center.
EO = exhaust opens.
EC = exhaust closes.
IO = inlet opens.
IC = inlet closes.
EO 1–3 = exhaust opens for cylinders 1 and 3.

138. Effect of Worn and Loose Parts on the Valve Action. — A cam shaft whose driving mechanism has become worn so that the shaft lags behind its correct position, retards both the opening and the closing of a valve. A cam whose fastening is loose so that the cam lags produces the same effect.

A loose cam that lags when opening a valve and then snaps forward under the pressure of the valve spring, retards the time of opening and allows the valve to close too early, thus decreasing the duration of the open period.

Wear of any part of the valve-operating mechanism of the usual construction, other than wear that allows a cam to lag as stated, causes late opening and early closing, shortening the duration of the opening.

The regrinding of a valve down on its seat has the effect of lengthening the valve stem. This causes early opening and late closing, which is compensative with the wear of the parts.

The methods of applying the remedies for the above troubles depend on the construction of the motor. When a lifting rod or a push rod is used for raising a valve, it is often made with some provision for adjusting its length. This affords a means of compensating, more or less completely, wear of all the usual kinds except that which allows a cam to lag or turn slightly on its shaft. When no provision for adjustment is made, the push rod or the valve stem can be cut off when necessary, or if it needs lengthening, a thimble-shaped cap can be placed over its end, or a pin inserted in the end to lengthen it. The pin may have an enlarged end to resist wear. In some designs the push rod is a short round bar inserted between the valve stem and the lifting mechanism. A new push rod of this form can be substituted readily at small expense, or in an emergency it can be elongated by hammering.

A worn cam can be built up by brazing or riveting a piece on it, first cutting away a portion if better results can be thus obtained. In case of doubt as to the exact form of the cam, it can be left a little full for the first trial of the valve action and then cut down accordingly.

139. **Adjusting the Ignition Timer.** — When a battery and an induction coil are used, the following method can be applied: Open the pet-cocks of the combustion chambers, or remove the spark plugs or disconnect the wires leading to them. Set the crank shaft on dead center with one piston at the end of its stroke between compression and impulse. Set the hand control a little in advance of the retard, or late ignition, position. Turn the rotor of the timer in the direction that it is to rotate until the circuit is just closed and a spark produced for the cylinder whose piston is set as given above, and fasten the rotor in this position.

If the speed of the motor is too high when running with a small load, the throttle well closed and the timer retarded as far as possible, then move the rotor back a little in the direction opposite its rotation, or adjust the connecting mechanism so that the stationary part of the timer is moved further in the direction of rotation of the rotor.

For an oscillating magneto the method of adjusting is the same in a general way. The part that engages with the lever or arm of the armature must be set so that the parts will disengage at the proper instant.

In low-tension ignition with cams to operate the contact points of other mechanism, the method of setting the ignition cams is similar to that for timing the valves.

A high-tension magneto with a rotary armature should have some part of the rotor or its attachments marked to indicate the position when the timer closes the circuit. In the absence of such marking, the current from a battery or a lighting circuit can be used to determine the instant that the timer closes the circuit. After this is done, the process of setting is of the nature of those just described. If current from a lighting system is used, there should be an incandescent lamp, water resistance, etc., in series with the generator in order to keep down the current.

140. Comparing the Time of Ignition in Different Cylinders. — It is important that there shall be very little variation in the time of ignition, relative to the positions of the respective pistons, in the various cylinders of a multi-cylinder motor. The following method can be used for testing the time at which the primary circuit is closed in a jump-spark system.

Set the crank shaft in one of its dead-center positions. (See marking the flywheel for valve setting.) If there are no dead-center marks on the flywheel or elsewhere, any mark or marks arranged to come opposite a stationary reference mark at such parts of a revolution as correspond to the intervals, as they should be, between ignitions, will answer equally well. (See impulse frequency for different arrangements of cylinders.)

Advance the timer of a jump-spark system from the retard position (late ignition) till the primary circuit is just closed and leave the timer in that position. Rotate the crank shaft in the direction of running and note whether the timer *always* closes all the circuits at the instant the timing marks register with the reference point. Only a very slight variation from this condition is allowable.

If the primary current is supplied by a rotary generator driven by the motor during regular service, a battery or other source of electricity must be substituted while making the test.

In the case of an oscillating generator (magneto) for either high-tension or low-tension ignition, it is generally sufficient to determine whether the armature is released and snaps back at the same relative position of the piston for each cylinder if the speed of rotation of the motor is not high. The method is practically the same as that just given. If the speed of the motor is very high, a test should also be made to determine whether the primary circuit is always closed at the same position of the armature in its snapping-back motion, or whether the different pairs of contact points of a low-tension system separate at the same position of the armature.

When a rotary generator is used for the low-tension (arc, make-and-break, break-and-make) system, a battery current of a few volts can be passed through the contact points and the time of their separation, as indicated by the interruption of the current, determined by rotating the crank shaft slowly and noting the position of the timing marks as above. The generator circuit should be broken before connecting the battery to the ignition system. One terminal of the testing circuit can be connected to the metal of the motor, and the other terminal to the insulated member of the ignition plug.

CHAPTER X.

TROUBLES, REMEDIES AND REPAIRS.

141. When operated and cared for with as much care, skill, and knowledge as are usual for steam engines and boilers, the internal-combustion motor is as reliable as the steam power plant. On account of the adoption of gas and oil motors to any considerable extent being comparatively recent, as compared with steam engines, they are not nearly so well understood by many of those who operate them.

The aim of this chapter is to set forth some of the many troubles met by the inexperienced, together with the means of preventing most of them and of remedying the others. In many cases a difficulty that seems insurmountable in the presence of ignorance is really insignificant when understood.

The following detailed list of causes of trouble may seem long. An equally long one can be made for steam engines and their accessories. The writer has experienced more trouble with steam engines than with internal-combustion motors, in proportion to the number of each dealt with.

Conaitions that Cause Trouble and Loss of Power.

142. Very few of these troubles ever occur in connection with intelligent operation, ordinary care and good construction.

In the Motor.

Leaks between the combustion chamber and jacket space:

Cracked cylinder;
Leaky joint between cylinder head and barrel;
Loose plug in the cylinder wall;
Blowhole in the cylinder wall;
Porous casting.

Leaks in the cylinder wall between the combustion space and the atmosphere:
- Ignition plug not in tight;
- Loose insulation or leaky packing in the ignition plug;
- Pet-cock partly open or not in tight.

Valve leaks:
- Pitted valve;
- Cracked valve;
- Warped valve;
- Flake of carbon under the valve;
- Valve stem too long so that valve cannot rest on its seat.

Valve binding or sticking:
- Carbon deposit on the valve stem;
- Bent valve stem.
- Valve spring weak or broken.

Piston leaks:
- Scored (grooved, cut) cylinder wall and piston rings;
- Piston rings broken, worn, or improperly fitted;
- Carbon and gummy oil under the piston rings;
- Cracked piston;
- Blowhole in piston;
- Carbon deposit on the cylinder and on the piston.

In the Cooling System.

Insufficient water or oil for cooling.

Inadequate cooling (radiating) surface.

Leaky pump packing and joints.

Pump not operating properly.

Steam from hot cylinders forced back into the pump.

Air lock in the circulating system:
- Large vertical reverse bends in the connecting pipes.

Clogged or stopped passages:
- Packing or gasket squeezed out into the passage;
- Loose lining in a rubber hose acting like a check valve;
- Cotton waste, rags, etc., in the passages;
- Short kinks in a hose or pipe so as to close the passage.

IN THE CARBURETER.

Passages clogged by particles of foreign matter (dirt, lint).

Water in the fuel reservoir of the carbureter.

Flooding on account of the float binding or sticking so as not to rise and cut off the inflow of fuel.

Leaky or "water-logged" float. Causes flooding.

Valve of float leaky so as to allow flooding.

Binding or sticking of the air valve.

Broken spring on the air valve.

Frost and ice in the mixture passage.

Air lock prevents fuel from flowing into the carbureter after it has been empty.

IN THE FUEL AND FUEL SUPPLY.

No vent in the fuel tank.

Air lock in the connections between the fuel tank and the carbureter.

Pipes stopped by gaskets, short bends or kinks, lint, etc.

Water in the fuel.

Dirt in liquid fuel.

Dust and grit in the gas, as in imperfectly cleaned blast-furnace gas.

Variation in the quality of the fuel (liquid or gaseous).

IN THE CONNECTIONS BETWEEN THE CARBURETER AND MOTOR.

Loose joints and holes through which air can leak into the mixture.

IN THE IGNITION SYSTEM.

Spark plug defective or dirty:

Carbon and oil deposit in the spark gap or on the insulation;
Spark gap too wide or too small;
Carbon on the contacts of the low tension system;
Contact-points fuse so as not to make electric contact;
Loose contact points;

Water on the points. Generally due to a cracked cylinder or blowholes in the cylinder casting;
Porcelain insulation cracked;
Mica insulation loose, open between the disks or crumbled;
Air leaks around the insulated parts.

Induction coil:

Contact points oxidized or fused so as not to make electric connection;
Dirt or other foreign matter between the contact points;
Contact points fused together;
Bent spring (vibrator, trembler, interrupter);
Loose contact points;
Loose connections or broken wires inside the coil box;
Defective or burned-out insulation in the coil box;
Difference of lag in producing sparks when two or more coils are used on one motor.

Timer:

Dirt or grit between contact points;
Springs weak or broken;
Loose screws, rivets, etc.;
Rotor (rotating part) loose on its shaft;
Failure to make contact on account of worn parts;
Circuit closed at wrong time on account of worn or loose parts.
Shaft not in continuous electric connection with the metal of the motor on account of separation by oil or grease (unusual);
Circuit not closed at the same relative position of each piston in its stroke.

Battery:

Connections between two batteries made so that a current flows when they are not in use;
Exhausted cells;
No insulation (paper, cardboard, glass, rubber, etc.) between the metal of adjacent cells;

- Binding posts of different cells touch each other;
- Too many cells for the induction coil (too much voltage);
- Cells not tightly secured to prevent shaking about and breaking the connections between them.

Generator (magneto or electromagnetic):

- Grease and dirt on the commutator;
- Brushes worn or bent;
- Commutator worn out of round, loose, or with poor insulation;
- Brushes binding in brush holder so as not to press on the commutator;
- Broken wires at the connections or inside the insulation;
- Defective or burned-out insulation;
- Loose parts;
- Magnetism lost (infrequent).

Connections (electric):

- Loose binding screws and joints;
- Poor quality of insulation, especially on the high-tension circuit;
- Broken wires at the binding posts;
- Broken wires inside the insulation (sometimes very difficult to find);
- Insulation chafed or worn off so as to allow electric contact with metallic parts. This may be only intermittent on account of a swinging or vibrating wire, or the movement of a part such as a brake rod, clutch lever, etc.

Symptoms and Diagnoses.

143. **Back-firing into the intake pipe and carbureter** is generally due to some of the following causes:

Lean mixture. A lean mixture may be due to leaks at the joints of the intake pipe between the carbureter and motor, or to improper adjustment of the carbureter. Water in gasoline will cause a lean mixture temporarily;

Carbon deposit on the piston head and the walls of the combustion chamber;

Overheating of the cylinder, piston, ignition points or exhaust valve, or of a projecting piece of metal in the cylinder;

Excessive rarefication of the charge by throttling or cutting off the charge in the very early part of the intake stroke, and the consequent slow burning;

Binding or sticking of the inlet-valve stem;

Weak spring on the inlet valve, especially if it is an automatic valve;

A particle of carbon scale or other foreign matter under the inlet valve;

It is impossible to prevent back firing when the amount of mixture admitted for a charge is about as small as will ignite. The remedy is either to cut off the charge completely or to admit more. Misfiring is apt to accompany back firing under this condition, and, less frequently, exhaust explosions also occur.

If preignition occurs in connection with back firing, the cause is either an overheated cylinder or other part in the combustion space, or incandescent carbon in the cylinder.

If the gas valve or carbureter has not been adjusted and operating satisfactorily, and back firing occurs when the charges are not cut down excessively in amount, the carbureter or gas valve may need adjustment.

If the carbureter has been operating satisfactorily, or the gas valve (of a gas motor) has been adjusted, then:

Note whether the cooling water or cooling oil is excessively hot or not circulating properly, and

Cut off the ignition completely from all the cylinders to see whether the explosions continue after the ignition is cut off.

If the explosions continue after the ignition has been cut off from all the cylinders, then there is either incandescent carbon deposit in one or more of the cylinders, a hot point or projecting piece of metal, or there is overheating. In case of continued explosions, and if they do not continue in all the cylinders, then:

Put on the ignition again and then cut it off from one cylinder at a time, or in pairs, to determine where the ignitions occur without the aid of the ignition apparatus. (See cutting out the ignition.)

If the explosions do not continue after the ignition is completely cut off, then:

Note the setting of the adjusting (needle) valve of the carbureter, and then close and open it again quickly so as not to stop the motor. This will generally remove dirt or other foreign matter from the passage at the needle valve.

Drain the carbureter to remove water;

Strike the carbureter a sharp, light blow to shake the float loose in case it is sticking in such a position as to keep the inlet valve of the carbureter partly closed;

Open the gas valve (of a motor using permanent gas) to compensate for the fuel becoming more lean;

Stop the motor and examine for a binding or sticking valve stem or a weak spring on the inlet valve.

Test the compression. If it is very poor, then:

Turn the mechanical inlet valve around on its seat while applying enough lifting force to it to allow it to press lightly on its seat. The lifting force can be applied by the valve-lifting cam by bringing the crank shaft to a position where the valve just begins to leave or to settle on its seat;

Look for a cracked or broken inlet valve.

144. **Misfiring not accompanied by other serious troubles,** but sometimes by exhaust explosions, is generally due to one or more of the following causes:

Ignition adjustment or trouble;

Carbureter adjustment or trouble giving too rich a mixture and causing carbon deposit in the cylinder;

Lubrication excessive or oil poor in quality for the purpose;

Valve troubles (infrequently).

If black smoke is discharged from the exhaust, adjust the carbureter or the gas valve to cut down the fuel.

If blue smoke is discharged, either cut down the amount of lubricating oil fed to the cylinder or get suitable lubricating oil for it.

Test the ignition system (see ignition system tests.)

Look for a weak exhaust-valve spring and for binding or sticky exhaust-valve stems.

Test the compression. If it is poor, then:

Twist the exhaust valve around while it presses lightly on its seat to remove flake carbon or other foreign matter from under it;

Look for a cracked or broken exhaust valve;

Test for a cracked cylinder or a leaky plug in the cylinder wall between the combustion chamber and water jacket. (See test for cracked cylinder and loose plug.)

145. Continuous Pounding, Thumping, or Hammering on Heavy Load. — When not accompanied by other evidences of trouble, this is generally due to one of the following faults:

Loose fit between the connecting rod and the crank pin or the wrist pin (piston pin);
Loose bearings on the crank shaft;
Fly wheel loose on its shaft (loose key).

The piston, if rather loose in the cylinder, may also thump at each explosion. This is not generally serious, although the noise may be disturbing.

The first three of these troubles should be remedied as soon as possible, for they are apt to be the sources of injury to the parts on account of the heavy pressures produced when they strike together at the time the sound is produced. The bearings are generally constructed so that the lost motion can readily be taken up.

146. Preignition and Sharp Snaps or Heavy Pounding in the Motor. — If the igniter is not set to give too early ignition, preignition is generally due to either an overheated cylinder, carbon deposit, or hot ignition points or projections in the combustion chamber. It also occurs when the motor compresses the charge more than is allowable for the kind of fuel used.

If the cylinder is overheated, it may be on account of too late ignition, too rich a mixture, or insufficient lubrication. The exhaust pipe will generally be very hot (sometimes red hot) if the ignition is too late or the mixture too rich.

Carbon deposit in the cylinder will cause preignition even if the cylinder is not overheated or the cooling water or oil not hotter than it should be.

In any case of preignition by means other than the early setting of the ignition apparatus, the motor may continue running after the ignition is cut off, and may kick if cranked soon after stopping. (See carbon deposit and cooling-water troubles.)

147. Power Decreases Rapidly at a Uniform Rate and the Motor Stops. — There may also be back firing and misfiring just before the motor stops. This behavior may be due to some of the following troubles:

No fuel;
Water in the carbureter. (Drain it out);
Valve suddenly jarred shut in the fuel pipe or the carbureter;
Broken connection in the fuel-supply pipe.

In an automobile this sudden loss of power will occur when the fuel tank is rather empty and the car is run along the inclined side of the road so that the end of the tank from which the fuel is drawn is on the high side of the car.

It also occurs when the fuel (liquid) is low and the car turns a curve at high speed so as to throw the gasoline away from the outlet of the tank. The power may drop off and then come on again quickly when this occurs. The action is especially noticeable when climbing a grade.

The remedies to the above troubles are obvious.

To drain the water out of a carbureter, open the valve at the bottom of the gasoline reservoir of the carbureter, or remove the bottom plug. If there is no means of opening the bottom of the carbureter for drainage, then remove the top and siphon the water out with a bent tube or a piece of small rubber hose. Or it can generally be drawn out by closing the air inlet with one's hand while rotating the motor. The carbureter can be removed and emptied without much trouble in some cases.

148. Power Decreases Slowly at a Uniform Rate and the Motor Finally Stops. — This may be accompanied by back firing and misfires after the impulses have become quite weak.

These are the characteristic symptoms of no vent in the fuel tank of a vapor motor with gravity feed, or of the fuel gas growing poor when taken from a gas producer about as fast as it is made.

The gradual jarring shut of a valve in the fuel-supply passages has the same effect.

The opening up of a joint or a valve in a gas-supply pipe or in the mixture passage, so that air is admitted, is another cause.

149. The Motor Behaves Erratically and the Timer Control Must be Set Differently from Usual Position to get the Best Results. — When the timer rotor (rotating part) is very loose on its shaft these results often occur. They are apt to be accompanied by preignition, back firing, and misfiring. If the timer rotor takes a permanent position for a while and the control agrees with it the motor will pull well. But when the rotor keeps moving on its shaft the power may be good for a while, and then erratic action will begin.

150. The Motor does not Develop Full Power at any Time. — When not accompanied by other symptoms, such as back firing, misfiring, overheating, etc., this is generally due to one of the following causes:

Insufficient lubrication, especially of the cylinder;
Piston leaks;
Valve leaks;
Particle of carbon under a valve;
Leaks from the cylinder into the atmosphere through or around the spark plug, pet-cock, etc.

The motor can be tested for some of the leaks while running (see running test), or some one of the compression tests can be applied (see compression tests).

In the case of a leaky valve it should be turned around while pressing lightly on its seat in order to remove a particle of carbon that may have lodged under it.

151. The Motor Runs Well for a While, then Loses Power and the Cooling Water Heats Unduly. — These are the symptoms of an opening between the combustion chamber and the water jacket. The opening may be on account of a loose plug in the cylinder wall or of a cracked cylinder. In such cases the opening closes up sometimes when the motor is cool, but opens out when it becomes hot.

The opening allows the hot gases of combustion to pass out into the cooling water and heat it, and also, during the suction stroke, some of the water or steam to be drawn into the combustion chamber from the water jacket. The water thus drawn into the cylinder is almost certain to cause misfiring.

After the motor has been stopped for a while and allowed to cool down, it will sometimes run well again for a short time and then behave as before.

If the crack or opening is rather large, there will be considerable loss of compression and power even when the motor is cool.

Any of the hand or the stationary tests for compression and leaks can be applied, but in case they do not show leaks between the combustion chamber and the water jacket, then

Apply the running test for a cracked cylinder and loose plug.

CHAPTER XI.

TESTS OF IGNITION SYSTEMS.

152. Test of High-Tension (Jump-Spark) Ignition System with Individual Induction Coils and Duplicate Batteries. — [The test when the primary current is furnished by an electric generator (magneto) is practically the same as the one given below, but the motor must be kept running if the generator is of the rotary type.]

It is assumed that one of the batteries is held as a reserve and the other used till exhausted, then a new battery put in and the old reserve one used for the regular service.

Switch on the reserve battery while the motor is running. An exhausted dry-cell battery often works well for a short time after a considerable period of rest and then fails gradually.

Press down the tremblers (vibrators, interrupters) one at a time, or in pairs, to find the cylinder in which the misfiring occurs. This can be done with the fingers.

Note whether all the tremblers vibrate strongly. If this cannot be done while the motor is running, stop it and either rotate it slowly by hand or close the battery circuit for each coil in turn by placing a piece of metal (wire, screw-driver, etc.) so as to connect the timer terminal of each coil, one at a time, to the metal of the motor or to the battery terminal of the timer.

If all the tremblers have weak action, then look for loose connections at the battery and between the timer and the induction coil. Examine the battery (low-tension, primary) circuit for bare places and wires broken inside of the insulation. See that there is good metallic (electric) connection between the rotor of the timer and the metal of the motor, or, in the case of a rotor that is insulated from its shaft, that the contact is good between the metal of the rotor and the part to which the wire from the battery is electrically connected.

If only one trembler has weak action (or, more strictly, if not all), then look for bare and broken wires and loose connections between it and the timer. Clean the contact points of the trembler and notice whether they are loose. (See induction-coil troubles.) Close the circuit at the timer as before and look for troubles in the circuit for the coil under inspection. (See induction-coil troubles.)

Test each spark plug and its wire in turn as follows:

Disconnect the high-tension (secondary) wire from the spark plug, hold the end of the wire about one-quarter of an inch from the metal of the motor or of the spark plug, and close the primary (battery) circuit for that plug. A spark should jump the quarter-inch air gap between the end of the wire and the motor or spark plug. If no spark jumps, look for poor insulation on the secondary (high-tension) wire under test;

Remove the spark plug from the motor, connect the high-tension wire to it again, place the outer metal of the plug against the metal of the motor, and close the primary circuit for the plug under test. If both sides of the spark plug are insulated and a wire leads to each side, it is not necessary to make contact with the metal of the motor for this part of the test. There should be a strong spark across the air gap of the plug. The spark may not jump the gap when the plug is in the motor, however, even though it is strong outside, for the reason that the resistance to its jumping is much higher in the compressed charge in the motor than in the open air;

Separate the spark points, if possible, so as to have a spark gap of one-eighth inch or slightly more, and test again as before. There should be a strong spark. Put the points back so as to have a spark gap of about one-thirty-second ($\frac{1}{32}$) of an inch.

If the spark is weak, clean the plug (see cleaning spark plug) and test it again as above. If the result is not satisfactory, then:

Put in a new plug, or new insulation in the old one;

Test the timer for uniformity of the time of ignition. (See comparing the time of ignition in different cylinders.)

153. Test of High-Tension Distributer Ignition System with Duplicate Batteries. — (When the primary current is furnished by a generator, the test is the same except that the motor must be kept running if the generator is of the rotary type.)

Switch on the reserve battery.

Cut off the ignition from the cylinders, one at a time or in pairs, while the motor is running, by short-circuiting the spark plug to determine which cylinder is misfiring. The short-circuiting of the spark plug can be done with a wooden-handled screw-driver placed against both the insulated central part of the plug and the metal of the motor, or across the insulated parts of the plug if both terminals are insulated. Care should be taken to hold the tool by the insulated part to avoid a shock, which, while not at all dangerous, is startling.

If there is misfiring in all of the cylinders, then:

Look for loose connections in the battery and the battery circuit;
Rotate the timer and distributer arm and notice whether the arm comes near or opposite the high-tension terminals at the instant the timer closes the primary circuit;
Clean the vibrator (trembler, interrupter) contacts and note whether the spring is bent;
Test each spark plug and its connections as in the latter part of the preceding section.

(See also "comparing the time of ignition in different cylinders.")

If the misfiring does not occur in all the cylinders, then:

Examine the timer contacts for the cylinder that misfires;
Apply the spark-plug test as in the preceding section.

154. **Test of High-Tension Magneto Ignition System.** — Short-circuit the spark plugs, one at a time or in pairs, as in the preceding section, to locate the misfiring.

If the misfiring is general, examine the magneto, especially the moving contacts, screw fastenings, and the connections. (See magneto test.)

If the misfiring is confined to only a portion of the cylinders, apply the spark-plug test. (See individual induction-coil system.)

(Also see "comparing the time of ignition in different cylinders.")

155. Test of Low-Tension Arc-Ignition System. — This test applies more especially when the electric generator is of the rotary type, but will also answer for the oscillating magneto generator.

Cut out the ignition from the cylinders successively to find which is misfiring. This can be done by opening the switches near the ignition plugs, or by disconnecting the wires at the plugs.

If the misfiring is general, then:

- Examine the generator for worn or loose brushes, commutator worn out of round, dirt on the commutator, loose connections, etc. (See electric-generator test);
- Clean the spark plugs; adjust the contacts to bring fresh parts together;
- Examine the spark plugs for weak springs and worn parts.

(Also see "comparing the time of ignition in different cylinders.")

If the misfiring is in only one cylinder, then make the tests just given, but reserve the examination of the generator till the last.

156. Test of Magneto Direct-Current Electric Generator. — The following tests can be applied without the aid of much apparatus in case the generator fails to operate satisfactorily. They apply especially to a magneto which has a commutator with several segments.

See that the brushes press against the commutator so as to make good contact. They may be worn out or bind in the brush holder.

Note whether the commutator is round and runs true.

See that the brushes have good contact with their holders.

Examine the commutator for a segment with a blackened or fused edge. This may be caused by a broken or loose connection between the segment and the armature winding, or by a partly burned out armature coil. The edge of the segment which passes under the brush immediately before one that is dead (connection broken) is the one that is affected.

Look for loose and broken connections in both the generator and the outside circuit.

A completely burned out coil can generally be readily seen by an examination of the outside of the armature.

See that the commutator is clean and free from grease and dirt. It can be cleaned by holding a piece of fine sandpaper (not emery paper or emery cloth) against it while running. It is advisable to lift the brushes while cleaning the commutator in this manner. Do not use gasoline to cut the gum. It will be ignited by the spark at the brushes.

Test the strength of the magnet by placing a piece of soft steel or iron (as a steel nail, door key, screw-driver) against one of the poles (ends) of the magnet. The magnet should be strong enough to hold the nail tight, even to hold it out horizontally from a flat surface, especially if the armature of the generator has been removed. No other metal or non-ferrous alloy will do for this test.

A weak magnet can be permanently magnetized, if it is steel that is hardened very hard, by the application of a powerful magnet. An electromagnet is best for this purpose. **To remagnetize,** place one pole of the electromagnet (say the north pole) near the middle of the permanent magnet and draw the electromagnet along the metal in the direction toward the end of the hard steel, keeping the two magnets in contact during the motion. Then place the other (south) pole of the electromagnet near the middle of the permanent magnet and draw the electromagnet along to the other end of the hard steel. By repeating these operations several times the hard steel will be fully magnetized and will remain a strong permanent magnet if the steel is hard enough, unless some demagnetizing influence other than that of the armature currents in regular service acts on it. Soft steel will not retain sufficient magnetism for a magneto generator.

The following test can be made with a portable magneto such as is used with telephones in which the magneto crank is turned to ring the bell when calling central:

Disconnect all wires, etc., leading out from the magneto to the exterior circuit.

Lift the brushes from the commutator. Connect the terminals of the portable magneto to the brushes, one terminal to each brush (of the two). The bell of the testing magneto should not ring when the crank of the testing magneto is turned rapidly (or otherwise). If the bell rings, the insulation of the brushes is poor. Test the insulation between the armature shaft and the brushes in the same manner. If the bell rings in either case, remove the brushes or brush holders and clean the insulation carefully.

Connect one terminal of the testing magneto to the armature shaft of the generator and the other terminal to several of the commutator segments in succession while turning the crank of the testing magneto. Turn the testing magneto rapidly. If the bell rings there is poor insulation between the armature winding and the armature core. The remedy for this is to partly or wholly rewind the armature. Some armatures are made so that a section or coil of the winding can be removed and another section put in its place without disturbing the other sections.

A broken or loose connection may make intermittent contact and cause erratic behavior of the generator.

Put one of the brushes down against the commutator so that it has good contact (the brush can be held as usual in its holder), connect one terminal of the testing magneto to the brush, and place the other terminal against the commutator segments, one at a time. The brush and the terminal should not touch the same segment. The armature must be rotated part of a revolution in order to test all the segments individually. The testing magneto should be turned only fast enough to make the bell ring. If there is a dead segment, the bell will not ring when the testing terminal is in contact with it. It should ring for all the live segments. The dead segment indicates a broken or loose connection between it and the armature. More rapid turning of the testing magneto may produce a pressure sufficient to send enough current across a break whose parts are only an extremely minute distance apart, to ring the bell.

A further test for a broken commutator connection can be made with a galvanic cell (not a storage cell) or some other source of electric energy of very low voltage and small current capacity. An ammeter suitable for measuring very small currents (milliammeter) should be placed in the circuit. The test can then be made as before by connecting one terminal of the cell to the brush that is in contact with the commutator and the other terminal to the commutator segments in turn. The amount of current should be noted in each case. If the broken parts are pressed but very lightly together, the current for the corresponding segment will be smaller than for the others. Due allowance must be made for the dropping off of the current capacity of the cell on account of polarization, etc.

Defective insulation between the different turns of the wire of an armature coil or section cannot readily be determined by an electric test with the more common electric instruments unless the armature sections or coils are disconnected from the commutator and from each other. Even then the measurement is one of electric resistance and generally requires delicate apparatus such as is used only in laboratories and electric works.

157. Test of Direct-Current Electro-Magnetic Generator. — Except the test of the field winding for magnetizing the soft steel or iron magnet cores and poles, this test is practically the same as for a magneto generator as given in the preceding section.

The test of the insulation and for broken wires in the field coil can be made first with a portable magneto. The terminals of the field winding should first be disconnected from the other parts, and then the tests made between the terminals of the winding, and also between the winding and the metal of the generator.

To determine whether there is a short circuit in the field winding the electric resistance of the coils can be measured and compared with what it was when the coils were new. The old and new values should be the same, after corrections have been made for differences of temperature. Laboratory or factory instruments are needed for the latter test.

If the magnets have not retained enough magnetism to cause the generator to "pick up" and produce pressure and current, they can be remagnetized by sending a current from a battery or other source through the field winding. This will remagnetize the field magnets. Care should be observed to have sufficient resistance in the magnetizing circuit while doing this, in order to prevent burning out the field winding by too great a current. An incandescent lamp, or two or more lamps in parallel, will answer if the current is taken from a commercial lighting circuit. Only circuits having direct current can be directly utilized (without a rectifier). Water resistance will answer in any case. Put a little acid in the water if enough current will not flow through pure water. The electromagnets are generally not very strong when the generator is not running.

158. Tests of Shuttle-Wound Electric Generators. — Most of the oscillating electric generators and those used in connection with transformer (induction) coils without vibrators (tremblers, interrupters) belong to this class. The tests in case of trouble are of the same nature as those already given, but simpler. By following such parts of these tests as apply to the case in hand the desired results can be obtained.

When one terminal of the single-coil armature winding is connected to the armature shaft, the test for the insulation of the winding from the core cannot be made unless this connection is opened up for the purpose.

159. Test of Shuttle-Wound Oscillatory Armature Generators. — A permanent magnet (or magnets) is used on this type of generator, and the armature is generally shuttle wound with only one coil. Ordinarily the current is taken off either by a pair of insulated collector brushes in contact with a corresponding pair of insulated slip rings, or one end of the armature winding is connected to the armature shaft, which has metallic connection to the frame of the machine, and the other end of the armature wire is connected to a slip ring on which a collector brush rests. When the armature coil is connected to the shaft electrically, the test of the insulation between the winding and the armature core cannot be made until the connection to the shaft is broken (electrically). Otherwise the test is the same in general as already given (see §156), except that there is only one ring or a pair of rings, instead of several segments of a commutator.

160. Tests of High-Tension Electric Generators. — The generators of this class are so varied in form that it is hardly possible to give directions that will apply generally.

The tests really amount to a combination of those for a generator, a timer, and an induction coil or transformer coil. By combining such parts of these tests as apply to a particular machine, a complete test can be made.

In a magneto generator whose armature is stationary, and whose rotor or oscillator is a permanent magnet without any wire winding, the sources of trouble are reduced to a minimum. The armature test for it is similar, but simpler than when the armature rotates. The test for magnetism can be applied after removing the magnet, sometimes without removing it.

CHAPTER XII.

TESTS FOR AIR AND GAS LEAKS IN MOTOR.

161. Examination for Leaks while the Motor is Running in Regular Service. — To detect a leak at the spark plug or other form of ignition apparatus, at a plug or other stop to an opening in the cylinder, or at any part of the cylinder that is accessible, put a plentiful supply of the cylinder lubricating oil where the examination for the leak is to be made, while the motor is running. Bubbles will appear where there is a leak if it is not so great as to blow off the oil. The oil may be drawn into the cylinder to some extent if the leak is large.

A piston leak of any considerable extent allows smoke to blow out around the piston during the impulse stroke. The smoke is especially noticeable when the combustion mixture is over rich or there is too abundant lubrication. It may be necessary to remove part of an enclosed crank case to see the end of the piston.

A cracked or porous cylinder, or a leaky plug in the cylinder wall between the combustion chamber and the water jacket, allows gas to pass from the combustion chamber into the jacket water during the compression and the impulse strokes. If a cooling tank is used, bubbles will appear where the hot water flows into the tank at the end of the pipe that carries the water from the motor to the cooling tank, provided that the opening of the pipe is entirely submerged. Bubbles may appear here on account of air carried into the jacket space with the cooling water. A chemical analysis will determine the nature of the gas in the bubbles. Air is not apt to be carried into a thermal circulating system. A piece of glass tube interposed in the pipe that leads from the water jacket affords a means of detecting bubbles in the water. The glass should not be placed so near the motor as to show steam bubbles that have not had time to condense. A glass jar filled with water and held inverted over the outlet of the submerged pipe with most of the jar above the water level can be used to determine whether the bubbles are steam.

162. Running Test for a Cracked Cylinder, Porous Metal, Leaky Plugs, and Leaks into the Jacket Space. — The motor should be cool at the beginning of the test, and the following preparations should be made before starting the motor: Disconnect the driving mechanism of the circulating pump and remove the pipe connected to the water outlet at the top of the jacket. Fill the jacket space full of water till it stands level with the top of the opening. If the motor is small, rotate or crank it by hand and note whether bubbles rise through the water. If the combustion chamber is plugged at the top, it can generally be observed whether the bubbles, if any, come from around the plug.

Start the motor and observe as before. If the water vibrates too much for the observation, a piece of glass can be placed over the opening with the water high enough to keep it in contact with the glass. Water may be flowed in slowly at the bottom of the jacket and allowed to escape under the glass. The load on the motor should be increased to the full capacity of the motor without much delay. Small bubbles of air will soon begin to form on the cylinder wall on account of the heat, as they do in a glass of water standing for some time on a warm day, and finally steam bubbles will form unless the water is allowed to flow rapidly enough to keep it below the boiling temperature. The air and steam bubbles must not be taken for gas from cylinder leaks.

In an oil-cooled motor the test is the same, except the use of oil instead of water.

163. Hand-Compression Tests for Cylinder and Piston Leaks in Small Motors. — Cut out the ignition, open the pet-cocks to the combustion chamber, and rotate the motor to see that it moves freely. Close the pet-cock of the cylinder to be tested. Rotate again till the compression stroke is nearly completed, hold the crank shaft in this position and note whether the effort necessary to hold it grows less on account of leakage. The crank shaft may also be worked back and forth to move the piston in and out. Note whether the compression resistance decreases during this action. If the compression resistance decreases more rapidly when the piston is moved than when it is held still at nearly the completion of the compression stroke, then the piston leaks more at nearly the middle of its stroke than at and near the end of the compression stroke.

In case the compression falls rapidly, the valves can be roughly tested for leaks by holding a piece of thin cloth or tissue paper over the end of the exhaust port while the piston is held stationary near the end of the compression stroke. This will hardly give definite results if the exhaust pipe has leaks. In such a case the exhaust pipe can be removed and the paper or cloth held near the opening, or the caps over the valves can be removed and the valves tested by putting oil, kerosene, or water around or over them, or talc powder or pulverized soapstone around the edges. A piece of sheet rubber held tightly over the exhaust opening, as by pressing a ring against it, will be bulged out by the gas that escapes through a leak. It may be necessary to prevent escape of gas around the stem of a mechanically operated valve by closing the crack with thick grease.

Leaks from the cylinder into the water jacket can be detected by noting whether bubbles escape into the cooling tank or rise through the water in the jacket when the pipe is disconnected from the top of the jacket. The circulating pump should not rotate during this part of the test. (See preceding section.)

Leaks in the spark plug, pet-cock, or other stopped openings into the cylinder can be detected by putting oil around the parts.

This test does not show whether the piston is tight when well out on the impulse stroke or during the early part of the compression stroke.

164. Compressed-Air Test for Leaks. — The air pressure for this test should be about the same as the explosion pressure of the motor. A pressure of 350 pounds per square inch is sufficient for all motors except those in which air alone (and residual gases) is compressed in the combustion space before the fuel is admitted to it, as in the case of one type of oil motor.

The connections for supplying the compressed air to the motor cylinder can be made by removing the cylinder pet-cock, the spark plug or other ignition apparatus from the cylinder and then connecting the compressed-air pipe to the opening.

Set the motor with the piston in position to begin the impulse stroke and lock the fly wheel so that it cannot rotate. Put on the full pressure of the air and examine for leaks by the methods already described (see preceding section and others).

Release the pressure from the motor cylinder and rotate the crank a little in the direction that it runs. Lock the fly wheel again and apply air pressure as before, but the full pressure need not be applied if the piston is about one-eighth of the way out on its stroke. A somewhat less air pressure will do for this position.

Repeat the tests through the full stroke of the piston.

The pressure can be gradually reduced to about 125 pounds per square inch at mid-stroke, and on down to 50 or 60 pounds at the end of the stroke.

It is generally difficult to observe directly whether the piston leaks on a standing test (motor not running). The elimination of other leaks is the method to be followed in such a case, until it is known that there is no leak at any other place.

If the cylinder has been detached from the frame of the motor and is small enough to be immersed in water, the piston can be held in by a wooden block and bolts while the air pressure is applied. Bubbles will then appear at every leak. The piston can be set at different positions and the air pressure regulated accordingly as above.

165. Hydrostatic Test for Piston and Cylinder Leaks. — Water or oil pressure can be applied to the interior of the cylinder in the same manner as compressed air, as just described.

In applying the hydrostatic test the pipe should be disconnected from the bottom of the jacket space and the water or oil drained out. Then if there is a leak from the cylinder into the jacket space, the water will run out at the bottom opening of the jacket space. The caps over the valves, etc., should be removed to allow the parts which may leak to be seen as far as possible. Piston leaks are clearly shown.

Thin oil or kerosene may be used instead of water. The kerosene will pass through openings that will retain water when the parts are oily or greasy.

The joints of commercial motors are seldom tight enough to warrant testing in the above manner with gasoline, and its use cuts the oil away so completely from the cylinder bore and piston rings that there is apt to be cutting between them afterward.

CHAPTER XIII.

CLEANING AND MISCELLANEOUS.

166. Carbon Deposit in the Cylinder. — When the combustible mixture is too rich, or when an unsuitable quality of lubricating oil is used, some carbon is always deposited on the cylinder walls and piston head. The rate at which it is deposited depends on the richness of the combustible mixture and the amount and unsuitability of the oil used in the cylinder.

The carbon is deposited in two forms. Some is soft like soot and some hard like coke.

The soft carbon mingles with the gummy residue of the lubricating oil and adheres to the walls of the combustion chamber and to the spark plug. If the lubricant is poor and insufficient in quantity, the soft carbon is deposited to some extent on the walls of the bore of the cylinder over which the piston passes. This does not occur with good oil plentifully applied.

The hard carbon forms chiefly at the hottest parts of the motor, and especially where the incoming mixture impinges against hot parts, as against the piston of a small motor. It always forms with an uneven, jagged surface, and often collects in lumps.

The carbon, especially the hard lumps, may become heated to a glowing temperature when the motor is working hard. When thus heated, the carbon will cause back firing and preignition. The preignition has the same effect as advancing the timer or igniter too far. The back firing is caused by the incoming charge striking the incandescent carbon. The incandescent carbon will often cause the motor to continue running after the regular ignition is completely cut out.

"Kicking" when starting the motor soon after stopping and while it is still hot is another result of hot carbon deposit.

The soft, gummy mixture of carbon and oil residue between the piston and the cylinder wall increases the frictional resistance of the motor, and thus reduces its effective power, at the same time increasing its tendency to heat, both on account of the increased frictional resistance and the larger or more frequent charges of combustible that must be used to overcome the friction. It also works around and under the piston rings so as to counteract their elastic action and prevent close conformation to the cylinder bore, thus causing leakage around the piston and loss of power.

A badly gummed piston offers considerable resistance to the rotation of the motor. The ease with which a small motor can be rotated by hand is an indication of the condition of cleanliness and lubrication of the piston.

The carbon and oil sometimes collect on the stem of the exhaust valve and become baked so as to form a hard coating that causes the stem to bind in its guide. Except in the case of continued back firing, the inlet-valve stem does not become carbon coated to an appreciable extent.

A sudden loss of compression and power in the motor is sometimes caused by a flake of the hard carbon detaching itself and lodging under one of the valves, generally the exhaust valve. The effect of this is the more noticeable the fewer the number of combustion chambers in the motor.

Scoring of the piston and cylinder may be caused by a loose flake of the carbon getting between them. This is very unusual when the lubricating oil is of the right quality and enough is applied.

A liberal supply of suitable lubricating oil while the motor is running will generally remove the carbon deposit from the valve stem and from between the piston and cylinder. After the motor has been stopped and cooled so as not to be very hot, kerosene can be applied for the same purpose, or gasoline may be used on an *entirely* cool motor. Kerosene left standing in the cylinder will dissolve the gum in a few hours. Slow rotation of the motor helps to cut out the deposit rapidly. The motor should be well lubricated before starting it after cleaning the cylinder with kerosene, and especially after using gasoline for cleaning.

Scraping and rubbing is the only method of removing the hard carbon deposit from the combustion chamber walls and piston head. It cannot be dissolved by anything that can be safely or economically used in the cylinder.

167. Cleaning the Spark Plug. — When the insulation of a spark plug is covered with a coating of carbon and oil, it can generally be cleaned, if accessible, with gasoline and a bristle brush or a piece of cloth and a string for getting into the angles. A wire brush should not be used, for it is apt to scratch and roughen the insulation so that it will gather and hold dirt and be impossible to clean again. Mica insulation should not be scraped with a knife under any circumstances, and the use of a knife must be with care even on porcelain. Foreign matter on the metallic points is not harmful except when it is between the ignition points or contacts.

Porcelain insulation can sometimes be successfully removed for cleaning it if the plug is not too old in service. The writer's experience in this direction has been that the porcelain generally sticks and binds so tight that it is necessary to break it in order to remove it from the rest of the plug. A new porcelain can be put in its place, which is better and not expensive.

168. Pitting and Warping of the Exhaust Valve. — When the ignition is late or the mixture is over rich, the flame is still burning in the cylinder when the exhaust valve is opened. The flame then passes out into the exhaust passages and heats the exhaust valve to a high temperature. The high temperature has a tendency to warp the valve, whatever its material. The combined heating and erosive action of the escaping burning gases often produce small pits and shallow cavities in the part of the valve that rests on the seat when the valve is closed. Forged-steel valves are more subject to pitting than cast-iron ones.

Pitting is apt to cause leakage at the valve, although a valve may sometimes be very much pitted and still remain tight. The pits are more or less circular in shape, and one may form in the middle of the bearing surface without extending to either edge, or in one side of the bearing surface without extending across it. Warping is certain to cause leakage and loss of power.

The remedy is to regrind the valve.

169. Regrinding a Leaky or a Pitted Valve. — Mix a finely granulated or pulverized abrasive, such as emery, ground glass, etc., with vaseline or grease. Stop the port with a piece of cloth or waste, if possible. It may be necessary to remove the valve to do this.

Place a small amount of the grinding mixture on the bearing surface of the valve. Put the valve back in place (if it has been removed) and rotate it back and forth with an oscillatory motion a few times while applying a slight pressure to hold it against its seat. The movements in one direction may always be a little less than in the other, so that the valve is slowly turned around as well as oscillated. Lift the valve slightly from its seat frequently to allow the abrasive to get between the bearing surfaces. A light spring placed under the valve is convenient for lifting it when the pressure is removed. It is not advisable to rotate the valve through complete revolutions in either direction, for such a movement is apt to make scratches completely around the bearing surfaces. An exception to this may be a valve that is in extremely bad condition from pitting or warping, etc. In such a case the grinding may be more rapid at first by rotating several times first in one direction and then in the other, lifting the valve from its seat at each reversal of the motion.

Remove the valve and examine it frequently to see how the grinding is progressing. The bearing surfaces take on the same dull appearance all the way around when the grinding becomes uniform and they are nearly or quite fitted together.

Badly pitted or warped valves can be ground to advantage in a lathe or grinding machine with an emery wheel (or other abrasive wheel), then finished in place as above.

If the valve is oscillated in the same position always, the surfaces may become ground off more in some places than in others. The valve will then fit in some positions but not in others.

An abrasive two or three grades coarser than flour emery may be used at first, and a finer grade to finish. The coarse grade should be removed before putting on the fine.

Great care should be exercised to prevent the abrasive from getting into the ports of the cylinder, especially the inlet port.

The parts should be cleaned with extreme care at the completion of grinding. Any abrasive that enters the cylinder will cut and score it, and cause rapid wear and piston leaks.

170. Running the Motor with a Disabled Valve or Valve Spring. — If a valve of one of the cylinders of a motor with more than one combustion chamber is broken or disabled, or the valve spring useless, the motor can be run in a disabled condition by permanently closing the inlet port of the combustion chamber whose valve is disabled. It is generally advisable to close the exhaust port also to prevent scale and carbon from being drawn into the cylinder through it.

The port can be closed by putting a piece of sheet metal or strong gasket material, in the form of a blank gasket, in place of the regular gasket in the joint of the connection near the motor. Or, if the valve stem is the part broken, the valve can be clamped down against its seat by removing the cap from over the valve and putting a piece of wood on the valve and then clamping it down by replacing the cap. When the inlet valve is automatic and located opposite the exhaust valve (so that the two open toward each other) the block can be placed between them. In any method of blocking down a mechanically operated valve, the means of lifting it should be removed before blocking it down.

The compression of the disabled cylinder can be relieved by removing the spark plug, if thought necessary.

A broken coiled valve spring can sometimes be kept in use by placing a washer-shaped piece of stiff material around the valve stem and between the broken parts of the spring. A round, flanged (shallow cup shaped) piece with a hole in the center may serve better if the coil of the spring is of large diameter in comparison with that of the valve stem; or a flat disk of metal slitted radially from the edge inward a short distance at several places, and part of the strips between the slits bent up and the others down so that they will fit over the outside of the broken parts of the spring, may answer better.

171. Carbureter Repairs. "Water-logged" Float. Grinding a Needle Valve. — A hole in the hollow metal float of a float-feed carbureter may let gasoline enter the float if the hole is below the level of the gasoline. The increased heaviness of the float on this account allows the gasoline to rise higher in the reservoir than it should and thus causes too rich a mixture. To repair it,

Take the float out of the carbureter and place it in hot water to locate the hole by the bubbles that come from it. Make a small hole in the float, dry it and drive out the gasoline by gentle heating. Solder the leak and test it by blowing into the small hole just made. Let the float cool completely and solder the small hole quickly with a soldering iron so as to heat the float as little as possible.

If a cork float becomes "water-logged" or heavy, remove it and dry by gentle heating, then varnish it again.

If the needle valve of the float becomes leaky, press it down on its seat and rotate it, being careful not to bend it. If this does not stop the leak, grind it in with very fine abrasive (as emery) mixed with vaseline or grease. Press lightly on the valve when rotating it to grind, and lift it from its seat frequently to allow the abrasive to get between the valve and its seat. Clean off all of the abrasive carefully when the grinding is finished.

172. Removing Frost and Ice from the Carbureter. — The frost is collected from the air and the ice may come from water which splashes in or is drawn in and freezes. Both obstruct the passage and may hinder the operation of the throttle.

The ice will generally thaw out if the motor is stopped for a short time. If it does not, lift one of the mixture inlet valves of the motor slightly and crank the motor while the valve is held open; or run the motor by its own power should there be more than one combustion chamber. Holding the inlet valve open will allow the heated gas from the cylinder to be forced back into the inlet passage and the ice will be melted by it.

Hot water from the cooling system can be poured on to melt the ice.

173. Pipe Stoppages by Gaskets and Loose Hose Linings. — If a gasket is of soft material, it may be squeezed out into the passage so as to partly or completely stop it. Such materials as leather, rubber composition, and lead (the metal) will act this way, especially if the leather or rubber becomes soaked and covered with water and oil. A heavy pressure on a lead gasket will invariably squeeze it out from between the surfaces. The best remedy is not to use such materials where the conditions are of this nature.

The lining of rubber hose such as is used for the cooling water not infrequently becomes partly detatched from the fabric of the hose. It will sometimes act as a check valve or a flap valve, especially if the loose part is just where the hose fits over a coupling into which the water passes from the hose. A loose piece of the hose lining will lodge at such a place and close the passage.

174. **A cracked cylinder or cylinder head** is very apt to be the result of overheating on account of failure of the cooling water or cooling oil to circulate. Lack of a full supply of cooling water or cooling oil will produce the same result. Both water-cooled and oil-cooled motors will withstand a great deal of this kind of abuse without cracking, however, when properly made of suitable material.

A crack in the cylinder or the head may be due to initial stresses in the casting on account of the design or the method of cooling the casting in the mold (or out of it) just after it is poured.

175. **Leaky Piston. Scored Cylinder.** — A leaky piston is almost invariably due to improperly fitted, worn, grooved, or broken piston rings or a scored (cut, abraded) cylinder bore. Very infrequently it is on account of a cracked piston, the crack generally being in the head end (the end next to the combustion chamber in a single-acting motor).

The best method of dealing with grooved, cut, or badly worn piston rings is to replace them with new ones. An improperly fitted piston ring or one slightly worn so that, in either case, the bearing against the cylinder bore is only part way around, can be improved by peening it on the inner surface by striking lightly with the ball peen of hammer while the outside of the ring rests on a smooth anvil. This will expand the ring and cause it to bear out against the cylinder harder and therefore to fit to it more closely, if the peening is done properly. Most of the peening should be done opposite the places on the periphery that have been worn bright by rubbing against the cylinder. The peening must be done with great care, since the rings are made of cast iron (except in possible unusual cases).

If the rings are loose sidewise in the grooves of the piston, it is advisable to get new ones. If a new one is very slightly too wide for the groove, it can be ground down on the sides by rubbing it on a piece of emery (or other abrasive) cloth or paper lying on a truly flat surface.

A piston ring that is loose sidewise sometimes makes a sharp click when the motor is running. This is more apt to occur if the cylinder is not well lubricated.

Before placing the rings on a piston, it should be noticed whether the pin or other device for preventing each ring from turning around in its groove is in place. The rings should be held by the pins or stops so that the cuts across them do not come near each other.

A piston ring can be removed by lifting one of the ends at the cross cut with a piece of soft metal, such as the flattened end of a copper wire, and then twisting the ring around while pressing it sidewise, still keeping the wire under it, or allowing the ring to ride on top of the pin or stop for preventing its rotation when in place. The ring can be kept from snapping back into the groove while removing it, by placing small pieces of wood, leather, wood fiber, etc., under its end in the groove after lifting the end and while twisting the ring around. The ring should not be sprung open any farther than is necessary to remove it. Rings of cast iron are easily broken on account of the brittleness of the metal.

Putting a piston ring in place is far less difficult than removing it, but the same care must be observed not to open and break it. To prevent its snapping into a groove that is to be passed over, it can be kept very slightly crooked on the piston.

The piston, if of the trunk type, can be tested for a crack by removing it from the cylinder, placing it with the open end up, and then pouring gasoline or naphtha inside. The liquid will almost instantly appear on the outside if there is even a very minute crack. Immersing it in gasoline will also show the crack or pore.

The only way of repairing a badly cut or grooved cylinder is to rebore it. If the wall is thick enough to allow it, the bore may be made large enough to put in a lining bored to correspond with the diameter of the piston. Otherwise a new piston will be required.

176. Care and Handling of Combustible Liquids. Removing Water. — Gasoline and naphtha vaporize rapidly when exposed to the air. The vapor is heavier than air, and therefore settles to the floor of a room, the bottom of a boat, etc. The mixture at the floor soon becomes rich enough to ignite readily.

Vents to remove the vapor must be at the bottom of the enclosed space. Openings under doors and through the wall to the atmosphere will generally allow the vapor to escape, but in very quiet, damp or humid weather the circulation of air (and vapor) is apt to be so slight as to leave them practically stagnant. The same is true of venting through flues that lead up from openings at the floor. Forced ventilation with a blower or a hot steam coil in the flue is effective and reliable.

The safest storage of inflammable liquids is in an underground tank, and the safest way to remove them from the tank is with a suction pump so constructed that any leakage of the valves and other parts will allow the liquid to drain back into the tank.

Gasoline and other volatile combustible liquids evaporate rapidly from a closed wooden barrel. This is especially true if the barrel is exposed to the sun. Covering the barrel with a heavy, damp cloth or blanket prevents the evaporation to some extent.

Gasoline, etc., should not be allowed to drain into sewers. It is liable to be the cause of explosions in them which will blow manhole covers high in the air and possibly wreck the sewers.

Water can be removed from gasoline and other volatile products of petroleum either by filtering (straining) or allowing the water to settle to the bottom. A water trap, which may be something like those used in plumbing, but larger and well out of the current of the liquid, will remove the water if the flow past the trap is slow. Chamois skin strains out water and dirt most effectively, but the process is apt to be slow. Felt, linen and cloth do well, but the material should be such as will not give off lint appreciably. The lint will clog the small passages of the carbureter and atomizer.

There should be as few sources of accidental ignition of inflammable vapor in a place where volatile combustibles are present as possible. Some of the things that will cause ignition are: a spark from a nail in one's shoe rubbing over or striking against a cement or stone floor; a spark from metal tools striking together or on a cement floor; an electric spark at a lamp switch or at the brushes of a generator or motor; electric sparks from a running belt; a lighted match, lamp, or candle; a leak in the exhaust connections of an internal-combustion motor.

The gasoline tank, or a joint in its connections, should never be located so that leakage or drip can fall on or otherwise reach the exhaust pipe, muffler, or other highly heated parts.

In a launch or boat it is advisable to give the fuel tank sea drainage. This can be done by placing the tank in a water-tight compartment with small openings through the hull to the sea. The tank may be either submerged or above the water level. The connections should have no joints from which leakage can drain into the boat. In no case should joints be hidden from view or inaccessible. It is best to have a solid length of pipe from the tank to the carbureter. Running the fuel pipe line outside of the hull is a safe precaution frequently found in practice. The carbureter should have overboard drainage, or something should be provided to catch any possible drip from it.

CHAPTER XIV.

INDICATOR CARDS FROM PRACTICE.*

177. **The indicator diagram** of an internal-combustion motor with reciprocating piston is obtained in the same general manner as for a similar type of steam engine. The diagram is a record, more or less accurate, of the pressure in the motor cylinder during the operation of the motor through one cycle.

The form of the diagram and the time required for the tracing point, ray of light, or other recording device to trace it on the card, measured in strokes of the piston, depend on the cycle of the motor. Four strokes of the piston, corresponding to two revolutions of the crank shaft (except in unusual cases), must be made to secure a complete card of a four-cycle motor. A two-cycle motor gives a complete card of the *combustion cylinder* during two strokes of the piston, corresponding to one revolution of the crank shaft.

When taking the card, the connections between the indicator and the motor combustion chamber should be as short and direct as possible, and as small in cross-section as will allow the pressure of the combustion chamber to be transmitted to the piston of the indicator without appreciable reduction by frictional resistance to the flow of the gas through the connecting passage. It is more important in the internal-combustion motor that the volume of the space added to the combustion chamber by the indicator and its connections shall be small in comparison to the volume of the motor cylinder than it is for a steam engine.

The increase of the volume of the compression space of a motor on account of connecting the indicator to it reduces the pressure of compression and consequently that of combustion or explosion,

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* For method of obtaining mean effective pressure from an indicator card see chapter on Pressure-Volume diagrams.

as well as the efficiency of the transformation of the heat energy of the gas into mechanical power.

An indicator card from a four-cycle motor operating on gas from a suction producer is accurately reproduced in Fig. 77.

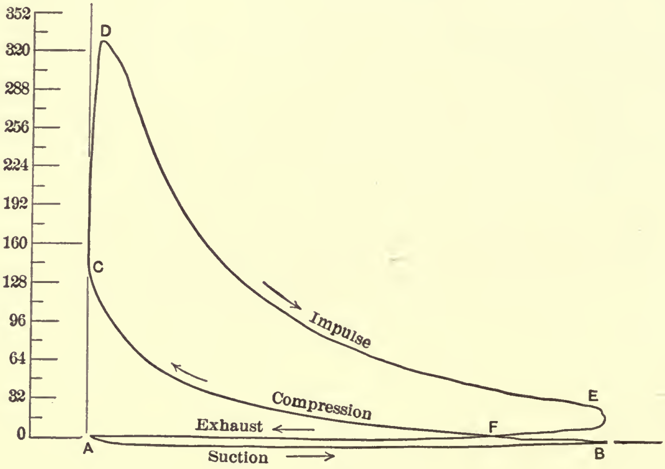

Fig. 77.

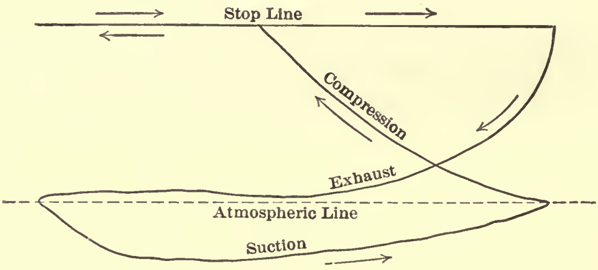

Fig. 78.

The atmospheric pressure line is only partly shown in order to leave the diagram as clear as possible. The arrows indicate the direction of motion of the tracing point over the card when making the lines of the diagram.

The suction stroke begins at *A* and ends at *B*. Compression begins at *B* and continues to the neighborhood of *C*, where ignition occurs, and the pressure rises rapidly to *D*, while the motor piston makes but little movement. The impulse stroke begins at some point between *C* and *D*. The point of ignition and that where the impulse stroke begins cannot be accurately determined on the card. Combustion is well completed at the reversal of the curve after it begins to drop on the impulse stroke. Expansion of the gases of combustion continues in the tightly closed cylinder till the exhaust valve opens at the point near *E*, where the expansion line again reverses its curvature. The impulse stroke is completed at the point farthest to the right of and just below *E*. The exhaust stroke then begins and continues along the upper and nearly horizontal line that crosses the compression line at *F* and terminates at the starting point *A*. The junction of the compression line with the combustion curve at about the point *C* is unusually smooth in this diagram and therefore makes the point *C* difficult to locate accurately. The ignition occurs slightly before the completion of the compression stroke.

The pumping action necessary to draw the air into the fuel bed of the gas producer, and the gas there formed, from the producer and through the scrubber and purifier to the motor, causes the suction line of this card to fall farther below the atmospheric pressure line than for a properly designed and installed motor using gas from pressure mains, volatile fuel through a carbureter, or oil injected into the combustion chamber or into a vaporizer.

The area of the upper loop *CDEFC* of the indicator card represents the energy that acts to drive the piston of the motor. It may be called the positive area. The area of the lower loop *ABFA* represents energy that acts to retard the motion of the piston, and may be called the negative area. The difference of the two areas (positive − negative) therefore represents the energy that is delivered to the piston during a complete cycle of the motor, dealing with one combustion chamber only, and may be called the net area or effective area of the indicator card. To put this in a more convenient form it may be written

Area $CDEFC$ = positive or impulse energy;
Area $ABFA$ = negative, retarding, or pumping energy;
Area $(CDEFC - ABFA)$ = net driving or effective energy.

The net area of the card can be found with a planimeter by starting at any point on the line and tracing continuously over the boundaries of both loops in the direction of the arrows back to the starting point. The planimeter will record positively for the upper loop and negatively for the lower loop. The net record will be the difference of the areas of the two loops.

The upper loop *CDEFC* is often referred to as the impulse diagram, impulse card, or simply the indicator card of the motor. The latter usage has probably arisen from the fact that the area of the lower loop is generally so small in cards from motors that do not draw their fuel through a suction producer, that it is impossible to measure its area with any degree of accuracy even when drawn with a sharp metallic tracing point, when the complete double loop is traced continuously, as in Fig. 77.

When the lines enclosing the area of the lower loop lie so close together as to make it impossible to determine its area with an error less than 50 per cent of its own area, its omission altogether from the complete card will not generally introduce an error as great in actual area as that of determining the area of the upper loop.

But since the area of the lower loop represents negative work done by the motor, it is desirable to reduce the value of this area to as small an amount as possible that is consistent with other factors to be considered.

In order to obtain a separate indicator card that will clearly show the characteristics of the lower loop, a weak spring is used in the indicator (in connection with a stop that will prevent the indicator piston and tracing point from being thrown too high if the instrument is not so constructed as to limit the motion of its piston and tracing point within a safe range without a stop). The card thus obtained shows the lower part of the diagram, as of that in Fig. 77, on an enlarged vertical scale, the upper part of the complete diagram being cut off by a line traced parallel to the atmospheric line by the tracing point of the indicator, while its moving parts are held at the limit of their motion caused by the pressure of the gases in the cylinder.

Such an indicator card is shown in Fig. 78, which is a vertical enlargement of the lower part of Fig. 77. It may be referred to as a low-spring card, pumping card, or pump card.

Many of the causes that effect changes in the form and area of the impulse card are different from those that produce similar variations in the pumping card. For this reason, as well as on account of the contracted form of the pumping card when taken in connection with the impulse card, it is customary to take a separate low-spring indicator card of the form just described to show the pumping action. A card of this kind is also very useful for examining the valve action.

The mean effective pressure of either card can be found in the usual manner, by dividing its area (square inches) by its length (inches) and then multiplying by the value of the indicator spring (pounds per inch of height of the indicator card).

The remainder obtained by subtracting the mean effective pressure of the pumping card from that of the impulse card, both reduced to the same scale, represents the net mean pressure that is effective in driving the motor piston when the complete cycle is taken into consideration.

The indicated horsepower of a single-cylinder, single-acting motor or of one combustion chamber of a multi-cylinder or double-acting motor is obtained by multiplying together the net mean effective pressure, the cross-sectional area of the clear space in the cylinder, the length of stroke and the number of explosions or impulses per minute, and dividing the product by 33,000.

The cross-sectional area of the clear space in the cylinder is customarily referred to as the piston area. When there is no piston rod extending through the combustion space this area is that of a circle of the same diameter as the bore of the cylinder; but when there is a piston rod in the space its cross-sectional area must be deducted from that of the circle. The form of the piston head (convex, concave, flat irregular) does not have to be considered.

In a throttle-controlled four-cycle motor of the common type, there is an explosive impulse every four strokes of the piston (two revolutions of the crank) in each combustion chamber provided there are no misfires. In a two-cycle motor there is an impulse every two strokes of the piston (every revolution of the crank) under similar conditions.

In a hit-or-miss controlled motor the number of explosions per minute is variable and must therefore be recorded to obtain the indicated horsepower.

The following notation will be used to write the mathematical expressions for the indicated horsepower of an indicator diagram:

A = piston area, effective, square inches;
G = strokes of piston per cycle;
L = length of stroke of piston, feet;
R = revolutions of crank per minute;
T = piston travel, feet per minute;
Y = number of explosions or impulses per minute;

I.h.p.I = impulsive indicated horsepower per combustion chamber;
I.h.p.R = retarding indicated horsepower per combustion chamber;
I.h.p.N = net indicated horsepower per combustion chamber;
M.e.p.I = mean effective impulsive pressure of impulse card (*CDEFC*, Fig. 77);
M.e.p.R = mean effective retarding pressure of pumping card (*ABFA*, Fig. 77);
M.e.p.N = M.e.p.I − M.e.p.R = net mean effective pressure.

For the general case, including hit-or-miss governing,

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, ALY}{33{,}000},$$

or

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, ATY}{33{,}000\, G}$$

For a four-cycle motor without misfires or complete cut-outs of charges (reduction of charge governing),

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, ALR}{2 \times 33{,}000},$$

or

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, AT}{4 \times 33{,}000}.$$

For a two-cycle motor without misfires or complete cut-outs of charges,

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, ALR}{33{,}000},$$

or

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\, AT}{2 \times 33{,}000}.$$

Equations similar to the above can be written for the mean effective pressure of the impulse loop and for the pumping loop of the diagram, the only change being the substitution of the proper mean effective pressure and indicated horsepower.

In a two-cycle motor the pumping loop does not appear on the diagram. If the usual type of indicator, in which the pressure of the gas acts on only one side of the piston, is used, it records only the impulse diagram. A separate card for the crank case of the simpler type of two-cycle motor must be taken for the pumping diagram. In the more complicated forms of two-cycle motors with precompression pumps, the pumping diagrams are to be taken from the pumps themselves.

178. Indicator Cards Representing American Practice. — A number of indicator cards from American gas, gasoline, and oil motors are reproduced with as much accuracy as possible in this section. In some of them the bottom loop is omitted on account of its being so narrow that it cannot be read or reproduced with a warrantable degree of accuracy. Its value is of course of little weight in determining the indicated power when the loop is so small.

The point of ignition is much more clearly defined in Fig. 79 than in Fig. 77. The compression pressure is determined by continuing the compression line as if there had been no ignition

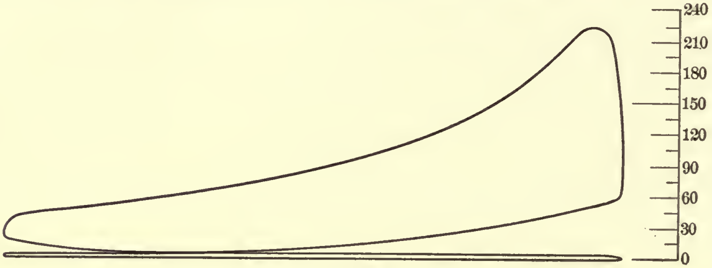

Fig. 79.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Illuminating gas.		Diameter of piston	13.5″
Compression pressure	60	Stroke	24″
Explosion pressure	220	Revolutions per minute	170
M.e.p. impulse	84	Piston travel, feet per minute	680

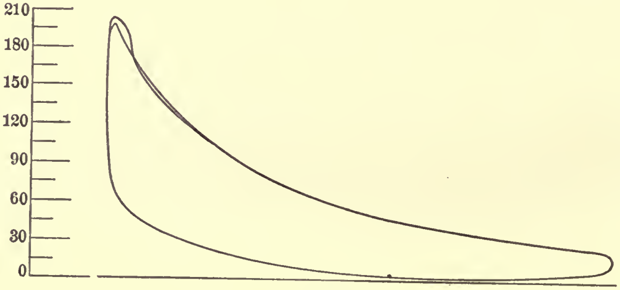

Fig. 80.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. PART LOAD.

Pressures in pounds per square inch above atmosphere.

Natural gas.		Diameter of piston	15″
Compression pressure	63	Stroke	24″
Explosion pressure	200	Revolutions per minute	170
M.e.p.I	58	Piston travel, feet per minute	680

till it intersects the line perpendicular to the atmospheric line and tangent to the combustion line at the right-hand end of the diagram. The bottom loop on the original card appears almost as a line, and is not reproduced.

Fig. 81 shows the effect of the vibration of the indicator point at the beginning of the impulse stroke, recorded as a wavy line. The area of the card was determined by drawing a smooth curve to represent, as nearly as could be judged, the true pressures that would have been recorded if the indicator had not vibrated.

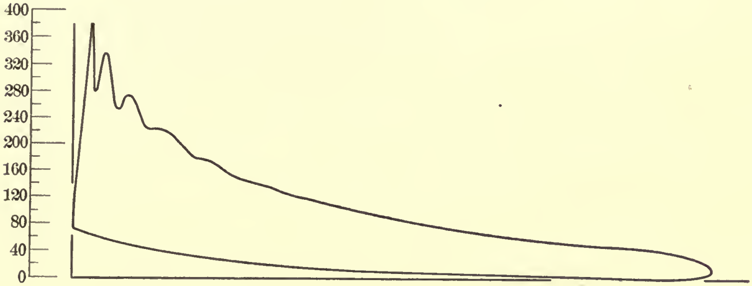

FIG. 81.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Illuminating gas.		Diameter of piston	11.25″
Compression pressure	72	Stroke	19″
Explosion pressure	334	Revolutions per minute	220
M.e.p.I	96.5	Piston travel, feet per minute	697

In this motor the ignition is electric in a small chamber connected to the combustion chamber by a straight narrow passage so that a flame spurts out into the main body of the charge to ignite it.

In Fig. 82 the sharp peak at the top of the diagram with rapidly rising combustion line at the peak seems to indicate that a sharp local explosion occurred in the connections to the indicator after the combustion of the main body of the charge was well under way.

The bottom loop of this card shows that the exhaust pressure dropped to about atmospheric when the piston was about one-quarter of the way back on the exhaust stroke and then rose higher later in the stroke. This might be caused by a very quick and full opening of the exhaust valve together with a straight exhaust pipe of such proportions that the inertia of the escaping gas tended to form a partial vacuum soon after their release, which tendency did not continue till the middle of the stroke was reached.

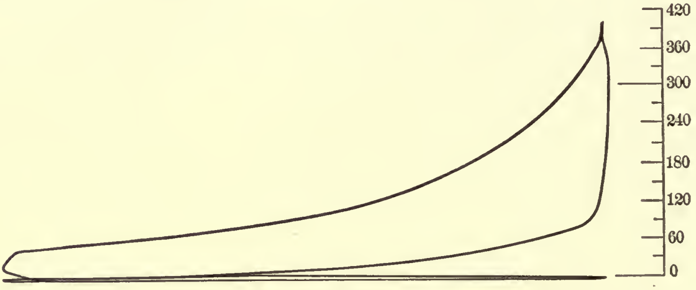

Fig. 82.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Natural gas.		Diameter of piston	15⅞″
Compression pressure	100	Stroke	18″
Explosion pressure	375	Revolutions per minute	175
M.e.p.I	104	Piston travel, feet per minute	525

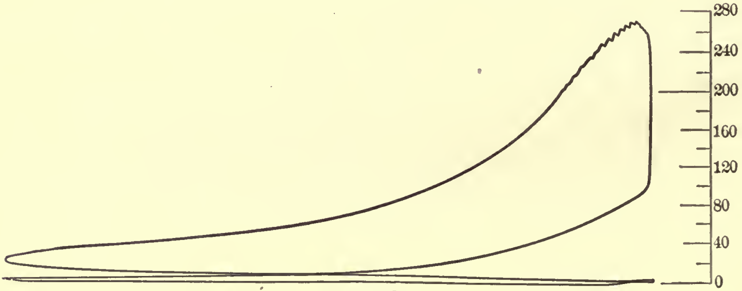

Fig. 83.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Gas.		Diameter of piston	19″
Compression pressure	92	Stroke	24″
Explosion pressure	270	Revolutions per minute	225
M.e.p.I	71.2	Piston travel, feet per minute	900

See Fig. 84 for card from same motor throttled to about seven per cent of the full load at the brake.

The lower loop of Fig. 83 has a larger area on account of the comparatively high piston speed than it would have at the lower piston speeds of the preceding cards.

Fig. 84 shows two consecutive diagrams drawn by keeping the tracing point on the card during two cycles of the motor.

Both combustion lines slope away from the perpendicular to the atmospheric line. This is due to the slower rate of inflammation and combustion on account of both the lower degree of compression and the greater dilution of the mixture than in Fig. 83. The time of ignition is the same for all three of the diagrams shown in the two cards. It occurs a little before the completion of the compression stroke in each case. The slower rate of combustion and the lower explosion pressure in the smaller of the two diagrams in Fig. 84 is probably due to less fuel in the charge for the smaller card, for the compression pressure is the same in both, as near as can be determined from a comparatively clear original card.

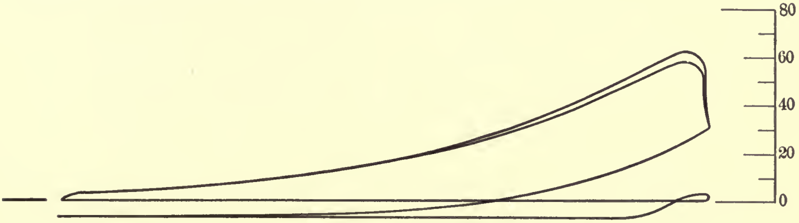

Fig. 84.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. THROTTLED TO ABOUT SEVEN PER CENT OF THE FULL CAPACITY BRAKE LOAD AS DELIVERED BY THE MOTOR.

Pressures in pounds per square inch above atmosphere.

Gas.		Diameter of piston	19″
Compression pressure	32	Stroke	24″
Explosion pressure	58	Revolutions per minute	232
	64	Piston travel, feet per minute	928
M.e.p.I., average	14.6		

See Fig. 83 for full-load card from same motor.

The slope of the combustion line away from the perpendicular to the atmospheric line would be greater if the indicator spring were of the same strength as that used for Fig. 83 instead of being 80 pounds per inch of compression while that of Fig. 83 is 200 pounds per inch of compression.

The expansion line of the light-load card drops to within a pound or two of atmospheric pressure. In the full-load card its lowest point is about twenty pounds above atmosphere.

The suction line of the light-load card falls to about six pounds below atmosphere soon after the beginning of the charging stroke, and continues to fall gradually to about eight pounds below atmosphere at the completion of the charging stroke. The area of the lower loop is not great, however, since the compression line follows it closely back about half way.

The suction line in Fig. 84 rises above the exhaust line during the early part of the charging stroke. This is probably due to a momentary increase of back pressure in the exhaust pipe, caused by the exhaust from another combustion chamber of the motor at about the time of the completion of the exhaust stroke of this card and while the corresponding exhaust valve was closed. It may be due to slight lost motion in the indicator, but this is hardly probable, since the cards come from one of the leading gas-engine builders.

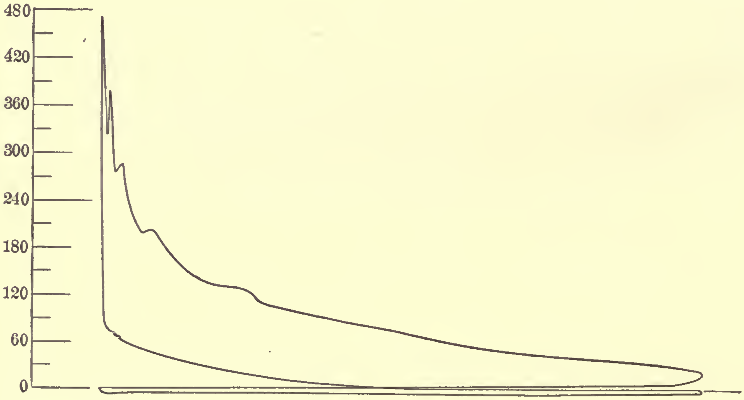

Fig. 85.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Gas.		Diameter of piston	8″
Compression pressure	80	Stroke	10″
Explosion pressure	380	Revolutions per minute	320
M.e.p.I	82	Piston travel, feet per minute	533

See Fig. 86 for light-load card from same motor.

The extreme sharpness and height of the peak in Fig. 85 are probably due to the inertia of the moving parts of the indicator causing it to record higher than the actual maximum pressure of the explosion. The sharp waves of the expansion line are records of rapid vibration of the indicator tracing point on account of the inertia of the parts.

Fig. 86.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. THROTTLED TO RUN ON ITS OWN FRICTION LOAD ONLY.

Pressures in pounds per square inch above atmosphere.

Gas.		Diameter of piston	8″
Compression pressure	22	Stroke	10″
Explosion pressure	37	Revolutions per minute	331
M.e.p.I	12.4	Piston travel, feet per minute	550

See Fig. 85 for full-load card from same motor.

Fig. 86 represents an extreme case of the retarding effects of low compression and great dilution on the rate of flame propagation and combustion. The card was taken from the same motor as that of Fig. 85. The time of ignition was the same in both cases slightly before the completion of the compression stroke.

The linear rate of flame propagation is so slow in Fig. 86 that the pressure of combustion is scarcely kept up to that of compression during the early part of the impulse stroke. But the rapidly increasing volume rate of propagation then causes the pressure to rise notwithstanding the increase in the rate of the travel of the piston and in the rate of increase of volume of the enclosed gases.*

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* The propagating flame moves out from the point of ignition with the same constant linear velocity in all directions (theoretically in a quiescent body of gas). The crest of the propagating flame therefore forms a spherical surface whose area increases as the square of the diameter or of the time elapsed after the initial ignition. The rate of inflammation, measured in the volume inflamed per unit time, therefore, increases as the square of the time. And the total

The short horizontal portion of the combustion line may be in part due to friction in the indicator after coming to rest at the completion of compression. In such a case it would at first move more rapidly immediately after starting from rest than the increasing pressure of the gases alone would cause. Such an action will produce a sharp bend in the curve such as that between the short horizontal line and the upward inclined line.

If the load on the motor is increased by successive steps from only the friction load, Fig. 86, to full load, Fig. 85, the inclination of the combustion line from the vertical on cards taken for each step of increase of load, will decrease as the load increases, finally reaching the direction of that in Fig. 85 for full load.

The same is true of Figs. 83 and 84.

The maximum pressures in Figs. 83 and 84 for full load and light load occur at about the same time in the stroke. But in Fig. 86 the maximum pressure is much later than for the full-load card, Fig. 85, from the same motor.

Two diagrams taken consecutively from a hit-or-miss governed motor with friction load only are shown in Fig. 87. One diagram was made after a charge was cut out by the governor action, and the other for the following impulse stroke. The compression lines of the two diagrams are coincident except for a short distance just before the completion of compression. They then separate slightly and the distance between them continues to increase till the end of the compression stroke.

The impulse line of the full-charge diagram lies above the compression line in the usual manner. The expansion line of the cut-out diagram drops slightly below the compression line during the stroke following compression (normally the impulse stroke). The drop of this expansion line at and near the end of the compression stroke is probably chiefly due to leakage. The "exhaust" line following expansion of the cut-out charge cannot

volume of the gas inflamed increases as the volume of the sphere, or as the cube of the time, the linear rate of propagation remaining constant. Some approximation of this condition probably occurs in a motor when the ignition is at a point in the main body of the charge, as distinguished from ignition in a pocket leading off from the mass of the gas.

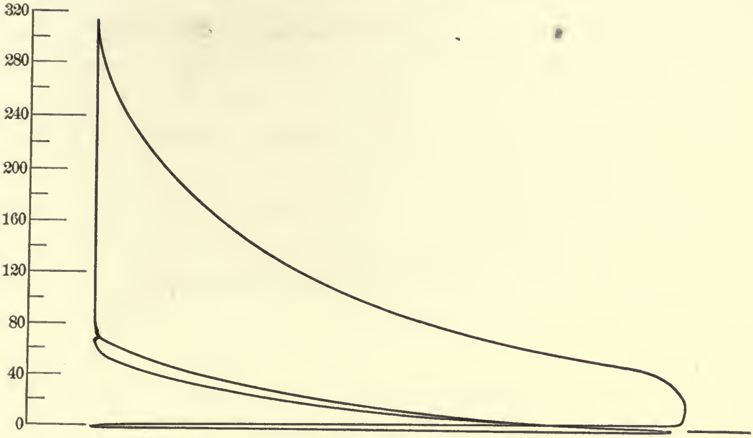

Fig. 87.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FRICTION LOAD.

Pressures in pounds per square inch above atmosphere.

Natural gas		Diameter of piston	13″
Compression pressure	70	Stroke	22″
Explosion pressure	310	Revolutions per minute	170
M.e.p.I	90	Piston travel, feet per minute	623

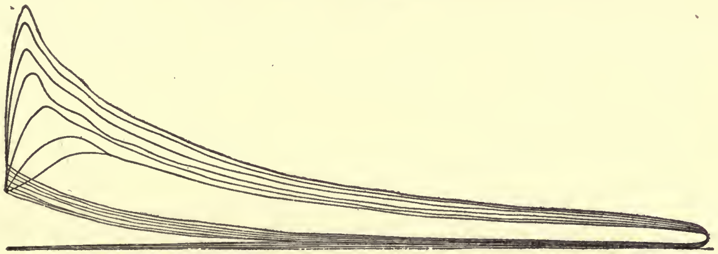

Fig. 88.

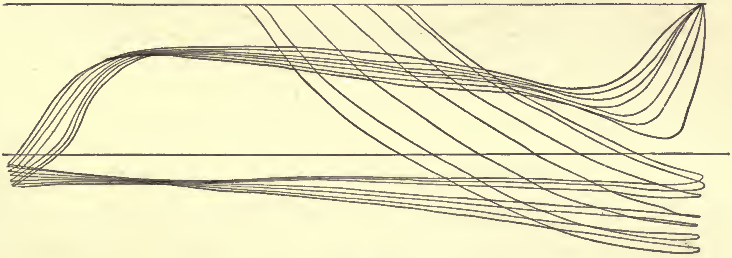

Fig. 89.

be distinguished from the suction line, but probably lies very slightly above it.

Fig. 88 shows a series of indicator cards from a gas motor governed by a cut-off valve that allows the mixture to begin to enter at the beginning of the suction stroke and cuts it off during the suction stroke when a volume proportional approximately to the work being done by the motor has entered the cylinder.

Fig. 89 shows the corresponding diagrams taken with a low spring and stop on the indicator.

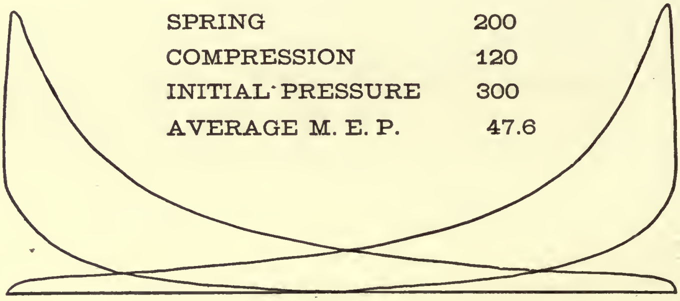

Fig. 90.

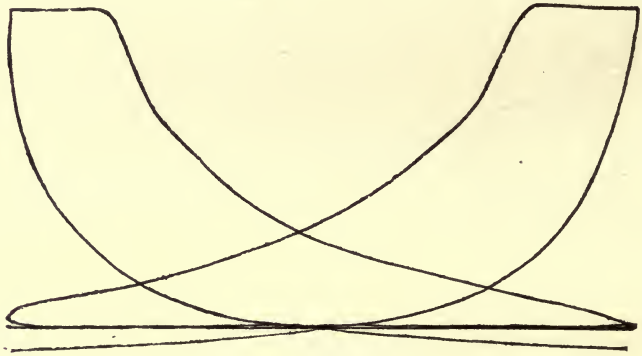

Fig. 91.

Figs. 90 and 91 are cards from the "complete expansion engine." They show respectively the upper loops of a pair of diagrams and the corresponding low-spring cards. The motor is four cycle and governed by admitting only air during the first part of the suction stroke, and then beginning the admission of gas at a time determined by the governor. The gas and air are both cut off at the same instant at about half stroke.

Fig. 92.

Fig. 92 is a series of diagrams from the same kind of a motor as that from which Figs. 90 and 91 were obtained. It shows the governing action during fifty consecutive cycles.

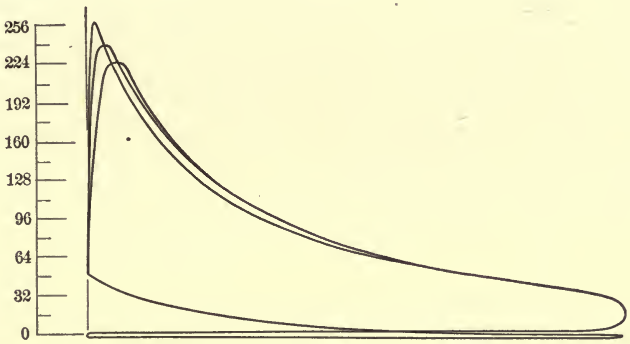

Fig. 93.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Gasoline.		Diameter of piston	12″
Compression pressure	50	Stroke	20″
Explosion pressure	245	Revolutions per minute	200
M.e.p.I	82	Piston travel, feet per minute	667

Three consecutive diagrams from a hit-or-miss governed motor are shown in Fig. 93. The ignition was at the same time in each. The rate of combustion (or of flame propagation) is different in each, however, as shown by the different inclinations of the combustion lines. The areas and mean effective pressures are practically the same in all three. This indicates that the same weight of fuel was burned and the same amount of heat energy produced by the combustion of each charge. All the charges were drawn in under the same condition of inlet passages, carbureter, and other parts, by virtue of the method of governing. The coincidence of the compression lines also shows that the charges were of the same weight.

The difference in the rate of inflammation, or of combustion, or of both, was probably due to a difference in the thoroughness of the mixture of the fuel and the air, or of its richness at and in the neighborhood of the ignition apparatus.

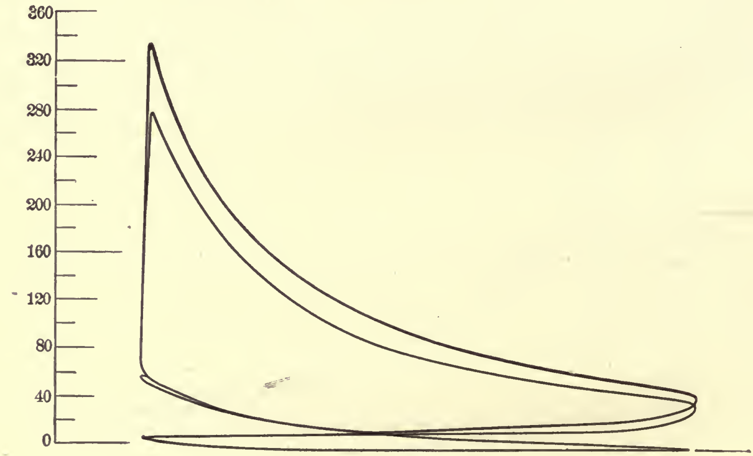

Fig. 94.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. LIGHT LOAD.

Pressures in pounds per square inch above atmosphere.

Gasoline.		Diameter of piston	12″
Compression pressure	60	Stroke	20″
Explosion pressure	270 330	Revolutions per minute	200
M.e.p.I.	77 94	Piston travel, feet per minute	667

Fig. 94 shows three diagrams from the same motor as that from which the preceding set of cards, Fig. 93, was taken, but the motor was running on light load in the last card. The large diagram is for the first explosion after several misfires. This was followed immediately by the smaller impulse diagram. The cut-out diagram is a composite of several diagrams.

The greater size of the larger diagram is due either to a greater weight of fuel or a better proportion of the mixture. A greater weight of mixture is generally drawn into the cylinder after several cut-outs on account of the cylinder becoming cooler. An inlet valve that lets combustible mixture leak into the cylinder during the suction stroke when the charge is cut out (as on account of too weak a valve spring) will allow scavenging of the cylinder during several consecutive cut-out strokes, so that the following charge is but slightly diluted by the inert products of combustion. The resulting diagram is then larger than those following.

The cut-out diagram in this card shows but little, if any, leakage. The expansion line of the cut-out diagram will fall below the compression line when the cylinder is cool, even if there is no leakage from the cylinder, for some of the heat of compression is given up to the cylinder during the time the gas is well compressed. The same may also be true with a hot cylinder when the incoming charge strikes the hottest parts, as the exhaust valve and ports, and the piston head when not water cooled. In such a case the charge becomes so highly heated while entering that its compression temperature is higher than that of the cylinder walls taken as an average.

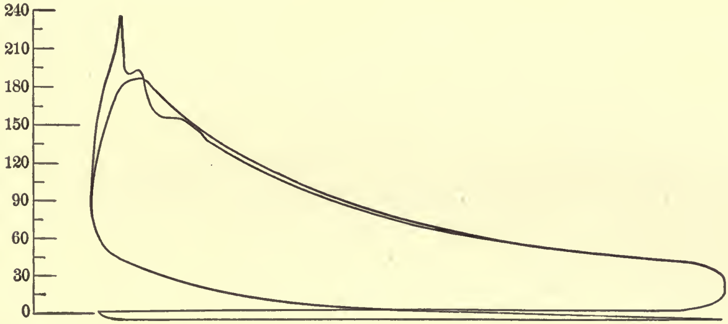

FIG. 95.

FOUR-CYCLE MOTOR. THROTTLE GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Gasoline.		Diameter of piston	10.5″
Compression pressure	60	Stroke	14″
Explosion pressure	210	Revolutions per minute	250
M.e.p.I	76	Piston travel, feet per minute	583

Fig. 95 shows a card with two diagrams from a gasoline motor of the throttle-governed type. There is considerable difference in the combustion lines, although the compression lines coincide so far as can be seen on the original, clearly drawn, fine line card. The higher combustion line has a decided reverse curve, which seems to indicate, as in Fig. 82, that there was a sharp explosion in the connections between the indicator and the combustion chamber after the main body of the gas was well inflamed. The expansion line of the higher card with the peaked top falls below that of the other, so that the areas of the two cards are practically equal.

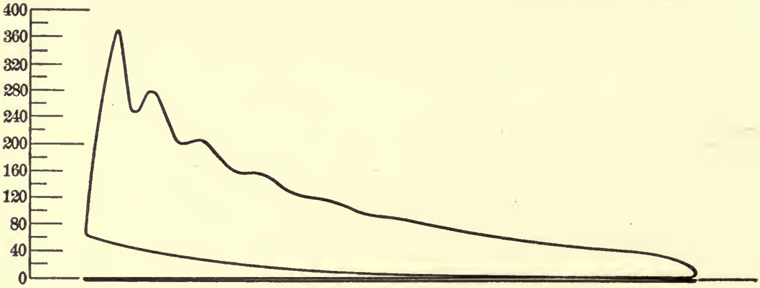

Fig. 96.

FOUR-CYCLE MOTOR. HIT-OR-MISS GOVERNED. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Gasoline.		Diameter of piston	6.75″
Compression pressure	62	Stroke	15.5″
Explosion pressure	360	Revolutions per minute	260
M.e.p.I	102	Piston travel, feet per minute	672

Motor took 126 charges per minute.

In Fig. 96 the sharp angle between the compression line and the combustion line indicates ignition at the completion of the compression stroke. It compares in this case with Fig. 81 from a motor of the same make operating on illuminating gas.

In both motors, Figs. 81 and 96, the ignition plug is placed in a small chamber connected to the combustion chamber by a small passage. The spark ignites the gas in the small chamber and the expansion of the gas while burning projects a flame into the body of the charge in the combustion chamber, thus inflaming a considerable amount of the charge suddenly. The gas currents caused by the projection of the gas and flame from the ignition pocket into the combustion chamber also help the rapidity of inflammation. This method of ignition accounts for the absence of the rapid falling away of the combustion line from the vertical, which occurs when ignition is at the completion of the compression stroke by a spark or arc in the main body of the gas in the combustion chamber.

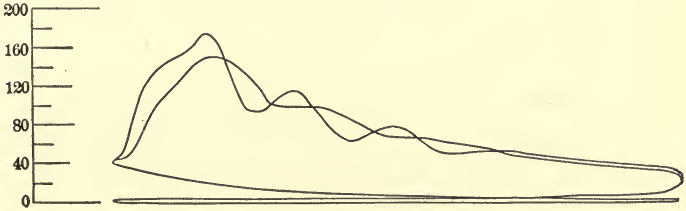

Fig. 97.

FOUR-CYCLE MOTOR. GOVERNED BY REGULATING THE AMOUNT OF FUEL PER CHARGE. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Kerosene.		Diameter of piston	6.5"
Compression pressure	40	Stroke	9"
Explosion pressure	150 170	Revolutions per minute Piston travel, feet per minute	405 607
M.e.p.I	63		

In Fig. 97 ignition occurs rather late, at dead center or very slightly before it, as indicated by the nearly horizontal direction of the first part of the combustion line. The difference of the areas of the two cards is due to the varying quantity of combustible mixture.

In Fig. 98 the three diagrams are from a Hornsby-Akroyd motor operating at full load. The difference in the areas of the diagrams is due to the governor action in regulating the amount of liquid fuel that is injected into the vaporizer extension of the motor cylinder during each cycle. The compression is of course always practically the same, since air is always freely admitted during the suction stroke. Ignition occurs some time before the completion of the compression stroke, and is caused by the high temperature of the walls of the vaporizer.

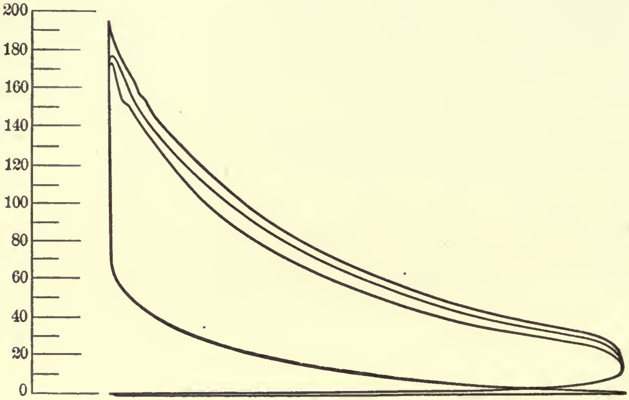

Fig. 98.

HORNSBY-AKROYD FOUR-CYCLE MOTOR. GOVERNED BY REGULATING THE AMOUNT OF FUEL PER CHARGE. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Distillate of petroleum.		Diameter of piston	23″
Compression pressure	58	Stroke	28″
Explosion pressure, average	180	Revolutions per minute	160
M.e.p.I. average	54	Piston travel, feet per minute	747

With regard to Fig. 99 it will be remembered that the full charge of air is taken in and compressed to a high pressure before the liquid fuel is injected (blown) into the combustion chamber, and that ignition is caused by the heat of compression. The work of compressing the air to blow the fuel into the combustion chamber must be deducted from that of the impulse card to determine the net indicated power.

Fig. 100 is a low-spring or pumping card corresponding to Fig. 99.

Fig. 101 is a card from a Koerting two-cycle motor, which has auxiliary cylinders for separately compressing the air and gas.

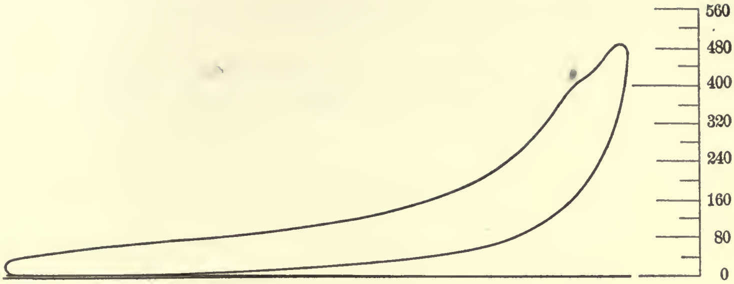

FIG. 99.

DIESEL TWO-CYCLE MOTOR. GOVERNED BY REGULATING THE AMOUNT OF FUEL PER CHARGE. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Petroleum distillate, specific gravity	.85	Diameter of piston	16″
Compression pressure	480	Stroke	24″
Combustion pressure	490	Revolutions per minute	160
M.e.p.I	97	Piston travel, feet per minute	640

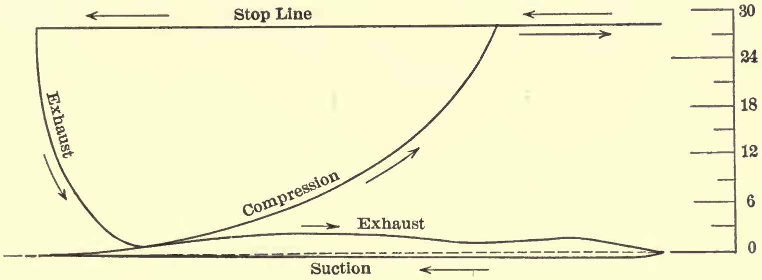

FIG. 100.

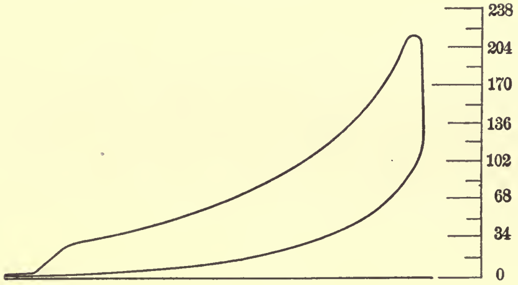

FIG. 101.

KOERTING TWO-CYCLE MOTOR. GOVERNED BY REGULATING THE AMOUNT OF FUEL PER CYCLE. FULL LOAD.

Pressures in pounds per square inch above atmosphere.

Producer gas.		Diameter of piston	25.5″
Compression pressure	120	Stroke	45
Explosion pressure	225	Revolutions per minute	100
M.e.p.I	53	Piston travel, feet per minute	750

The governing is by admitting the gas during the latter part of the charging stroke for such a length of time as the governor determines.

The exhaust comes earlier than in a properly adjusted four-cycle motor on account of the necessity of having the piston uncover the exhaust port early enough to allow the spent gases to escape and the new charge to enter while the port remains uncovered.

The pumping or charging diagram does not appear on the card, since this part of the work is done in the two auxiliary cylinders. Separate diagrams must be taken from the auxiliary cylinders to obtain the pumping, or charging, diagrams.

179. Indicator Diagrams Showing Abnormal Pressures. — If the pipe connections to the indicator are long, and especially if the passage is contracted at the end next the combustion chamber, the combustion of the gas in the pipe after the pressure has become high in the combustion chamber on account of the explosion, will generally give diagrams showing abnormally high and suddenly increasing pressures. The inertia of the moving parts of the indicator adds to the recorded apparent pressure. Pockets in the combustion space of the motor will give similar but generally less marked results when the ignition is not in the pocket.

It has already been pointed out that the indicator connections should be as short as possible, and without contracted passages.

180. Incorrect Valve Setting as Shown by the Indicator Diagram. Four-Cycle Motors. — Figs. 102 to 107 are portions of indicator diagrams showing the characteristic effects of extremely early or late opening or closing of the inlet and exhaust valves. Those for the inlet valve apply only to those that are mechanically operated valves.

Fig. 102 shows the latter part of the expansion line and the early part of the exhaust line. The early opening of the exhaust allows the burned gases to escape before the expansive action and impulse pressure against the piston are completed as far as is practicable and advantageous and can be done without causing too much pressure against the piston during the early part of the exhaust stroke. The result is a reduction of the area of the impulse loop and of the mean effective pressure of the impulse.

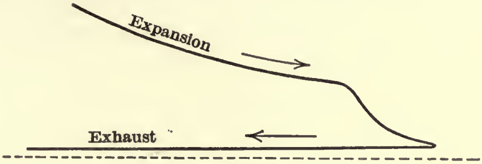

Fig. 102.

This should not be confused with the necessary earlier exhaust of the two-cycle motor, as compared with the four-cycle type.

Fig. 103 indicates too late an opening of the exhaust valve. This causes considerable pressure resisting the motion of the piston during the early part of the exhaust stroke. The area of the impulse loop and the mean effective pressure are both reduced.

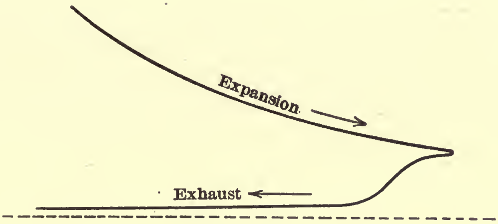

Fig. 103.

Fig. 104 is characteristic of an exhaust valve closing too early when the inlet valve opens at the end of the stroke. When the inlet valve opens under this condition, the slightly compressed exhaust gases puff out into the inlet passage and are then drawn in again as the piston moves out on the suction stroke. This causes fouling of the inlet valve and its stem, and is a condition that should be particularly avoided.

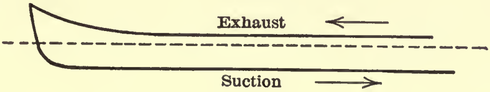

Fig. 104.

In Fig. 105 the exhaust valve closes too early, as in the preceding figure, but the inlet valve opens later than it should for proper setting of the exhaust valve. The conditions of Fig. 105 are better than those of Fig. 104 mainly because there is no puffing out of the exhaust gases through the inlet valve, but also because the area of the pumping card loop is smaller. The latter is generally insignificant in comparison with the former.

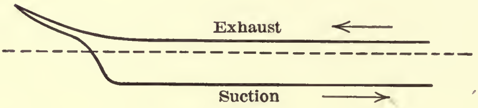

Fig. 105.

Fig. 106 indicates, by the horizontal portion of the compression line, too late closing of the inlet valve. Under this condition part of the charge that has been drawn in and diluted by the residual inert gases is forced back through the inlet valve during the early part of the compression stroke. Compression does not begin till the inlet valve closes. The following charge is somewhat weakened, or made lean, by the inert gases that were forced back into the inlet passage, and the power of the motor is thus reduced.

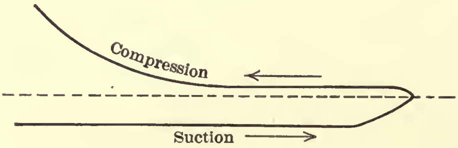

Fig. 106.

Fig. 107 shows early closing of the inlet valve. This is accompanied with no undesirable results. The charge is rarefied after the inlet valve closes, and then compressed along the same line again up to suction pressure, after which the compression continues in the usual manner. This is characteristic of the method of governing by reducing the amount of the mixture per charge by opening the mixture inlet valve always at the same time and closing it at such a part of the stroke as the speed and governor determine.

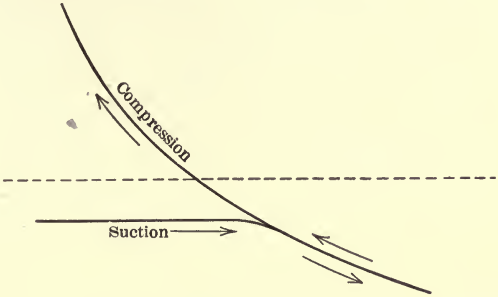

FIG. 107.

This method of operation is also characteristic of the "complete expansion" engine.

181. **Momentary Back Pressure.** — Fig. 108 shows the effect of back pressure in the exhaust pipes at the time of exhaust of another cylinder whose exhaust opens one-half a revolution from that of the cylinder from which the indicator card is taken.

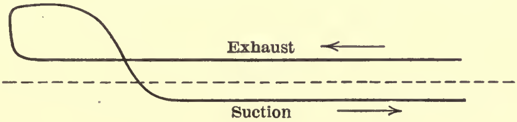

FIG. 108.

The back pressure comes into the cylinder just before the exhaust valve closes, and drops when the inlet valve opens (after the exhaust valve has closed). This is not an indication of incorrect valve setting. (See disposal of exhaust gases.)

182. **Variation of the Time of Ignition as Affecting the Indicator Card. Four-Cycle Motor.** — When all the other conditions remain constant, and the time of ignition is varied, the effects on the indicator diagram are shown characteristically in Figs. 109 to 111.

Fig. 109 indicates ignition that is later than is suitable for the best results in economy of fuel in motors of the usual construction. The great inclination of the combustion line is due to the rapid increase of volume of the burning gases as the piston travels out, and also to the consequent lower rate of flame propagation and combustion on account of the rarefication of the charge by the movement of the piston.

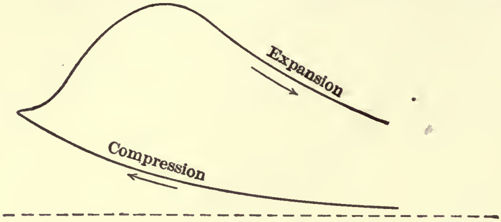

Fig. 109.

In Fig. 110 the ignition is extremely late, not occurring till the piston has moved out some distance on the impulse stroke. The completion of compression and the early part of the impulse stroke are therefore the same as for a cut-out stroke of a hit-or-miss governed motor. The combustion line rises very slowly on account of the comparative low pressure of the charge at the time of ignition and the consequent slower rate of flame propagation; also on account of the speed of piston travel being greater after the piston has moved out some distance on the impulse stroke than it is near the beginning of the stroke.

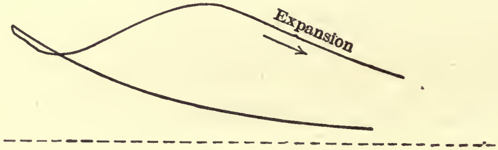

Fig. 110.

Fig. 111 indicates extremely early ignition. The explosion pressure rises to its maximum before the completion of the compression stroke, and then drops before the piston has moved far out on the impulse stroke, thus causing a loop at the top of the card. The area of this loop indicates retarding action on the motion of the piston. The pressure falls so as to make a low expansion line.

The area of the impulse card is the difference of the areas of the two upper loops in a complete card. This condition could hardly exist for any considerable length of time in a single-cylinder, single-acting motor, on account of the small amount of power that the motor would deliver. But it can occur continuously in one cylinder of a multi-cylinder motor, as on account of a defect in the timer affecting that cylinder only, and the motor will continue to run by the impulses of the other cylinders.

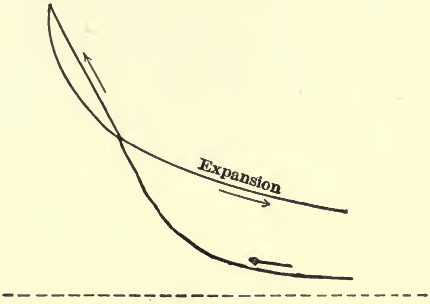

Fig. 111.

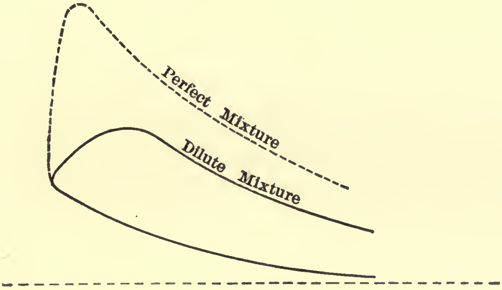

Fig. 112.

183. A dilute mixture gives the full-line part diagram of Fig. 112 in comparison with the broken-line part diagram for a normal mixture in the same figure. The greater inclination of the combustion line and the lower maximum pressure for the dilute mixture are both due to the slower rate of combustion and the smaller amount of total heat liberated by combustion of the charge.

184. Variation of Compression Effects on the Indicator Diagram. — Fig. 113 shows two diagrams such as come from a motor when its compression is changed while all the other conditions remain the same, including the weight and heat value of the charge.

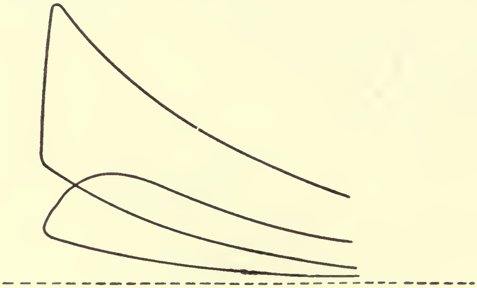

Fig. 113.

185. Speed Variation Effects on the Indicator Diagram. — Changing the speed of the motor while all the other conditions remain constant has an effect on the diagram that is of the same nature as diluting the mixture. It may be remembered that increasing the speed of rotation of a motor causes the ignition to become later for any form of electric ignition apparatus other than the interrupted-current type with contact points separated by the action of rigid mechanism. The writer's experience with a four-cylinder motor having the latter type of ignition system, operating at too high a speed to take indicator cards, has been that the motor gives practically its maximum torque at high and low speeds without changing the time of ignition when the speed varied from 300 to more than 1000 revolutions per minute. The speed of rotation of the electric generator was proportional to that of the motor. A stronger or "hotter" arc was therefore drawn at the igniter at high speed than at low. This naturally tended to decrease the time interval between the separation of the contact points and the complete inflammation of the charge, and thus to counteract, in a measure at least, the effect of the increased speed in modifying the form of the indicator diagram.

But when the jump-spark ignition system with an induction coil and vibrating interrupter was put into action and the other thrown out, a very considerable advance of the *timer* was necessary to obtain the maximum torque at high speed when the motor was speeded up.

Therefore, could indicator diagrams have been taken in this latter case, there would undoubtedly have been a greatly inclined combustion line and low explosion pressure when the speed was increased and before the timer was advanced.

CHAPTER XV.

ECONOMY AND EFFICIENCY.

186. Units of Heat Energy and Mechanical Energy. — The function of the internal-combustion motor is to transform the heat energy of the fuel into mechanical energy which is delivered to machinery or other apparatus that is driven by the power developed by the motor.

In order to deal with the economy and efficiency of the transformation, it is necessary to select units for measuring the heat energy and the mechanical energy.

The foot-pound (ft.-lb.) is the unit of measure of mechanical energy most used in this country. It is the energy required to lift one pound (avoirdupois) one foot high. (Strictly at about sea level. A mass that weighs one pound on spring scales at sea level weighs less at higher altitudes.)

The horsepower (h.p.) is the unit of the rate of working or of delivering mechanical energy. The mechanical value of a horsepower is 550 foot-pounds per second = 33,000 foot-pounds per minute = 1,980,000 foot-pounds per hour.

The British thermal unit (B.t.u.) is the measure of heat energy most used in this country. It is the amount of heat that will raise the temperature of one pound (avoirdupois) of water one degree by the Fahrenheit thermometer scale, starting from the temperature of maximum density of the water (39.1° F. about).

The heat value of a fuel is stated, in the discussion which follows, in the number of British thermal units that a specified quantity of the fuel, as a pound or a cubic foot, will give up when burned.*

The British thermal unit is equivalent to 778 foot-pounds of

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* For higher and lower heat values, and methods of determining, see chapter on Combustion and Heat Values.

mechanical energy transformed into heat, as by friction between two solid bodies. This is the generally accepted value.

If mechanical energy is transformed into heat at the rate of one horsepower during a period of one hour, the amount of heat produced will be 1,980,000 ÷ 778 = 2545 B.t.u. The relation between British thermal units and horsepower per hour, horsepower per minute, and horsepower per second, can therefore be written, for convenience:

One h.p.-hour = 2545 B.t.u.
One h.p.-min. = 42.416 B.t.u.
One h.p.-sec. = .70694 B.t.u.

187. Motor Economy Defined. — It is of course desirable to obtain as great an amount of mechanical energy from a given quantity of fuel as is possible under suitable conditions of operation, thus securing the greatest *economy of fuel* that is compatible with conditions exterior to the motor. Since the term "economy of fuel" does not have a definite meaning when applied to the internal-combustion motor, for the reason that a gas producer may be sometimes included in this economy and at other times not included, it is advisable to use the term *motor economy* when dealing with the motor only.

The unqualified terms *fuel economy of motor* and *motor economy* will be taken to mean either the amount of fuel or the heat value of all the fuel that is supplied to the motor per delivered horsepower per hour (D.h.p. or B.h.p. hour). The amount of fuel may be expressed in different ways, as pounds of coal, cubic feet of gas, pounds of combustible, British thermal units, etc.

Motor economy does not have any assumed conditions under which the delivered mechanical energy is equal to the equivalent heat energy of the fuel that it receives.

If a motor is operating on suction producer gas and drawing the gas through and from the producer by its own power, it will require more pounds of fuel gas to deliver a horsepower than if the motor received the same gas at atmospheric pressure or from gas mains at a pressure higher than atmospheric. More power is required to pump or draw the gas through the producer into the motor than from the atmosphere direct. This additional power must be furnished by a part of the mechanical energy produced by the combustion of the gas in the motor.

188. Motor Efficiency Defined. — The measure of the economy of the motor is the ratio between the amount of energy that it delivers during a specified time and the amount of energy that is supplied by the fuel during the same time. The former is equal to the product obtained by multiplying the rate of working (D.h.p.) by the time of working. The two quantities of the ratio must be expressed in the same units. This can be done by multiplying the delivered horsepower hours by the value of one horsepower-hour = 2545 British thermal units.

The following are convenient forms for expressing the efficiencies:

$$\text{Motor efficiency} = \frac{2545\ (\text{D.h.p.})\ \text{hours}}{\text{B.t.u. of all fuel used}},$$

or

$$\text{Motor efficiency} = \frac{2545}{\text{B.t.u. of fuel used per h.p. per hour}},$$

in both of which the numerator represents the number of B.t.u.'s that are equivalent to the delivered mechanical energy.

In the case of a motor whose piston diameter = 11 inches, stroke = 12 inches, running at 290 revolutions per minute, and whose guaranteed fuel economy is 1200 B.t.u. per delivered horsepower per hour, the

$$\text{Motor efficiency} = \frac{2545 \times 1 \times 1}{1200} = .212 = 21.2 \text{ per cent.}$$

And in another motor whose piston diameter = 18 inches, stroke = 19 inches, running at 180 r.p.m. and guaranteed to deliver one horsepower-hour at a fuel consumption of 10.5 cubic feet of gas whose lower heat value is 1050 B.t.u. per cubic foot at the temperature and pressure at which the gas is delivered to the motor, the

$$\text{Motor efficiency} = \frac{2545 \times 1 \times 1}{10.5 \times 1050} = .231 = 23.1 \text{ per cent.}$$

Another motor with piston diameter = 8.5 inches, stroke = 12.75 inches, running at 300 r.p.m., is guaranteed to run 10 hours on full load of 17 h.p. (D.h.p.) with a total consumption of 17 gallons of commercial gasoline.

The heat value of gasoline has not been accurately determined on account of difficulty in getting accurate calorimetric results. Neither is the heat value the same for all gasoline. It probably lies between 18,000 and 21,000 B.t.u. per pound. The specific gravity of gasoline is different for the different grades. It may be taken as .65 for this case. The weight of a gallon of pure water at a temperature of 62° F. is 8.3356 pounds. The weight of a gallon of gasoline at 62° F. closely approximates $.65 \times 8.3356 = 5.42$ pounds. Taking the heat value of the gasoline as 20,000 B.t.u., the

$$\text{Motor efficiency} = \frac{2545 \times 17 \times 10}{17 \times 5.42 \times 20{,}000} = .2347 = 23.47 \text{ per cent.}$$

A quite commonly accepted standard of fuel economy of small motors is one pint of gasoline per horsepower per hour. A pint of gasoline weighs about .678 pounds at 62° F. If the heat value is taken as 20,000 B.t.u. per pound, then the

$$\text{Motor efficiency} = \frac{2545 \times 1 \times 1}{.678 \times 20{,}000} = .1877 = 18.77 \text{ per cent.}$$

If the heat value of the gasoline is taken at 18,000 B.t.u. per pound, then the

$$\text{Motor efficiency} = \frac{2545 \times 1 \times 1}{.678 \times 18{,}000} = .2085 = 20.85 \text{ per cent.}$$

Under favorable conditions large gas engines reach a motor efficiency as high as 30 per cent, corresponding to a fuel economy of 8480 B.t.u. per brake horsepower (delivered horsepower) per hour.

189. Impulse-Output Efficiency. — The mechanical power that the motor delivers (D.h.p.), which may be called the output of the motor, is what remains of the indicated impulse power

(I.h.p.I) after deducting from it (*a*) the power lost on account of the mechanical friction of the motor, (*b*) the power required to pump or force the charge into the combustion cylinder, and (*c*) possibly some other small consumption of power such as that for driving an oil pump. The latter would generally be taken as part of the mechanical friction of the motor.

The impulse-output efficiency is the ratio of the output to the indicated horsepower as determined from the impulse loop of the indicator diagram. The equation for it is

$$\text{Impulse-output efficiency} = \frac{\text{D.h.p.}}{\text{I.h.p.I}}.$$

This ratio is sometimes called the mechanical efficiency of the motor, but this seems hardly correct, since the value of the ratio is changed by variation of the pressure at which the fuel gas is received, or drawn to the intake of the motor. Thus the ratio has a different value when the gas is drawn through a suction producer by the motor, as compared with its value when the gas is received at atmospheric pressure, even though the friction losses in the motor remain unchanged.

Applying the last equation to a motor whose piston diameter = 6.75 inches (piston area = 35.78 square inches, there being no piston rod in the combustion chamber), stroke = 15.5 inches, running at 260 r.p.m. and taking 126 charges per minute, whose average M.e.p.I is 102 pounds per square inch, and whose D.h.p. = 15.32, first finding the I.h.p.I, gives

$$\text{I.h.p.I} = \frac{(\text{M.e.p.I})\, ALY}{33{,}000} = \frac{102 \times 45.78 \times 15.5 \times 126}{33{,}000} = 18.1$$

and

$$\text{Impulse-output efficiency} = \frac{15.32}{18.1} = .846 = 84.6 \text{ per cent.}$$

190. Mechanical Efficiency of Motor. — The mechanical efficiency of the motor is the ratio of the output (D.hp.) to the net indicated power (I.h.p.N). The mean effective pressure of the pumping diagram of the motor referred to in the preceding section is too small to be determined accurately, and no low-spring card was taken. It will be assumed that the mean effective pressure of the pumping card (M.e.p.R) = two pounds per square inch. The M.e.p.I is 102 pounds per square inch. Therefore the M.e.p.N = 102 − 2 = 100 pounds per square inch. The net indicated horsepower is

$$\text{I.h.p.N} = \frac{(\text{M.e.p.N})\,ALY}{33{,}000} = \frac{100 \times 45.78 \times 15.5 \times 126}{33{,}000} = 17.74,$$

and the

$$\text{Mechanical efficiency} = \frac{\text{D.h.p.}}{\text{I.h.p.N}} = \frac{15.32}{17.74} = .864 = 86.4 \text{ per cent.}$$

This is but slightly different from the impulse-output efficiency, but in a case like that shown in Fig. 77, where the pumping loop is large, there is a very marked difference between the two efficiencies.

In a two-cycle motor the average rate of the work of precompressing the charges so as to force them into the combustion cylinder is to be deducted from the average impulse rate of working in order to obtain the net indicated horsepower.

191. Thermodynamic or Thermal Efficiency of the Motor. — This is the efficiency of transforming heat into mechanical energy. It is the ratio of the mechanical energy delivered to the piston to that of the heat energy liberated by the combustion of the fuel, as applied to a combustion motor. Both quantities must be expressed in the same unit of measure. The energy delivered to the piston is that of the impulse stroke as determined from the impulse loop of the indicator diagram. Remembering that one horsepower-hour equals 2545 British thermal units, the equation can be written,

$$\text{Therm. efficiency} = \frac{2545\ (\text{I.h.p.I})\ \text{hours}}{\text{B.t.u. of all fuel used}},$$

or

$$\text{Therm. efficiency} = \frac{2545}{\text{B.t.u. of all fuel used per I.h.p.I per hr.}},$$

in both of which B.t.u. represents the amount of heat given up by the fuel to produce the mechanical energy represented by the numerator of the fraction.

Applied to a motor whose impulse loop of the diagram represents twenty horsepower (20 h.p.) and which operates on 1.7 gallons of gasoline per hour, taking the heat value of the gasoline as 20,000 B.t.u. per pound and the weight as 5.42 pounds per gallon, the

$$\text{Therm. efficiency} = \frac{2545 \times 20 \times 1}{1.7 \times 5.42 \times 20{,}000} = .276 = 27.6 \text{ per cent.}$$

In a motor with piston diameter = 15.185 inches, stroke = 18 inches, running at 175 r.p.m. per minute with an indicated horsepower (I.h.p.I) = 75 and a delivered horsepower (D.h.p.) = 65.1, using 10.5 cubic feet of gas having a heat value of 1050 B.t.u. per cubic foot, the

$$\text{Therm. efficiency} = \frac{2545 \times 75 \times 1}{65.1 \times 10.5 \times 1050} = .266 = 26.6 \text{ per cent.}$$

192. Plant Economy and Efficiency. — In the case of a suction gas producer operating in connection with an internal-combustion motor, when the power plant is entirely self-contained and there is no demand for power or fuel from outside the plant to operate auxiliary apparatus, the fuel economy of the plant may be expressed as the amount of fuel fed to the producer per delivered horsepower per hour. The amount of fuel may be stated as pounds of coal, or pounds of combustible, etc., per horsepower per hour.

If fuel is used outside the producer for operating auxiliary apparatus, then the total amount of fuel, or of combustible, etc., must be taken into consideration in stating the economy of the plant. When steam or mechanical or electrical energy from some exterior source is used, and the fuel for developing the power or generating the steam cannot be determined, then the value of the external energy in foot-pounds or B.t.u. may be taken as a basis for determining the equivalent amount of fuel that would have to be used if the power were generated from fuel at the plant under consideration. The details of the various steps depend so much on the conditions existing that it is hardly possible to give any general statement of the method to be followed other than that the efficiency of the transformation of the heat energy into mechanical energy may be taken the same as that of the complete plant as nearly as this efficiency can be determined.

The efficiency of a self-contained plant is the ratio of the delivered horsepower for any specified period of time to the heat value of the fuel fed to the producer during the same period. And when all the power used for the motor and auxiliary apparatus is generated from fuel whose amount can be directly determined, the efficiency is the ratio of the power delivered to the heat value of the fuel used. For these two cases the mathematical expression of the efficiency is

$$\text{Plant efficiency} = \frac{2545 \times \text{D.h.p.} \times \text{hours}}{\text{B.t.u. of all fuel used}},$$

or

$$\text{Plant efficiency} = \frac{2545}{\text{B.t.u. of all fuel used per D.h.p. per hr.}}.$$

193. **Comparison of Efficiencies.** — In comparing motors with regard to either their motor efficiency, impulse-output efficiency, or their thermodynamic efficiency, and also in comparing plant efficiencies, it should be carefully observed that corresponding heat values of the fuel are used in all cases. Either the higher heat values should be used for all cases or the lower heat values should be used for all.

A discussion of heat values is taken up in the chapter on Combustion and Heat Values.

CHAPTER XVI.

PHYSICAL PROPERTIES OF GASES.

194. Introductory to the matter to follow, some of the laws of perfect (or assumed to be perfect) gases will be stated. These are the laws which some of the actual gases follow more or less closely, and which a "perfect" gas would follow absolutely if such a gas were existent.

Within certain limited ranges of temperature not greatly removed from atmospheric conditions, the actual gases follow the laws of a perfect gas with sufficient accuracy to allow them to be considered perfect gases for the purposes of this work. This does not apply to temperatures as high as those of combustion, or, in some cases, even as high as the temperatures produced by compression in the combustion motor.

At temperatures as high as those at which the burned gases are discharged from a combustion motor, the actual gases depart so far from the laws of a perfect gas that any assumption that they follow the perfect gas laws even approximately will lead to totally erroneous results.

195. Density and Weight of Gases. — The density of a gas is its heaviness or weight referred to some standard. The standard may be another gas whose density is taken as unity, or a unit of weight used in connection with a unit volume. For the present purpose it is convenient to express the density in pounds per cubic foot.

The specific volume of a gas is the space occupied by a given weight or mass of it. It will be expressed in cubic feet per pound. The specific volume in cubic feet per pound is equal to the reciprocal of the weight in pounds per cubic foot.

Since changes in temperature and pressure affect the volume of a given weight of gas, the density and specific volume must be given with reference to a definite temperature and pressure.

TABLE I.

DENSITY AND SPECIFIC VOLUME OF GASES.

14.7 lbs. per sq. in. = **2116.8** lbs. per sq. ft. pressure.

Name.	Chemical Form.	Density. Lbs. per Cu. Ft.		Specific Volume. Cu. Ft. per Lb.	
		32° F.	62° F.	32° F.	62° F.
Oxygen	O_2	.0893	.0841	11.20	11.90
Nitrogen	N_2	.0785	.0739	12.73	13.53
Carbon dioxide	CO_2	.1227	.1156	8.15	8.65
Air	....	.0807	.07612	12.39	13.14
Hydrogen	H_2	.0056	.00528	178.2	189.4
Carbon monoxide	CO	.0780	.0736	12.82	13.61
Methane or marsh gas	CH_4	.0447	.0421	22.39	23.75
Ethylene or olefiant gas	C_2H_4	.0780	.0735	12.82	13.60
Propylene	C_3H_6	.1172	.1104	8.53	9.06
Benzene vapor or benzol.*	C_6H_6	.2173	.2048	4.60	4.88

* This is not the benzine from petroleum.

In Table I the densities and specific volumes of the gases with which the combustion motor is most concerned are given for atmospheric pressures and temperatures of 32° F. and 62° F.

196. Laws of a Perfect Gas. — A perfect gas is one which in passing through changes of temperature, pressure, and volume, behaves in accordance with the following laws, using **absolute temperatures and pressures:**

Pressure varies inversely as the volume when the temperature is constant. (Law of Mariotte and Boyle.)

Pressure varies directly as the absolute temperature when the volume is constant.

Volume varies directly as the absolute temperature when the pressure is constant. (Law of Charles.)

* Specific heat (per unit weight) is constant for all temperatures and pressures. This refers to both the specific heat of constant volume and the specific heat of constant pressure. The values of these specific heats are different for any gas, but each has its own constant value peculiar to that perfect gas.

The absolute pressure zero is about 14.7 pounds per square inch below atmospheric pressure near sea level.†

The zero of absolute temperature is about 459 degrees below the ordinary Fahrenheit zero (−459° F.). To obtain the absolute temperature corresponding to any reading of the Fahrenheit thermometer, 459 degrees must be added to the reading.

Absolute temp. Fahr. = Thermometer reading + 459° F.

The volume change of a perfect gas for each Fahrenheit degree change of temperature (at any temperature) is $\frac{1}{491}$ of its volume at 32° F. when the pressure remains constant. If the volume of the gas at 32° F. is 491 cubic feet, then at 31° F. it will be 490 cubic feet; at 22° F. 481 cubic feet; at zero F. by the thermometer it will be 459 cubic feet; and at − 459° F., which is the absolute zero, its volume will be zero theoretically for the perfect gas.

At a temperature of 33° F. the volume of the gas will be 492 cubic feet; at 62° F. it will be $491 + (62 - 32) = 491 + 30 = 521$ cubic feet.

The pressure change of a perfect gas for each Fahrenheit degree change of temperature (at any temperature) is $\frac{1}{491}$ of its pressure at 32° F. when the volume remains constant. The pressure at absolute zero is therefore zero.

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* The term "specific heat" without further qualification is understood to mean the specific heat of unit weight. Volumetric specific heat is also used. The latter is the specific heat of unit volume and is variable with changes of temperature and pressure if the specific heat per unit weight is constant, or in any case except where the specific heat per unit weight varies inversely as the temperature and pressure.

† A sufficiently accurate approximation of the decrease of pressure with increase of altitude, for the present purpose, is one-half pound per square inch decrease of pressure for each 1000 feet of altitude.

The above laws of a perfect gas may be expressed mathematically as follows:

$$\left.\begin{aligned} \frac{P_1}{P_2} &= \frac{T_1}{T_2} \\ P_1T_2 &= P_2T_1 \end{aligned}\right\} \text{For constant volume.}$$

$$\left.\begin{aligned} \frac{V_1}{V_2} &= \frac{T_1}{T_2} \\ V_1T_2 &= V_2T_1 \end{aligned}\right\} \text{For constant pressure.}$$

$$\left.\begin{aligned} \frac{V_1}{V_2} &= \frac{P}{P_1} \\ P_1V_1 &= P_2V_2 \end{aligned}\right\} \text{For constant temperature.}$$

In each of these equations the same subscript indicates coincident values, and the notation is:

P = absolute pressure. (The zero pressure is at 14.7 lbs. per sq. in. = 2116.8 lbs. per sq. ft. below atmospheric pressure at sea level);
V = volume;
T = absolute temperature. (The zero temperature is at −459° F., which is 491° F. below the freezing point of water at atmospheric pressure);
P_1, V_1, T_1 = the initial condition;
P_2, V_2, T_2 = the changed or final condition.

And, in accordance with the laws of a perfect gas,

$$\frac{P_1V_1}{P_2V_2} = \frac{T_1}{T_2}.$$

197. Example. — Find the weight of a cubic foot of air at a temperature of 102° F. and a pressure of 20 pounds per square inch absolute.

In Table I the density in pounds per cubic foot is given for both 32° F. and 62° F. at 14.7 pounds per square inch absolute pressure. The air can be reduced to its equivalent volume at either of these temperatures and its weight obtained by multiplying the volume at that temperature by the weight per cubic foot at the same temperature. The temperature of 62° F. will be taken as that at which the equivalent volume is to be found. The given quantities are:

Initial volume = 1 cu. ft.;
Initial temp. = 102° F. = 102 + 459 = 561° absolute F.;
Initial pres. = 20 lbs. per sq. in. absolute;
Final temp. = 62° F. = 62 + 459 = 521° absolute F.;
Final pres. = 14.7 lbs. per sq. in. absolute.

The computations will be made in two steps by first finding the change of volume due to the change of temperature at constant pressure and then the change of volume due to change of pressure at constant temperature.

The equations of section 196 can be applied. The subscript 1 will be taken to represent the initial conditions for the change under consideration for the moment, and the subscript 2 to represent the final condition of the same change.

The equation for the change at constant pressure, modified in form for convenience, is

$$V_2 = \frac{V_1 T_2}{T_1}.$$

The substitution of the initial values in this equation gives

$$V_2 = \frac{1 \times 521}{561} = .928 \text{ cu. ft.}$$

at 62° F. and 20 pounds per square inch pressure.

The equation for the change of pressure and volume at constant temperature, modified in form for convenience, is

$$V_2 = \frac{V_1 P_1}{P_2}.$$

The initial volume to be substituted in this case is the .928 cubic foot obtained by the last computation. By substituting this and the other quantities in the last equation it becomes

$$V_2 = \frac{.928 \times 20}{14.7} = 1.26 \text{ cu. ft.},$$

which is the volume at 62° F. and 14.7 pounds per square inch pressure.

The weight of air at this temperature and pressure, as given in Table I, is .07612 of a pound per cubic foot. The weight of a cubic foot of air at the given temperature of 102° F. and pressure of 20 pounds per square inch absolute, is therefore

$$1.26 \times .07612 = .096 \text{ lb.}$$

Instead of making the computations in two steps, as above, for reducing a cubic foot of gas at the observed temperature and pressure to its equivalent volume at 62° F. and 14.7 pounds per square inch pressure, the reduction can be made direct by the last equation of section 196. This equation, after transposing to a suitable form for application, is

$$V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}.$$

Whence, by substitution,

$$V_2 = \frac{20 \times 1 \times 521}{14.7 \times 561} = 1.26 \text{ cu. ft.}$$

198. The specific heat of a gas (per unit weight) is the amount of heat required to raise the temperature one degree. It is often given for two different conditions, one for constant pressure and the other for constant volume. It is convenient for the present purpose to express the specific heat in British thermal units per pound of gas.

TABLE II.

SPECIFIC HEATS OF GASES.

For Atmospheric Temperatures.

Gas.	Chemical Form.	Specific Heat. Can be taken as B.t.u. per Lb.					
		Per Pound.		Per Cu. Ft. at 14.7 Lbs. per Sq. In.			
		Constant Pressure.	Constant Volume.	Constant Pressure.		Constant Volume.	
				32° F.	62° F.	32° F.	62° F.
Oxygen	O_2	.2175	.155	.0194	.0183	.0138	.0130
Nitrogen	N_2	.2438	.173	.0191	.0180	.0136	.0128
Carbon dioxide	CO_2	.2170	.171	.0266	.0251	.0210	.0198
Air	......	.2375	.169	.0192	.0181	.0136	.0127
Hydrogen	H_2	3.409	2.406	.0191	.0180	.0135	.0127
Carbon monoxide	CO	.2479	.173	.0195	.0182	.0135	.0127
Methane or marsh gas	CH_4	.5929	.467	.0265	.0250	.0209	.0197
Ethylene or olefiant gas	C_2H_4	.4040	.332	.0343	.0297	.0259	.0244

The specific heat of constant volume (by weight) is the amount of heat, in British thermal units, that must be given to a pound of gas to raise its temperature one degree Fahrenheit while the volume remains unchanged. This corresponds to adding a B.t.u. of heat to a pound of gas enclosed in a vessel of fixed volume whose walls are impermeable to heat.

The specific heat of constant pressure (by weight) is the amount of heat that must be given to a pound of the gas to raise its temperature one degree Fahrenheit while the pressure remains constant. This corresponds to heating the gas in a vertical cylinder with a free frictionless piston closing the upper end, whose weight determines the gaseous pressure. When heat is added to the gas its temperature rises and it expands so as to lift the piston against the constant resistance of the weight of the piston (and also against atmospheric pressure if the latter acts on the exposed side of the piston), which gives a constant gas pressure.

The specific heat of constant pressure is greater than that of constant volume. At constant volume only enough heat is added to raise the temperature, but at constant pressure there must be enough heat added not only to increase the temperature but also to do the work of expanding the gas, as in the case of lifting the piston, just mentioned.

The specific heats just mentioned can be taken as practically constant for atmospheric temperatures. But for the high temperatures of combustion the specific heat has been found to increase rapidly with increase of temperature. Variation of pressure, dealing with pressures as high as those of the combustion motor, also causes variation of the specific heats.

199. Example. — Find the amount of heat necessary to raise the temperature of 3 pounds of carbon monoxide (CO) from 32° F. to 62° F. at atmospheric pressure.

This is a case of change of temperature at constant pressure. The specific heat of constant pressure for CO is given in Table II as .248 B.t.u. per pound. The amount of heat required to raise the temperature as stated is

$$3\,(62 - 32)\,.248 = 3 \times 30 \times .248 = 22.32 \text{ B.t.u.}$$

200. Volumetric Specific Heat. — It is sometimes convenient to use the amount of heat that will change the temperature of a unit volume (as a cubic foot) of gas one degree.

The volumetric specific heat of a cubic foot of gas at any temperature and pressure can be found by multiplying the specific heat of the gas in British thermal units per pound of the gas by the weight of the gas per cubic foot at the temperature and pressure taken. The specific heat by weight must be that for the temperature and pressure at which the gas is taken. The volumetric specific heat is really the specific heat of a weight of gas determined by the pressure and temperature. It is not the same at different temperatures or at different pressures.

In Table II the specific heats of the more important fuel gases for the combustion motor, and of the products of combustion, are given in British thermal units per pound and also per cubic foot for temperatures of 32° F. and 62° F. at atmospheric pressure.

201. **Example.** — Find the heat required to raise the temperature of 3 cubic feet of carbon monoxide (CO) from 32° F. to 62° F. at atmospheric pressure. The volumetric specific heat of CO is given in the table as .0195 B.t.u. per cubic foot for a constant pressure of 14.7 pounds per square inch pressure and at a temperature of 32° F. The amount of heat necessary for the required change is

$$3\ (62 - 32)\ .0195 = 3 \times 30 \times .0195 = 1.755 \text{ B.t.u.}$$

Example. — What amount of heat will a cubic foot of CO give out while cooling from 62° F. to 32° F. at atmospheric pressure?

The volumetric specific heat of CO at 62° F. and 14.7 pounds per square inch pressure is given in the table as .0182 for constant pressure. The heat given out during the change will be

$$3\ (62 - 32)\ .0182 = 3 \times 30 \times .0182 = 1.638 \text{ B.t.u.}$$

CHAPTER XVII.

COMBUSTION AND HEAT VALUES.

202. Combustion and Volumetric Change Due to Combustion. — Combustion, taken in the broadest sense, is the chemical combination of elements or compounds accompanied by the liberation or production of heat. As used in relation to the internal-combustion motor and to the manufacture of combustible gases from solid and liquid fuels for the motor, combustion means, as has been previously stated, the chemical union of oxygen with the carbon, hydrogen, or other chemical elements and compounds in the fuel. Carbon, hydrogen, the hydrocarbons (which are numerous compounds of hydrogen and carbon in different proportions), and carbon monoxide are practically all the fuels that are considered, however.

The volume of the gaseous products of combustion differs in many cases from that of the combustible mixture that is burned when both the combustible mixture and the gaseous products of combustion are brought to and compared at the same temperature and pressure. In some cases there is a decrease of specific volume due to combustion, in others an increase, and in still others no change of specific volume.

If hydrogen and oxygen are chemically combined by burning, the volume of the steam formed is less than that of the mixture of hydrogen and oxygen before combustion, both taken at the same temperature, as just stated. This is shown by the following chemical equation, which deals with molecular quantities.

$$\overset{\text{2 vol.}}{2\,H_2} + \overset{\text{1 vol.}}{O_2} = \overset{\text{2 vol.}}{2\,H_2O} \qquad \text{(Hydrogen. Contraction} = \tfrac{1}{3}.)$$

The same contraction is shown in the combustion of carbon monoxide burned to carbon dioxide, as follows:

$$\overset{\text{2 vol.}}{2\,CO} + \overset{\text{1 vol.}}{O_2} = \overset{\text{2 vol.}}{2\,CO_2} \qquad \text{(Carbon monoxide. Contraction} = \tfrac{1}{3}.)$$

In both the above cases three volumes of the combustible mixture (two volumes of hydrogen and one of oxygen in the first case, and in the second case two volumes of carbon monoxide and one of oxygen) produce two volumes of gas by burning. The volume of the burned gases is only two-thirds that of the mixture in each case.

But in the combustion of marsh gas (methane) there is no change of volume, and the same is true of ethylene (olefiant gas), as shown in the two following equations.

$$\overset{\text{1 vol.}}{CH_4} + \overset{\text{2 vol.}}{2\,O_2} = \overset{\text{1 vol.}}{CO_2} + \overset{\text{2 vol.}}{2\,H_2O} \quad \text{(Methane. Volume change} = 0.)$$

$$\overset{\text{1 vol.}}{C_2H_4} + \overset{\text{3 vol.}}{3\,O_2} = \overset{\text{2 vol.}}{2\,CO_2} + \overset{\text{2 vol.}}{2\,H_2O} \quad \text{(Ethylene. Volume change} = 0.)$$

In each of the last two cases three volumes of the combustible mixture produce three volumes of the burned gases.

Propylene and benzol both show an increase of volume in the products of combustion, as the following two equations indicate.

$$\overset{\text{2 vol.}}{2\,C_3H_6} + \overset{\text{9 vol.}}{9\,O_2} = \overset{\text{6 vol.}}{6\,CO_2} + \overset{\text{6 vol.}}{6\,H_2O} \quad \text{(Propylene. Expansion} = \tfrac{1}{11}.)$$

$$\overset{\text{2 vol.}}{2\,C_6H_6} + \overset{\text{15 vol.}}{15\,O_2} = \overset{\text{12 vol.}}{12\,CO_2} + \overset{\text{6 vol.}}{6\,H_2O} \quad \text{(Benzol. Expansion} = \tfrac{1}{17}.)$$

Contraction of volume, at equal temperatures and pressures, by combustion has the effect of reducing the pressure that would be produced by combustion if there were no contraction of volume. The indicator diagram takes into account such variation of volume by combustion. The reduction of volume is not as great when air is used to furnish the oxygen for combustion as is shown by the above equations, which deal only with the chemically active constituents of the combustible mixture. The residual inert (burned) gases in the motor cylinder also help to reduce the ratio of contraction. There is therefore a certain advantage, in relation to contraction, in having the combustible mixture diluted with the nitrogen of the air and by the inert residual gases of a preceding combustion.

There is also an advantage in the dilution of the combustible mixture on account of keeping down the temperature of the products of combustion in view of the fact that the specific heat increases rapidly with the rise of temperature for temperatures as high as those of combustion, under the conditions of operation of the combustion motor.

203. Complete and Incomplete Combustion. — Complete combustion is the combination of chemical elements in the proportion to form their most stable compound.

Incomplete combustion with oxygen is the process of the chemical union of the fuel element with the oxygen in a proportion that produces a compound which is not stable in the presence of more oxygen under proper conditions for adding more of the oxygen to the compound.

As an example, carbon combines with oxygen in either of two proportions, according to the conditions of combustion, to form either CO or CO_2. When there is enough oxygen present, CO_2 is formed. An excess of oxygen does not modify this proportion of combination. The change from C to CO_2 is complete combustion, for if the CO_2 is heated in the presence of more oxygen it will not combine with any more of it.

But if there is just enough oxygen present to combine with the carbon to form CO, then all the carbon will burn to CO. This is incomplete combustion. The CO is not a stable compound, for if it is mixed with more oxygen and ignited, all or part of the CO will burn to CO_2 according to the amount of free oxygen present.

If there is more than enough oxygen present with the carbon to form CO, but not enough to form CO_2 of all the carbon, then burning the mixture will produce both CO and CO_2 in such proportions as will take up all the oxygen. This action is also called incomplete combustion in engineering practice.

The chemical reactions of combustion are expressed in the following atomic equations:

$C + 2\,O = CO_2$. Complete combustion of carbon.
$C + O = CO$. Incomplete combustion of carbon.
$CO + O = CO_2$. Complete combustion of CO.

The first equation represents the change that occurs when coke or charcoal is burned with a plentiful supply of air and the temperature of the fuel is kept high, as indicated by a white heat. The second equation indicates the change if there is but a scant supply of air and the fuel shows only a red heat. The third equation is the expression for the combustion of the unstable product, CO, of incomplete combustion of carbon.

204. **Heat of Combustion is Constant.** — The chemical combination of carbon with oxygen in the proportion to form carbon dioxide, CO_2, always liberates the same amount of heat, whether the rate of combustion is rapid or slow. The amount of heat liberated is also always the same whether the combination is made directly into the form CO_2, or first into CO and then from CO to CO_2. The heat liberated while changing from C to CO is always a fixed amount, and so is that for the combination of CO with O to form CO_2. The sum of the amounts of heat produced during the last two steps (C to CO and the resulting CO to CO_2) is equal to that produced during the direct change from C to CO_2.

In the same manner, hydrogen always liberates the same amount of heat when combined with oxygen to form water vapor or steam, H_2O. The other combustible elements and compounds follow the same law.

When a number of different kinds of gases, as H, CO, CH_4, etc., are mechanically mixed together, as in the case of power gas and illuminating gas, the heat liberated by the combustion of the mixture is the same in amount as if each constituent (H, CO, CH_4, etc.) were burned separately and all the heat thus produced added together. This does not apply to the breaking up of a chemical compound (such as CH_4) into its elements.

205. **The heat value or calorific power of a fuel,** when not qualified more definitely, is ordinarily understood to mean the amount of heat that is liberated by burning a unit weight or a unit volume of the fuel and bringing the temperature and pressure of the products of combustion back to the same values that the fuel and the supporter of combustion (generally air) had before ignition. Since it is practically impossible to maintain such a final pressure and temperature during the burning of the fuel in

a calorimeter, the necessary corrections in the readings obtained are made to secure the same result as if the initial and final temperatures and pressures had been the same. And since water is used in the calorimeter to take up the heat of combustion, both the initial and final temperatures at the calorimeter are necessarily below the boiling point of water. The water vapor produced by combustion when hydrogen is present is therefore condensed into liquid water.

The proportions by weight in which the fuel and oxygen combine, the weight of air necessary to supply the required oxygen when air is used in accordance with the method of commercially burning any fuel, and the weight of the resulting products of combustion can all be determined by the aid of the chemical equations and atomic weights of the chemical elements. In the following illustrative equations, the atomic weights are taken for convenience in the approximate round numbers commonly used for such purposes.

TABLE III.

APPROXIMATE ATOMIC WEIGHTS.

Substance.	Symbol.	Atomic Weight.
Carbon	C	12
Hydrogen	H	1
Oxygen	O	16

The accurate atomic weight of hydrogen as reported by the American Chemical Society is 1.008.

The relative proportions by weight in which CO and oxygen combine are shown in the equation

$$\begin{array}{cccccl} CO & + & O & = & CO_2 & \\ 28 & & 16 & & 44 & \text{Proportions by weight.} \end{array}$$

When one pound of CO is burned to CO_2, the weight of the oxygen required and the weight of the products of combustion are directly obtained by dividing the above equation by 28 (which is the weight of CO burned as represented in the above equation) with the following result.

$$\begin{array}{lccccc} & \mathrm{CO} & + & \mathrm{O} & = & \mathrm{CO_2} \\ \text{Pounds.} & 1 & & .57 & & 1.57 \end{array}$$

When the oxygen is supplied by bringing air into contact with the fuel, the weight of the air required and of the resulting products is obtained in a similar manner.

Air is composed chiefly of oxygen and nitrogen in the proportion of 1 part oxygen and 3.326 parts nitrogen by weight. Water vapor is also present in variable amounts. To get the .57 pounds of O that must be supplied, there must be $4.326 \times .57 = 2.470$ pounds of air, neglecting moisture, of which $2.47 - .57 = 1.9$ pounds are nitrogen. The nitrogen remains chemically inert during combustion. The chemical equation is

$$\begin{array}{lccccc} & \mathrm{CO} & + & \mathrm{O} & = & \mathrm{CO_2} \\ \text{Pounds.}\left\{\begin{array}{l} \\ \\ \\ \end{array}\right. & \begin{array}{l} 1 \\ \\ \\ \end{array} & & \begin{array}{l} .57 \\ 1.90\text{ N} \\ \hline 2.47\text{ Air.} \end{array} & & \begin{array}{l} 1.57 \\ 1.90\text{ N} \\ \hline 3.47\text{ Products.} \end{array} \end{array}$$

When carbon is burned to CO_2 the equations similar to the above two are

$$\begin{array}{ccccc} \mathrm{C} & + & \mathrm{O} & = & \mathrm{CO} \\ 12 & & 16 & & 28\text{ Proportions by weight.} \end{array}$$

and

$$\begin{array}{lccccc} & \mathrm{C} & + & \mathrm{O} & = & \mathrm{CO} \\ \text{Pounds.}\left\{\begin{array}{l} \\ \\ \\ \end{array}\right. & \begin{array}{l} 1 \\ \\ \\ \end{array} & & \begin{array}{l} 1.33 \\ 4.43\text{ N} \\ \hline 5.76\text{ Air.} \end{array} & & \begin{array}{l} 2.33 \\ 4.43\text{ N} \\ \hline 6.76\text{ Products.} \end{array} \end{array}$$

The additional air for burning the products, as determined in the last equation, to CO_2, and the resulting final products, are

$$\begin{array}{lccccc} & \mathrm{CO} & + & \mathrm{O} & = & \mathrm{CO_2} \\ \text{Pounds.}\left\{\begin{array}{l} \\ \\ \\ \end{array}\right. & \begin{array}{l} 2.33 \\ 4.43\text{ N} \\ \hline 6.76 \end{array} & & \begin{array}{l} 1.33 \\ 4.43\text{ N} \\ \hline 5.76\text{ Air.} \end{array} & & \begin{array}{l} 3.66 \\ 8.86\text{ N} \\ \hline 12.52\text{ Products.} \end{array} \end{array}$$

When carbon is burned directly to CO_2 in air,

$$\begin{array}{ccccccl} C & + & 2\,O & = & CO_2 & & \\ 12 & & 32 & & 44 & & \text{Proportions by weight.} \end{array}$$

and

$$\begin{array}{l} \begin{array}{ccccccc} \qquad\qquad & C & + & 2\,O & = & CO_2 & \end{array} \\ \text{Pounds.}\left\{\begin{array}{llll} 1 & 2.66 & & 3.66 \\ & 8.86\ N & & 8.86\ N \\ & \overline{11.52}\ \text{Air.} & & \overline{12.52}\ \text{Products.} \end{array}\right. \end{array}$$

By adding together the heat of burning one pound of carbon to CO, which is 4206 B.t.u., and that of burning the resulting $2\frac{1}{3}$ pounds of CO to CO_2, which is $2\frac{1}{3} \times 4476 = 10{,}444$ B.t.u., the sum,

$$4206 + 10{,}444 = 14{,}650 \text{ B.t.u.,}$$

is the same as the heat produced by burning the pound of carbon direct to CO_2.

The proportions by volume for the burning of CO with O are shown in the following molecular equation.

$$\begin{array}{cccccl} 2 & & 1 & & 2 & \text{Volume proportions.} \\ 2\,CO & + & O_2 & = & CO_2 & \\ 56 & & 32 & & 88 & \text{Weight proportions.} \end{array}$$

The burning of one cubic foot of CO in air is represented in the following equation, in which the volumes are taken at 62° F. and 14.7 pounds per square inch pressure.

$$\begin{array}{lccccc} \text{Cu. ft.}\left\{\begin{array}{l} \\ \\ \\ \end{array}\right. & \begin{array}{c} \\ \\ 1 \end{array} & & \begin{array}{l} 2.39\ \text{Air.} \\ \overline{1.89}\ N \\ \quad .50 \end{array} & & \begin{array}{l} 2.89\ \text{Products.} \\ \overline{1.89}\ N \\ 1.00 \end{array} \\ & CO & + & O & = & CO_2 \\ \text{Pounds.} & .0736 & & .0421 & & .1157 \end{array}$$

The cubic feet of oxygen and air involved in burning one pound of carbon to CO, and then burning the resulting CO to CO_2, are shown in the next two equations.

Cu. ft.			75.8 Air.		91.7 Products.
			60.0 N		60.0 N
			15.8		31.7
	C	+	O	=	CO
Pounds.	1		1.33		2.33

Cu. ft.	91.7		75.8 Air.		151.7 Products.
	60.0 N		60.0 N		120.0 N
	31.7		15.8		31.7
	CO	+	O	=	CO_2
Pounds.	$2\frac{1}{3}$		$1\frac{1}{3}$		$3\frac{2}{3}$

For one pound of carbon burned direct to CO_2 the following applies:

Cu. ft.			151.7 Air.		151.7 Products.
			120.0 N		120.0 N
			31.7		31.7
	C	+	2 O	=	CO_2
Pounds.	1		$2\frac{2}{3}$		$3\frac{2}{3}$

And for one pound of CO burned to CO_2:

Cu. ft.			32.5 Air.		39.3 Products.
			25.7 N		25.7 N
	13.59		6.8		13.6
	CO	+	O	=	CO_2
Pounds.	1		.57		1.57

Dealing with hydrogen in a similar manner, the equation for relative weights is

$$\underset{2}{2\,H} + \underset{16}{O} = \underset{18}{H_2O}$$ Weight proportions.

And for the volumetric proportions:

$$\overset{2}{2\,H_2} + \overset{1}{O_2} = \overset{2}{2\,H_2O}$$ (Steam).

The weight and volume proportions of the gases involved in the combustion of hydrogen in air are given in the following equation for one pound of hydrogen.

$$\begin{array}{llcccc}
 & & & \underline{455}\ \text{Air.} & & \underline{550}\ \text{Products.}\\
\text{Cu. ft.} & \left\{\right. & & 360\ \text{N} & & 360\ \text{N}\\
 & 190 & & 95 & & 190\\
 & 2\,\mathbf{H} & + & \mathbf{O} & = & \mathbf{H_2O}\\
 & 1 & & 8 & & 9\\
\text{Pounds.} & \left\{\right. & & \underline{26.6}\ \text{N} & & \underline{26.6}\ \text{N}\\
 & & & 34.6\ \text{Air.} & & 35.6\ \text{Products.}
\end{array}$$

And for one cubic foot of hydrogen:

$$\begin{array}{llcccc}
 & & & \underline{2.39}\ \text{Air.} & & \underline{2.89}\ \text{Products.}\\
\text{Cu. ft.} & \left\{\right. & & 1.89\ \text{N} & & 1.89\ \text{N}\\
 & 1 & & 50 & & 1.00\\
 & 2\,\mathbf{H} & + & \mathbf{O} & = & \mathbf{H_2O}\\
 & .00528 & & .04205 & & .0473\\
\text{Pounds.} & \left\{\right. & & \underline{.13968}\ \text{N} & & \underline{.1397}\ \text{N}\\
 & & & .17175\ \text{Air.} & & .1870\ \text{Products.}
\end{array}$$

206. Economy and Efficiency of a Combustion Motor as Affected by using Calorimeter Determinations of the Heat Value of Hydrogen. — The combustible parts of the fuels used in combustion motors are hydrogen and carbon with possible inappreciable amounts of other chemical elements. The carbon of the fuel is combined with either oxygen in the combustible compound CO or with hydrogen in some of the numerous hydrocarbons. Sometimes more than half of the volume of the fuel gas is free hydrogen, as in some of the water gases.

In calorimeter determinations of the heat value of fuels the products of combustion are always cooled enough to condense the steam resulting from the combination of H with O. But in the case of the internal-combustion motor the H_2O, CO_2, and N are all discharged in a gaseous state.

The fuel economy of an internal-combustion motor, or any efficiency that involves the transformation of heat energy into mechanical energy when using fuel mixtures whose combustible part is CO only, will not be the same in value as when the same motor is using a fuel mixture that contains H if the heat value of the H, or of its compounds, is based on calorimeter determinations that take into account the heat given up by the condensation of the steam produced by the combustion of the H, when all other conditions that affect the thermal efficiency of the motor are the same in both cases.

The extreme differences of efficiencies and of economies will occur when the combustible part of the fuel in one case is CO only, and in the other case free H only. While the combustible portions of the fuels that are used in combustion-motor practice are never exclusively CO or H, the assumption that a motor operates at one time on CO as the sole combustible, and at another time on H as the only combustible, gives the simplest means of showing the differences of fuel economies and of efficiencies, as stated above.

It will also be assumed that a given motor operates under a given load and at a constant speed. The indicated horsepower of the impulses (I.h.p.I) must then always be the same without regard to the kind of fuel used, if the mechanical efficiency remains constant. Constant mechanical efficiency will be assumed.

The indicated horsepower of the impulses (I.h.p.I) of a given motor at constant speed is directly proportional to the mean effective pressure of the impulse (M.e.p.I). The M.e.p.I must therefore have a constant value for a constant load.

To obtain a given M.e.p.I with the same compression pressure of the fuel charge, the amount of heat added to the charge by combustion in the motor must be the same in all cases, whatever fuel is used, provided the specific heat of the gases in the cylinder after combustion is the same whether CO or H is the combustible part of the fuel used. Equal specific heats will be assumed for the purpose of illustration.

The only part of the heat of combustion of H, as determined by the water-cooled calorimeter in which the steam of combustion is condensed, that is effective in producing temperature and pressure changes in the steam, is that in excess of the amount given up during the condensation of the steam produced and the cooling of the water resulting from condensation. This may appear clearer by following the application of heat to water to convert it into steam and then to superheat the steam in a closed vessel which has a free-moving piston. The first part of the heat raises the temperature of the water till the boiling point is reached. Further addition of heat converts the water into steam without increase of temperature, the pressure remaining constant, and when the water is completely evaporated more heat applied goes to superheat the steam, increasing both its temperature and volume if the pressure is still kept constant by the movement of the piston; or, if the piston is locked in position when the evaporation is complete, the temperature and pressure are both increased, while the volume remains constant. The steam behaves as a permanent gas as long as the temperature is kept somewhat above that of condensation at the corresponding pressure. The only part of the heat that is effective in raising the temperature and pressure of the steam is that which is added after the water is completely evaporated. And, conversely, when the steam is cooled, the heat that is given up before condensation begins represents all the heat that is useful for changing the pressure, volume, and temperature of the steam. The same is true whenever steam gives up its heat, from whatever source the heat was received.

Each pound of steam formed by the combustion of hydrogen gives up 1146.6 B.t.u. of heat when it is condensed from 212° F. and 14.7 pounds per square inch absolute pressure and the water cooled to 32° F. The 9 pounds of steam formed by the combustion of one pound of H therefore give up, during the same change,

$$9 \times 1146.6 = 10{,}320 \text{ B.t.u. about.}$$

None of this heat (10,320 B.t.u.) acts on the gases in the motor to cause changes of temperature and pressure, for the temperature and pressure at which the gases are discharged from the motor are higher than those at which steam condenses.

The total heat of combustion of H, as determined by the calorimeter, when the initial temperature of the combustible mixture is 32° F. and the pressure is 14.7 pounds per square inch absolute, and the resulting products cooled to the same temperature, is about 62,100 B.t.u. per pound of H. Of this there are 10,320 B.t.u. that have no effect on the temperature and pressure of the steam in the application to the combustion motor. The remainder,

$$62,100 - 10,320 = 51,780,$$

is all that is effective in producing changes of temperature and pressure in the gases in the motor.

Therefore the ratio of the total heat of combustion of H (from 32° F. and 14.7 pounds per square inch absolute pressure to water at the same temperature) to the part of the heat that is active in the motor is

$$\frac{62,100}{51,780} = 1.2.$$

Under the assumptions made, if 100 B.t.u. value of CO is necessary to produce the required mean effective pressure of impulse (M.e.p.I) in the motor when CO is the only fuel, then when H alone is used as the fuel 120 B.t.u. value of the H will be required to obtain the same M.e.p.I, dealing with the heat values of the fuels as determined by the calorimeter.

The ratio of the thermal efficiency with CO to that with H as the fuel is 1.2 in this case. The ratios of the total efficiencies will also be greater than unity. The economies will show 20 per cent more combustible for H than for CO when expressed in heating values.

In making a guaranty of the performance of a motor, expressed in B.t.u. per delivered horsepower, or in efficiency, it would therefore be necessary to know the composition of the fuel to be used if the calorimeter-determined heat values are to be taken. This would bring on endless difficulties. In order to avoid such complications, a modification of the heat value of H, or of any fuel containing H, as determined by the water-cooled calorimeter, has been brought into engineering use. This modification is known as the "lower heat value" of the fuel. In order to distinguish between the calorimeter-determined value and the lower heat value the former is called the "higher heat value."

207. Higher Heat Values. — Two higher heat values or calorific powers of a combustible find use in the combined fields of engineering, physics, and chemistry. The initial temperature is generally taken as 32° F. in physics and chemistry. The engineer uses a higher initial and final temperature in order to be nearer to the actual conditions of practice. This higher temperature will be taken as 62° F.

The heat values of combustibles that do not contain H are not appreciably different for the different temperature bases, but there is a marked difference when H is present in considerable proportion.

208. Higher Heat Values of Hydrogen. — The higher heat value of H from 32° F. and 14.7 pounds per square inch pressure to water at the same temperature and pressure has already been given as 62,100 B.t.u. per pound.

When the initial temperature of the combustible mixture is higher than 32° F., and the water of combustion is condensed to the same (higher) temperature, there will be a modification of the higher heat value just given on account of the difference of the specific heats of the combustible mixture and of the water formed. The combustible mixture contains more heat at the higher temperature than at 32° F., and this additional heat is a gain in the heat value. But the condensed water also has more heat at the higher temperature than at 32° F., and this causes a loss in the heat value, since this heat is retained in the condensed water and not given up to the calorimeter.

For illustrating this, the specific heats of the substances involved must be used.

	B.t.u.
Specific heat of H per pound at constant pressure..........	3.409
Specific heat of O per pound at constant pressure..........	.2175
Specific heat of water per pound can be taken as sufficiently accurate for this purpose at..........................	1.000

For an initial temperature of 62° F. the gain of heat over that at 32° F. for 1 pound of H and 8 pounds of O is:

	B.t.u.
Gain for the H = 1 (62 − 32) 3.409 = ...	102.27
Gain for the O = 8 (62 − 32) 2175 = ...	52.20
Total heat gain for 9 pounds combustible = . .	154

The heat deduction for the final temperature (62° F.) of the 9 pounds of water produced is,

	B.t.u.
Heat loss for 9 pounds water = 9 (62 − 32) = ...	270

Therefore the

	B.t.u.
Net loss = 270 − 154 = ...	116

and the

	B.t.u.
Higher heat value of H per pound from 62° F. to 62° F. water = 62,100 − 116 = ...	61,984
This value will be taken as	62,000

209. Lower Heat Values. — The lower heat value of H is sometimes assumed as the amount of heat that would be given up to the calorimeter if the steam product of combustion were to remain gaseous and behave in the same manner as the products of combustion of the other chemical elements of the fuel (and the inert nitrogen when the O for combustion is supplied by air), instead of condensing at 212° F. and 14.7 pounds per square inch pressure.

Under this assumption the lower heat value is less than the higher by an amount which is the difference between (*a*) the heat given up by the steam while changing from steam at 212° F. to water at whatever final temperature is taken (below 212° F. and 14.7 pounds per square inch pressure) and (*b*) the heat that would be given up by an equal weight of (imaginary) gas while cooling from 212° F. to the same assumed final temperature.

The amount of heat given up by a pound of steam in condensing and cooling from 212° F. and atmospheric pressure (14.7 pounds per square inch) to water at 32° F. is 1146.6 B.t.u. The amount of heat that would be given up by a pound of gas whose specific heat is .24 * while cooling from 212° F. to 32° F. (through 180° F.) is $180 \times .24 = 43.2$ B.t.u. The difference between the heat actually given up by the pound of steam and that given up by the same weight of the imaginary gas is $1146.6 - 43.2 = 1103.4$ B.t.u. One pound of H produces 9 pounds of steam. Therefore the difference between the high and low heat values of one pound of H when the products of combustion are cooled to 32° F. at atmospheric pressure is

$$9 \times 1103.4 = 9930 \text{ B.t.u.}$$

When the pound of steam is condensed from 212° F. and atmospheric pressure to water at 62° F., it gives up 30 B.t.u. less of heat than when it is cooled to water at 32° F. The amount of heat given up by a pound of steam when cooled from 212° F. and atmospheric pressure to water at 62° F. is therefore $1146.6 - 30 = 1116.6$ B.t.u. One pound of gas with a specific heat of .24 (as has been assumed) gives up while cooling from 212° F. to 32° F. at constant pressure, heat to the amount of

$$1\,(212 - 62)\,.24 = 150 \times .24 = 36 \text{ B.t.u.}$$

The difference between the amount of heat actually given up by the pound of steam and that assumed as given up by the same weight of imaginary gas is $1116.6 - 36 = 1080.6$ B.t.u. Therefore the difference between the high and low heat values of one pound of H when the initial and final temperatures are 62° F. and the pressure 14.7 pounds per square inch is

$$9 \times 1080.6 = 9725 \text{ B.t.u.}$$

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* There is no way of determining what the specific heat of this imaginary gas should be. Its value can only be assumed on what appears to be a reasonable basis. The specific heat per pound of superheated steam increases rapidly as the degree of superheat increases. If the specific heat of the imaginary gas is assumed to have the same values and follow the same law down to 32° F., its mean specific heat per pound would be in the neighborhood of .24 probably. If the imaginary gas were taken as CO_2 the specific heat would be about .22 on the weight basis. Fortunately only a very small relative percentage change is caused in determining the lower heat value by using different values, within reasonable limits, of this assumed specific heat.

The amount of heat deduction per pound of steam (or water) in the products of combustion which must be made from the higher heat value to obtain the lower value, appears in both of the above cases. It is shown as 1103.4 B.t.u. in the first case and as 1080.6 B.t.u. in the second.

In applying the correction to the calorimeter-determined heat values of a mixed gas to obtain its lower heat value, it is often convenient to use the correction factor for each pound of steam (or water) in the products of combustion. The values just given can be used for this method of correcting, each in its proper place.

A summary of the above, together with the lower heat values of H, under the two conditions stated, is given below.

Deduction per pound of H to be made from the higher heat value of 1 pound of H to obtain the lower heat value:

	B.t.u.
For initial and final temperatures of 32° F	9930
For initial and final temperatures of 62° F	9725

By making the appropriate deductions, whose values have just been given, from the higher heat values of H, the lower heat values are obtained. Thus:

	B.t.u.
Lower heat value of one pound of H burned from 32° F. and 14.7 pounds per square inch and 62° F. and the products cooled to water at 32° F. is 62,100 − 9930 = ...	52,170
Lower heat value of one pound of H burned from 62° F. and 14.7 pounds per square inch and the products cooled to water at 62° F. is 62,000 − 9725 = ...	52,275

Deduction per pound of steam (or water) in the products of combustion, to be taken from the higher heat value of a fuel to obtain the lower heat value:

	B.t.u.
For initial and final temperatures of 32° F	1103
For initial and final temperatures of 62° F	1080

Whenever H, either free or combined, is present in the gas-motor fuel to any considerable proportion of the total mixture that enters the combustion space of the motor, the difference between the higher and the lower heat values of the fuel is great enough to need consideration in accurate economy and efficiency determinations.

TABLE IV.

Combustion of Carbon.

Volumes at 62° F. and 14.7 pounds per square inch.

	Heat Value. B.t.u.	Air Required.		Products.	
		Lbs.	Cu. Ft.	Lbs.	Cu. Ft.
1 lb. C to CO	4206	5.76	75.8	6.76	91.7
1 lb. C to CO_2	14650	11.52	151.7	12.52	151.7

TABLE V.

Heat Values of Gases.

32° Fahrenheit. **Pound units.**

Gas.				Air per Lb. of Gas for Perfect Mixture. Lbs.*	Perfect Mixture. B.t.u. per Lb.		Product per Lb. of gas. Lbs.		
Name.	Chemical Form.	B.t.u. per Lb.							
		Higher.	Lower.		Higher.	Lower.	CO_2	H_2O	N
Hydrogen	H_2	62,100	52,170	34.6	1744	1465	......	9.00	26.6
Carbon monoxide	CO	4,476	4,476	2.46	1294	1294	1.57	......	1.89
Methane or marsh gas	CH_4	23,850	21,368	17.3	1303	1167	2.75	2.25	13.3
Ethylene or olefiant gas	C_2H_4	21,440	20,022	14.83	1354	1261	$3\frac{1}{7}$	$1\frac{2}{7}$	11.4
Propylene	C_3H_6	21,420	20,002	14.83	1353	1262	$3\frac{1}{7}$	$1\frac{2}{7}$	11.4
Benzol or benzene vapor	C_6H_6	18,450	17,686	13.31	1290	1236	$3\frac{5}{13}$	$\frac{9}{13}$	10.25

* 4.326 lbs. air per lb. of Oxygen.

Air = 76.9% H and 23.1% O by weight.

TABLE VI.

Heat Values of Gases.

Cubic foot units at 32° **F.** and 14.7 lbs. per sq. in. pressure.

Gas.				Air per Cu. Ft. of Gas for Perfect Mixture. Cu. Ft.*	Perfect Mixture. B.t.u. per Cu. Ft.	
Name.	Chemical Form.	B.t.u. per Cu. Ft.				
		Higher.	Lower.		Higher.	Lower.
Hydrogen	H_2	348	292	2.39	102.6	86.
Carbon monoxide	CO	349	349	2.39	103.0	103.
Methane or marsh gas	CH_4	1065	955	9.57	101.4	90.
Ethylene or olefiant gas	C_2H_4	1673	1562	14.35	109.0	101.7
Propylene	C_3H_6	2509	2343	21.52	111.4	104.0
Benzol or benzene vapor	C_6H_6	4010	3845	35.87	108.7	104.3

* This is the amount of air required for a perfect mixture. An excess of air is generally used in practice.

4.78 cu. ft. air for one cu. ft. Oxygen.

TABLE VII.

Heat Values of Gases.

Cubic Foot units at 62° **F.** and 14.7 lbs. per sq. in. pressure.

Gas.				Air per Cu. Ft. of Gas for Perfect Mixture. Cu. Ft.	Perfect Mixture. B.t.u. per Cu. Ft.	
Name.	Chemical Form.	B.t.u. per Cu. Ft.				
		Higher.	Lower.		Higher.	Lower.
Hydrogen	H_2	328	275	2.39	96.6	81.
Carbon monoxide	CO	329	329	2.39	97.0	97.
Methane or marsh gas	CH_4	1003	900	9.57	95.5	85.
Ethylene or olefiant gas	C_2H_4	1577	1472	14.35	102.7	96.
Propylene	C_3H_6	2364	2205	21.52	105.0	98.
Benzol or benzene vapor	C_6H_6	3779	3624	35.87	102.5	98.3

When no H is present in the fuel, there is only one heat value for the fuel between any stated initial and final temperatures. (This of course does not refer to different numerical values expressed in different units of measure.)

Table V gives the heat values per pound at 32° F. and 14.7 pounds per square inch pressure, of the gases with which combustion motors are most concerned; also the heat values of a perfect combustible mixture of each gas with air.

Table VI gives the heat value of gases per cubic foot at 32° F. and 14.7 pounds per square inch pressure.

Table VII gives the heat values of gases per cubic foot at 62° F. and 14.7 pounds per square inch pressure.

TABLE VIII. PRODUCER GAS.*

Determination of Heat Value from Chemical Analysis.

62° F. and 14.7 lbs. per sq. in pressure.

Components.	Chemical Form.	Percentage by Volume.	B.t.u. per Cu. Ft. Lower.	B.t.u. for Each Component. Lower.
		p.	h.	$\frac{p \times h}{100}$.
Hydrogen.............	H_2	9.7	275	26.67
Carbon monoxide......	CO	16.4	329	53.96
Methane..............	CH_4	5.6	900	50.40
Carbon dioxide........	CO_2	8.2	....	....
Oxygen...............	O_2	1.0	....	....
Nitrogen..............	N_2	59.1	....	....
Total..........	....	100.0		131.03

* Gas made in a pressure producer from black lignite of the following percentage composition by weight: H = 6.07; C = 57.46; O = 28.78; N = 1.15; S = .55; Ash = 5.99; Total = 100.

Lower heat value of gas at 62° F. and 14.7 lbs. per sq. in. = 131 B.t.u. per cu. ft.

The volumetric composition of a sample of producer gas, as determined by chemical analysis, is given in Table VIII; also the tabulated results of computations for the lower heat value of the gas per cubic foot at 62° F. and 14.7 pounds per square inch pressure.

TABLE IX. PRODUCER GAS.

Density, Air Required, and Heat Values of Gas and Mixture Determined from Chemical Analysis.

62° F. and 14.7 lbs. per sq. in. pressure.

Components.	Chemical Form.	Per Cent Volume of Components.	B.t.u. per Cu. Ft. of Component. Lower Value.	B.t.u. per Component. Lower Value.	Density of Component. Lbs. per Cu. Ft.	Weight of Each Component. Lbs. per Cu. Ft. of Gas.	Air per Cu. Ft. of Gas for a Perfect Mixture. Cu. Ft.	Air for Each Component in a Perfect Mixture. Cu. Ft.
		$p.$	$h.$	$\frac{p \times h}{100}$	$D.$	$\frac{p \times D}{100}$	$a.$	$\frac{a \times p}{100}$.
Hydrogen........	H_2	8.5	275	23.37	.0053	.00045	2.39	.203
Carbon monoxide .	CO	24.8	329	81.59	.0736	.01825	2.39	.593
Methane.........	CH_4	5.2	900	46.80	.0421	.00219	9.57	.498
Ethylene.........	C_2H_4	0.40	1472	5.89	.0735	.00029	14.35	.057
Carbon dioxide....	CO_2	5.6	......	......	.1156	.00647	....	......
Oxygen..........	O_2	0.40	......	......	.0841	.00034	−4.873	−.019
Nitrogen.........	N_2	55.1	......	......	.0738	.04055	....	......
Totals...........		100.0	B.t.u.=157.65		Dens'y=.06854		Air=1.332	

B.t.u. per cubic foot of gas = 157.65 lower value.

Air per cubic foot of gas for perfect mixture = .332 cubic foot.

B.t.u. per cubic foot of perfect mixture $= \frac{157.65}{1+1.332} = 67.5$ lower value.

Density of gas = .0685 pound per cubic foot at 62° F. and 14.7 pounds per square inch.

Table IX gives the volumetric composition of another sample of producer gas together with the computed density, air required, and lower heat values of the gas and combustible mixture.

Table X is similar to Table IX for an illuminating gas made by distilling off the volatile parts of the coal in a retort.

TABLE X. RETORT ILLUMINATING GAS.

Density, Air Required, and Heat Values of Gas and Mixture. Determined from Chemical Analysis.

62° F. and 14.7 lbs. per sq. in. pressure.

Components.	Chemical Form.	Per Cent Volume of Components.	B.t.u. per Cu. Ft. of Component. Lower Value.	B.t.u. per Component. Lower Value.	Density of Component. Lbs. per Cu. Ft.	Weight of Each Component. Lbs. per Cu. Ft. of Gas.	Air per Cu. Ft. of Gas for a Perfect Mixture. Cu. Ft.	Air for Each Component in a Perfect Mixture. Cu. Ft.
		p.	h.	$\frac{p\times h}{100}$.	D.	$\frac{p\times D}{100}$.	a.	$\frac{a\times p}{100}$.
Hydrogen	H_2	39.8	275	109.45	.0053	.00211	2.39	.951
Carbon monoxide	CO	7.6	329	25.00	.0736	.00559	2.39	.184
Methane	CH_4	36.2	900	325.80	.0421	.01524	9.57	3.464
Propylene *	C_3H_6	3.8	2205	83.79	.1104	.00420	21.52	.818
Benzol †	C_6H_6	0.6	3624	21.74	.2048	.00123	35.87	.215
Oxygen	O_2	0.8	......	......	.0841	.00068	−4.873	−.038
Nitrogen	N_2	11.2	......	......	.0738	.00827	....	......
Totals		100.0	B.t.u.=565.78		Dens'y=.03732		Air=5.594	

* Heavy hydrocarbons taken as propylene.
† Light hydrocarbons taken as benzol.

B.t.u. per cubic foot of gas = 565.78 lower value.

Air per cubic foot of gas for perfect mixture = 5,594 cubic feet.

B.t.u. per cubic foot of perfect mixture $= \frac{565.78}{1+5.594} =$ 85.8 lower value.

Density of gas = .0373 pound per cubic foot at 62° F. and 14.7 pounds per square inch.

210. Illuminants, light hydrocarbons and heavy hydrocarbons. — The illuminating property of a gas flame depends on the presence of certain hydrocarbons known as the "illuminants" or "heavy hydrocarbons." In their absence the flame has little or no illuminating power.

In gas analysis the illuminating hydrocarbons are not generally separately determined, but are either taken as a single group or divided into two groups known as the "light hydrocarbons" and the "heavy hydrocarbons." These light hydrocarbons are soluble in alcohol, and the heavy hydrocarbons in either fuming sulphuric acid or bromine.

When all the illuminants are determined as a group, they are often considered as propylene (C_3H_6). When divided into two groups, the light hydrocarbons may be taken as benzol or benzene (C_6H_6) and the heavy hydrocarbons as propylene.

The illuminants are also sometimes all taken as ethylene (olefiant gas, C_2H_4).

211. Saturated and Unsaturated Hydrocarbons. — The hydrocarbons whose chemical compositions agree with the formula C_nH_{2n+2}, of which CH_4, C_2H_6, C_3H_8, C_4H_{10} are examples, are called the "paraffins." They are also called "saturated hydrocarbons." The carbon in them is completely saturated with hydrogen, or at least more completely saturated than any of the other known hydrocarbons.

The other hydrocarbons with which the combustion motor and gas manufacture for it are concerned, are called the "unsaturated hydrocarbons." They are the illuminants mentioned in the preceding section. They conform to various chemical formulas, some of which are given below.

The olefine group has the formula C_nH_{2n}. Some of the compounds are C_2H_4, C_3H_6, C_4H_8.

The acetylene group has the formula C_nH_{2n-2}. Acetylene gas has the composition C_2H_2.

The benzols or benzenes (not the benzine from petroleum) are represented by the general formula C_nH_{2n-6}. Of them benzene, C_6H_6, is found in coal gas.

Naphthalene, of another group, has the composition $C_{10}H_8$.

The tar of coal gas is composed of naphthalene and other compounds of a similar nature.

212. Physical Form of Hydrocarbons. — At or near atmospheric pressure the hydrocarbons with which this work is most concerned have the following conditions as to being gas, liquid, or solid.

Methane (marsh gas, CH), ethylene (olefiant gas, C_2H_4), propylene, C_3H_6, ethane, C_2H_6, and acetylene, C_2H_2, all are permanent gases at atmospheric temperatures.

Propane, C_3H_8, is a gas above 1.4° F.

Butane, C_4H_{10}, is a gas above 34° F.

Benzole or benzene, C_6H_6 (not the benzine from petroleum, or the refined benzol which is used in the same manner as gasoline in combustion motors), melts at 42° F. and boils at 177° F., above which temperature it is a gas. Refined benzol freezes at about − 20° F.

Naphthalene, $C_{10}H_8$, melts at 175° F. and boils at 424° F.

The vapors of substances present but not gaseous under the conditions existing are generally present in the gas with which the substance is, or has been, in contact. This is similar to the presence of water vapor in air at atmospheric temperatures.

213. Dissociation or Decomposition of Chemical Compounds. — Experiments have shown that if steam is heated to a high temperature part of it is separated into its elements H and O. The proportion of the whole mass that is dissociated or "split up" is greater the higher the temperature. As far as has been determined and made public, the temperature at which dissociation of H_2O begins is in the neighborhood of 1800° F. When the temperature is lowered again, the elements H and O recombine if they have not been acted on by other chemical elements.

Several of the chemical compounds of hydrogen and carbon (hydrocarbons) that are contained in petroleum and its distillates (kerosene, naphtha, gasoline, etc.) and in bituminous coals, are decomposed or split up when heated to a temperature far lower than that of combustion of the liquid or coal. The elements of the hydrocarbons thus separated generally unite immediately in different proportions from those in which they were combined before heating, and thus form new hydrocarbons whose physical and chemical properties are unlike those of the original compound.

Dissociation is the reverse of chemical combination, and the heat required to cause the dissociation is the same in amount as that which was liberated during the combination of the same amount of elements to form the chemical compound.

214. Combustion Pressures and Temperatures. — If the specific heats of gases, or the total amount of heat in the gases, were known for all temperatures between those of combustion and atmospheric, then the theoretical temperature of the products of combustion could be readily calculated. These heat properties of the gases are not known, however, for the high temperatures of combustion.* It is therefore impossible to calculate even approximately on this basis the pressure that a combustible mixture will produce when burned either in a vessel of fixed volume or in one of variable volume, or otherwise.

The cooling effect of the walls of the cylinder or vessel in which the gas is contained has much to do with lowering the pressure below that which would be attained if there were interchange of heat between the gas and the walls. The walls of a metal vessel abstract heat with great rapidity from gases at as high temperatures as those produced by the combustion of the fuels used in gas-engine practice, when the walls are kept as cool as they must be in the motor.

Investigations by different experimenters with combustible mixtures of illuminating gas and air, exploded at atmospheric pressure in cast-iron cylinders some 7 or 8 inches in diameter and somewhat longer than the diameter, show, for proportions of air and gas giving the higher pressures, that the pressure drops

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* Recent investigations show that the specific heats of CO, CO_2, and steam all increase with rise of temperature. The results obtained by different experimenters for CO and CO_2 are so far different at the higher temperatures as to make it impossible to select approximately correct values. The specific heat of steam has been determined by Prof. C. C. Thomas for temperatures up to something more than 850° F. and 300 pounds per square inch pressure. (Proceedings Amer. Soc. Mech. Engrs., December, 1907.) Neither this temperature nor pressure is as high as in the combustion motor. The temperature especially is far below that of combustion in the motor.

from the maximum to about half the maximum in one-fourth of a second or less, and during a full second falls to about one-fifth of the maximum, but as low as one-seventh of the maximum in some cases. The maximum pressures of the mixtures giving the higher values are attained in one-fifteenth to one-twentieth of a second, as indicated by the recording apparatus. These values make no allowance for the inertia lag of the moving parts of the indicator.

With the higher temperatures and pressures that occur in the combustion motor on account of compression before ignition, the rate of heat absorption by the cylinder walls is much more rapid during the early part of the stroke than later in the stroke, except possibly in the case of a very hot motor cylinder.

215. **Rate of Flame Propagation and Combustion.** — When a quiescent mass of combustible gas and air mixture is ignited by a spark, the flame propagates itself through the mixture by spreading in a spherical wave, at least theoretically. The actual propagation is something of this nature, at least. An appreciable period of time in comparison with that required for one stroke of the piston of a high-speed motor is required for the flame to pass through the entire mass. The location of the igniting spark in the mass of mixture therefore has to do with the time required for complete inflammation of the charge. If the spark occurs in a pocket leading off from the main combustion chamber, as is the case in many gas motors, the charge will not be inflamed as quickly as if the spark were in the center of the combustion chamber. Again, if there is a pocket on each side of the combustion chamber, the inflammation will be completed sooner by making simultaneous sparks in the two pockets than by igniting in only one pocket. With the two sparks the flame has only about half as far to travel as with the one.

When the initial ignition of the charge is in a relatively small reservoir connected to the main mass of the gas by a narrow passage, a jet of flame is projected into the main body of the gas and ignites a large portion quickly. The indicator card in such a case shows a rapidly rising combustion line without any sign of ignition before the completion of the compression stroke. The ignition must be somewhat before the completion of compression, however, in order to have the flame project into the main mass before the piston has moved appreciably on the impulse stroke.

After inflammation, some time is required for the completion of combustion. This is plainly noticeable in the burning of a candle or a Bunsen flame. In the flame the period of uniting is that during which the atoms travel from the bottom to the top of the flame.

The rate of combustion is affected by variation of pressure and of the proportions of the air and fuel within the range of combustible mixtures. It is probable that the rate of combustion also varies with the temperature, but this has not been conclusively proved.

The combustion is more rapid the higher the pressure of the mixture.

A perfect mixture burns more rapidly than one that is "lean" or too "rich." A theoretically perfect mixture is one in which there is just enough oxygen present to unite with the fuel in the proportion to form the most stable compound. A practically perfect mixture contains a slight excess of oxygen above the amount for a theoretically perfect mixture. A lean mixture has too little fuel and more oxygen than is necessary for complete combustion. The same name is also applied to a mixture having the proper proportions of fuel and oxygen but which is diluted with inert gases such as those remaining in the combustion chamber of a motor and mixing with the next charge. A rich mixture has more fuel than is necessary for the proper proportion relative to the oxygen present for complete combustion.

The "time of combustion" as herein used means the interval between the ignition of the first part of the mixture and the ceasing of combustion. It includes ignition, inflammation, and combustion, more or less chemically complete, as the case may be.

216. Unusual Pressures of Combustion. — Under certain conditions the pressure produced by the combustion of a gas and air mixture is higher than those ordinarily occurring. The conditions conducive to such unusual pressure, so far as they seem to have been determined, are those in which the combustion of one portion of a mass of gas produces high pressure in an unignited portion, and the latter then appears to suddenly ignite and burn with a resulting high pressure.

The effect of pockets and contracted ducts has already been mentioned in connection with indicator cards. In this relation it may be pointed out that the cooling action of a small contracted duct may prevent the passage of the propagating flame into a pocket thus partly cut off from the main body of the gas till the pressure has become so high that the mixture in the pocket explodes violently.

There seem to be no conclusive proofs of the infrequent occurrence of combustion pressures enormously higher than the usual values in gas-engine practice. For many years it was supposed that these pressures did occur in the motor and were the chief cause of broken parts, especially the cylinder. The writer has searched for but never been able to find such a case. Internal stresses due to heating seem to be more accountable for breakages of this nature.

217. **When an over-rich mixture** of air and gasoline vapor is ignited, all, or nearly all, of the hydrogen (of the hydrocarbons of which the gasoline is composed) unites with the oxygen present, thus not leaving a sufficient amount of O for all the carbon to unite with. The carbon thus left appears as soot or smoke which, in the case of a combustion motor, is discharged with the exhaust gases, except such of it as adheres to the walls of the combustion chamber, ports, and other parts with which it comes in contact.

The imperfect combustion is responsible for a loss of heat both on account of the heat required for dissociating the hydrocarbon, part of which is not burned, and on account of the failure of the carbon to burn.

In the case of gaseous fuels, smoke may or may not appear, according to the nature of the fuel, but in all cases the imperfect combustion of course means loss of heat. A gas rich in illuminants will give off smoke when the mixture is too rich.

Producer gas from bituminous coals is generally richer and contains a greater proportion of illuminants just after a fresh lot of fuel has been charged on than after there has been no fresh fuel added for some time. This is on account of the distillation of the volatile part of the fresh fuel soon after it is put into the producer.

218. Moisture in Air and Gas. — The moisture in air and gas exists in the state of vapor when the quantity does not exceed the limit that the air or gas will take up as vapor. When this limit is reached, the air or gas is said to be saturated with water vapor.

In the case of fog in air (or gas) there is present more than enough moisture to produce saturation, and the excess is in the form of finely divided (atomized, in popular language) liquid water. The same is true when dew is falling. This atomized water may be called entrained water.

The weight of the water whose vapor will just saturate a given volume of space varies with the temperature, but is not changed by change of pressure or of the kind of gas present. The weight of water vapor for just saturating a cubic foot of space at a given temperature is the same whether the space contains air or gas, or is a vacuum before the water vapor is added. If liquid water is flowed into the vacuum it will vaporize very much more quickly to saturate the space than if the "space" is filled with dry air or dry gas at atmospheric pressure before the water is flowed in; but the weight of the water that will finally vaporize is the same in either case. As a concrete example, if something more than 14.79 grains of water are added to dry air, dry gas, or a vacuum of one cubic foot enclosed volume, the space will be saturated at 90° F. by the vaporization of 14.79 grains of the water. The water in excess of this amount will remain liquid.

The water vapor in a saturated space has an invariable pressure for each temperature. The pressure of the water vapor is not changed by the presence or absence of air, gas, or other vapors. When the water vaporizes in the enclosed dry space, the pressure against the enclosing walls is increased by the amount of the vapor pressure for the corresponding temperature. The vapor pressure for saturation at 90 degrees is .691 pound per square inch. The pressure against the enclosing walls will be increased by this amount on account of the vaporization of the water. If the cubic foot of space is originally filled with dry air or dry gas at 14 pounds per square inch pressure, it will have, when saturated with water vapor, a pressure of 14 + .691 = 14.691 pounds per square inch at 90° F.

The relative volumes occupied by the dry air and water vapor are proportional to their individual pressures. At 90° F. the ratio of the volume of the water vapor to that of the dry air is .691 to 14, which corresponds to 4.7 per cent water vapor and 95.3 per cent dry air.

Table XI gives data of the above nature for different temperatures. The table shows that the proportion of water vapor increases rapidly with increase of temperature.

If the vapor pressure is kept constant at (or below) the saturation pressure, all of the liquid will vaporize. Heat must be added to keep the temperature constant. Water boiling in the open air is an example of this. In an enclosed space with an opening for allowing the vapor to escape, the vapor or steam thus ultimately occupies the entire volume of the space.

The extent of the effect of variation of moisture on the working of a combustion motor can be seen by the aid of a concrete case. A motor operating on gasoline is convenient to deal with. It will be assumed that when the inlet closes the charge has the same temperature in the motor as the air outside.

At 92° F. and 100 per cent humidity (complete saturation), the moist air will be 95 per cent dry air and 5 per cent water vapor by volume. At 92° F. and 50 per cent humidity (half saturation) the volume of the vapor will be only half as great, as will be the vapor pressure and weight of vapor per cubic foot. The air at 90 degrees and 50 per cent humidity will therefore be 97.5 per cent dry air and 2.5 per cent water vapor. This is an increase of about 2.6 per cent in the volume of dry air. The oxygen for supporting combustion is increased in the same proportion. The motor will therefore develop more power on the dry air than on the saturated. A range of humidity as great as that stated, or even greater, is not unusual, and fog gives greater moisture than 100 per cent humidity.

The cooling of air or gas precipitates moisture if present in sufficient quantity, as in the familiar example of dew.

TABLE XI.*

Moisture in Air, Gas, or Vacuum Completely Saturated With Water Vapor at Different Temperatures.

Complete saturation corresponds to 100 per cent humidity.

Temperature.		Vapor Pressure.		Percentage by Volume in a Saturated Mixture at 14.7 Lbs. per Sq. In.		Weight of Water Vapor per Cubic Foot.	
Deg. Fahr.	Deg. Cent.	Inches of Mercury.	Pounds per Sq. In.	Water Vapor.	Dry Gas.	Grains.	Pounds.
−20	−28.9	.0126	.0062	.04	99.96	.166	.000024
−10	−23.3	.0222	.0109	.07	99.93	.285	.000041
0	−17.8	.0383	.0188	.13	99.87	.481	.000069
5	−15	.0491	.0241	.16	99.84	.610	.000087
10	−12.2	.0631	.0310	.21	99.79	.776	.000111
15	− 9.4	.0810	.0398	.27	99.73	.986	.000141
20	− 6.7	.1026	.0504	.34	99.66	1.235	.000176
25	− 3.9	.130	.0639	.43	99.57	1.551	.000221
30	− 1.1	.164	.0806	.55	99.45	1.935	.000276
32	0	.180	.0884	.60	99.40	2.113	.000302
35	1.7	.203	.099	.62	99.38	2.366	.000338
40	4.4	.247	.121	.82	99.28	2.849	.000407
45	7.2	.298	.146	.99	99.01	3.414	.000488
50	10.0	.360	.177	1.20	98.80	4.076	.000582
52	11.1	.387	.190	1.29	98.71	4.372	.000625
54	12.2	.417	.205	1.40	98.60	4.685	.000669
56	13.3	.448	.220	1.50	98.50	5.016	.000717
58	14.4	.482	.236	1.61	98.39	5.370	.000767
60	15.6	.517	.254	1.73	98.27	5.745	.000821
62	16.7	.555	.273	1.86	98.14	6.142	.000877
64	17.8	.595	.292	1.99	98.01	6.563	.000938
66	18.9	.638	.314	2.14	97.86	7.009	.001001
68	20.0	.684	.336	2.28	97.72	7.480	.001069
70	21.1	.732	.359	2.44	97.56	7.980	.001140

* Inches of mercury for vapor pressure and grains weight of water vapor taken from Psychrometric Tables of the United States Weather Bureau. Other items computed by the author.

TABLE XI.* — CONTINUED.

Moisture in Air, Gas, or Vacuum Completely Saturated With Water Vapor at Different Temperatures.

Complete saturation corresponds to 100 per cent humidity.

Temperature.		Vapor Pressure.		Percentage by Volume in a Saturated Mixture at 14.7 Lbs. per Sq. In.		Weight of Water Vapor per Cubic Foot.	
Deg. Fahr.	Deg. Cent.	Inches of Mercury.	Pounds per Sq. In.	Water Vapor.	Dry Gas.	Grains.	Pounds.
72	22.2	.783	.384	2.61	97.39	8.508	.001215
74	23.3	.838	.412	2.79	97.21	9.066	.001295
76	24.4	.896	.440	2.99	97.01	9.655	.001379
78	25.6	.957	.470	3.20	96.80	10.277	.001468
80	26.7	1.022	.502	3.42	96.58	10.934	.001562
82	27.8	1.091	.536	3.65	96.35	11.626	.001661
84	28.9	1.163	.572	3.89	96.11	12.356	.001765
86	30.0	1.241	.610	4.15	95.85	13.127	.001875
88	31.1	1.322	.650	4.42	95.58	13.937	.001991
90	32.2	1.408	.691	4.70	95.30	14.790	.002113
92	33.3	1.499	.736	5.00	95.00	15.689	.002241
94	34.4	1.595	.784	5.33	94.67	16.634	.002376
96	35.6	1.696	.833	5.67	94.33	17.626	.002518
98	36.7	1.803	.887	6.03	93.97	18.671	.002667
100	37.8	1.916	.942	6.41	93.59	19.766	.002824
102	38.9	2.035	1.00	6.81	93.19	20.917	.002988
104	40.0	2.160	1.061	7.22	92.72	22.125	.003161
106	41.1	2.292	1.126	7.67	92.33	23.392	.003341
108	42.2	2.431	1.194	8.12	91.87	24.720	.003531
110	43.3	2.576	1.264	8.60	91.40	26.112	.003730
210	98.9	28.75	14.11	96.00	4.00	....	....

* Inches of mercury for vapor pressure and grains weight of water vapor taken from Psychrometric Tables of the United States Weather Bureau. Other items computed by the author.

A cubic foot of saturated air at 32° F. contains but 13.5 per cent as much moisture by weight as a cubic foot at 92° F. and the volume occupied by the vapor is but 12 per cent of that at 92° F. A cubic foot of saturated air at 92° F. when cooled to 32 degrees contains only 11.5 per cent as much water vapor by weight as at 92° F.

Compressing saturated air or gas at constant temperature reduces the weight of water vapor in it by condensation. For the vapor pressure remains constant and the weight of vapor in the reduced space is proportional to the volume of the space; but compressing air or permanent gas does not decrease its weight, therefore the weight proportion of water vapor is decreased by compression.

Sudden expansion of saturated compressed air or gas cools it so that some of the water vapor is condensed and may be precipitated.

Producer gas is, on account of cooling while being washed with water, saturated with water vapor when it leaves the scrubber. It may also carry entrained liquid water. In warm weather the amount of moisture may be enough to affect the power of the motor sufficiently to deserve attention.

Saturated gas at 92° F. and 14.7 pounds per square inch has only 95 per cent of the heating capacity of dry gas at the same temperature and pressure, dealing with volumes.

A saturated combustible mixture at 92° F. and 14.7 pounds per square inch also has 95 per cent of the heating value per cubic foot that the dry mixture has. The pressure of combustion is reduced by the water vapor both on account of the reduction of the heat value and the higher specific heat of water vapor or steam. Water in suspension requires heat to vaporize it, which is lost in gas-engine practice.

The moisture can be largely removed by compressing and cooling the gas and then allowing it to expand suddenly. Centrifugal motion after compression will remove water of condensation.

219. Gas Analyses Relative to Moisture. — Published reports of gas analyses seldom make any statement regarding moisture.

Computed heat values based on chemical analyses which do not take moisture into account give higher heat values for the gas than the actual values.

Humidity of gas, or moisture not exceeding the saturation point, can be determined by the wet- and dry-bulb thermometer apparatus in common use by the Weather Bureau. Entrained moisture can be measured by absorption methods.

CHAPTER XVIII.

FUELS AND GAS MAKING.

220. General. — The commercial form in which fuel is obtainable, its cost, and the convenience with which it can be used in the internal-combustion motor are the chief items in the consideration of the selection of the type of motor and in determining the kind of fuel.

The fuels either found on the market or resulting as by-products of industrial processes, with which the combustion motor is mostly concerned, and the general methods of utilizing them, are:

Coal. Lignite. Peat. Wood. Charcoal	Converted into gas in a gas producer before using. Washing and purifying the gas are generally advisable.
Crude petroleum. Heavy distillates of petroleum.	Injected into the motor cylinder or transformed into permanent gas by the application of heat.
Kerosene.	Injected into the motor cylinder or vaporized in a heated carbureter.
Naphtha. Gasoline. Alcohol. Benzol.	Vaporized in a carbureter.
Natural gas. Illuminating gas. Fuel gas. Blast-furnace gas. Coke-oven gas.	Used as received, except that cleaning or washing is necessary for the by-product gases of the blast furnace and coke oven.

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* The recently invented process of making alcohol from peat by Professor Lagerheim and Mr. Frestadius seems to open up great possibilities in this

The solid fuels are transformed, more or less completely, into permanent combustible gases before using in the motor. The cheaper soft coals can be utilized in this manner about as well as the more expensive grades. The lignites can also be transformed into satisfactory power gas with practically the same ease as bituminous coal. Even peat can be dealt with in the same manner. Wood, refuse, straw, bagasse, and other vegetable matter not too wet can also be used. Anthracite coal is more easily converted into fuel gas than any other fuel.

In the transformation of solid fuel into power gas it is desirable, especially in power plants of small and moderate capacities, to convert all of the fuel part of the solid combustible into permanent gas, and thus avoid the formation of any by-products. In a large plant, by-products can generally be disposed of to advantage, but not usually in those of small power capacity.

In general there are in common use two types of producers for converting solid fuel into permanent gas for power purposes. The distinguishing features are that in one type pressure produced by auxiliary apparatus is used to force air, or steam, or both together, through the bed of solid fuel; and in the other the air and water are drawn through by the suction of the motor itself, or of an auxiliary "exhauster." In the pressure producer the gas is made at a more or less uniform rate while the producer is operating, and the gas is stored in tanks, generally of small capacity, from which it is drawn to meet the varying needs of the motor. In the suction producer plant without auxiliary exhauster there is no storage of gas. The gas is generated at the rate that the motor demands it, stroke by stroke. When the motor stops, the generation of gas stops with it.

In the methods especially applied to making power gas from

field on account of the small cost at which the alcohol can be produced and the fact that all necessary materials for the process, except sulphuric acid exist in some of the immense peat swamps of the United States. See *Engineering Magazine*, August, 1908.

The improved method of recovering sulphuric acid during the reduction of copper ore etc., recently adopted by the Ducktown Copper Company of Ducktown, Tennessee, makes possible the use of sulphuric acid on a commercial basis for the production of alcohol from peat.

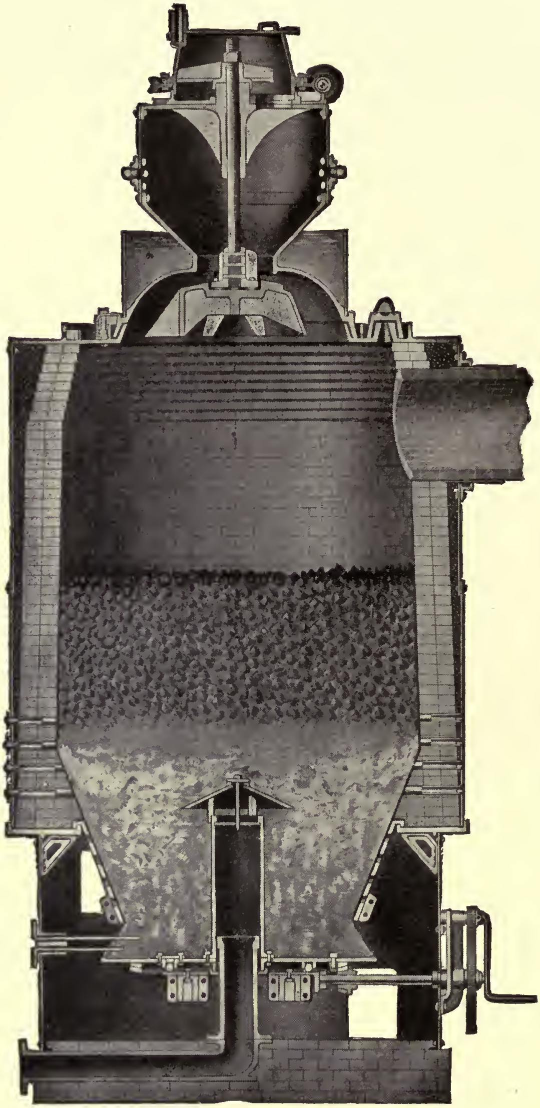

Fig. 114.

Fig. 114.

Continuous Updraught Gas Producer for Bituminous Coal with Automatic Feed. Air-and-Water Gas Process. Pressure or Suction Draught. R. D. Wood & Co., Philadelphia, Pa.

The fuel is charged on from the small hopper at the top with conical bottom. The vertical shaft of the automatic feed passes through the central part of the hopper and has a worm-wheel at the top for power driving by means of the intermeshing worm. The fuel-distributing device is attached to the bottom of the vertical shaft and is so shaped as to distribute the fuel evenly over the fuel bed.

The blast enters at the bottom through the central pipe and passes out from under the small hood into the ash and then up into the fuel. The blast is caused either by a steam jet or a mechanical blower. In either case steam enters with the air.

The ash bed is supported on a revolving table which can be rotated by means of the hand crank, pinion and spur gear outside of the ash pit, and the small bevel gear that meshes with the large bevel gear on the under side of the table. The rods projecting from the outside into the ash just above the revolving table are for scraping the ash from the table as it revolves; they are adjustable as to the distance they extend into the ash.

The gas passes out through the side flue near the top of the gasification chamber. The ash pit is tightly closed while the blast is on.

Small holes for observing and poking the fuel are provided at the top and sides.

This producer is practically the same as that used in the tests at St. Louis by the U. S. Geological Survey, operated as a pressure producer. One of these tests was run 562 hours continuously. See Chap. XXI.

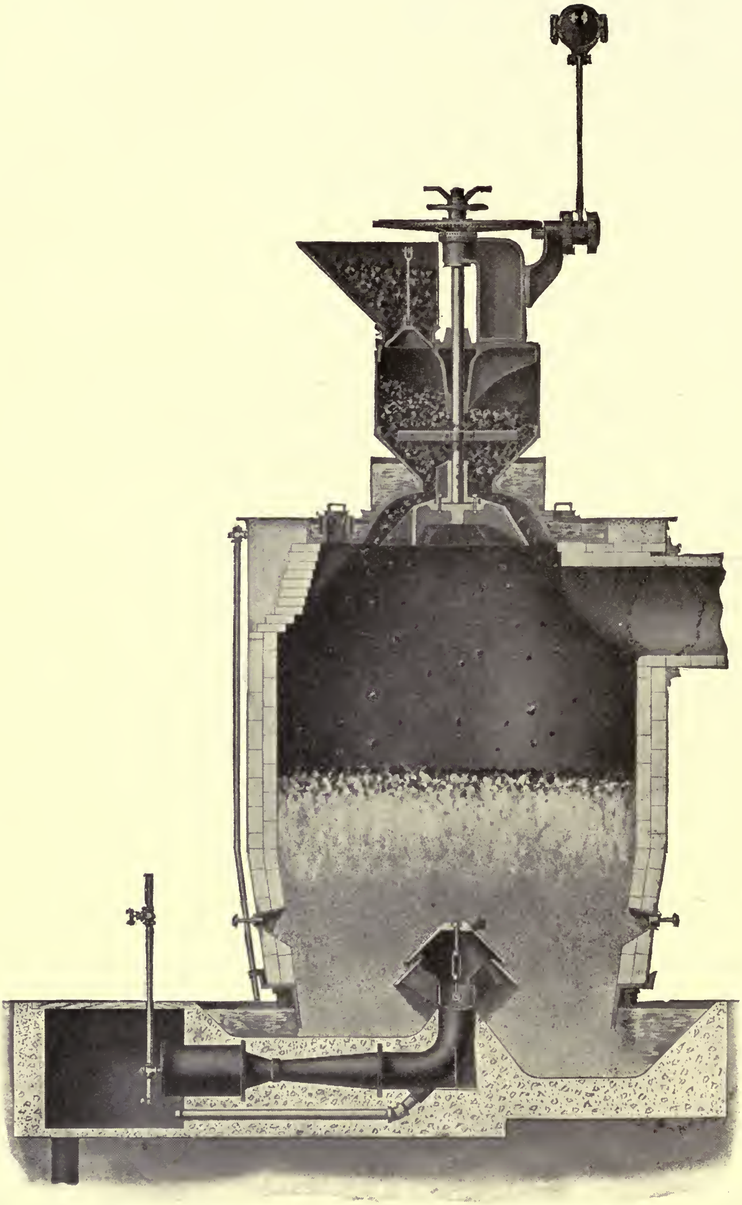

Fig. 114a.

Fig. 114a.

Continuous Updraught Pressure Producer for Bituminous Coal, with Automatic Feed and Water-sealed Ash Pit. Either Pressure or Suction Draught.
R. D. Wood & Co., Philadelphia, Pa.

This is much the same as the producer shown in Fig. 114 except the water seal at the bottom. This method of closing the ash pit allows the removal of ashes while the blast is on, and thus the continuous operation of the producer for an indefinite period without cutting off the blast.

The pipe for carrying the steam to the jet that produces the blast is shown at the lower left-hand side.

A producer of this general type, without the automatic feed, is in use at the works of the American Locomotive Co., Richmond, Va. A test of the gas power plant at these works is reported in the Proc. Amer. Inst. Elec. Engrs., July, 1908.

solid fuel, the process is either one of burning the fuel with so small a supply of air that only incomplete combustion takes place with the production of combustible gases, or one in which water vapor or steam is brought into contact with the hot fuel and the fuel and steam act mutually on each other so that fuel gas is formed. Both methods are often applied simultaneously to the fuel. The only solid matter left in any appreciable quantity is the ash. In some methods practically all of the combustible of the fuel is converted into permanent gas. In others an appreciable quantity of semi-liquid matter is formed by the condensation of some of the gas. This is abstracted from the gas. Some of the methods of making gas for illuminating purposes differ radically from those for power gas.

The heat values per cubic foot of the combustible mixtures formed by mixing different fuels with air are different. For example, a mixture of blast-furnace gas and air has only about 60 per cent of the amount of heat available per cubic foot that a mixture of gasoline vapor and air has, both mixtures being proportioned for perfect combustion. And a mixture of illuminating gas and air has about 90 per cent of the heat value of the gasoline vapor and air mixture, both mixtures taken at the same volume, temperature, and pressure.

The power that a motor will develop is in a measure proportional to the lower heat value per cubic foot of the combustible mixture used (but not to either the lower or the higher heat value of the fuel gas). If the compression pressure is kept the same for all mixtures, then the power capacity of the motor on the different mixtures is nearly proportional to the heat value of the mixture.

A motor that is to develop a certain amount of power at a given speed of piston travel must be considerably larger in cylinder capacity for blast-furnace gas than for natural gas, illuminating gas, gasoline, naphtha, kerosene, or fuel oil. The compression pressure can be carried considerably higher for blast-furnace gas than for the other fuels just mentioned. Since the higher compression pressure increases the efficiency of heat transformation into mechanical energy, the ratio of the cylinder capacity of the motor using blast-furnace gas to that of the one using natural gas is therefore somewhat less for the same power developed than the ratio of the lower heat value of the natural gas and air mixture to that of the blast-furnace gas and air mixture.

221. Retort Gas by Distillation of Bituminous Coal. Coal Gas. — Bituminous coal (soft coal) is placed in a retort which is then tightly closed except where a pipe is connected for carrying off the gas. An external fire heats the retort to incandescence and drives off from one-fourth to one-third of the coal as gas, according to the grade of coal used. The gas is passed through a water-cooled pipe, where some of the unstable gas is condensed to the form of tar. The remaining gases are still further cooled, washed with water, and chemically treated to remove the remaining tar vapors, ammonia vapor, carbon dioxide, sulphur, and any other impurity that may be present. If the coal is of a certain composition, the resulting gas is suitable for illuminating purposes when burned as an open flame. But when there are not enough illuminants present in the distilled gas it is enriched with illuminants, generally from petroleum or petroleum products. Two-thirds to three-quarters of the weight of the coal remains in the retort as coke, composed of carbon and earthy matter. The principal by-products of the retort process are coke (gas coke), tar, and ammonia. These and the other by-products are converted into almost innumerable other substances by suitable processes.

The composition of retort-distilled gas varies with both the kind of coal used and the temperature (or rapidity) of distillation.

Assuming, for a very rough method of comparison between the heat value of the gas distilled and of the coal, that each pound of coal gives 5 cubic feet of gas having a heat value of 600 B.t.u. per cubic foot before enriching, which is a high value, and that the heat value of the coal is 15,000 B.t.u. per pound, it will be seen that only twenty per cent of the heat of the coal appears in the gas.

While retort gas made as just described burns with entire satisfaction in the combustion motor, it is too expensive for use in large motors on account of the method of production and the high grade of coal that must be used. This refers especially to power plants of medium size where recovery of by-products is not commercially advantageous.

The other extreme point of view is that a coal-distilling plant may be operated with gas as a by-product, and the other substances produced as the valuable commodities sought. This condition is realized in the manufacture of coke and the use of the excess gas for combustion motors.

222. Air Gas by Burning Solid Fuel with Insufficient Air. — While this method is not used for producing gas for power purposes, it will be described because various combinations of it and the water-gas process (to be described later) constitute practically all the commercial methods of manufacturing power gas (and also fuel gas for furnaces).

The air-gas process is similar, in a way, to incomplete combustion in a furnace whose function is to produce heat. This is such a condition as exists, to some extent, when the fuel bed is carried too thick or too deep for heating purposes. In such a case the products of combustion, especially when anthracite coal or coke is used as a fuel, contain a large percentage of carbon monoxide, CO.

In the simpler forms of air-gas producers in which air enters the fuel bed at the bottom and passes off at the top, there is generally a considerable thickness of ash between the burning fuel and the grate bars or other device for supporting the charge.

When the air comes into contact with the incandescent carbon, the O of the air and some of the carbon unite to form either CO or CO_2. Just what the chemical reactions are has never been determined. The resulting gases that pass from the fuel contain both CO and CO_2 under ordinary conditions of operating a producer. Since the CO_2 is not combustible, the process is carried out so as to cause the C to combine with the O as CO as far as possible.

Most of the heat liberated by the burning of the carbon goes to raise the temperature of the products of combustion and is carried from the producer by the gas. A small proportion goes to raise the temperature of the fuel, to vaporize the volatile part, and to balance the heat lost by radiation, etc.

There is generally an appreciable amount of water vapor (moisture) in the air. The coal contains water, or hydrogen and oxygen in the proportion to form water, sometimes to the extent of several per cent of its weight. But even with the cooling effects of atmospheric and fuel moisture, radiation and excess of air, and other causes, the temperature of the gases passing from the fuel is high. The complete combustion of some of the carbon which occurs keeps the temperature higher than that of incomplete combustion alone.

When bituminous coal is used in the gas producer, the volatile parts are first distilled off in much the same manner as in the retort process, so far as the action on the coal is concerned. The coke thus formed is then burned by the oxygen of the air. Tar and ammonia products, etc., are formed as in the retort process, unless the generator is especially constructed to dissociate the unstable gases and allow recombination of their elements into stable gases. This latter action will be taken up in connection with the processes more suitable for making power gas.

A large amount of heat is carried from the fuel by the gases in the air-gas process. This heat can be utilized to some extent for heating the air going to the producer, but still the gas will be very hot even after the heat for this purpose has been abstracted.

The gas must be washed and otherwise purified before going to the motor. This has the effect of cooling it. The major part of the heat that is carried from the producer by the gas is thus lost unless unusual means are provided to utilize it for purposes other than for the motor. On account of this great waste of heat the simple air-gas process is not economical for generating power gas.

The theoretical value of all the heat that can be obtained by chemically accurate carrying out of the air-gas process when the fuel is assumed to be pure carbon, can be determined as follows:

	B.t.u.
Heat value of 1 pound C burned to CO_2	14650
Heat liberated by burning 1 pound C to CO	4206
Heat in $2\frac{1}{3}$ pounds CO produced $= 14650 - 4206 =$	10444

$$\left.\begin{array}{l}\text{Ratio of heat value of total}\\ \text{CO produced to that in the C}\end{array}\right\} = \frac{10444}{14650} = .713 = 71.3 \text{ per cent.}$$

This is the theoretical limit of the efficiency of the air-gas process with pure dry carbon and no moisture in the atmosphere.

The theoretical efficiency of the air-gas process with coals containing volatile matter will in general be somewhat different from the value just obtained. Moisture in the fuel and the atmosphere also modifies this efficiency.

223. Water Gas in General. — Water gas is made by bringing steam into contact with highly heated fuel. The steam is decomposed into its elements, H and O, and the O then combines with the C of the fuel to form carbonic oxide, CO. The hydrogen escapes as free H. This is when the only combustible in the fuel is C and the process is theoretically perfect. In practice some carbonic acid, CO_2, is also formed. There are also other combustible substances generally present in the gas formed on account of impurities and hydrocarbons in the fuel.

The chemical equations representing the theoretical process of water-gas formation from the carbon constituent of the fuel are:

$$\overset{\text{2 vol.}}{2\,H_2O} + C_2 = \overset{\text{2 vol.}}{2\,CO} + \overset{\text{2 vol.}}{2\,H_2},$$

$$\begin{array}{lcccccccl} & H_2O & + & C & = & CO & + & 2\,H & \\ & 18 & & 12 & & 28 & & 2 & \text{Weight proportions.} \\ \text{Pounds} & 1 & & \frac{2}{3} & & \frac{14}{9} & & \frac{1}{9}. & \end{array}$$

The last two equations show that the volumes of CO and H produced are equal to each other, and that the total volume of the combustible gas produced is twice that of the steam used, dealing with equal temperatures and pressures.

The equations also show that the weight of the CO produced is fourteen times that of the H that is set free.

There are two distinct methods of manufacturing water gas. One is known as the continuous or retort process, and the other is an intermittent process. The retort process is but little used. The intermittent process finds a large field of application.

There is also a process of alternately making air gas and water gas in a producer. It is only a slight modification of the intermittent water-gas process, and finds broad application.

Water gas does not give an illuminating flame, since it contains little or none of the heavy hydrocarbons which, as has been stated, are the illuminating constituents of a gas. Water gas can be made illuminating by carbureting by the addition of heavy hydrocarbons. This is generally done by adding to it the heavy hydrocarbon gases of petroleum, obtained, in some cases at least, by decomposing the heavy distillates of petroleum by heat. Carburation increases the cost of production per cubic foot.

The three processes which have been mentioned in this section will be separately discussed later.

224. Producer Gas by Combined Air-Gas and Water-Gas Processes. — The gas intended especially for power (and heating) purposes is practically all made by processes that are combinations of the air-gas and water-gas processes. There are several different ways in common use for combining these two processes. One method is to admit both air and steam or water vapor simultaneously and continuously to the fuel, thus producing continuously a mixture of air- and water-gas. Another method is to burn the fuel with air for a while till the fuel bed has become highly incandescent, and then to cut off the air and pass steam or water vapor into the hot mass, alternating the periods of air and water admission so as to keep the temperature of the fuel within a range suitable for satisfactorily carrying on the manufacture of the gas. Air gas is made during the period of "blowing" while the air alone is admitted, and water gas only during the "run" while steam alone is admitted.

The name "producer gas" is quite generally understood to mean the mixture of air- and water-gas made by any of these processes, but it is also applied sometimes to air gas alone and sometimes to water gas alone.

225. Suction Producer for Anthracite Coal or Coke. Suction Due to Intake Stroke of Motor Piston. — Power gas for motors up to three hundred horsepower can be made satisfactorily by drawing air and steam or water vapor by suction through a deep bed of anthracite coal. The more common form of suction producer is a vertical cylinder of metal lined with fire-brick. The fuel is supported by a grate or some other form of rest that partly fills the lower part of the enclosed space, leaving a circular opening near the wall through which the ash can drop out. The producer is closed air tight except the openings for admitting air and steam and another for the escape of the gas. In the usual forms the suction of the motor draws air and steam or water vapor through the fuel, where the chemical changes of dissociating the steam and burning the coal take place. In one type of suction producer plant the gases pass from the producer to an economizer and there give up part of their heat for warming the air that is going to the producer, and also to vaporize the water to supply the requisite amount of steam to the producer. The gases then pass into the bottom of a scrubber for cleaning the gas by washing it with water. The scrubber is generally a vertical cylinder filled with rather finely broken coke, or having a large number of wood slats, etc., over and through which water trickles from the top to the bottom. The gas is freed more or less completely from soot, dust, and some of the other impurities while passing upward through the scrubber. From the top of the scrubber the gas goes into a purifier, dry cleaner, or moisture separator, in which it passes through some finely divided substance such as sawdust or fine wood shavings, for final cleaning and freeing from moisture and solid particles. From the purifier the gas goes directly to the motor cylinder in the required amount during the charging stroke of the piston. A small drum is sometimes placed between the motor and the purifier. It provides a mass of gas for expanding and flowing into the motor during the suction stroke, thus maintaining a more steady flow through the producer and its accessories and offering less resistance to the suction of the motor than when no such drum is used.

The air going to the producer passes through the economizer, where it receives heat from the producer gas before entering the ash pit or air space of the producer. The steam from the vaporizer also passes into the sealed ash pit, from which the mingled air and steam are drawn into the fuel.

The function of the economizer is to utilize as much as possible the heat carried from the producer by the gases.

The exhaust from the motor is sometimes utilized for preheating the air that goes to the producer.

The theoretical changes that take place in the producer are the incomplete combustion of a part of the carbon of the fuel by the oxygen of the air to form CO; the decomposition of the steam into its elements H and O; and the combination of the O thus liberated with the remainder of the carbon to form more CO.

The decomposition of the steam absorbs sensible heat in a larger amount than is liberated by the combustion of its O with the C to form CO. Heat is therefore required for the water-gas part of the process of gas generation.

The air-burned part of the fuel supplies the heat necessary for the water-gas part of the process, and also the heat carried off by the gas, lost by radiation, required to heat the fuel, etc.

Since, in the suction producer direct connected to the motor as described, the demand for gas varies with the amount of power that the motor must furnish at any moment, and because the temperature of the fuel bed should remain nearly constant, it is evident that the rate of supplying steam to the fuel bed must be variable in somewhat the same proportion as the rate at which gas is generated. Automatic regulation of the amount of steam supplied therefore becomes a necessity for the direct-connected suction gas producer.

The construction of the gas-generating plant just described is such as to secure automatic control of the steam supply. In it as long as the gas is generated at a certain rate the steam will be formed at a practically constant corresponding rate, for if the temperature of the fire and the gas passing from it should rise, the gas will carry more heat to the water in the vaporizer and the rate of steaming will consequently be increased. The increased amount of steam will in turn cool the fire down to the proper temperature. A reverse action occurs when the fire tends to get too cool.

Again, when the load on the motor increases, more air is drawn into the generator than before. The increased amount of air increases the temperature of the fire slightly, and the greater amount of slightly warmer gas carries more heat over to the vaporizer, so that more steam is formed to keep both the temperature and the composition of the gas constant. The reverse occurs when the load on the motor decreases.

In some designs of suction producers the vaporizer is part of the producer. The water space in such cases is generally over the top and around the upper part of the generator.

The steam is sometimes admitted to the fuel some distance above the bottom of the fire. This is done to secure the most complete consumption of the fuel by allowing only air to come in contact with it at the lowest zone of combustion and thus to maintain a high temperature while the last of each piece of fuel is consumed. The fact that considerable coal passes unburned into the ash in some types of producers makes it essential to consider some means, as that just mentioned, for the prevention of fuel waste in this manner.

For starting the fire in a suction producer of the size and type under discussion, or for bringing up the fire after it has been idle for some time, as over night or a holiday, an air blower is necessary. When the blower is hand operated, which is generally the case for the small plants, the plant is entirely independent of any other source of power. While blowing up the fire a vent is opened between the producer and scrubber to allow the gas to pass off. The vent is generally between the economizer and scrubber. When the vent is thus located, the economizer is heated during the period of blowing up the fire.

226. Theoretical Case of Gas Producer. — A convenient method of following out the operations of a gas producer operating continuously in the manner of the suction type described in the preceding section, is to assume that there is neither loss of heat by radiation, carrying off by the gas, etc., nor gain of heat from energy supplied by any exterior source. Such a case cannot possibly exist, of course. But this manner of simplifying the operations of the process warrants such assumptions in order to secure ready means for following out the essential parts of the process.

It will therefore be assumed, for the purpose just stated, that the producer delivers gas at the same temperature and pressure as that of the atmosphere, that there is no heat loss by radiation, and that the gain of heat on account of the energy consumed in creating a draft through the apparatus is just balanced by the loss in the heat carried off by the ash.

Under such assumptions the total heat value of the gas produced is the same as that of the fuel consumed. The computations which are given below deal with the gas produced from a pound of carbon burned by the combined air- and water-gas process.

227. Computations for Theoretical Gas Producer. — Supplies received and products delivered at 62° F. and 14.7 pounds per square inch pressure.

Higher heat values used.

Heat liberated by 1 lb. C burned to CO_2...... 4206 B.t.u.

Heat required to vaporize and decompose 1 lb. water = 61,984 ÷ 9 = ... 6887 B.t.u.

Heat liberated by burning two-thirds lb. C to CO with the eight-ninths pound O liberated by the decomposition of 1 lb. of water = $\frac{2}{3} \times 4206$ = ... 2804 B.t.u.

(See section 223 and table of heat values.)

Heat to be supplied by air-burned C for maintaining a uniform temperature of the fuel while 1 lb. water is decomposed and its O united with C to form CO = 6887 − 2804 = ... 4083 B.t.u.

Water per pound of air-burned C that will keep the temperature of the fuel bed uniform.......................... $\Bigg\} = \frac{4206}{4083} = 1.0301$ lbs.

Carbon burned by O from above amount of water = $1.0301 \times \frac{2}{3}$ = ... .6867 lb.

Total C burned for each pound of air-burned C 1.6867 lbs.

Water dissociated and resulting O combined with C per lb. of C burned. $\Big\} = \frac{1.0301}{1 + .6867} = .6107$ lb.

Percentage of air-burned C = $\frac{100 \times 1}{1.6867}$ = ...59.29 per cent.

Percentage of water-burned C = $\frac{100 \times .6867}{1.6867}$ = 40.71 per cent.

For the air-burned part of 1 *pound carbon.*

	Pounds	Cubic Feet
Air-burned part of 1 lb. C..	.593	.....
Air for burning .593 lb. C = .593 × 5.76 = ...	3.415	44.8
CO formed by air burning = $2\frac{1}{3} \times .5928$ = ... (1 lb. C forms $2\frac{1}{3}$ lbs. CO.)	1.383	18.83
N from air burning = 3.415 × .7688	2.625	35.51
Total products from air-burned part of 1 lb. C	4.008	54.34

Total heat value of air gas from air-burned part of 1 lb. carbon = 1.383 × 4476 = ...6190 B.t.u.

B.t.u. per cubic foot of air gas = $\frac{6190}{54.31}$ = ...114 B.t.u.

For the water-burned part of 1 *pound carbon.*

	Pounds	Cubic Feet
Water-burned part of 1 lb. C	.4071	.....
Water used for burning .4071 lb. C	.6107	.....
CO formed by water burning = $2\frac{1}{3} \times .4071$ =	.9500	12.93*
H set free = $\frac{.6107}{9}$ =	.0679	12.85*
Total product from water-burned part of 1 lb. C =	1.0179	25.78

Heat value of CO from water-burned part of 1 lb. C = .95 × 4476 = ...4252 B.t.u.

Higher heat value of H from water-burned part of 1 lb. C $= \frac{.6107}{9} \times 61984 =$ 4206 B.t.u.

Total higher heat value of water gas from water-burned part of 1 lb. C = 4252 + 4206 = ... 8458 B.t.u.

B.t.u. (higher) per cubic foot of water gas = $\frac{8458}{25.78}$ = 328 B.t.u.

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* According to the volumetric relations in the chemical equation for water-gas formation, the volume of *H* = volume of CO. This result is not obtained in the computations, partly at least on account of using the approximate atomic weights in the application of the equations in connection with tabular values that are based on the accurate atomic weights. The atomic weight of *H* is taken as 1 in the computations, while its accurately determined and accepted value is 1.008.

For burning 1 *pound carbon to CO by the combined air- and water-gas process; theoretical case of* 100 *per cent efficiency.*

PRODUCTS.

	Weight of Each Product. Lbs.	Volume Each Product. Cu. Ft.	Heat Value of Each Product. B.t.u. Higher.	Percentage.	
				By Weight.	By Volume.
CO.......	2.333	31.76	10,444	46.42	39.64
H........	.068	12.85	4,206	1.35	16.04
N........	2.625	35.51	....	52.23	44.32
Totals ..	5.026	80.12	14,650	100.00	100.00

Air used in producer per lb. of carbon = 3.45 lbs. = 44.8 cubic feet.

Water used in producer per lb. of carbon = .6107 lb.

Higher heat value of gas produced $= \frac{14.650}{80.12} = 183$ B.t.u. per cubic foot.

Specific heat of gas produced = .288 B.t.u. per lb. at constant pressure.

Air per cubic foot of gas for perfect combustible mixture $(.3964 + .1614)\ 2.39 = .5578 \times 2.39 = 1.33$ cubic feet.

B.t.u. per cubic foot perfect mixture $= \frac{183}{1 + 1.33} = 78.4$ B.t.u.

The total heat carried in by each pound of carbon is 14,650 B.t.u., which is the same as is returned in the combustible gas under the theoretical conditions assumed.

The results obtained above can be checked by comparing (*a*) the product of the heat liberated by the formation of 1 pound of CO multiplied by the pounds of CO formed with (*b*) the product of the heat absorbed per pound of H liberated multiplied by the pounds of H liberated. The two products should be equal for the 100 per cent efficiency assumed. The same reasoning is true for cubic foot units (or any other units).

The amounts of heat liberated or absorbed per unit of product are given below for 62° F. and 14.7 pounds per square inch pressure absolute.

Heat liberated during the combination of:

C and O to form 1 cu. ft. CO = 132.5 B.t.u. per cu. ft. CO.
C and O to form 1 cu. ft. CO_2 = 462. B.t.u. per cu. ft. CO_2.
C and O to form 1 lb. CO = 1803 B.t.u. per lb. CO.
C and O to form 1 lb. CO_2 = 3995 B.t.u. per lb. CO_2.

Heat absorbed during the dissociation of:

H_2O to liberate 1 cu. ft. H = 328 B.t.u. per cu. ft. H.
H_2O to liberate 1 lb. H = 61,984 B.t.u. per lb. H.

The amounts of CO and H resulting from the gasification as assumed above are 39.64 cubic feet CO and 16.04 cubic feet H. By multiplying these amounts by their respective heat factors, just given, the results are:

$$132.5 \times 31.76 = 4208 \text{ B.t.u.}$$
$$328 \times 12.85 = 4214 \text{ B.t.u.}$$

which is as near an agreement of values as can be expected with the use of round numbers for the heat values and the other errors due to approximate values.

Using pound units in a similar manner, the results are:

$$1803 \times 2.333 = 4206 \text{ B.t.u.}$$
$$61{,}984 \times .0679 = 4208 \text{ B.t.u.}$$

The percentage composition can be used in a similar manner, the percentage of each constituent of the gas being considered as cubic feet in 100 cubic feet, or as pounds in 100 pounds of the gas.

If the C were burned to CO_2 in a theoretical case similar to that just considered when there are no hydrocarbons in the gas, the relative amounts of CO_2 and H for 100 per cent efficiency of gas production are obtained from the following equations:

For cubic foot units,

$$328\,H = 462\,CO_2;$$

for pound units,

$$61{,}984\,H = 3995\,CO_2,$$

in which the numerical quantities are the higher heat values of the gases.

The composition of suction producer gas from fuel that has only C as the combustible can be determined from these equations for the theoretical assumed case, as is done below.

Since each pound of H in the gas represents 8 pounds of O from the decomposed water, and each pound of O combines with twelve-thirty-seconds of a pound of C to form CO_2 ($CO_2 = 12$ parts C and 32 parts O by weight), therefore

For each pound of H in the gas produced there are $8 \times \frac{12}{32} = 3$ pounds C water-burned to CO_2.

Heat liberated in burning 3 lbs. C to $CO_2 \times 14,650 = 4390$ B.t.u.
Heat to be supplied by air-burned C for each lb. of H in the gas produced $= 61,984 - 43,950 =$ . . 18,034 B.t.u.
Pounds of air-burned C $= \frac{18,034}{14,650} =$ . . . . 1.231 lbs. C
Total C burned per lb. of H in the gas $= 3 + 1.231 = 4.231$ lbs. C
Nitrogen carried in with air for air-burning 1.231 lbs. C $= 1.231 \times 8.86 =$ . . . . 10.9 lbs. N
Lbs. CO_2 from 4.231 lbs. C $= 4.231 \times 3\frac{2}{3} =$ . . . . 15.515 lbs. CO_2

Composition of Gas when C is Burned to CO_2 by the Combined Air- and Water-Gas Processes.

Theoretical case of 100 per cent efficiency.

	Weights.	Volumes.	Percentage by Weight.	Percentage by Volume.
CO_2. . . .	15.514	134.2	56.58	28.48
H.	1.000	189.4	3.65	40.20
N.	10.906	147.6	39.77	31.32
Totals	27.320	471.2	100.00	100.00

The weights and volumes per lb. of C burned can be obtained by dividing by 4.231.

Pounds of gas produced per lb. of C $= \frac{27.32}{4.231} = 6.46$ lbs. gas.

Cu. ft. of gas produced per lb. of C $= \frac{471.2}{4.231} = 111.4$ cu. ft. gas.

Hydrogen produced per lb. of C $= \frac{189.4}{4.231} = 44.7$ cu. ft. H.

Heat value of H liberated per lb. of C. burned = 44.7 × 328 = 14,650 B.t.u. about.

Higher heat value of gas for 40.2 per cent H, which is the only combustible, = .402 × 328 = 131.8 B.t.u. per cu. ft.

Specific heat of gas produced = .345 B.t.u. per lb. at constant pressure.

Air per cu. ft. of gas for perfect mixture = .402 × 2.39 = .96 cu. ft.

B.t.u. per cu. ft. of perfect mixture $= \dfrac{131.8}{1 + .96} = 67$ B.t.u. higher.

A comparison of the above two cases shows that both the gas produced and the perfect mixture have higher heating values per cubic foot when the carbon is burned to CO than when it is burned to CO_2. There is a smaller quantity of gas in the former case, however, so that the total heat values of the gas produced from a given amount of carbon are the same in both cases.

When both CO and CO_2 are formed in and carried from the producer, the equations for the heat balance in the theoretical case of 100 per cent efficiency have the forms:

For cubic foot units,

$$328\,H = 132.5\,CO + 462\,CO_2;$$

for pound units,

$$61{,}984\,H = 1803\,CO + 3995\,CO_2,$$

in which the numerical coefficients are heat values at 62° F. and 14.7 pounds per square inch absolute pressure.

The accuracy of the above equations depends on the correctness of the heat values used. The ones here adopted seem to have been determined with great care.

If when numerical substitutions and computations are made for these equations the left-hand member in either is greater than the right-hand member, it is an indication that the producer is absorbing more heat for the decomposition of water than is being generated by the combustion of carbon in the producer. Such a condition can exist temporarily in a producer that does not receive heat or energy from outside sources, but must be paid for with leaner gas during a consecutive period of operation.

The above equations are not applicable when hydrocarbons are present in the fuel or in the gas produced.

228. Comparative Heat Losses for Burning C to CO or to CO_2 in the Air-and-Water-Gas Process When the Gas Leaves the Producer at a High Temperature. — It was shown in the preceding section that when C is burned to CO in the producer there are theoretically 5.026 pounds of gas, whose specific heat is .288 B.t.u. per pound, generated per pound of C burned to CO; and that when the C is burned to CO_2 in the producer there are 6.46 pounds of gas, having a specific heat of .345 B.t.u. per pound, generated per pound of C burned to CO_2.

The heat required for raising the temperature of the gas 1° F. in each case is:

For 1 pound C burned to CO,

$$5.026 \times .288 = 1.446 \text{ B.t.u.},$$

and for 1 pound C burned to CO_2

$$6.46 \times .345 = 2.225 \text{ B.t.u.}$$

The ratio of the two amounts of heat,

$$\frac{2.225}{1.446} = 1.54,$$

shows that when in the air-and-water gas process the gas leaves the producer at a higher temperature than that of the air, water, and fuel used, 54 per cent more heat is carried from the producer by the gas when the C is burned to CO_2 than when it is burned to CO. This numerical value applies only to the theoretical case of the preceding section, and also assumes that the specific heats of the gases produced by the two methods of burning retain the same ratio through all temperatures up to that at which the gas leaves the producer. The latter assumption is probably true in a measure.

The heat thus carried out from the producer is mostly lost during the cooling of the gas by the usual methods. It is therefore desirable to have a minimum of CO_2 in the gas.

229. Fuels for Continuously Operated Suction Producers. — Since the continuously operated updraught suction producer cannot be opened above the combustion zone for stoking or otherwise breaking up the fuel, on account of air being drawn in through such an opening, it is necessary to use a fuel that does not cake or adhere to the walls of the combustion space. This means that the fuel must be practically free from volatile hydrocarbons. Mechanical stoking or stirring devices that enter above the combustion zone are subject to detrimental leaks.

Hard coal (anthracite) and coke are therefore the only fuels that are adapted to the continuously operated suction producer direct connected to the motor after the manner that has been described.

230. Pressure Gas Producers for Continuous Operation. — The general form of this class of producer is much the same as that of the continuous suction producer. The draught through the producer and its accessory apparatus is caused generally by either a steam jet blower that forces both steam and air into the tightly sealed bottom of the producer or by a mechanical blower which forces the air in while steam is brought in separately. In the latter case the steam may be generated, at least in part, in a vaporizer heated by the gases escaping from the producer. The steam is sometimes taken from an entirely detached steam-generating plant.

The gas passes, in the more usual construction, from the producer successively through a vaporizer, an economizer for heating the air going to the producer, a scrubber, a purifier, and thence to a storage tank. A tar extractor is sometimes placed between the scrubber and the purifier, and tar drips are suitably located. There is generally one between the economizer and the scrubber, with drainage from both. Water seals are used, through which the gas passes on its way to storage, but cannot return. The seals act as check valves.

The fuel can be stoked through openings above the combustion zone by temporarily reducing the blast that forces the air through the producer. This can be done without checking the operation of the motor, since the storage tank will supply gas during a short stoking interval.

The charging apparatus is made so that fresh fuel can be charged on at any time during the operation of the producer.

A pair of small doors or gates, placed in series after the manner of those in an air lock, are used for charging the fuel when it is done by hand. Mechanical chargers have suitable provisions enabling them to be used at any time.

Caking coals, as well as any other kinds, can be used in the pressure producer. The convenience with which stoking can be done by hand to break up caked coal makes it entirely practicable to use those which cake to the highest extent. Mechanical stokers or stirrers driven from above the combustion space for continuously stirring the fuel are used to some extent. Leakage and rapid deterioration by the heat are serious features to be dealt with in the use of a mechanical stoker of this class.

Various methods of sealing the ash pit find application. Water is very commonly used for the seal. Mechanical sealing is also extensively used.

When fuel containing volatile hydrocarbons is used, the volatile part is distilled off and passes out with the other constituents of the gas. Unless care is taken to have the producer of a suitable form, and to operate it properly, a large portion of the volatile gas will be of such a nature as to condense at or above atmospheric temperature and pressure, that is, during the cleaning and cooling of the gas. But if the producer has ample and properly formed space above the fuel bed and the temperature is kept high, part of the hydrocarbons that are distilled off from the fuel as condensable gases (at atmospheric temperatures and pressures) will be dissociated and their elements will recombine in gases that are permanent under the ordinary conditions of utilization. There are objections to keeping the temperature of the fuel bed very high. Some of these objections are on account of the increased loss of heat carried away by the gases, and increased fusing and clinkering of the fusible part of the ash.

The government tests at St. Louis, of bituminous coals and lignites in an up-draught, pressure producer for continuous operation and of the general class just described, gave tar in quantities approximately from 10 gallons to 23 gallons per ton of coal used in the producer. The volatile matter in the coal varied from about 21 to 40 per cent in the different varieties. The tar from the bituminous coals was black, and that from some of the lignites was of a brown color.

The tar is practically all waste in such cases, and is disagreeable to have about the apparatus.

The aim of many producers using bituminous coals and lignites is to completely break up the condensable hydrocarbons so that they will form into others that are permanent gases.

Tar-burning apparatus for burning the tar under steam boilers is used in connection with some gas power plants. The method of burning is similar to that for oil fuels, the tar being preheated to liquefy it.

231. **Down-Draught Continuous Gas Producer.** — If coal is charged or fed on at the top of the fuel bed and the draught through it is downward from the top to the ash pit, then the volatile gases distilled off from the green fuel will have to pass down through the hot zone of combustion before escaping from the producer. By this process the heat of the fuel bed dissociates the condensable hydrocarbons and converts them into permanent gases more completely than when the draught is upward and the fuel fed on at the top.

In practice both air and steam are blown or drawn into the upper part of the continuous producer and the gas taken out from the bottom. Hand stoking for breaking up the caked fuel can be done readily when the draught is produced by the suction of an exhauster connected to the bottom of the producer for drawing out the gas.

232. **Under-Feed Continuous Gas Producer.** — Another method of causing the distilled gases to pass through the hot bed of the fuel before leaving the producer, is to feed the fuel in at the bottom of the producer and have the draught through the fuel from the bottom to the top. Numerous forms of this class of producer have been used more or less extensively. The steam and air may be either blown in or drawn in by suction, entering the producer below the fuel bed, and the produced gases taken out at the top of the producer.

233. **Air and Carbon Dioxide Continuous Gas-Making Process.** — It has been pointed out that when simple air gas is made there

is a great loss of heat on account of the high temperature at which gas leaves the producer, when the gas is cooled before using, unless unusual means are adopted for utilizing its sensible heat. The combined air- and water-gas processes that have been mentioned prevent the loss of heat to so great an extent on account of keeping down the temperature of the gas by utilizing the surplus heat of combustion to some extent for dissociating the water.

A method of keeping down the temperature of the fuel and of the gas without the use of water or steam has recently been devised and put into operation. In this method exhaust gases from the combustion motor are mixed with the air entering the fuel bed in the producer. Since no water is used in the process, the exhaust gas from the motor contains a large amount of CO_2. The CO_2 upon entering the fuel bed with the air is transformed into CO in the producer by dissociation, during which part of the O of the CO_2 takes up C from the fuel. The heat absorbed by the dissociation of the CO_2 is greater than that liberated by the recombination of the nascent O with C, so that the net result is a cooling effect. The temperature of the fuel bed is kept up by the air-burned part of the fuel.*

The plant was operated on both anthracite and bituminous coal. The cooling effect of the water vapor from the motor exhaust gas when hydrocarbons are present in considerable quantity with the use of bituminous coal, is not taken up by the inventor of the process in his description of it as referred to.

A fuel consumption of .7 of a pound of coal per horsepower per hour when the plant operated continuously at full load for 24 hours a day for a considerable period is reported. When operating ten hours a day and closing down Sundays with a load factor of about two-thirds, the fuel per horsepower per hour averaged $1\frac{1}{4}$ pounds of coal.

The motor was of the four-cycle, single-acting, three-cylinder vertical type with a capacity of about 100 horsepower.

234. Combined Pressure and Suction Producer. — By combining both the pressure and the exhaust methods of operating a producer, the pressure above the fuel can be maintained at or

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* Proceedings Amer. Soc. Mech. Engrs., June, 1908, Vol. 30.

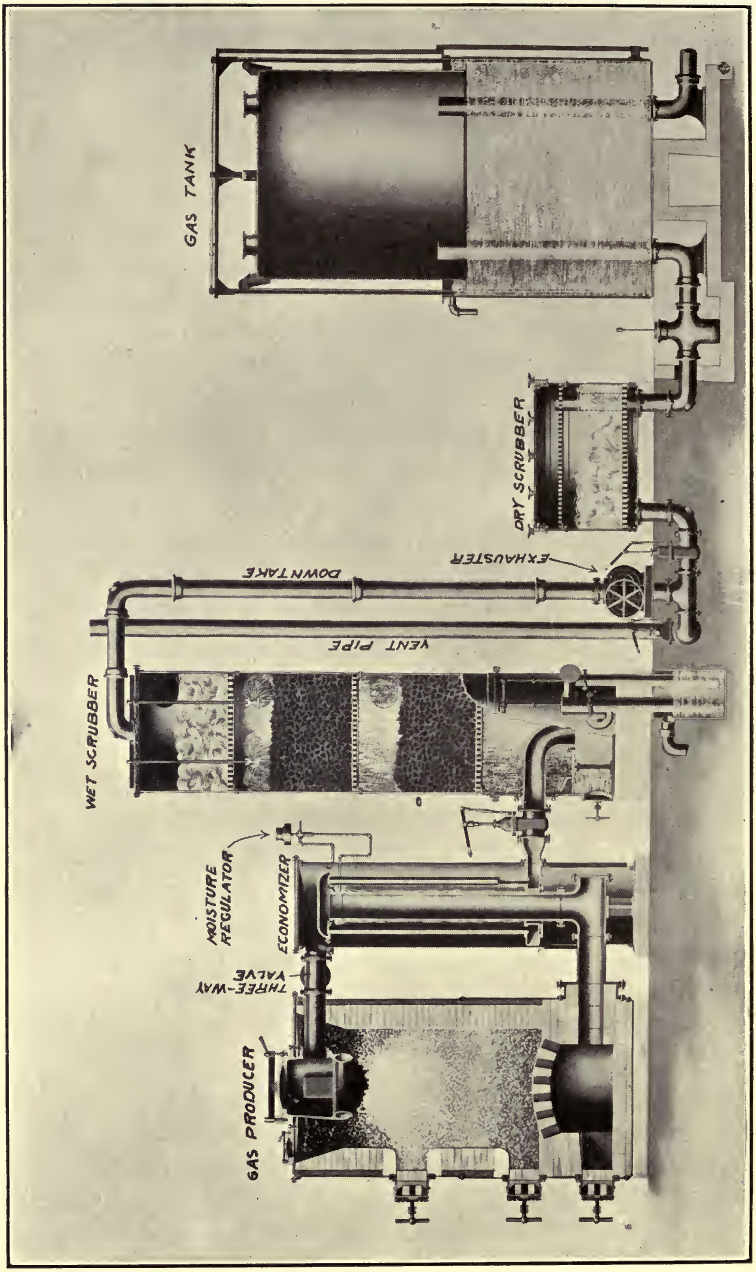
GAS TANK
DRY SCRUBBER
EXHAUSTER
DOWNTAKE
VENT PIPE
WET SCRUBBER
MOISTURE REGULATOR
ECONOMIZER
THREE-WAY VALVE
GAS PRODUCER

FIG. 115.

Fig. 115.

Down-draught Continuous Gas Producer Plant. Loomis-Pettibone System. Power & Mining Machinery Co.

The power-driven exhauster draws air in through an opening near the bottom of the hot economizer and up through the latter, thence through the three-way valve to the top of the producer and down through the central opening of the water-cooled hollow ring or torus to the top of the fuel under the ring. The gas is drawn out from the fuel through the openings of the bottom arch, up through the central tube of the economizer and down through several smaller tubes (arranged in a circle around the central tube), then through the pipe to the wet scrubber and up through two layers of coke and one of excelsior consecutively, and on through the downtake to the exhauster. The latter forces the gas on through the excelsior in the dry scrubber and thence into the storage tank.

Water in automatically regulated quantity flows through the lower pipe from the water regulator to a somewhat V-shaped trough surrounding the central tube of the economizer, and overflows from the trough so as to trickle down the outside of the central tube. The heat of the tubes vaporizes the water and the vapor mingles with the air passing to the producer.

In the wet scrubber water is sprayed continuously on the top of the upper layer of coke and runs down through it and the lower layer to the bottom of the scrubber and passes out through the overflow pipe to the water seal in the floor pit and thence to drainage.

The amount of moisture passing into the producer is controlled by the regulator. So far as the principle of operation is concerned, the regulator consists of a pan of water in which a deep cup is partly immersed with the open end down. The air space in the upper part of the cup is connected by a pipe to the upper part of the air space in the economizer. The suction of the exhauster lifts the water in the cup so that it flows into an opening in the upper part of the water pipe that leads from the regulator to the economizer. When the rate of gas making is high the suction is greater and the water is lifted higher in the cup, so that more flows into the economizer than when the rate of gasification is slow. The water in the pan is kept at a practically constant level by means of an overflow pipe.

The fire is stirred by compressed gas blown into the bottom of the producer. During this operation the valve between the economizer and the wet scrubber is closed and the three-way valve is set to allow the gas to escape to the atmosphere through suitable passages.

For starting a fresh fire in the producer, the valve between the exhauster and dry scrubber is closed, and the other valves are set as for regular operation. The exhauster is driven as usual, and the gases escape to the atmosphere through the vent pipe near the downtake.

The fuel is charged on at the top of the producer through suitable openings which are ordinarily kept closed during the operation of the plant, but can be opened for charging fuel into the producer during its operation.

very slightly above atmospheric, so that stoke holes can be opened into the gas space without appreciable escape of gas while the gasifying process is under way. This combination is found in the practical field.

235. Miscellaneous Types of Continuous Gas Producers for Volatile Coals. — There are numerous types of continuous-acting gas producers intended to eliminate the tarry products from the gas generated from coals containing volatile hydrocarbons. In all of them the object is to heat the distilled gases to a high temperature before they leave the producer.

A quite common method of doing this when the coal is charged on at the top or upper part of the producer and the steam and air enter from the bottom or from the ash pit, is to have the inner orifice for the outlet of the gas from the producer below the top level of the fuel. The distilled gases then fill such a portion of the upper part of the chamber above the zone of combustion as is not occupied by fuel, and pass down through the incandescent fuel to the orifice of the outlet. The outlet is sometimes a water-jacketed tube or pipe extending down into the central part of the fuel bed and open at the lower end. In other cases there are a number of ports in the wall of the producer below the top level of the fuel.

Air and steam are sometimes admitted at both the top and bottom of the fuel bed and the gas is carried out through ports well below the top level of the fuel bed and of the combustion zone.

Another method of highly heating the distilled gases is to have a secondary fire in the producer so located that the gas from the main fuel bed must pass through the secondary fire before escaping from the producer. The secondary fire is naturally of a non-volatile fuel, as coke or anthracite coal.

Still another method is to have a pipe or other down-take passage lead from the top of the gasification chamber to the ash pit so that the distilled gases will be carried down and enter the bottom of the fuel bed with the air and steam. Some means of creating a down draught, as a steam blower, is necessary in the down-take passage.

Two producers are sometimes used in conjunction for the continuous production of gas from bituminous coal. The draught is in either direction in the first one, but enters the fuel bed of the other at the green or fresh fuel side, so that all the gases from the first producer and all the distilled gases from the second must pass through the hot combustion zone of the second producer. Air and steam are added to the gas from the first producer before it enters the fuel of the second one.

236. Intermittent Gas-Making Processes in General. — Instead of carrying out the combined operations of burning coal with air and decomposing steam to burn more of the carbon and liberate hydrogen, the two processes are carried on separately in some cases.

For power gas purposes, a pair of producers operating in conjunction are generally used for the intermittent process. This is not always the method, however.

If in any of the forms of producers that have been briefly discussed, air only is blown or drawn through the fuel at a rate as great as compatible with gas-making processes, the body of the fuel will soon become highly heated. Then, after it has attained a sufficiently high temperature, if the air is cut off and steam blown into the incandescent fuel, water gas will be formed as long as the fuel remains hot enough to cause the necessary chemical changes. When the fuel becomes as cool as allowable, turning the air blast on again after cutting off the steam will reheat the fuel, and so on.

The nature of the gases passing off during the blow with air depends chiefly on the compactness and thickness, or depth, of the fuel bed and the rate of blowing. If the fuel bed is deep and compact, the resulting gas will be combustible on account of containing a considerable amount of CO and generally very little CO_2. But, on the other hand, if the fuel bed is thin and open, a strong blast will send so much air into the fuel that CO_2 will be the principal compound of C and O formed, and the gas will not be combustible. The heating of the fuel bed will be much more rapid when CO_2 is formed chiefly than when a combustible air gas is produced.

Both the above methods of blowing air into the fuel find application in intermittent gas-making processes. Which shall be selected depends on the kind of gas desired. That in which combustible gas is made during the period of air blowing seems to have been in use much longer and finds far more extensive application than that in which non-combustible gas is made during the period of blowing. The air gas and water gas of the latter method can be mixed and used together in the combustion motor with entirely satisfactory results.

237. **Twin Producers for Intermittent Gas Making.** — Producers are often used in pairs, the main object in pairing them being to secure the secondary fire action on the unstable gases that are distilled from the green fuel. A third producer is sometimes installed as a relay in such plants when there is a practically continuous demand for gas — no shut downs.

One method of operating the twin producers on bituminous coal is to blow both (with air only) from the top in parallel so that the air passes down through the fuel that is charged on at the top and the non-stable gases of distillation are broken up into stable gases (and some free carbon generally) by passing down through the hot zone of combustion. The blow is continued till the fuel is sufficiently hot. The air is then cut off and the steam admitted into the sealed space below the fuel in one of the producers, so that it passes up through the fuel in one of the producers and then over to the top of the other producer, and thence down through the second fuel bed. All the gases distilled during the "run" with steam have to pass through the incandescent fuel in the second bed and are there acted on by the heat to dissociate and convert the unstable ones into permanent gases. Air is then blown in again after shutting off the steam. After sufficient heating the air is cut off again and another run made with steam, but this time the steam is admitted at the bottom of the other producer, so that the path of the water gas and the distillates that accompany it is reversed. Air blowing then comes again and the whole cycle is repeated.

If the draught of air during the blowing period is induced by an exhauster interposed in the gas main from the producer, the

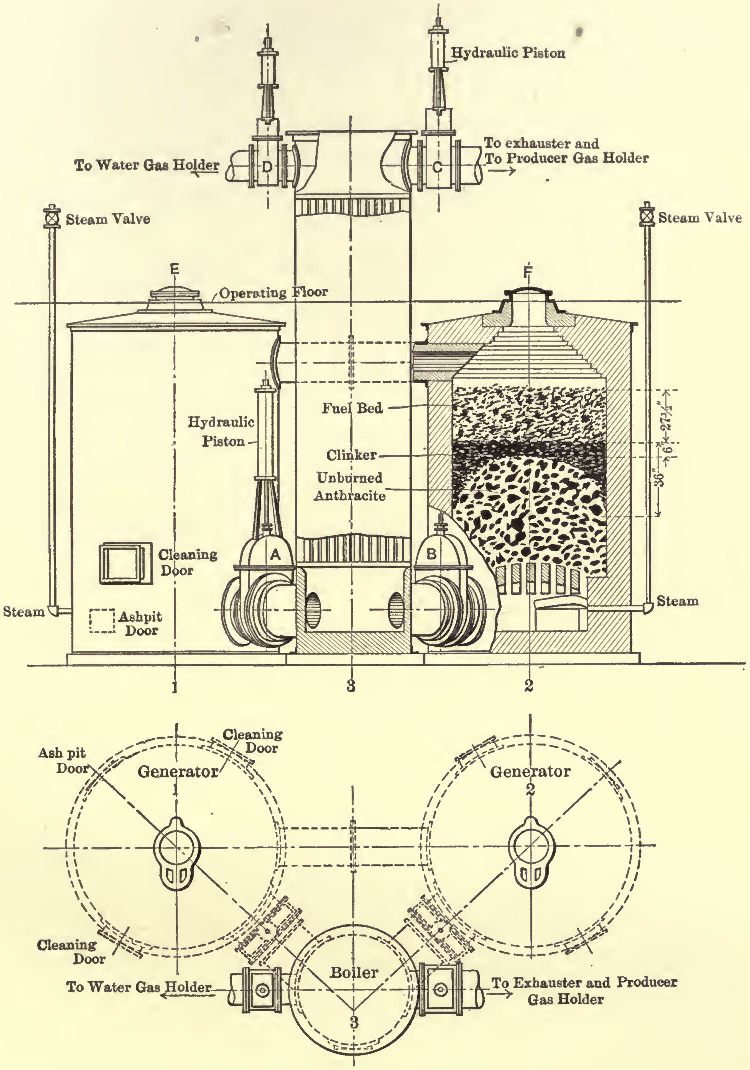

FIG. 116.

Intermittent Downdraught Gas Producer Plant.

Showing contents of producer after 51 hours' run at practically full load without shutdown of engine. 500-horsepower engine.

The fresh or green fuel charge was made up largely of anthracite with a topping of bituminous coal. Bituminous coal was charged on at the top as needed.

The producers were blasted at the same time in parallel with a down draft of air. Steam was blown into the bottoms of the producers alternately between air-blasting periods; into No. 1 after the first period of air blasting, and into No. 2 after the second air blast, etc. Proc. Amer. Soc. Mech. Engrs., mid-November, 1907.

producers can be left open at the top during this part of the operation and fuel fed in. This obviates the use of an air lock at the charging door.

It can doubtless be seen that there are several other methods of working producers in pairs while always securing the breaking up of the unstable gases by passing them through hot fuel.

238. Blast-Furnace Gas. — The blast furnace for reducing iron ore to pig iron discharges combustible gas from the top of the burden of ore, fuel, and flux that is charged into it. Air only is blown in through the tuyeres near the bottom of the enclosed chamber. In the lower part of the burden the process is probably nearly identical with that for making air gas. As the air gas made in the lower part passes upward it undergoes various chemical changes of which the net result is the addition of oxygen to a part of the CO that started up from the lower part of the furnace. This additional oxygen comes from the ore during its reduction from an oxide of iron to metallic iron. When limestone, $CaCO_3$, is used for the flux, CO_2 is driven off from it at the upper part of the furnace and mingles with the escaping gas.

$$CaCO_3 = CaO + CO_2.$$

The air gas that was formed at the lower part of the furnace is therefore reduced in richness (made leaner) as it passes up through the furnace. If lime is used as a flux, there is less dilution of the gas than with limestone as the flux. If the fuel contains volatile hydrocarbons, these will be distilled off and the gas will be enriched by them.

The composition of blast-furnace gas varies therefore with the kinds of fuel, flux, and ore. As produced in the general method of practice of iron-ore reduction, it has a lower heating value per cubic foot than that made by any of the producer methods under proper conditions of operation. A richer gas will generally come from a blast furnace using coal than from one using coke, the increased richness being due to the volatile portion of the coal.

With coke as a fuel in the blast furnace there is very little hydrogen in the gas, since the moisture in the air and the charge is then the chief source of hydrogen. It has been pointed out by those dealing with blast furnaces that if the blast carries water in from a slight water leak at a tuyere, there will be a very material addition of hydrogen to the gas and a change of heat value. The gas must of course be cleaned so as to be free from dust and grit before using in the combustion motor.

239. **Coke-Oven Gas.** — In the manufacture of coke, bituminous coal is heated so that the volatile part is driven off almost completely. The remainder is the coke product for which the operation is carried on. Coke making is in a general way similar to gas making by the retort process with bituminous coal. The chief product in one case is the by-product in the other. The chief difference in the two processes is in the rate of gasification. In gas making the rate of distillation is such as to secure the best results in the gas made; in coking the rate is regulated to procure the best coke, which is generally that which is the strongest for resisting mechanical stress. The coals for the two processes are of course selected with a view to the best results in each case.

In retort processes of coking coal the heat is supplied by burning the gas that is distilled off. With a fat coal there is more of the gas than is needed for coking when the coke oven is suitably made. This excess of gas can be used in the combustion motor successfully. It is a richer gas generally than that made by any of the producer processes that have been mentioned. Its richness varies with the kind of coal and the stage of completion of the distillation. The following is taken from a paper on "The By-Product Coke Oven" by Mr. W. H. Blauvelt.*

"The surplus from the by-product coke oven is the portion remaining after sufficient gas has been used for heating the ovens, and the amount varies greatly with the fuel used. In lean coals, low in volatile matter, there might perhaps be no surplus, while in rich gassy coals the amount may be from 4000 to 4500 feet per

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* Proceedings Amer. Soc. Mech. Engrs., March, 1908, Vol. 30.

net ton of coal. . . . the gas is essentially similar to that made in gas works. Following is a typical analysis:

Carbon dioxide	1.3
Benzene	1.2
Ethylene	4.2
Oxygen	0.5
Carbon monoxide	5.1
Methane	35.5
Hydrogen	48.0
Nitrogen	4.2
B.t.u. per cubic foot	679

"The calorific value of the gas may vary from 550 to 750 B.t.u. per cubic foot."

240. Oil Gas from Petroleum. — When petroleum is destructively distilled by bringing small quantities at a time in contact with red-hot substances, the heavy hydrocarbons are changed into others which are mostly permanent gases under atmospheric conditions. The gas varies in composition with the temperature of distilling and the fineness of division of the liquid when it comes into contact with the hot surface. In a general way the oil gas made in this manner resembles coal gas by the retort process. Oil-water gas is also made from petroleum by mixing steam with the vaporized oil.

Oil gas is too expensive for economical use in the combustion motor.

241. Gasoline Gas or Carbureted Air. — If air is caused to bubble through gasoline, or is brought into contact with fabrics, wire gauze, etc., that are saturated with gasoline, it will become impregnated with the vapor of gasoline to an extent that depends on the time and intimacy of contact of the air with the gasoline. If the amount of gasoline taken up does not exceed two gallons per 1000 cubic feet of air, the gasoline vapor will remain a vapor in the air under atmospheric conditions.

Gas made in this manner can be used in the internal-combustion motor and for illuminating. The gas must be mixed with air for burning in the motor, after the manner of other gases.

242. Tar Destruction in Gas Making. — Some of the methods of tar destruction by passing the unstable gases from coal and lignites through carbon or fuel heated to incandescence have been mentioned in connection with different processes of gas making. The destruction of the tar is practically complete by at least part of these methods when the apparatus is properly operated.

There is generally a formation of free carbon in a granular or graphitic state accompanying the destruction of tar vapors in this manner. The gas-making plant must therefore be designed with provision for cleaning the carbon deposit from such places as it may lodge, and for removing the carbon from the gas. The graphitic carbon does not wash out in the ordinary coke or other types of scrubber as well or completely as the carbon that comes from a producer that has no special provision for tar destruction and which allows most of the heavy hydrocarbons to pass out as condensable gases that form tar.

The graphitic carbon can be filtered out by passing the gas through excelsior, cloth, burlap, etc., which should not be so closely woven or packed as to prevent reasonably free flow of the gas through it. This method is similar to that used sometimes for cleaning air for ventilation.

243. Variation in Quality of Producer Gas. — There are several causes that make considerable variation in the quality or heating power of the gas from a producer.

It has already been pointed out that temporary increase of the steam or water supplied to a continuous producer will give a temporarily richer gas than the producer can regularly supply. Cutting down the steam temporarily or continuously will give a leaner gas.

Cracks in the bed of fuel, or settling of the fuel away from the walls of the producer when bituminous coal is used, tends to let the air and steam pass through without undergoing the required chemical changes. Generally more than the normal amount of CO_2 and a lean gas result. This trouble can be obviated by proper attention to stoking and charging of the fuel.

Variation in the thickness of the fuel bed, as by the bed becoming thin by the accumulation of ash while the top level is kept at a constant height, also affects the quality of the gas.

The chemical changes are not the same in their ultimate results when the temperature of the fuel is low as when it is high. Different qualities of gas result under the two conditions. The nature of the variation with the change of temperature depends so much on the condition and kind of fuel, the thickness of the fuel bed, and the force of the blast, that it is hardly possible to make general statements regarding them.

244. Observation of Quality of Gas from a Producer. — When operating a gas producer in regular service, it is desirable to know practically all the time the quality or heating value of the gas flowing from the producer, and essential to know it at frequent intervals. Some means that indicate the quality of the gas within a few seconds at most after it has passed from the producer is necessary for the best operation. Promptness in indicating the quality is of more importance than accuracy of the results except when efficiency tests of the producer or motor are being made.

An open flame of the gas is a fair indication to the trained eye of its nature. The gas burner can be attached to the gas main leading from the scrubber. If the gas is led to the burner through a glass tube stuffed with absorbent cotton, the condition of the cleanliness of the gas can be observed.

Since most producer gas burns with a non-luminous flame, the quality can often be observed more accurately by the use of an incandescent mantle on the burner, or some other device which immediately shows change of temperature to the eye. The pressure of the gas going to the burner must be kept constant for such a burner.

The pressure of the gas at the burner can be kept constant by the use of a simple and inexpensive aspirator or other device for drawing it continuously from the mains and delivering it to the burner at constant pressure.

If the incandescent test burner is placed near a light of uniform strength, a still more accurate means is arrived at for noting the quality of the gas. A simple photometric device for comparing the degree of luminosity of the incandescent parts obviates the error incident to direct observation of the lights.

The temperature of the products of combustion when some of the producer gas is burned in an open flue is a prompt method of determining the quality of the gas for the purpose of managing a producer.

The temperature of the gases leaving the producer is also an indication of how the producer is working. It can be taken with a thermometer inserted in the gas main, which may be arranged to read at a distance in a suitable location.

245. **Continuous Calorimeter Tests of Gas from Producer.** — More refined tests of the quality of the gas within a short time after it leaves the producer can be made by suitable types of calorimeters. Several instruments for this purpose have been devised and operated. The principle of operation is generally that of feeding the calorimeter both gas and water in predetermined rates and observing the change of temperature of the water while flowing through the calorimeter. The most common method seems to be to keep a constant ratio between the water passed through the calorimeter and the amount of gas consumed in the same instrument.

The gas for the calorimeter is generally drawn continuously at a constant rate from the gas main of the producer at a suitable point. The calorimeter will therefore show the average heat value of the gas only when the rate of flow from the producer is uniform. If there is any variation in the rate at which the producer makes gas, the mean value of observations of the calorimeter taken at equal time intervals, or a continuous record, will not give the average heat value of the gas that is stored in a tank during the operation of the producer for any period of time. There is generally considerable variation in both the quality of the gas and the rate of its production even in continuous types of producers.

For accurate results in the use of a continuous calorimeter of the kind just mentioned, the gas should be drawn from the producer main at a rate proportional to the rate at which the gas flows through the main; in other words, at a rate proportional to the rate at which the producer is making gas of a standard temperature and pressure. Since it would be difficult to burn the gas in the calorimeter at a greatly different and rapidly varying rate, another method is to give each reading of the calorimeter a weight in averaging that is proportional to the rate of gas production at the instant the gas corresponding to the reading was taken from the main, or to move a recording chart at a rate similarly proportional to the rate of making the gas. There would generally be difficulty in getting accurate records in the latter manner, however, on account of the lag of the calorimeter in indicating the quality of the gas.

The nature and extent of the error introduced in determining the average heat value of gas flowing through a main by the use of the method of taking samples of gas from the main at equal time intervals and giving each determination equal weight in averaging is shown by the following numerical example.

A combustion motor delivering mechanical power at a constant rate requires 2,000,000 B.t.u. of gas per hour. The gas varies in lower (effective) heat value from 100 to 125 B.t.u. per cubic foot of standard gas. When the gas is of the 100 B.t.u. quality, the motor will take 20,000 cubic feet per hour; and when it is of the 125 B.t.u. quality, 16,000 cubic feet per hour will be consumed. The required volume of the leaner gas is 25 per cent greater than that of the richer gas.

If the motor runs on each kind of gas an hour, the average heat value of the total amount of gas used, taking volumes into account, which is the correct method, is

$$\frac{20{,}000 \times 100 + 16{,}000 \times 125}{36{,}000} = 111 \text{ B.t.u. per cu. ft.}$$

The incorrect average heat value, as found by giving each determination (100 and 125 B.t.u.) equal weight, is

$$\frac{100 + 125}{2} = 112.5 \text{ B.t.u. per cu. ft.}$$

The difference of the two heat values thus obtained is 1.5 B.t.u. The incorrect method gives a value $1\frac{1}{3}$ per cent greater than the true average heat value.

The same amount of error occurs when the readings of a continuous calorimeter that takes gas from a main at uniform rate are used without correction for the different rates of flow of the lean and rich gas through the main.

The error just pointed out is favorable to the producer and against the motor.

Variations in the heat value of producer gas as great as those that have been used in this example, and even greater, are not unusual in practice.

246. Efficiency Bases of Gas Producers. — The efficiency of the gas producer that is of interest to the manufacturer and consumer of gas for the internal-combustion motor is the ratio of the heat value of all the gas produced from a stated amount of fuel to the heat value of all the fuel and all the mechanical or electrical energy used for all purposes relative to the production of the gas. The rate of gasification is also of importance, since the higher the rate the less the initial cost of a gas plant of a given capacity.

It is an open question whether the higher or the lower heat value of the gas shall be taken in determining the efficiency of a gas producer. It should therefore be distinctly stated which heat value is to be used in any guaranty of efficiency.

Instead of expressing the effectiveness of the action of the producer as efficiency, a convenient and suitable method is to state the amount of gas at a standard temperature and pressure, and the heat value (higher or lower) per unit volume (as a cubic foot) that a producer and its accessories will deliver from a stated weight of coal or other fuel of a stated quality (heat value per pound, from a specified mine and how prepared, etc.), also taking into account the mechanical, electrical, or other energy received from outside sources.

In both the above cases the loss of unburned fuel in the ash counts against the producer.

On account of the loss of unburned fuel in the ash, the efficiency is, for some purposes, divided into grate efficiency and efficiency of such other parts of the process as are under consideration. The product obtained by multiplying together the grate efficiency and the efficiency of the other parts of the process under consideration is the real efficiency of such parts of the process.

The expressions for the commercial efficiency and the grate efficiency of a gas producer are:

$$\left.\begin{array}{r}\text{Commercial}\\ \text{efficiency}\end{array}\right\} = \frac{\text{B.t.u. of total gas made.}}{\text{B.t.u. of fuel fed to producer} + \text{B.t.u. equivalent of energy received by producer from outside sources.}}$$

$$\text{Grate efficiency} = \frac{\text{B.t.u. of fuel actually burned in producer.}}{\text{B.t.u. of fuel fed to producer.}}$$

For other efficiencies the items included depend so much on the kind of producer and the methods of operating the auxiliaries that it is hardly possible to give formulas that will cover more than one type of producer and its accessories. Outside of the commercial efficiency and the grate efficiency it is practically always necessary to define the efficiency by the items included rather than by a specific name.

The comparison of different steps of the process in producers similarly operated with regard to the method of producing draught is not generally difficult. But in some cases, as when the draught is induced by mechanical means in one producer, and by a steam blower in the other, the refinements necessary to compare efficiencies that exclude the energy for inducing the draught become such as to necessitate the greatest care and judgment in determining the required data by trial.

In the case of a gas power plant producing its own gas, the total efficiency of the conversion of the heat energy of the coal into mechanical energy delivered by the motor is determined more frequently than the efficiency of the producer alone. The reason for this is that there are seldom adequate means for measuring the amount of gas produced. Gas meters of sufficient capacity are cumbersome and expensive, and less expensive means are not sufficiently accurate for reliable results under ordinary circumstances.

CHAPTER XIX.

PRESSURE-VOLUME DIAGRAMS.

247. Equations for Work. — When the pressure of a gas or liquid acts on a piston and moves it with a rectilinear motion, then, if the piston face acted on by the pressure is flat and perpendicular to the direction of its motion, the energy expended, or work done in moving the piston, is expressed by the equation

$$W = pAL,$$

in which

$p =$ pressure per unit area,
$A =$ area of piston face,
$L =$ length of stroke of piston.

When the piston face does not lie in a plane perpendicular to the direction of its motion, as when the face is crowned, convex, irregular, or slanted, then A can be taken as the area of the cross-section of the space through which the piston moves, the cross-section being perpendicular to the direction of motion of the piston.

In the equation just written, the product of

$A \times L =$ volume swept through by face of piston.

The equation for the energy expended can therefore be written

$$W = pv,$$

in which

$v =$ volume swept through by face of piston,

and the other notation is as given for the preceding equation.

If the piston moves against (toward) the resistance of the pressure on its face, then the energy delivered to the gas or liquid by the piston is expressed by the same equations.

The expression $W = pv$ can be represented graphically on a diagram with rectangular coördinates. This is done in Fig. 117. Pressures are measured from the horizontal axis OV in a direction perpendicular to OV. Volumes are measured from the vertical axis OP in a direction perpendicular to OP.

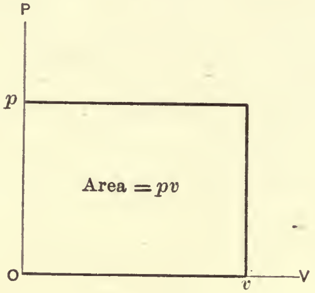

Fig. 117.

When the pressure is constant, as has been assumed, it is represented throughout the stroke of the piston by the horizontal line at a distance Op from the V axis. The volume swept through by the face of the piston is represented by the distance Ov. The product $Op \times Ov$ is therefore represented by the area of the rectangle bounded by the coördinate axes OP and OV together with the lines drawn through p and v to complete the rectangle. Instead of taking Op and Ov as the notation to indicate corresponding distances, it is customary to use only p and v for this purpose. By this notation

$$pv = \text{area of rectangle.}$$

The area of the rectangle represents, in accordance with the scales of pressure and volume selected, the energy transferred from the gas or liquid to the piston, or vice versa.

If the pressure is variable during the stroke of the piston, as indicated by the curved line in Fig. 118, then the area enclosed by the curved pressure line, the coördinate axes, and the vertical through V can be determined approximately by dividing it into several vertical strips or partial areas by lines parallel to the vertical coördinate axis, then multiplying the width of each strip by its average, or mean, height, and adding all the products together. The mean height of each strip must be determined by judgment, and is therefore not mathematically accurate. The sum of the partial areas determined as stated is therefore the approximate area of the total enclosed space.

The area thus determined for each small strip approximately represents the work done while the piston is sweeping through a volume corresponding to the width of the strip. If the width of the first strip is $\Delta_1 V$, and its mean height is P_1, then the work done while the piston sweeps through the volume $\Delta_1 V$ is $w_1 = P_1\Delta_1 V$. And similarly for the second partial area, $w_2 = P_2\Delta_2 V$. And so on for all the partial areas.

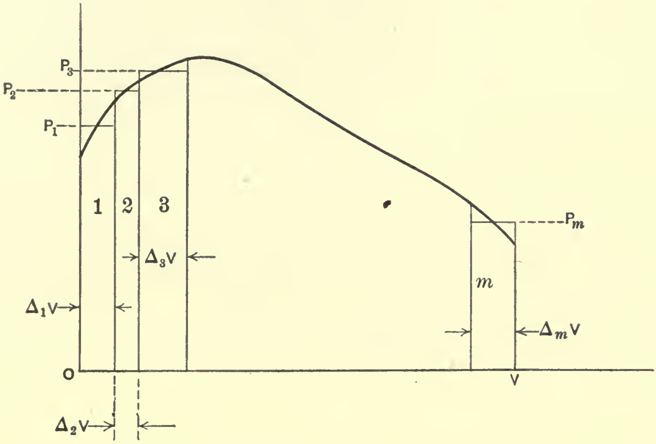

Fig. 118.

The total work done during the complete stroke of the piston is therefore approximately

$$W = P_1\Delta_1 V + P_2\Delta_2 V + P_3\Delta_3 V + \ldots + P_m\Delta_m V.$$

If all the partial areas are of the same width, so that $\Delta_1 V = \Delta_2 V = \Delta_3 V$, etc., the mean value of the pressure can be found by adding together all the P's and dividing their sum by the number of partial areas. The total area is then found by multiplying the volume V by the mean value of the pressure, thus,

$$W = \text{total area} = P_{\text{mean}}\, V.$$

When the partial areas into which the total area is divided become almost infinitely great in number, then the method of determining the total area becomes that of integral calculus. The width of each strip is then represented by the differential quantity

dV, and the height of each strip is represented by p, as in Fig. 119. The area of each differential strip is therefore pdV. The value of p is in general different for each elementary strip. The work or mechanical energy corresponding to each differential strip can be called dW. The equation for the differential quantities is then

$$dW = pdV.$$

The accurate total area, or work, is represented by the integral of the differential areas, thus,

$$W = \text{total area} = \int pdV.$$

This integration can be performed mathematically only when there is a definite known relation between p and V. In general there is no such relation, so the mathematical integration is in general impossible.

The planimeter can always be used to make the integration mechanically.

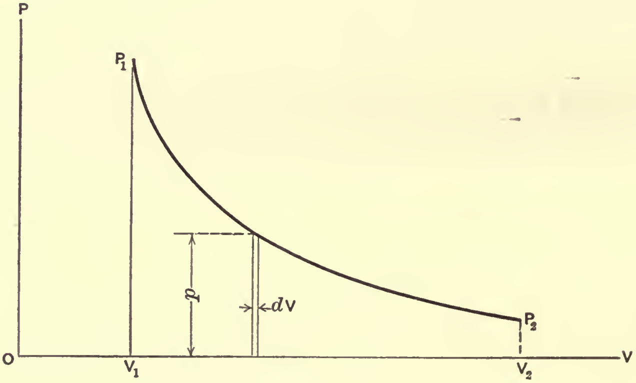

FIG. 119.

Fig. 119 shows in a general way the nature of the variation of the pressure when gas compressed in a closed cylinder to the volume V_1 is allowed to expand and drive out a piston until the volume becomes V_2. The work or energy transferred from the gas to the piston is here represented by the area bounded by the lines $V_1P_1P_2V_2V_1$. The calculus expression for the work or area is

$$W = \text{total area} = \int_{V_1}^{V} p dV.$$

If the piston compresses the gas from the volume V_2 to V_1, the energy that the piston delivers to the gas is represented by the same area.

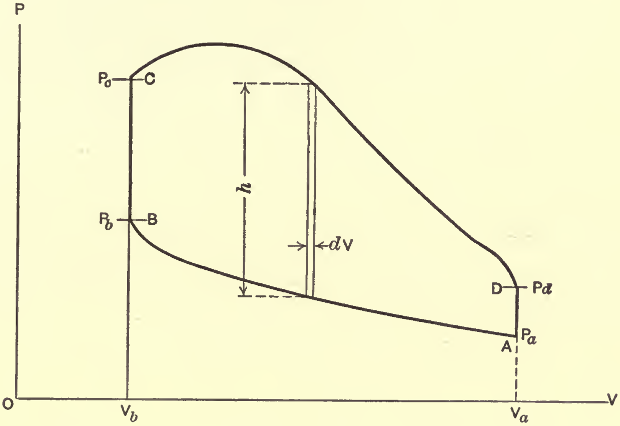

FIG. 120.

248. Pressure-Volume Diagram for Complete Cycle. — Fig. 120 represents in a general way the events in a combustion motor from the time the charge of combustible mixture is received in the motor cylinder till the charge has been compressed, burned, expanded, and discharged so that the pressure in the cylinder is again the same as at first and the piston has returned to its initial position. In this case the horizontal axis OV represents zero pressure (about 14.7 pounds per square inch below atmospheric pressure).

The charge at the initial position of the piston has the volume V_a and the pressure P_a at the point A on the diagram. During the instroke of the piston the charge is compressed to the volume V_b and the pressures during compression are represented by the line AB. After the completion of compression the pressure is increased from P_b to P_c by the partial combustion of the charge, while the volume remains unchanged. The volume then increases during the outstroke of the piston from V_b to the initial value V_a. The pressure line during the expansion is CD. The pressure then falls from P_d to the initial pressure P_a, while the volume remains constant.

The energy delivered to the gas by the piston during compression is represented by the area AV_aV_bBA; and the energy delivered to the piston by the gas during the outstroke is represented by the area CDV_aV_bC. The difference of these two areas, which is the area $ABCDA$, represents the energy received by the piston during the complete cycle. No mechanical energy is received or delivered by the piston during the changes of pressure at constant volume from B to C and from D to A.

The diagram $ABCD$ is the pressure-volume diagram of the motor during the cycle. Its area can be found by the methods given above. The calculus expression of its area and of the energy transferred is

$$W = \text{area } ABCD = \int_{V_b}^{V_a} h\,dV,$$

in which h is the height of any differential vertical strip of the area enclosed by the lines of the diagram and is in general a variable. The value of h for any differential strip is equal to the difference of the pressures acting on the piston while it occupies the two corresponding positions on the instroke and on the outstroke.

When the area of the diagram has been determined with a planimeter, the mean value of h is found by dividing the area by the horizontal length of the diagram $= V_aV_b$. The mathematical expression is

$$h_{\text{mean}} = \frac{\text{area } ABCD}{\text{length of diagram}} = \frac{\text{area } ABCD}{V_a - V_b},$$

or

$$\begin{array}{c}\text{Mean effective}\\ \text{pressure}\end{array} = \text{M.e.p.} = \frac{\text{Area of diagram.}}{\begin{array}{l}\text{Length of diagram} \times \text{lbs. per sq. in. per}\\ \text{inch compression of indicator spring}\end{array}}$$

which is the mean effective pressure of the diagram.

249. Indicator Diagram. — The indicator diagram is essentially a pressure-volume diagram, generally on a miniature scale. The fact that the horizontal length represents volumes is seldom taken into consideration, however, in determining indicated power by its aid. In this connection its use is to give the mean effective pressure. The latter is generally determined from it either by the aid of a planimeter for finding its area, and then dividing the area by the length of the diagram, or by the use of an averaging instrument that gives a direct reading of the mean height of the diagram after its tracing point has been passed around its profile in a proper manner.

The mean effective pressure thus determined is then used in connection with the proper factors for determining horsepower, etc.

Mechanical integrators which, when set to correspond to the piston area, length of stroke, and speed of rotation of the motor from which the indicator card was taken, give a direct reading of the horsepower, are also used.

CHAPTER XX.

THEORETICAL HEAT CYCLES.

250. Assumptions for Theoretical Cycles. — By the assumption of conditions that differ more or less from those under which an internal-combustion motor actually operates, it becomes possible to obtain theoretical pressure-volume diagrams whose boundary lines represent mathematical equations and whose areas can be determined by mathematical integration. Such diagrams are useful in pointing out in a general way the features essential to securing the greatest efficiency in actual practice for the kind of cycle under consideration, and the kind of cycle that will give the greatest theoretical efficiency with a perfect gas.

Among the assumptions to be made from the theoretical cases there are three that are common to all the theoretical cycles. They are:

First. That the piston moves without frictional resistance.

Second. That the walls of the space in which the gas is enclosed during the cycle are impervious to heat; or expressed otherwise, that the motor piston, cylinder, etc., neither abstract heat from the gas nor give up heat to the gas.

Third. That a **perfect gas** is used.

251. Notation. —

C_p = specific heat of constant pressure, B.t.u. per pound.

C_v = specific heat of constant volume, B.t.u. per pound.

$G = \frac{1}{J}$ = factor for converting foot-pounds into B.t.u.; GW = B.t.u.

H = total heat added to or abstracted from the gas, B.t.u.

H_i = heat input by combustion, B.t.u.

H_d = heat discharged or discarded, B.t.u.

J = mechanical equivalent of heat. $J = 778$ ft.-lbs. = 1 B.t.u.

P = absolute pressure, pounds per square foot = 144 × lbs. per sq. in.

$R = \frac{P_0V_0}{T_0} = \frac{P_1V_1}{T_1}$ = mechanical work done by the expansion of unit weight or mass of a perfect gas at constant pressure while heat is added to increase its temperature one degree. Foot-pounds per Fahrenheit degree for one pound of gas.

S = sensible heat added to or taken from a gas to cause change of temperature. Sensible heat is that which affects the thermometer. B.t.u. per pound.

T = absolute temperature, Fahrenheit degrees. The zero of absolute Fahrenheit temperature is 459° below zero Fahrenheit, which is 491° F. below the freezing point of water at atmospheric temperature.

V = volume, cubic feet.

W = mechanical work, foot-pounds.

β = ratio of specific volume of products of combustion to specific volume of the charge before combustion.

$\lambda = \frac{C_p}{C_v}$ = ratio of specific heat of constant pressure to specific heat of constant volume.

$\varepsilon = 2.71828 = 10^{.4342945}$ = the base of hyperbolic, natural, or Naperian logarithms. $\text{Log}_{\varepsilon}A = 2.3026 \times \log_{10}A$. $\text{Log}_{10}A$ is the common logarithm of A.

252. **Additional Laws of a Perfect Gas.** — Some of the laws of a perfect gas have been given in Chapter XVI. The last equation of section 196, modified as to subscripts, is

$$\frac{PV}{P_0V_0} = \frac{T}{T_0},$$

in which P, V, and T represent the pressure, volume, and temperature of a perfect gas for any assumed condition, and P_0 and T_0 may be taken conveniently as the pressure and temperature at which the specific volume of gas is usually given. V_0 is then the corresponding specific volume. The latter is usually given at atmospheric pressure and either the freezing point of pure water or at a slightly higher temperature that approaches more nearly to average atmospheric temperature.

The specific volumes of actual gases are given in Table I for both 32° F. and 62° F., corresponding to 491 and 521 degrees absolute Fahrenheit.

By transposition, the last equation can be brought to the form

$$PV = \frac{P_0 V_0}{T_0} T.$$

The expression

$$\frac{P_0 V_0}{T_0} = \text{a constant for any particular perfect gas.}$$

Its value can be found by substituting numerical values belonging to the gas. The numerical values must, of course, accord with the system of units adopted. Thus, for a pressure of 14.7 pounds per square inch = 2116.8 pounds per square foot, and 32° F. = 491 degrees absolute Fahrenheit, the specific volume of air is 12.39 cubic feet per pound. Therefore, for air, taking the pressure in pounds per square foot to correspond to the cubic foot unit of volume,

$$PV = \frac{2116.8 \times 12.39}{491} T = 53.42\ T,$$

whence

$$\frac{PV}{T} = 53.42 \text{ for air.}$$

The expression $P_0 V_0$ represents, for any perfect gas, the mechanical work done by its expansion, while the pressure remains constant at P_0, from an initial condition of zero volume to a final condition represented by P_0, V_0, T_0. The change of volume for each degree of temperature $= \frac{V_0}{T_0}$. The mechanical work done by the expansion of the gas during a rise of temperature of one degree while the pressure remains constant is therefore

$$\frac{P_0 V_0}{T_0}.$$

When the temperature is taken at 32° F. ($T_0 = 491°$ abs. F.), the change of volume of a perfect gas for each degree Fahrenheit change of temperature, when the pressure remains constant during the change, is $\frac{1}{491}$ of its volume at 32° F.

The mechanical work done by the expansion of 1 pound of air while enough heat is being added to it to increase its temperature 1° F., the pressure remaining constant, is, in accordance with the numerical computation just made, 53.42 foot-pounds for air considered as a perfect gas.

When a gas is cooled by abstracting heat from it, the work it does during contraction is negative. The amount of this negative work per degree change of temperature is the same as when the temperature is increased one degree, the pressure remaining constant in each case. For air the negative mechanical work due to cooling 1° F. at constant pressure is 53.42 foot-pounds as before.

$\frac{P_0 V_0}{T_0}$ will, for convenience, be represented by R. One of the general expressions of the relation between the pressure, volume, and temperature of a perfect gas thus becomes

$$PV = RT.$$

The numerical value of R can be computed for any perfect gas in a manner similar to that by which it has been computed for air, for which $R = 53.42$ foot-pounds. (This must not be taken to mean that air is a perfect gas.)

Another property of a perfect gas is that when the temperature of any given quantity (mass, weight) of the gas is increased any given amount (as a specified number of degrees) by the addition of heat, the amount of heat that is *retained in the gas* to produce the given change of temperature is always the same whether the pressure or the volume remains constant or both change. The significance of this is that none of the heat energy added is converted into latent heat for changing the internal or molecular condition of the gas with change of pressure, volume, and temperature.*

The heat which causes change of temperature only is called "**sensible**" heat.

253. Relation between Specific Heat of Constant Volume and of Constant Pressure for a Perfect Gas. — The specific heat of constant volume of a gas has already been defined as the amount of heat required to increase the temperature of a given weight of gas 1 degree while the volume remains constant; and the specific heat of constant pressure has also been defined as the amount of heat required to increase the temperature of a given weight of the gas 1 degree while the pressure remains unchanged.

In the case of the specific heat of constant volume no external (mechanical) work is done, since there is no change of volume during the change of temperature.

The specific heat of constant pressure includes both the heat to

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* The conversion of water into steam by the addition of heat is an example that affords a means of conceiving what is meant by "latent heat." When heat is added to water after it has been brought up to the boiling point (about 212° F. at atmospheric pressure) the water is all converted into steam without rise of temperature if the pressure is kept constant. One pound of water at 212° F. and 14.7 pounds per square inch pressure requires to convert it into steam at the same pressure and temperature, about 965.7 B.t.u. of heat. The pound of water makes about 26.36 cubic feet of steam at the given pressure and temperature, which practically measures the increase of volume during the change from water to steam. (The volume of the water is so small in comparison with that of the steam as to be negligible.)

The mechanical work done by the expansion of the water into steam is therefore $(14.7 \times 144)\ 26.36 = 55{,}800$ foot-pounds about, which corresponds to $55{,}800 \div 778 = 71.7$ B.t.u. The difference between this last quantity and the total heat of conversion, $965.7 - 71.7 = 894$ B.t.u., is the amount of heat that has become latent and is not measurable in the steam as change of temperature, or in mechanical work done during the formation of the steam.

increase the temperature of the gas 1 degree and that converted into external (mechanical) work done by the expansion of the gas at constant pressure while heat is added to increase the temperature 1 degree. It has been shown in the preceding section that the external work done during 1 degree change of temperature while the pressure remains constant is $\frac{P_0V_0}{T_0} = R$. It has also been stated as one of the properties of a perfect gas, that the amount of heat retained in the gas to increase the temperature of a given weight of the gas 1 degree is always the same whether the pressure or the volume is constant, or both vary. Therefore the amount of heat *retained in the gas* to increase its temperature 1 degree when the pressure is kept constant and the volume changes is the same as the specific heat of constant volume when unit weight of the gas is taken. The specific heat of constant pressure, for a perfect gas, is therefore equal to the specific heat of constant volume plus the heat equivalent of the external work done by the expansion of the gas on account of its increase of temperature.

The mathematical expressions given below show the relation between the specific heat of constant volume and the specific heat of constant pressure for unit weight (or mass) of a perfect gas.

$$C_p = C_v + GR = C_v + \frac{R}{J} = C_v + \frac{GVP}{J} = C_v + \frac{PV}{JT}.$$

In foot-pound and Fahrenheit-degree units, the specific heat of constant volume, C_v, for air is .1687 B.t.u. per pound. The value of R has been calculated for air as 53.42 foot-pounds. The mechanical equivalent of heat in the units taken is $J = 778$ foot-pounds per B.t.u. By substitution in the above equation,

$$C_p = .1687 + \frac{53.42}{778} = .1687 + .0688 = .2375 \text{ B.t.u. for air.}$$

254. Thermodynamic Changes in which One of the Quantities, Pressure, Volume, Temperature, or Total Heat in the Gas, Remains Constant. — The four methods of change in the condition of a gas for which the relations between P, V, and T are most readily computable in the case of a *perfect* gas, and for which the heat added to or discarded by the gas, as well as the corresponding work done, can also be mathematically determined for the perfect gas, are:

a. Pressure and temperature change at constant volume. (Isometric change.)

b. Volume and temperature change at constant pressure. (Isobaric or isopiestic change.)

c. Pressure and volume change at constant temperature. (Isothermal change.)

d. Pressure, volume, and temperature all change, but no heat is supplied to or abstracted from the gas. (Adiabatic change.)

In all the following changes it is convenient to assume that one pound of gas is used.

255. Isometric Change. — In Fig. 121 isometric change is represented on the pressure-volume diagram by the vertical line 1 2 parallel to the pressure axis. Since the volume remains constant, the changes of pressure and temperature due to the addition or abstraction of heat are both directly proportional to the change in the amount of heat in the gas. The amount of heat to be added to the gas to change its temperature from T_1, corresponding to P_1V, to T_2, corresponding to P_2V, at constant volume is

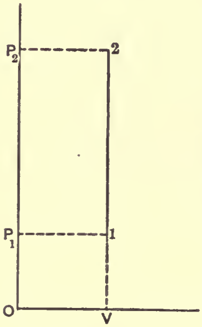

FIG. 121.

$$H = C_v (T_2 - T_1),$$

whence

$$T_2 - T_1 = \frac{H}{C_v}; \quad \text{and} \quad T_2 = T_1 + \frac{H}{C_v}.$$

The corresponding increase of pressure due to the heat H can be determined from the above equations by substituting for T_1 and T_2 their values in terms of the pressure. These values are obtained from the relation, common to all perfect gases, $PV = RT$, whence

$$T_2 = \frac{P_2V}{R}; \quad \text{and} \quad T_1 = \frac{P_1V}{R}.$$

The substitution of these values in the equation $H = C_v (T_2 - T_1)$ gives

$$H = \frac{C_vV}{R} (P_2 - P_1),$$

$$P_2 = P_1 + \frac{RH}{C_vV}.$$

The following equations are also true for a perfect gas at constant volume:

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}; \quad \text{and} \quad \frac{P_2 - P_1}{P_1} = \frac{T_2 - T_1}{T_1}.$$

There is no external (mechanical) work done, since there is no change of volume. This is expressed by the equation

$$W = 0.$$

256. Isobaric Change. — In Fig. 122 the change at constant pressure is indicated by the horizontal line 1 2 parallel to the volume axis of the diagram. Heat must be added to keep the pressure constant while the volume increases. Part of the heat added goes to perform external work, and the remainder to increase the temperature of the gas so as to maintain a constant pressure.

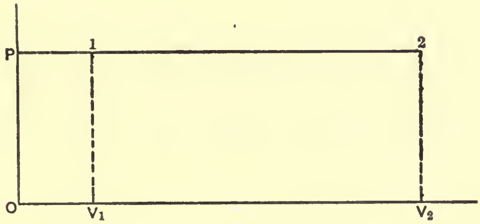

FIG. 122.

The amount of external (mechanical) work done during the expansion of the gas from V_1 to V_2 is

$$W = P(V_2 - V_1).$$

The amount of sensible heat retained in the gas necessary to increase the initial temperature T_1 to the final temperature T_2 corresponding with the volume V_2 is

$$S = C_v(T_2 - T_1).$$

The values of T_1 and T_2 in terms of the corresponding volumes are determined by the equation $PV = RT$, in which P is constant in this case. Thus,

$$T_2 = \frac{P}{R} V_2; \quad \text{and} \quad T_1 = \frac{P}{R} V_1,$$

whence

$$S = \frac{C_v P}{R}(V_2 - V_1).$$

The total amount of heat that must be added to the gas to produce the change of temperature and do the external work is

$$\begin{aligned} H &= S + GW \\ &= \frac{C_v P}{R}(V_2 - V_1) + GP(V_2 - V_1) \\ &= \frac{C_v + GR}{R} P(V_2 - V_1) \\ &= \frac{C_p}{R} P(V_2 - V_1). \end{aligned}$$

The relation between the volume and the temperature is

$$\frac{T_2}{T_1} = \frac{V_2}{V_1}; \quad \text{and} \quad \frac{T_2 - T_1}{T_1} = \frac{V_2 - V_1}{V_1}.$$

257. Isothermal Change. — In this case only enough heat is added to the gas during its expansion to keep the temperature constant.

In Fig. 123 the line 1 2 represents the general form of the diagram for limited expansion of a perfect gas at constant temperature.

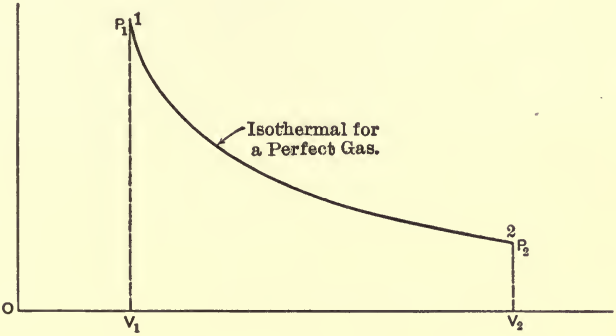

FIG. 123.

The external (mechanical) work done during the expansion from V_1 to V_2 is represented by the area $V_1 1\ 2 V_2 V_1$. The mathematical expression for the external work is

$$W = \int_{V_1}^{V_2} PdV.$$

Since the temperature is constant, the pressure varies inversely as the volume; therefore if V = volume at any point of the curve, then

$$\frac{P}{P_1} = \frac{V_1}{V}; \quad \text{whence} \quad P = \frac{P_1 V_1}{V}.$$

By substituting this value of P in the quantity under the integral sign, the equation for the external work done becomes

$$W = \int_{V_1}^{V_2} P_1 V_1 \frac{dV}{V} = P_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= P_1 V_1 (\log_\epsilon V_2 - \log_\epsilon V_1)$$

$$= P_1 V_1 \log_\epsilon \frac{V_2}{V_1}. \qquad (\text{Log}_\epsilon = \text{natural log.})$$

For P_1V_1 may be substituted the equivalent value as given in the equation $PV = RT = P_1V_1$, whence

$$W = RT \log_\epsilon \frac{V_2}{V_1}.$$

Since the temperature of the gas does not change, all the heat given to it is converted into mechanical work. Therefore

$$H = \frac{W}{J} = GW = GP_1V_1 \log_\epsilon \frac{V_2}{V_1}$$

$$= GRT \log_\epsilon \frac{V_2}{V_1}.$$

258. Adiabatic Change. — Since in this case no heat is either added to or abstracted from the gas during its change of volume, the pressure falls more rapidly during expansion than for isothermal expansion. The temperature also drops during expansion.

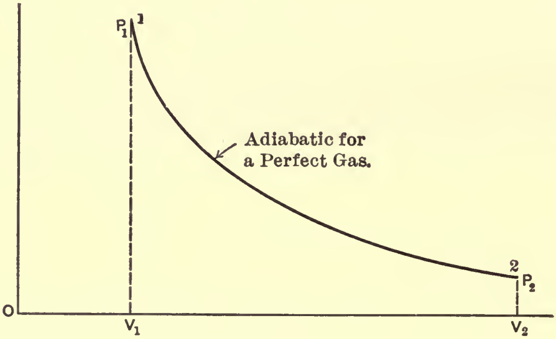

FIG. 124.

In Fig. 124 adiabatic expansion is represented by the line 1 2. The initial volume is V_1 and the final volume V_2.

The external (mechanical) work done by the gas during any infinitesimal increase of its volume is

$$dW = PdV$$

and the corresponding decrease of sensible heat in the gas, as indicated by its change of temperature, is

$$dS = C_v dT.$$

There being no heat added to or abstracted from the gas by any exterior source, the change of sensible heat must be equal to the heat equivalent of the external work done. This is expressed by the equation

$$dS = - GdW; \quad \text{or} \quad C_v dT = - GPdV.$$

The negative sign appears in the last two equations because when positive work is done by the expansion of the gas it causes a decrease in the sensible heat in the gas, and the negative work done by the gas during its compression causes an increase in the sensible heat of the gas.

The last equation may be written, for convenience in further development, in the form

$$0 = C_v dT + GPdV.$$

The value of dT can be expressed in terms of dV and dP as found from the equation $PV = RT$, which, by differentiating, becomes (remembering that p, V, and T are all variables in adiabatic change)

$$PdV + VdP = RdT; \quad \text{whence} \quad dT = \frac{P}{R} dV + \frac{V}{R} dP.$$

By substituting this value of dT in the next to the last equation, it becomes

$$0 = \frac{C_v}{R} VdP + \left(\frac{C_v}{R} + G\right) PdV$$

$$= \frac{C_v}{R} VdP + \left(\frac{C_v + GR}{R}\right) PdV,$$

which, by multiplying by R, dividing by PV, and writing for $C_v + GR$ its value C_p, becomes

$$0 = \frac{dP}{P} + \frac{C_p}{C_v} \frac{dV}{V},$$

and by putting the ratio $\frac{C_p}{C_v} = \lambda$ in the last equation, it is reduced to the form

$$0 = \frac{dP}{P} + \lambda \frac{dV}{V}.$$

The integration of the last equation from zero to the values P and V gives

$$\begin{aligned} \text{Constant} &= \log_\varepsilon P + \lambda \log_\varepsilon V \\ &= \log_\varepsilon P + \log_\varepsilon V^\lambda \\ &= \log_\varepsilon PV^\lambda, \end{aligned}$$

whence

$$PV^\lambda = \text{constant}.$$

Since PV^λ has a constant value,

$$PV^\lambda = P_1V_1{}^\lambda = P_2V_2{}^\lambda,$$

of which the following are convenient forms for application:

$$P_1V_1{}^\lambda = P_2V_2{}^\lambda; \quad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\lambda; \quad \text{and} \quad \left(\frac{P_2}{P_1}\right)^{\frac{1}{\lambda}} = \frac{V_1}{V_2}.$$

And from the equation $PV = RT$, in which R is a constant for any particular perfect gas, the relations between the temperatures and volumes are:

$$\frac{T_2}{T_1} = \frac{P_2V_2}{P_1V_1} = \frac{V_2}{V_1}\left(\frac{V_1}{V_2}\right)^\lambda = \left(\frac{V_1}{V_2}\right)^{\lambda-1}$$

and

$$\left(\frac{T_2}{T_1}\right)^{\frac{1}{\lambda-1}} = \frac{V_1}{V_2}.$$

Again, for the relation between temperatures and pressures,

$$\frac{T_2}{T_1} = \frac{P_2V_2}{P_1V_1} = \frac{P_2}{P_1}\left(\frac{P_1}{P_2}\right)^{\frac{1}{\lambda}} = \left(\frac{P_2}{P_1}\right)^{1-\frac{1}{\lambda}}$$

and

$$\left(\frac{T_2}{T_1}\right)^{\frac{1}{\lambda-1}} = \frac{P_2}{P_1}.$$

The total external work done by the expansion of the gas from V_1 to V_2 is

$$W = \int P dV.$$

The value of P as determined from the equation $PV^\lambda = P_1 V_1^\lambda$ is

$$P = \frac{P_1 V_1^\lambda}{V^\lambda} = P_1 V_1^\lambda V^{-\lambda},$$

which, when substituted in the preceding equation, gives it the form

$$\begin{aligned}
W &= P_1 V_1^\lambda \int_{V_1}^{V_2} V^{-\lambda} dV \\
&= \frac{P_1 V_1}{\lambda - 1} V_1^{\lambda-1} \left(V_1^{1-\lambda} - V_2^{1-\lambda}\right) \\
&= \frac{P_1 V_1}{\lambda - 1} V_1^{\lambda-1} \left(V_1^{\frac{1}{\lambda-1}} - V_2^{\frac{1}{\lambda-1}}\right) \\
&= \frac{P_1 V_1}{\lambda - 1} \left[1 - \left(\frac{V_1}{V_2}\right)^{\lambda-1}\right] \\
&= \frac{P_1 V_1}{\lambda - 1} \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\lambda-1}{\lambda}}\right].
\end{aligned}$$

Or, since $P_1 V_1^\lambda = P_2 V_2^\lambda$, the second from the last equation can be brought to the form

$$\begin{aligned}
W &= \frac{P_1 V_1}{\lambda - 1} \frac{V_1^{\lambda-1}}{V_1^{\lambda-1}} - \frac{P_2 V_2}{\lambda - 1} \frac{V_2^{\lambda-1}}{V_2^{\lambda-1}} \\
&= \frac{P_1 V_1 - P_2 V_2}{\lambda - 1}.
\end{aligned}$$

Whence, by substituting for $P_1 V_1$ its value RT_1, and for $P_2 V_2$ its value RT_2,

$$W = R \frac{T_1 - T_2}{\lambda - 1}.$$

The equation for the change of sensible heat in the gas is

$$S = C_v (T_2 - T_1)$$

$$= \frac{C_v}{R} (P_2V_2 - P_1V_1),$$

which has a negative value for expansion of the gas.

A check on the computation can be made by use of the equation

$$S = - GW.$$

259. Comparison of Expansion and Compression Lines. — Fig. 125 shows the relative positions of the expansion lines of a perfect gas whose initial condition is *A*, for expansion in accordance with the four methods of expansion for which equations have just been developed. The expansion lines are respectively for constant volume, constant pressure, for isothermal and for adiabatic change. The initial condition of the gas is the same in each case and is represented by the point *A*. The constant

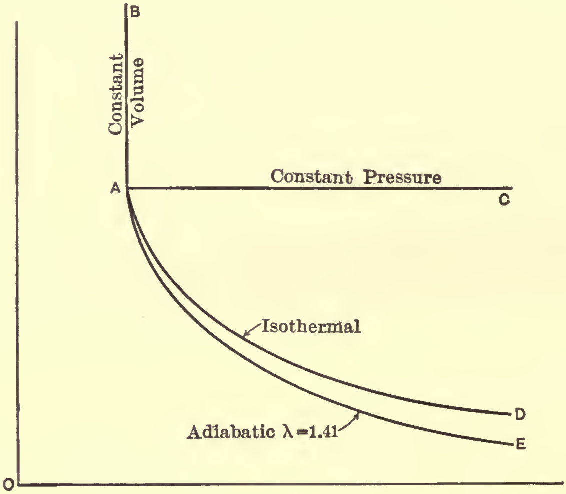

FIG. 125.

volume and constant temperature lines are the same for all gases, perfect or imperfect. The isothermal line occupies the same position for all perfect gases. The adiabatic line is generally different for each gas, or more definitely, it has a different position for each value of the ratio of the specific heat of constant pressure to the specific heat of constant volume. This ratio has been distinguished by the letter λ in the notation. The adiabatic line of expansion lies below the isothermal expansion line.

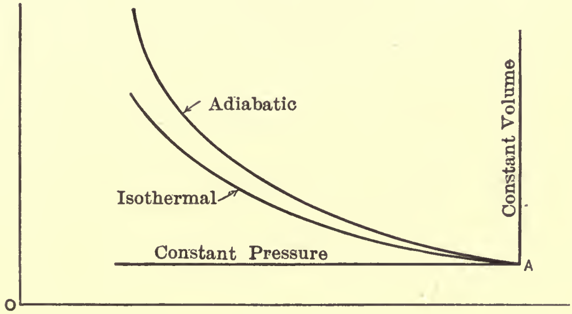

FIG. 126.

Fig. 126 shows the relative positions of the compression lines of a perfect gas, starting in each case from the same initial condition *A*.

260. Theoretically Perfect Otto Cycle. — Fig. 127 shows the pressure-volume diagram of a theoretically perfect Otto cycle.

As applied to the internal-combustion motor, the initial state of the combustible charge is represented by the point *A*. The charge is compressed adiabatically from *A* to *B*. It is then heated by its own total combustion, while the volume remains constant at V_b. During combustion the pressure rises to P_c at *C* with a corresponding temperature T_c. The products of combustion then expand adiabatically from V_b back to the initial volume V_a, the condition at the completion of adiabatic expansion being represented on the diagram by the point *D*. Heat is then abstracted at constant volume V_a till the pressure falls to the initial value as represented by the point A and the temperature is the same as that of the charge in its initial state. The last change (the reduction of pressure and temperature at constant volume) has an approximate equivalent in the actual Otto cycle in the discharge of the burned gases from the cylinder of the motor and the taking in of a new charge.

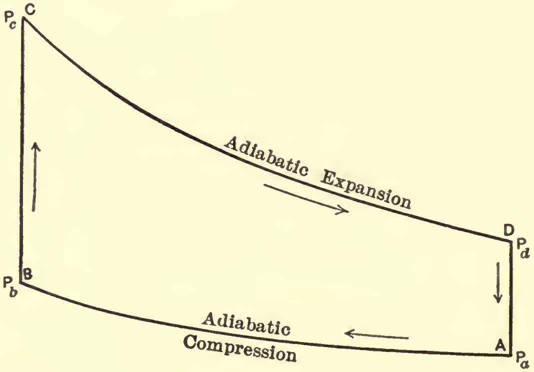

FIG. 127.

In order that the products of combustion, when brought to the initial volume and pressure of the charge, V_a and P_a, shall have a temperature the same as the initial temperature of the charge, the conditions are, in general, that the specific heats of constant pressure, C_v and C_p, of the burned gases shall be the same as those of the combustible charge, and that the products of combustion and the combustible mixture, when both are at the same temperature and pressure, shall have equal volumes.*

Since the introduction of a factor for the variation of specific volume (at equal temperatures and pressures) due to combustion has but a slight effect on the form of those of the equations already written that apply to this cycle, such a factor β will be introduced for following out the cycle mathematically. And since the introduction of different specific heats of the charge and of the

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* See chapter on Combustion and Heat Values for contraction and expansion of specific volume due to the chemical reactions of combustion.

products of combustion merely means the use of different values of the specific heats and their ratios in part of the equations that have been developed, different values of specific heats will be used. The following section treats the cycle on this basis.

261. Equations for Otto Cycle. — In Fig. 127 the initial pressure, volume, and temperature are P_a, V_a, and T_a. The same letters with subscripts *b*, *c*, and *d* are used to indicate the corresponding values at the points *B*, *C*, and *D* on the diagram.

The factor β = the ratio of the volume of the burned gases to the initial volume of the combustible mixture when both are at the same temperature and pressure = the ratio of the specific volumes of the products and of the charge.

The specific heats, C_v' and C_p', and the ratio of the latter to the former = λ' for the charge, have, in general, values that differ from the corresponding values of C_v'', C_p'', and λ'' for the burned gases. The combustible mixture and the mixture of burned gases are both assumed to be perfect gases.

The equations relate to a definite weight, as 1 pound, of the fuel gas.

For adiabatic compression of the combustible charge from A to B,

$$PV^{\lambda'} = \text{constant}.$$

$$P_b = P_a\left(\frac{V_a}{V_b}\right)^{\lambda'}; \quad T_b = T_a\left(\frac{V_a}{V_b}\right)^{\lambda'-1}; \quad \frac{P_bV_b}{P_aV_a} = \frac{T_b}{T_a}.$$

The work done on the gas during compresssion is

$$W' = \frac{P_bV_b - P_aV_a}{\lambda' - 1}.$$

The heat stored in the gas during adiabatic compression is

$$S' = \frac{C_v'}{R'}(P_bV_b - P_aV_a)$$

$$= GW'.$$

Combustion at constant volume of combustion space:

$$T_c = T_b + \frac{H_i}{C_v''},$$

$$P_c = \beta P_b + \frac{R'' H_i}{C'' V_b},$$

$$\frac{P_c}{\beta P_b} = \frac{T_c}{T_b}; \quad \frac{P_c - \beta P_b}{\beta P_b} = \frac{T_c - T_b}{T_b}.$$

The work done is

$$W'' = 0.$$

The heat stored in the gas during combustion at constant volume is

$$S'' = H_i.$$

For adiabatic expansion of the products of combustion from C to D,

$$PV^{\lambda''} = \text{constant}.$$

$$P_d = P_c \left(\frac{V_b}{V_a}\right)^{\lambda''}; \quad T_d = T_c \left(\frac{V_b}{V_a}\right)^{\lambda''-1}; \quad \frac{P_d V_a}{P_c V_b} = \frac{T_d}{T_c}.$$

The mechanical work done by the gas during adiabatic expansion is

$$W''' = \frac{P_c V_b - P_d V_a}{\lambda'' - 1}.$$

The heat abstracted from the gas during adiabatic expansion is

$$S''' = \frac{C_v''}{R''}(P_c V_b - P_d V_a).$$
$$= GW'''.$$

Discharge of products of combustion:

No useful work is done during the discharge of the products of combustion after they have expanded in the motor to the initial volume V_a of the charge. The portion of the heat, of that added to and stored in the gas during compression and combustion, which is still retained in the products of combustion at the condition V_a, P_d, T_d is therefore wasted so far as transformation into mechanical energy by the motor is concerned.

The heat stored in the gas during adiabatic compression and during combustion equals

$$S' + S'' = GW' + H_i.$$

The heat abstracted during adiabatic expansion equals

$$S''' = GW'''.$$

The heat wasted is the difference between the quantities represented in the last two equations, and equals

$$\begin{aligned} H_d &= S' + S'' - S''' \\ &= GW' + H_i - GW''' \\ &= H_i - G\,(W''' - W'). \end{aligned}$$

It may be noted that, on account of the difference between the specific heats (by weight) of the charge and of the products of combustion, the heat that would be abstracted from the exhaust gases by cooling them to the initial temperature of the charge will not be the same in amount, at the initial pressure, as the wasted heat. The total heat in the charge and in the discharged products above absolute zero temperature must therefore be taken into consideration to obtain the waste heat by equations involving temperatures. The practical value of such equations is slight.

In cases where there is no change of specific heat the following equation can be applied:

$$H_d = C_v''\,(T_d - T_a).$$

Efficiency. The efficiency of the transformation of heat energy into useful mechanical energy during this theoretical Otto cycle is the ratio of (*a*), the difference between the total heat added to the gas and that discharged to (*b*), the total heat added by combustion. That is,

$$\text{Efficiency} = \frac{H_i - H_d}{H_i}.$$

The efficiency can also be expressed as the ratio between the heat equivalent of the mechanical work done and the total heat of combustion. Thus,

$$\text{Efficiency} = \frac{G\,(W''' - W')}{H_i}.$$

262. Efficiency as Affected by Variation of Compression. — It has been stated that increase of the pressure of compression increases the efficiency of an internal-combustion motor as determined in the actual operation of the motor. The reason for this can be shown by the aid of the theoretical pressure-volume diagram.

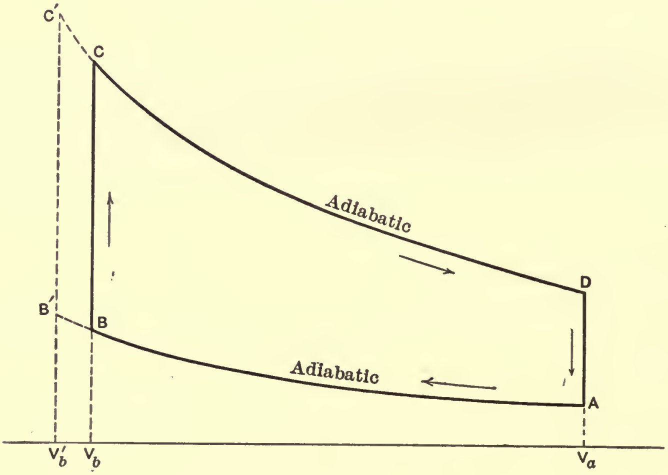

FIG. 128.

In Fig. 128, suppose that the theoretical pressure-volume diagram is at first as shown by the full-line diagram. The mechanical work done is represented by the area $ABCD$. Now suppose that, starting with the same amount of charge at the same condition A as before, the compression is carried to the point B' on the adiabatic AB, so that the compressed volume of the charge is smaller than on the full-line diagram. When the heat added, as by combustion, is the same as before, the pressure will rise on account of the added heat to the point C', which is on an extension of the adiabatic line CD. The expansion will then follow the line $C'CD$. The new diagram with the higher compression ratio will be larger than the first one by the area $BB'C'CB$, which represents a corresponding increase of work over that of the first diagram.

The ratio of the efficiencies of the two cases will be the same as that of the areas $B'C'DAB'$ and $BCDAB$, since the same amount of heat is added by combustion in each case.

263. Effect of Variation of Specific Volume on Account of Combustion. — In Fig. 129 the full-line diagram $ABCD$ is the theoretical form for a combustible mixture whose specific volume does not change on account of combustion. Another gas which has the same specific heats and heat value but whose specific volume contracts on account of the chemical action of combustion, will give the diagram $ABC'D'AB$, in which the expansion line $C'D'$ falls below that of the gas that has no contraction of specific

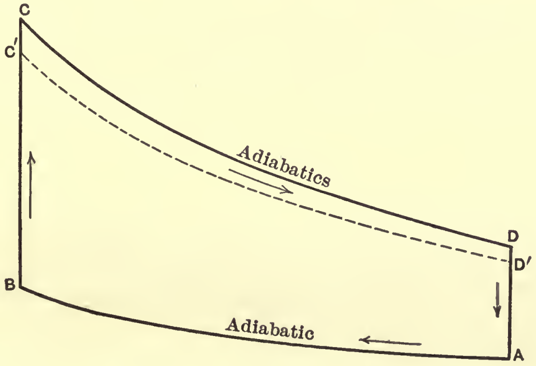

FIG. 129.

volume on account of combustion. The mechanical work that the gas whose specific volume contracts by combustion will do is therefore less per unit of its heat value, and its efficiency will consequently be less than that of one that undergoes no contraction.

On the other hand, a gas whose specific volume increases by combustion will do more work, other conditions being equal, than one whose specific volume does not change by combustion.

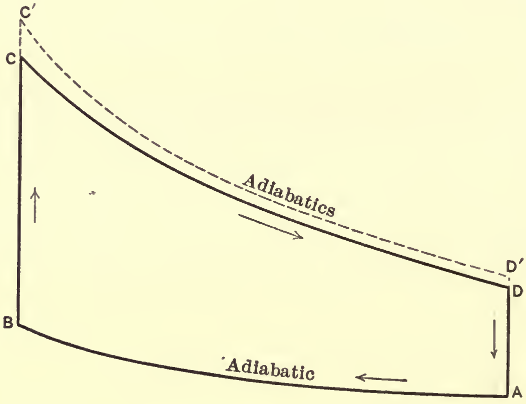

FIG. 130.

(Increase of specific volume by combustion means that the volume of the products of combustion is greater than that of the combustible mixture, both at the same temperature and pressure, as has been stated before.)

The effect of specific expansion of a gas during combustion is indicated by the dotted line in Fig. 130.

264. Effect of Different Specific Heats of Combustible Gases and of Products of Combustion. — Fig. 131. The full-line diagram is for a perfect gas whose products of combustion have the same specific heats as the combustible charge. Another combustible gas having the same specific heats and heat value but whose products have higher specific heats, will give the diagram whose expansion is represented by the dotted line. It will be seen that the increased specific heat has the effect of decreasing the area of the diagram. The efficiency is correspondingly decreased.

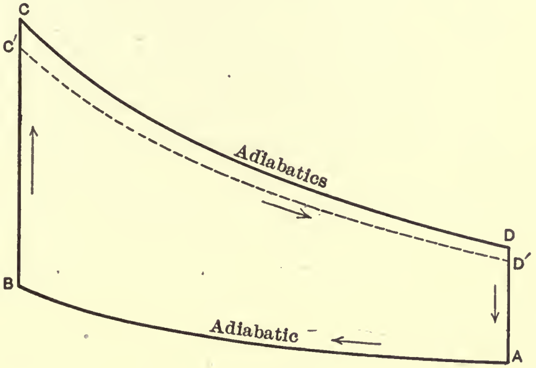

Fig. 131.

265. Effect of Change of Ratio λ of Specific Heats by Combustion. — If the ratio of the specific heat of constant pressure to that of constant volume, $\frac{C_p}{C_v} = \lambda$, is less for the products of combustion than for the combustible mixture, then the expansion line will not drop so rapidly as when the ratio is the same in both cases.

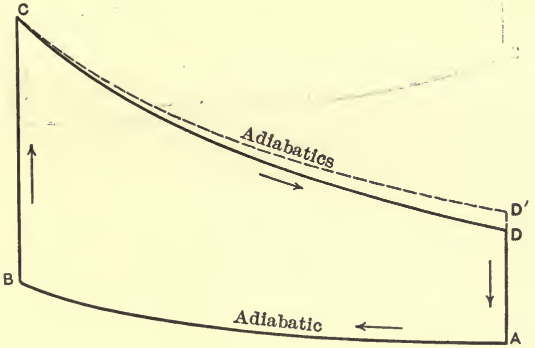

Fig. 132.

This is indicated in Fig. 132, in which the full lines form the diagram for the same value of the ratio λ in both the charge and the products. The dotted line CD' is for products of combustion having a lower value of λ than its value for the charge.

266. Effect of Imperfect Gas on the Theoretical Otto Cycle. — The products of combustion of the gases used in internal-combustion motors do not have constant values of their specific heats. The specific heat increases with increase of temperature, and, so far as is known, decreases with increase of pressure. The net result is generally that the specific heats are higher as the temperature and pressure both increase on account of combustion. While not positively known, it will be assumed for the purpose of illustration that the ratio $\frac{C_p}{C_v} = \lambda$ decreases as the products of combustion expand.

The effect of these departures from the properties of a perfect gas is illustrated in Fig. 133. The full line represents the theoretical pressure-volume diagram for a perfect gas. The dotted line is the expansion line for an imperfect gas having the properties just set forth.

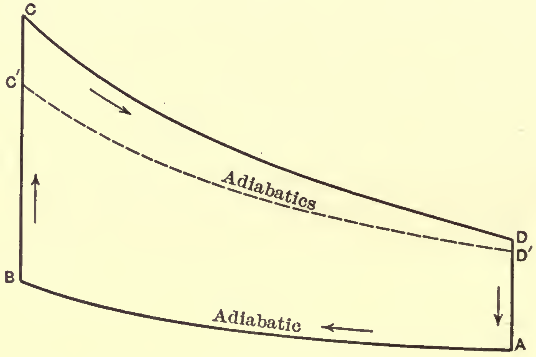

Fig. 133.

On account of the increased specific heat of constant volume, the pressure rises only to C' instead of C during combustion. It may be assumed that the specific heats of the perfect gas and of the imperfect gas are equal at B.

The decreasing value of λ as the gases expand causes the line $C'D'$ to become more nearly horizontal than a corresponding line for a constant value of λ, so that the terminal pressure at D' is higher than that for a perfect gas expanding from C'.

267. Other Causes that Modify the Theoretical Otto Cycle. — The principal causes, in addition to those already cited, that modify the theoretical Otto cycle in its practical application are:

1. Heat transfer between the cylinder walls and the gas.
2. Combustion is not at constant volume.
3. Discharge of products of combustion is not at constant volume of cylinder space.
4. Leakage of gas from motor cylinder around the piston, valves, etc.).

Under normal conditions of operation with a water-cooled or oil-cooled cylinder, the charge of gas receives heat from the metal of the cylinder at least during the early part of compression. As the temperature increases during compression, it is possible that the gas has a higher temperature than the metal during the latter part of compression and thus loses heat to the metal. During combustion and at least the early part of expansion heat is abstracted from the gas by the metal. Whether this abstraction of heat from the gas continues till the exhaust port is opened depends on the temperature of the charge, the extent of expansion, and the temperature of the metal. It is probable that the metal abstracts heat from the gas during all or nearly all of the expansion stroke under the usual conditions of working.

In an air-cooled motor working with a very hot cylinder the charge probably receives heat from the metal during all of the compression stroke, and heat is abstracted from the products during at least the early part of expansion.

The effects of the other three causes are shown in the indicator cards from practice in the chapter under that heading.

268. Modified Theoretical Otto Cycle. — Fig. 134 shows the theoretical type of diagram that gives the highest thermodynamic efficiency for cycles of the nature of the Otto. The initial volume of charge is V_a at the pressure P_a. It is compressed adiabatically to V_b, heated by combustion at constant volume V_b to T_cP_c, and then expanded adiabatically till the pressure falls to the initial pressure P_a at the volume V_e.

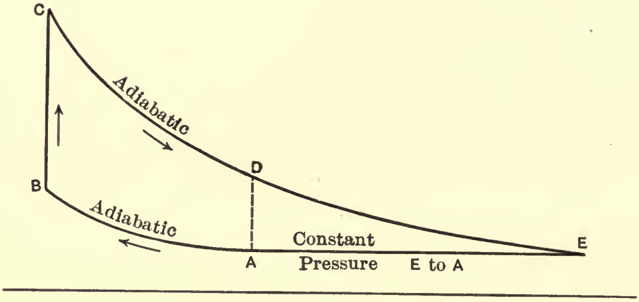

FIG. 134.

Taking $P_a = P_e =$ atmospheric pressure, the line AE is a line of atmospheric pressure. This corresponds in practice to the displacement of the products against atmospheric resistance while the piston moves from E to A. The heat wasted is that necessary to increase the volume of the gas from V_a to V_e at constant (atmospheric) pressure. The area of the diagram is larger than that in which the initial and final volumes are equal, by the amount $ADEA$.

This diagram is of the same nature as those of a four-stroke Otto cycle motor that cuts off the admission of combustible mixture completely when the piston has moved only part way on the suction stroke. (See Fig. 107.)

While this cycle has a high thermodynamic efficiency in relation to indicated power, it does not have a correspondingly high efficiency for the conversion of heat into delivered mechanical energy which must take into account the mechanical efficiency of the machine (motor). At some point on the expansion line CDE the pressure falls to an amount that is just sufficient to overcome the mechanical friction of the motor. After this point is reached there is no gain in the amount of power delivered by the motor during the remainder of the expansion, but an actual loss of power occurs if expansion is carried out beyond the point just mentioned.

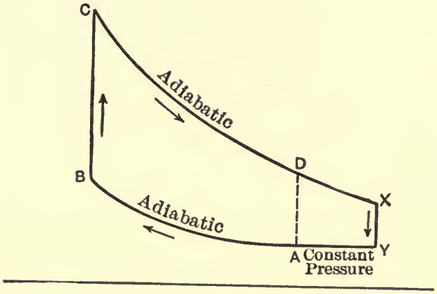

Fig. 135.

In Fig. 135, if X is the point where the driving effort of the expanding gas and the frictional resistance of the machine just balance each other, then this diagram is the one for the maximum motor efficiency at a fixed compression pressure. (See Fig. 107 for method of approximating this diagram in practice.)

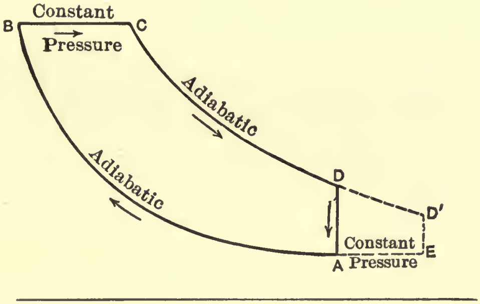

Fig. 136.

269. Theoretical Brayton Cycle. — Fig. 136. This cycle theoretically consists in adiabatically compressing a charge of non-combustible gas from the condition A to B, and then maintaining a constant pressure during the early part of the outstroke of the piston by adding more gas which is combustible and burns as it enters the motor cylinder, thus increasing the temperature of the charge as the volume in the cylinder increases. The addition and burning of gas are stopped at C, and the contents of the cylinder expand adiabatically to the end of the stroke. The burned gas is then expelled, while the volume of the cylinder space remains constant, which completes the cycle.

The expansion may be carried to any point D on the adiabatic DD', and the exhaust valve kept open on the compression stroke till the point A, where compression is to begin, is reached.

270. General Equations for Thermodynamic Change. — In the preceding discussion the equation PV^{λ} = constant has been used for adiabatic expansion, in which λ is the ratio of the specific heat of constant pressure to that of constant volume. This equation can be extended to more general application by making the exponent such that it can be assigned any value. This is done in the equation,

$$PV^n = \text{constant},$$

in which any value may be assigned to n.

If $n = 1$ then the equation applies to isothermal expansion or compression. By making $n = 0$ the equation for constant pressure is obtained, since $V^0 = 1$ and therefore PV^0 = constant. When $n = \infty$ the equation becomes that for constant pressure, since $V^{\infty} = \infty$.

For any finite value of n, equations can be developed for determining points on the expansion and compression lines of a perfect gas.

In view of the fact that there are so many modifying factors met with in the application of these equations to practical conditions, as has been pointed out in relation to the Otto cycle, they are of little or no use in practice.

271. Other Thermodynamic Cycles. — It will doubtless readily be seen that by combining different lines of expansion and compression, an infinite number of thermodynamic cycles can be obtained. In the present state of the internal-combustion motor art none of the cycles except those that have been mentioned seem to find application however, and there appear to be such great difficulties in utilizing efficiently cycles other than the ones now in use as to prevent their early application.

CHAPTER XXI.

RESULTS OF TRIALS.

272. Introductory. — The matter relative to tests which is given in this chapter has been selected on account, on the one hand, of its covering a great variety of bituminous coals and lignites, and on the other hand as being representative of modern gas engine practice in regular service. Also because two kinds of gas producers are brought into consideration. In one case a continuous updraught producer was used, and in the other a pair of intermittent downdraught producers.

273. United States Government Tests at St. Louis. — These tests were made largely for the purpose of determining the suitability of various bituminous coals, lignites and peat for conversion into gas for combustion motor use. A great number of different coals and lignites were tested. The trials were so extensive, complete and fully reported as to be the most valuable information in this connection. A very small proportion of the mass of data will be presented.

The gas producer used was of the continuous, updraught pressure type, of the general form of Fig. 114. The gasification chamber was about 7 feet diameter (inside) at the fire zone. The producer was rated at 250 horsepower capacity.

The gas engine was of the three-cylinder, single-acting, vertical four-cycle type, rated 235 horsepower at 200 r.p.m. The engine cylinders were 19 inches diameter and the stroke 22 inches.

A gas tank 20 feet diameter, 13 feet high and of 4000 cubic feet capacity was used in connection with the producer.

Steam for producing the blast and aiding in the gasification of the fuel was taken from separate boilers. Power was used for driving the automatic fuel-feeding device attached to the producer, and also for driving the centrifugal tar extractor. The items in the tables under headings containing the words "equivalent used by producer plant" include the energy of the steam supplied and that used for driving the apparatus auxiliary to the producer, including the tar extractor.

Tables XII to XVI, compiled from the report, and Figs. 137 and 138, reproduced from the report, give several of the items of the tests.

Test 29 is notable on account of running continuously for 562 hours.

The fuels used in tests 71–78, lignites, peat, and bone coals, show what can be done with fuels that have been practically unused in this country heretofore. Bone coal is ordinarily thrown out as waste at the mines. Some of that tested was composed of so much hard, stony matter that a hammer would strike fire from it. The hand-picked bone coal was of larger sizes than the run of such coal and therefore was not as rich in combustible matter as the run (of bone) on account of the softer parts breaking off in small pieces when the bone was thrown aside from the tipple.

The tar collected from the producer gas, as shown in Table XIII, represents a considerable loss of the heat value of the coal and a consequent reduction of the efficiency of the producer, as these tests were carried out. The tar was not utilized so far as the production of power from the coal was concerned.

The heat values of the tars from the different fuels naturally vary greatly on account of the different compositions of the tars. Some tars are black and heavy as compared with others. The brown tar from the lignites is generally much lighter than the black from bituminous coal. The heavy tars generally have higher heating values than the lighter ones, as they occur in connection with producer gas manufacture.

The gain in economy by breaking up the tar during the gas-making process into compounds that are permanent gases, or of providing some means of usefully burning the tar, will appear when the amount formed in some cases is noted as given in the table.

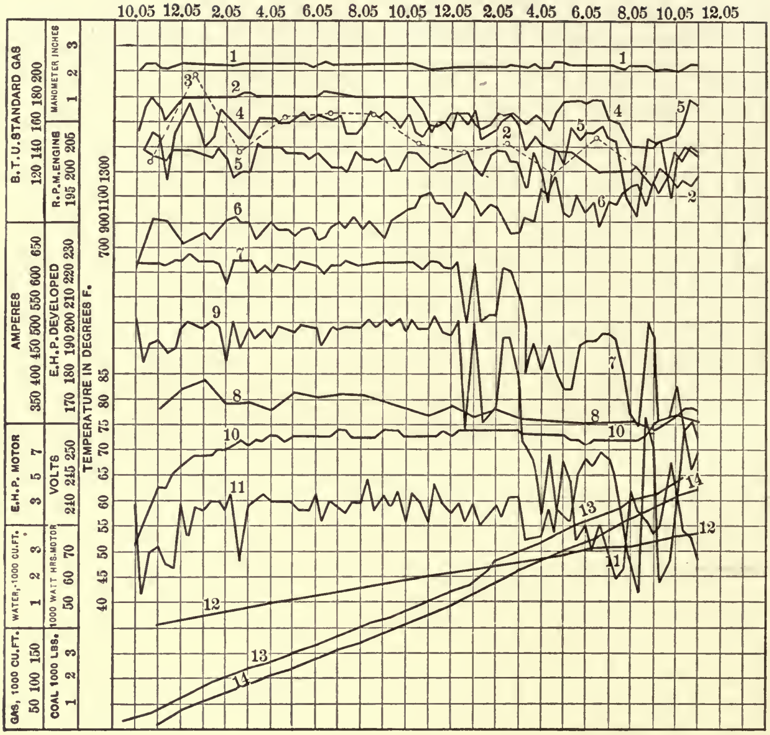

Fig. 137.

GRAPHIC LOG SHEET, PRODUCER GAS TEST, IOWA NO. 2 COAL.

From "Report on Coal-Testing Plant," U. S. Geological Survey, 1906.

1. Manometer No. 1 at gas meter.
2. Manometer No. 2 at gas meter.
3. B.t.u. of gas by analysis. (Higher value.)
4. B.t.u. of gas by calorimeter. (Higher value.)
5. Rev. per min. of engine.
6. Temperature of gas leaving producer
7. Amperes, generator load.
8. H.p. of auxiliary motor.
9. H.p. output of generator.
10. Temperature of gas at meter.
11. Volts, generator load.
12. Water used by producer plant
13. Coal consumed by producer.
14. Cubic feet of gas produced.

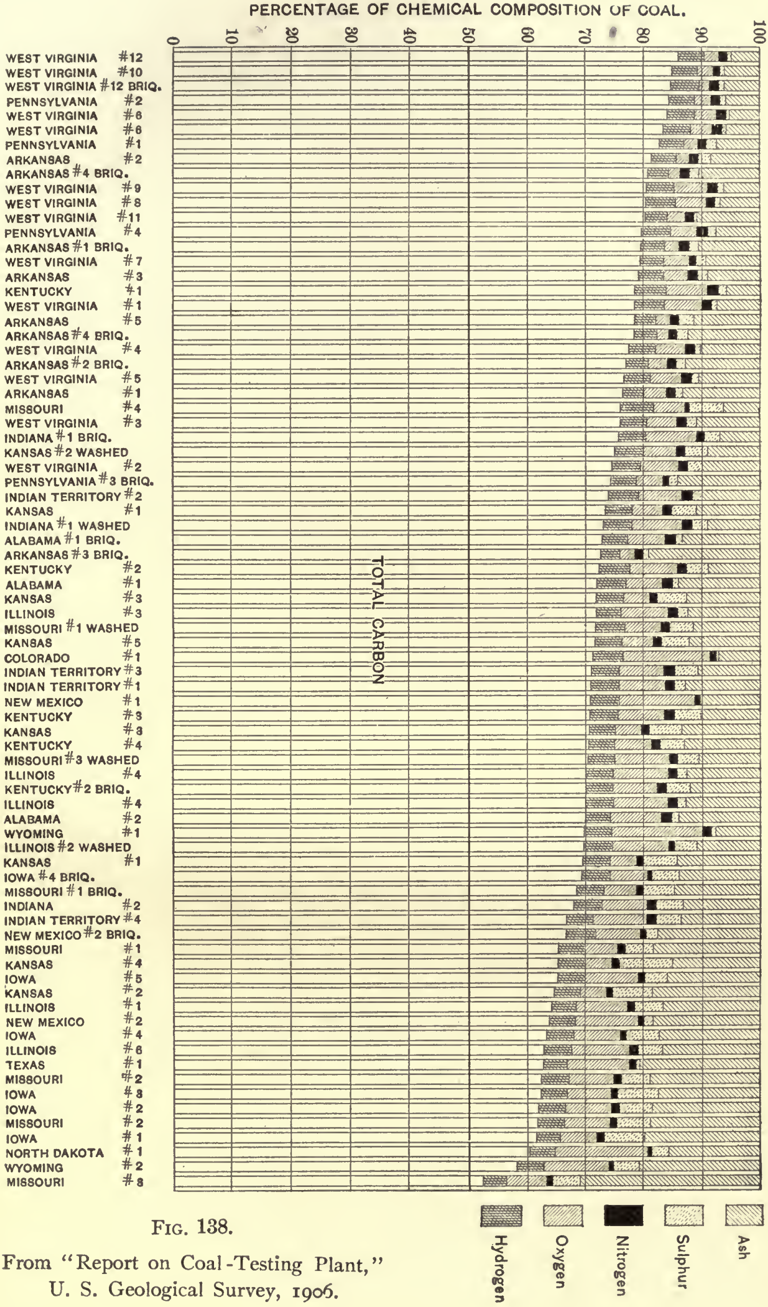

FIG. 138.

From "Report on Coal-Testing Plant," U. S. Geological Survey, 1906.

TABLE XII.

Average Compositions of Producer Gases from Various Bituminous Coals and Lignites.*

(See also Tables XIII, XIV, XV, XVI, and Fig. 138.)

All gas made in the same producer of the continuous up-draught pressure type.

Number.	Name of Coal or Lignite.	Average Composition of Gas by Volume. Per cent.					
		CO_2	O_2	CO	H_2	CH_4	N_2
1	Alabama No. 2 Clean and hard.	8.16	0.10	16.65	7.20	5.64	62.24
2	Colorado No. 1 Black lignite.	10.11	.55	17.38	11.05	5.00	55.90
† 3	Illinois No. 3	10.53	.15	15.31	8.35	4.46	61.19
† 4	Illinois No. 4	9.72	.12	15.12	9.98	6.00	59.06
† 5	Indiana No. 1	9.89	.25	14.10	9.56	6.08	60.13
† 6	Indiana No. 2	11.80	.07	11.46	10.60	6.10	59.97
7	Indian Territory No. 1	8.25	.11	19.39	7.69	4.92	59.65
8	Indian Territory No. 4	7.29	.236	17.636	10.427	6.30	58.109
9	Iowa No. 2	10.057	.171	12.571	9.529	7.671	60.000
10	Kansas No. 5 Fine slack, good prod'r coal	10.267	.133	12.40	9.05	7.417	60.733
† 11	Kentucky No. 3 Good, hard producer coal	10.87	.29	12.45	10.92	6.52	58.95
† 12	Missouri No. 2	12.07	.20	10.53	7.63	6.33	63.23
† 13	Montana No. 1	9.04	.36	18.67	9.00	4.84	59.10
† 14	North Dakota No. 2 Brown lignite.	8.69	.23	20.90	14.33	4.85	51.02
† 15	Texas No. 1 Brown lignite.	11.10	.22	14.43	10.54	7.85	56.22
16	Texas No. 2 Brown lignite.	9.60	.20	18.22	9.63	4.81	57.53
17	West Virginia No. 1	10.50	.10	14.34	2.81	5.56	66.69
18	West Virginia No. 4	10.16	.24	15.82	11.16	3.74	58.88
19	West Virginia No. 7	9.617	.084	12.75	10.308	6.758	60.483
20	West Virginia No. 8	10.327	.218	11.927	9.454	6.40	61.672
21	West Virginia No. 9	10.40	.20	11.70	9.55	6.60	59.55
22	West Virginia No. 9	8.90	.33	14.77	9.508	6.65	59.856
† 23	West Virginia No. 12	10.34	.12	14.21	12.98	4.61	57.75
24	Wyoming No. 2	10.21	.59	15.46	10.79	5.52	57.43

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* From "Report on Coal-Testing Plant," United States Geological Survey, 1906. See pages 407 and 409 for composition of coal.

† Gas producer hopper leaked during these tests.

TABLE XIII.

Proximate Analyses of Bituminous Coals and Lignites. Temperatures and Tar Products of Gasification.*

(See also Tables XII, XIV, XVI, and Fig 138.)

Number.	Average Composition of Coal. Per cent.					Total Coal Consumed in Producer. Pounds.	Total Tar Collected.	Average Temp. of Gas Leaving Producer. Deg. Fahr.†
	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.			
1	3.76	33.45	53.29	9.50	0.86	13350	?	?
2	20.24	32.26	41.65	5.85	0.60	10933	?	650
3	7.62	30.87	51.78	9.73	1.69	10500	60 gal.	753
4	12.43	32.65	45.70	9.22	1.41	10500	75 gal.	882
5	11.51	36.04	42.37	10.08	2.61	11700	70 gal.	975
6	8.72	39.60	41.95	9.73	4.23	6900	?	914
7	5.00	36.51	49.98	8.51	1.43	11200	2.5 bbl.	?
8	9.00	33.96	40.68	16.36	4.12	6300	50 gal.	686
9	16.69	31.42	31.19	20.70	5.50	4833	50 gal.	893
10	4.35	31.97	52.43	11.25	3.00	4000	?	840
11	7.28	38.57	45.16	8.99	3.86	11100	100 gal.	?
12	11.60	35.28	38.28	14.84	4.56	3300	?	883
13	11.40	34.55	43.31	10.74	1.72	10200	?	738
14	39.56	27.78	26.30	6.36	0.93	13800	50 gal.	?
15	33.50	32.34	23.80	10.36	0.63	12800	150 gal.	?
16	33.71	29.25	29.76	7.28	0.53	9050	60 gal.	559
17	1.61	36.85	55.40	6.14	0.87	6900	?	768
18	1.99	28.89	60.30	8.82	0.79	2100	?	804
19	2.99	21.19	69.15	6.67	0.92	6000	?	1228
20	2.66	32.58	59.00	5.76	0.94	6900	75 gal.	847
21	2.66	32.00	59.61	5.73	1.00	1300	120 gal.	752
22	2.22	31.05	59.83	6.90	0.79	6000	50 gal.	1064
23	1.43	18.93	73.19	6.45	0.95	8100	50 gal.	898
24	9.44	35.02	34.82	20.72	3.91	12100	60 gal.	680

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* Compiled from "Report on Coal-Testing Plant," United States Geological Survey, 1906.

† Temperature of gas taken in main gas flue near producer.

TABLE

Rate of Gasification and Average Heat Values of Producer

(See also Tables XII, XIII, XV, XVI,

All gas made in the same producer of the continuous, updraught
at 62° F. and 14.7 pounds

Number.	Coal per Hour. Pounds.					
	Consumed in Producer.			Equivalent Used by Producer Plant.		
	Coal as Fired.	Dry Coal.	Combustible.	Coal as Fired.	Dry Coal.	Combustible.
a	*b*	*c*	*d*	*e*	*f*	*g*
1	310.5	299.0	280.0	341.4	328.7	306.8
2	364.4	290.7	269.3	428.4	341.7	316.6
† 3	350.0	323.3	289.3	386.0	356.7	319.2
† 4	350.1	306.3	274.1	398.2	348.5	311.9
† 5	394.5	349.3	309.5	434.6	384.8	341.0
† 6	300.0	274.0	244.8	338.0	312.0	278.8
7	361.0	344.0	312.0	392.7	374.0	339.3
8	278.0	253.2	207.8	312.5	284.6	233.6
9	362.5	302.5	227.5	408.4	340.7	256.2
10	307.8	294.3	259.8	338.4	323.6	285.7
† 11	370.0	343.3	310.0	410.8	381.2	344.2
† 12	346.5	306.0	255.0	384.5	339.6	283.0
† 13	456.5	404.5	355.8	506.8	449.1	395.0
† 14	460.0	278.0	249.0	510.0	308.0	275.8
† 15	590.0	393.0	332.0	660.0	439.5	371.3
16	468.0	310.3	276.2	519.5	344.4	306.6
17	287.5	283.0	265.5	320.6	315.6	296.1
18	233.0	229.0	208.0	262.8	258.2	234.5
19	269.9	256.9	239.1	299.2	290.2	270.1
20	328.6	320.8	301.1	364.7	355.1	334.1
21	300.0	290.0	274.9	328.9	320.1	301.4
22	250.0	244.5	227.0	284.8	278.5	258.6
† 23	270.0	266.1	248.7	304.9	300.5	280.9
24	403.2	365.3	281.6	459.8	416.5	321.1

* Partly from " Report on Coal-Testing

† Gas producer hopper leaked during

‡ Lower heat values computed by the

XIV.

Gases from Various Bituminous Coals and Lignites.*

and Fig. 138.)

pressure type, about 7 feet inside diameter at fire zone. Gas taken per square inch pressure.

British Thermal Units, Higher Heat Values.					B.t.u. per Cu. Ft. of Gas Computed from Average Chemical Analyses. Lower Value.‡	Number.
Coal as Fired per Pound.	Dry Coal per Pound.	Combustible per Pound.	Gas from one Pound Dry Coal Consumed in Prod'r.	Per Cu. Ft. of Gas.		
h	*i*	*j*	*k*	*l*	*m*	*n*
12865	13365	14820	9000	149.2	125	1
9767	12245	13210	7860	149.0	133	2
12046	13041	14506	8330	154.8	113	3
11237	12834	14344	8840	151.5	131	4
11534	13037	14720	7730	153.7	127	5
11822	12953	14500	10140	159.3	122	6
12787	13455	14800	8620	159.2	129	7
10364	11392	13890	9980	161.1	143	8
8735	10489	13950	9300	160.2	136	9
12836	13421	15200	10500	167.2	132	10
12283	13226	14650	8610	155.9	130	11
10505	11882	14280	8820	140.0	113	12
10575	11934	13580	6580	160.8	127	13
6802	11255	12600	7830	188.5	152	14
7267	10928	12945	7260	169.7	144	15
7348	11086	12450	8060	156.2	130	16
14166	14396	15350	9260	144.4	104	17
13918	14202	15600	11610	143.2	117	18
14283	14720	15800	13140	154.2	132	19
14168	14558	15470	9070	155.1	133	20
14195	14580	15500	8150	151.0	131	21
14224	14548	15650	11380	160.5	134	22
14614	14825	15860	10150	142.5	124	23
9650	10656	13820	6168	151.0	130	24

Plant," United States Geological Survey, 1906.

these tests.

writer, using heat values given in Table VII.

TABLE XV.

Cubic Feet of Gas from Various Bituminous Coals and Lignites.*

(See also Tables XII, XIII, XIV, XVI, and Fig. 138.)

All gas made in the same producer of the continuous updraught pressure type. Gas at 62° F. and 14.7 pounds per square inch pressure.

Number.	Cubic Feet of Gas Produced.					
	Per Pound Consumed in Producer.			Per Pound Equivalent Used by Producer Plant.		
	Coal as Fired.	Dry Coal.	Combustible.	Coal as Fired.	Dry Coal.	Combustible.
o	*p*	*q*	*r*	*s*	*t*	*u*
1	58.1	60.4	64.5	52.9	55.0	58.9
2	42.1	52.8	57.0	35.8	44.9	48.5
† 3	49.8	53.9	60.2	45.1	48.8	54.5
† 4	51.1	58.4	65.3	44.8	51.4	57.4
† 5	44.5	50.3	56.7	40.4	45.6	51.5
† 6	58.2	63.6	71.3	51.6	55.9	62.6
7	51.6	54.1	59.4	47.4	49.9	54.6
8	56.4	61.9	75.5	50.2	55.1	67.1
9	48.5	58.1	77.2	43.0	51.6	68.5
10	60.1	62.8	71.2	54.6	57.2	64.8
† 11	51.2	55.1	61.1	46.2	49.7	55.0
† 12	55.7	66.0	75.7	50.2	56.8	68.2
† 13	36.2	40.9	46.5	32.6	36.8	41.9
† 14	25.2	41.5	46.4	22.7	37.5	41.9
† 15	28.4	42.7	50.6	25.5	38.2	45.3
16	34.2	51.6	57.9	30.8	46.4	52.2
17	63.2	64.1	68.4	56.6	57.5	61.3
18	79.6	81.2	89.2	70.6	71.9	79.2
19	82.5	85.1	91.4	73.0	75.3	80.9
20	56.9	58.4	62.0	51.3	52.6	55.9
21	52.6	54.0	57.4	48.0	49.3	52.3
22	69.3	70.9	76.3	60.9	62.2	67.0
† 23	70.1	71.2	76.2	62.1	63.2	67.5
24	37.0	40.9	53.0	35.5	35.8	46.5

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* From "Report on Coal-Testing Plant," United States Geological Survey, 1906.

† Gas producer hopper leaked during these tests.

TABLE XVI.

Pounds of Various Coals and Lignites per Brake Horsepower per Hour Delivered by Gas Engine.*

See also Tables XII, XIII, XIV, XV, and Fig. 138.

Three-cylinder, single-acting gas engine, 19 inches diameter by 22 inches stroke. Rated 235 brake horsepower at 200 revolutions per minute.

All gas made in the same producer of the continuous up-draught pressure type, about 7 feet inside diameter at the fire zone.

No.	Pounds of Coal per Brake Horsepower Hour.					
	Consumed in Producer.			Equivalent Value Used by Producer Plant.		
	Coal as Fired.	Dry Coal.	Combustible.	Coal as Fired.	Dry Coal.	Combustible.
v	*w*	*x*	*y*	*z*	*z*1	*z*2
1	1.32	1.27	1.19	1.45	1.40	1.30
2	1.55	1.23	1.14	1.82	1.45	1.34
† 3	1.49	1.38	1.23	1.64	1.52	1.36
† 4	1.50	1.31	1.17	1.71	1.50	1.34
† 5	1.68	1.49	1.32	1.85	1.64	1.45
† 6	1.27	1.16	1.03	1.43	1.32	1.18
7	1.50	1.43	1.30	1.64	1.56	1.41
8	1.18	1.08	.89	1.33	1.21	1.00
9	1.56	1.30	.98	1.76	1.47	1.10
10	1.31	1.25	1.10	1.44	1.37	1.21
† 11	1.57	1.46	1.32	1.75	1.62	1.46
† 12	1.48	1.31	1.09	1.65	1.45	1.21
† 13	1.95	1.72	1.52	2.16	1.91	1.68
† 14	2.91	1.76	1.58	3.23	1.95	1.74
† 15	2.54	1.69	1.43	2.83	1.99	1.60
16	1.98	1.31	1.17	2.20	1.46	1.30
17	1.22	1.20	1.13	1.36	1.34	1.26
18	.99	.98	.89	1.12	1.10	1.00
19	1.13	1.10	1.02	1.28	1.24	1.15
20	1.40	1.36	1.28	1.55	1.51	1.42
21	1.27	1.24	1.16	1.39	1.35	1.27
22	1.07	1.04	.97	1.21	1.19	1.10
† 23	1.15	1.13	1.06	1.30	1 28	1 20
24	1.70	1.54	1.19	1.94	1.76	1.36

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* Compiled from "Report on Coal-Testing Plant," United States Geological Survey, 1906.

† Gas producer hopper leaked during these tests.

TABLE XVII.

Proximate Analyses of Bituminous Coals.*

Percentage composition. See also Tables XX and XXII.

No.	Name of Coal.	Moisture.	Volatile Matter.	Fixed Carbon	Ash.	Sulphur.
25	Alabama No. 4 Rm.	3.05	29.53	54.78	12.64	1.15
26	Alabama No. 6 Rm.	2.44	25.96	64.70	6.90	.59
27	Arkansas No. 7A Lump	4.27	16.04	67.43	12.26	2.15
28	Illinois No. 19C Rm.	9.82	29.64	50.34	10.20	.49
29	Illinois No. 29 Lump	14.68	30.98	42.93	11.41	1.33
30	Illinois No. 22A Lump	11.29	35.60	39.94	13.17	4.88
31	Illinois No. 23 Slack	11.87	36.37	39.87	11.89	4.65
32	Illinois No. 24B Lump	11.44	33.93	43.92	10.71	4.94
33	Illinois No. 25B Lump	11.64	35.41	44.29	8.66	3.41
34	Illinois No. 26 Rm.	13.29	32.02	38.81	15.88	3.52
35	Illinois No. 27 Rm.	11.35	33.59	41.20	13.86	4.54
36	Illinois No. 29B Rm.	12.25	33.76	41.66	12.33	4.42
37	Illinois No. 30 Washed	5.59	39.30	45.45	9.66	3.37
38	Indiana No. 12 Rm.	10.42	36.29	40.75	12.54	3.96
39	Indiana No. 13 Rm.	11.53	34.80	40.44	13.23	3.11
40	Indiana No. 14 Rm.	7.88	36.85	41.07	14.20	5.14
41	Indiana No. 16 Rm.	7.79	32.32	44.97	11.92	4.01
42	Indiana No. 18B Lump	12.11	34.19	46.87	6.83	1.44
43	Kansas No. 6 Lump	9.85	30.19	46.68	13.28	3.04
44	New Mexico No. 3A Rm.	3.62	31.56	45.19	19.63	.72
45	New Mexico No. 4A Rm.	2.42	34.82	49.23	13.53	.63
46	New Mexico No. 5 Rm.	1.79	31.32	51.40	15.49	.66
47	Ohio No. 10 Lump	4.05	39.28	47.75	8.92	3.02
48	Ohio No. 11 Lump	3.44	36.04	47.58	12.94	4.32
49	Ohio No. 12 Rm.	3.82	37.77	47.42	10.99	3.39
50	Pennsylvania No. 11 Rm.	1.95	34.07	56.69	7.29	1.18
51	Pennsylvania No. 12 Rm.	1.96	30.55	58.24	9.25	2.19
52	Pennsylvania No. 13 Rm.	1.65	33.06	53.22	12.07	1.80
53	Pennsylvania No. 15 Lump	2.57	18.09	69.01	10.33	3.97
54	Pennsylvania No. 16 Rm.	5.32	21.75	64.94	7.99	1.60
55	Pennsylvania No. 17 Rm.	4.40	28.01	54.87	12.72	1.72
56	Pennsylvania No. 22 Rm.	3.98	28.13	57.73	10.16	1.00
57	Tennessee No. 1 Rm.	2.72	31.81	53.20	12.27	1.26
58	Tennessee No. 2 Rm.	3.40	37.58	54.27	4.75	.83
59	Tennessee No. 3 Rm.	4.88	34.84	53.57	6.71	1.16
60	Tennessee No. 4 Rm.	3.29	34.49	54.82	7.40	.88
61	Tennessee No. 5 Rm.	2.54	34.64	53.96	8.86	3.39
62	Tennessee No. 6 Rm.	3.55	26.00	49.88	20.57	.76
63	Tennessee No. 7A Rm.	3.03	34.91	49.21	12.85	3.26
64	Tennessee No. 8 Washed Rm.	2.43	35.41	52.29	9.87	3.06
65	Utah No. 1 Rm.	5.83	42.46	47.05	4.66	.57
66	Virginia No. 6 Rm.	4.51	22.77	62.64	10.08	1.59
67	Washington No. 2 Lump	4.01	34.61	47.49	13.89	.38
68	West Virginia No. 25 Lump	3.83	34.34	53.61	8.22	.62
69	Wyoming No. 4 Rm.	11.30	40.32	41.07	7.31	.28
70	Wyoming No. 5 Rm.	11.44	36.37	48.49	3.70	.91

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* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

Rm. = run of mine.

TABLE XVIII.

Pounds of Bituminous Coal per Brake Horsepower Delivered by Engine.*

See also Tables XVII and XXI. Three-cylinder, single-acting gas engine, 19 in. diam. by 22 in. stroke, rated 235 brake horsepower at 200 rev. per min. All gas made in the same producer of the continuous up-draught pressure type, about 7 feet inside diameter at the fire zone.

No.	Consumed in Producer.			Equivalent Value Used by Producer Plant.			Length of Test. Hours.	Total Coal Fired. Pounds.
	Coal as Fired.	Dry Coal.	Combustible.	Coal as Fired.	Dry Coal.	Combustible.		
25	1.06	1.03	.90	1.16	1.12	.97	24	5,850
26	.77	.75	.70	.84	.82	.76	50	9,000
27	1.60	1.53	1.34	1.74	1.66	1.45	50	12,900
28	1.74	1.57	1.39	1.90	1.71	1.52	50	14,400
29	1.64	1.40	1.22	1.76	1.50	1.30	562	208,350
30	1.50	1.33	1.13	1.59	1.41	1.20	47	16,300
31	1.54	1.36	1.18	1.63	1.43	1.24	50	18,000
32	1.24	1.10	.97	1.32	1.17	1.03	50	14,650
33	1.36	1.20	1.02	1.43	1.27	1.08	50	16,000
34	1.56	1.36	1.11	1.70	1.47	1.20	50	16,050
35	2.19	1.94	1.63	2.36	2.10	1.77	?	16,050
36	1.51	1.33	1.14	1.62	1.42	1.22	50	17,250
37	1.38	1.31	1.17	1.45	1.37	1.23	50	16,200
38	1.50	1.35	1.16	1.59	1.43	1.23	50	17,200
39	1.26	1.13	.99	1.39	1.22	1.07	24	6,750
40	1.45	1.34	1.13	1.54	1.42	1.20	50	16,200
41	1.82	1.68	1.46	1.54	1.42	1.24	50	16,100
42	1.26	1.12	1.03	1.35	1.20	1.11	36	10,350
43	1.41	1.27	1.08	1.49	1.35	1.15	13⅔	4,500
44	1.10	1.06	.85	1.18	1.14	.91	50	12,850
45	1.18	1.15	.99	1.29	1.26	1.08	50	13,110
46	1.20	1.18	.99	1.29	1.26	1.06	45	12,500
47	1.08	1.04	.94	1.15	1.10	1.00	50	12,650
48	1.18	1.14	.99	1.26	1.22	1.06	50	13,850
49	1.23	1.18	1.05	1.32	1.27	1.13	50	14,350
50	1.22	1.19	1.10	1.32	1.29	1.20	50	12,200
51	.95	.93	.84	1.05	1.03	.93	28	6,100
52	1.02	1.00	.88	1.10	1.09	.95	50	11,750
53	1.05	1.03	.92	1.17	1.14	1.02	24	5,700
54	.85	.80	.74	.95	.90	.82	50	9,950
55	1.19	1.14	.99	1.26	1.21	1.05	50	13,200
56	1.01	.97	.86	1.07	1.03	.92	50	11,700
57	1.24	1.20	1.05	1.32	1.29	1.12	50	12,300
58	.95	.92	.87	1.05	1.02	.96	50	11,250
59	1.10	1.04	.97	1.19	1.13	1.05	50	12,950
60	1.13	1.10	1.01	1.23	1.19	1.10	50	12,150
61	1.18	1.15	1.04	1.28	1.25	1.14	50	12,900
62	1.45	1.39	1.10	1.59	1.53	1.20	30	7,950
63	1.27	1.23	1.07	1.38	1.35	1.16	50	14,400
64	1.18	1.15	1.03	1.26	1.23	1.10	24	6,550
65	1.38	1.30	1.24	1.17	1.11	1.05	50	14,250
66	.97	.92	.83	1.06	1.01	.91	50	11,000
67	1.15	1.11	.95	1.22	1.17	1.01	35	9,300
68	1.11	1.07	.98	1.17	1.12	1.03	50	13,000
69	1.76	1.56	1.43	1.91	1.69	1.55	50	20,200
70	1.36	1.21	1.16	?	?	?	50	15,600

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* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

TABLE XIX.

Proximate Analyses of Lignites, Peat, Bone Coal, Subbituminous, Semianthracite, Anthracite, and Coke.*

See also Tables XX and XXII.

Percentage Composition.

No.	Name of Fuel.	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.
	Lignites:					
71	Arkansas No. 10 Rm.	39.43	26.49	24.37	9.71	.49
72	Montana No. 2	8.51	31.58	44.52	15.39	.60
73	Montana No. 3	8.56	32.36	45.69	13.39	.54
74	Texas No. 3 Lump	32.20	30.11	28.82	8.87	.88
75	Texas No. 4 Rm.	34.08	33.15	25.32	7.45	.49
	Peat: †					
76	Florida No. 1 Compressed	21.00	51.72	22.11	5.17	.45
	Bone coal:					
77	West Virginia No. 11 B Hand picked from waste	.47	8.83	46.96	43.74	.27
78	West Virginia No. 24	2.91	11.81	57.19	28.08	.54
	Subbituminous:					
79	Washington No. 1A Pea	16.17	34.00	37.27	12.56	.53
80	Washington No. 1B Rm. Small sizes	16.02	33.27	36.81	13.90	.59
81	Wyoming No. 6 Rm.	18.26	37.18	41.82	2.74	.47
	Semianthracite:					
82	Arkansas No. 8	2.74	9.70	71.95	15.61	2.45
	Anthracite:					
83	Virginia No. 5A Pea	3.34	11.28	67.24	18.14	.75
	Coke:					
84	Miscellaneous	7.86	.69	79.94	11.51	1.14

* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

† Peat from a bog at Orlando, Orange County, Florida, on the Seaboard Air Line Railway. The raw peat contains about 92 per cent of moisture. The sample tested was machined and sun dried. In this process the raw peat is first passed through a condenser to disintegrate it and destroy the fiber. It is then passed through a molding machine which molds it into bricks 8 × 4 × 2.5 inches. The bricks are taken to the drying ground and left till they lose from 60 to 75 per cent of their moisture.

Rm. = run of mine.

TABLE XX.

Pounds of Fuel per Brake Horsepower Delivered by Engine.*

See also Tables XIX and XXII. Three-cylinder, single-acting gas engine, 19 in. diam. by 22 in. stroke, rated at 235 horsepower at 200 rev. per min. All gas made in the same producer of the continuous up-draught pressure type, about 7 ft. inside diam. at the fire zone.

No.	Consumed in Producer.			Equivalent Value Used by Producer Plant.			Length of Test. Hours.	Total Coal Fired. Pounds.
	Coal as Fired.	Dry Coal.	Combustible.	Coal as Fired.	Dry Coal.	Combustible.		
71	3.03	1.83	1.54	3.45	2.09	1.76	18	8250
72	1.74	1.59	1.32	1.91	1.75	1.45	40	15450
73	1.39	1.27	1.08	1.48	1.35	1.15	49	15950
74	2.17	1.47	1.28	2.33	1.58	1.38	50	25500
75	2.16	1.42	1.26	2.33	1.54	1.36	50	24550
76	2.43	1.92	1.79	2.57	2.03	1.90	50	29250
77	1.65	1.64	.92	?	?	?	50	18900
78	1.26	1.22	.87	?	?	?	50	11000
79	2.79	2.34	1.99	2.93	2.45	2.08	40	18900
80	2.03	1.71	1.43	2.20	1.85	1.54	14	6550
81	1.86	1.52	1.47	2.02	1.65	1.59	50	21900
82	1.58	1.54	1.29	1.72	1.67	1.40	26	8550
83	1.13	1.09	.89	1.22	1.18	.96	30	7950
84	.87	.80	.70	?	?	?	41	8400

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* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

TABLE XXI.

Average Compositions of Producer Gases from Bituminous Coals.*

See also Tables XVII and XVIII. All gas made in the same producer of the continuous up-draught pressure type. Average composition of gas by volume. Per cent.

No.	CO_2	O_2	CO	H_2	CH_4	N_2	C_2H_4
25	10.1	....	17.0	14.5	1.9	56.1	.4
26	9.6	....	19.5	14.9	1.7	54.2	.1
27	14.8	....	12.1	16.1	1.6	55.4	....
28	11.6	....	16.8	16.2	1.9	52.9	.3
29	9.2	....	20.9	15.6	1.9	52.0	.4
30	9.4	....	20.2	13.7	2.0	54.0	.7
31	8.4	....	20.9	12.9	1.6	55.7	.5
32	8.4	.1	22.6	13.8	2.1	52.5	.5
33	8.3	....	22.5	13.6	2.2	52.9	.5
34	10.5	....	19.4	15.5	1.7	52.5	.4
35	12.4	....	15.0	12.9	1.6	57.7	.4
36	11.4	....	17.3	14.0	2.0	54.8	.5
37	9.3	....	19.6	13.8	2.0	54.7	.6
38	9.0	....	19.0	13.0	2.0	56.0	1.0
39	10.9	....	18.0	15.2	1.9	53.6	.4
40	9.8	....	20.4	14.4	2.2	52.7	.5
41	11.4	....	16.8	13.3	1.7	56.3	.5
42	10.0	....	19.4	16.0	2.1	52.2	.3
43	8.2	....	21.0	12.7	2.1	55.4	.6
44	9.2	....	20.5	14.5	2.0	53.4	.4
45	10.6	....	17.0	12.6	2.0	57.2	.6
46	8.6	....	21.4	14.6	2.2	52.7	.5
47	9.4	....	20.7	14.2	2.6	52.6	.5
48	9.0	....	20.2	15.3	2.7	52.3	.5
49	9.3	....	19.9	15.2	2.5	52.6	.5
50	10.4	....	18.5	16.3	2.0	52.6	.2
51	10.8	....	16.6	14.9	2.4	54.8	.5
52	11.1	....	11.5	12.6	2.1	57.1	.6
53	10.7	....	17.2	15.8	2.2	53.8	.3
54	10.1	....	18.2	15.8	2.3	53.2	.4
55	10.0	.1	17.5	13.7	2.2	56.1	.4
56	10.1	....	17.6	13.3	2.2	56.4	.4
57	10.0	....	19.6	15.3	2.1	52.6	.4
58	10.9	....	18.8	18.6	2.2	49.0	.5
59	9.8	....	20.2	16.5	2.4	50.7	.4
60	10.4	....	19.0	16.7	2.4	51.0	.5
61	11.3	....	17.0	15.3	1.7	54.2	.5
62	12.3	....	15.0	14.0	1.9	56.4	.4
63	11.2	....	17.4	15.3	2.3	53.3	.5
64	9.7	....	19.1	15.1	2.1	53.5	.5
65	8.5	....	22.2	15.7	2.6	50.5	.5
66	10.5	....	17.4	14.3	2.0	55.5	.3
67	7.9	....	22.2	15.4	2.6	51.5	.4
68	7.9	....	23.4	17.1	2.1	49.1	.4
69	12.2	....	16.4	15.1	2.7	53.2	.4
70	10.1	....	20.4	18.2	2.6	48.3	.4

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* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

TABLE XXII.

Average Compositions of Producer Gases from Lignites, Peat, Bone Coal, Subbituminous, Semianthracite, Anthracite, and Coke.*

See also Tables XIX and XX. All gas made in the same producer of the continuous up-draught pressure type. Average composition of gas by volume. Per cent.

No.	CO_2	O_2	CO	H_2	CH_4	N_2	C_2H_4
71	13.5	....	14.0	9.2	2.4	60.9	....
72	13.2	.2	14.2	16.0	2.9	52.9	.6
73	8.0	....	23.2	15.9	3.3	49.2	.4
74	10.3	.7	19.8	14.8	2.4	51.3	.7
75	10.3	....	20.0	15.4	2.5	51.8	....
76	12.4	....	21.0	18.5	2.2	45.5	.4
77	9.7	....	19.5	16.6	1.6	52.6	....
78	12.4	....	14.0	13.8	1.2	58.6	....
79	11.3	....	15.4	10.5	3.6	59.2	....
80	12.6	.2	13.9	12.8	2.6	57.4	.7
81	12.1	....	18.7	19.3	3.0	46.5	.4
82	11.3	.2	15.9	14.7	1.0	56.7	.2
83	10.2	....	19.1	20.5	1.9	48.2	.1
84	9.2	....	21.9	11.1	.2	57.5	.1

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* Compiled from "Report on U. S. Fuel Testing Plant," Geological Survey, 1908.

274. Test of a 500-Horsepower Gas Engine Plant at Worcester, Mass.* — The gas engine tested was rated 500 horsepower at 155 r.p.m. It was of the tandem, double-acting, horizontal, four-cycle type (four combustion chambers) with cylinders 23.5 inches diameter and a stroke of 33 inches, direct connected to an electric generator.

The gas producers were of the intermittent, down-draught type. Two were used as a pair.

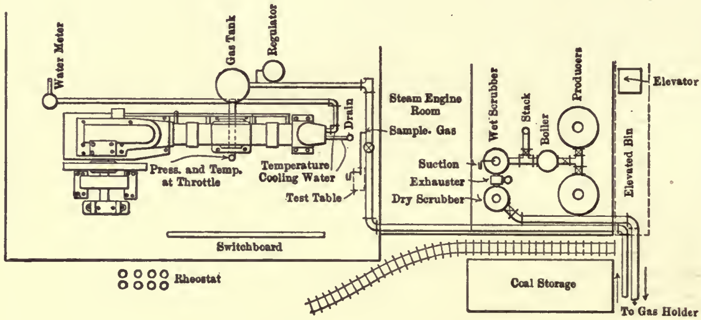

FIG. 139. Plan of Gas Engine Power Plant.

The general arrangement of the plant is shown in Fig. 139. The producers are shown more in detail in Fig. 116.

The fuel used was bituminous coal, except the lower part of the fuel bed, which was anthracite coal put on when building the fires at the beginning of the test. The analyses of the fuel are given in Table XXVI.

It is worthy of note that the engine ran at 522 brake horsepower (D.h.p.) for six consecutive hours on gas of 109 B.t.u. per cubic foot, lower heat value, and that it ran for a few moments at slightly more than 600 brake horsepower, 20 per cent overload, "without evidence of 'stalling.'"

In the gas producers the duration of the run with steam for making water gas (blowing in steam at the bottom with the air blast shut off) was from 20 to 30 seconds. The ratio of the time of duration of the water gas run to that of the air blasting is shown in Fig. 141.

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* Trans. Amer. Soc. Mech. Engrs., Vol. 29, 1907.

The "holder drop tests" were made by completely cutting off the producers from the gas holder, so that no gas was admitted to the holder. The drop of the holder was measured as the engine drew gas from it, and the amount of gas used computed from the drop.

The "digest of results" is taken verbatim from the report. The tables and such of the figures as are used are reproduced practically unchanged. They are self-explanatory. A few foot-notes have been added to transform certain expressions into the terms used in the text of this book.

Lower or effective heat values are used throughout the report.

Digest of Results of Test of 500-Horsepower Gas Engine Plant.

1. Full load test, 51 hours duration, continuous run without service interruptions of any kind; average load 11 per cent above generator rating, or practically full engine rating 332 kw., 483 b.h.p.

2. Fractional load tests by the holder drop method; runs made at five different loads, from no load to full engine rating.

3. A load of 600 h.p., sustained for a short time without abnormal drop in speed.

4. Average coal consumption at the producer, 1.4 lb. per kw.-hr., equivalent to 0.97 lb. per b.h.p. hr., using Clearfield bituminous run-of-mine (14,321 B.t.u. per lb.).

5. Average heat consumption at the engine, 10,100 B.t.u. per b.h.p. hr. at full load; 10,200 B.t.u. per b.h.p. hr. at average test load, equivalent to 25.29 per cent thermal efficiency * at full rating.

6. Mechanical efficiency,† full rating, 83.8 per cent, average test load, 83.5 per cent.

7. Average water consumption for engine only, 9.74 gal. per b.h.p. hr. with 66° F. inlet temperature and 47.1° F. rise, equivalent to 9.4 gal. per b.h.p. hr. at full rating.

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* Corresponds to motor efficiency as defined in Chapter XV.

† Corresponds to impulse-output efficiency as defined in Chapter XV.

8. Average cylinder oil consumption, 1.44 gal. per 24 hour, equivalent to 0.6 gal. per operating day, or 3.2 gal. per operating week.

9. Speed regulation, no load to full load, 2.5 per cent above and below mean.

10. Average producer efficiency, 74.4 per cent at full load; 73.8 per cent at average test load — both based upon lower or effective heat value of gas.

11. Producer gas, average, 114.6 effective * B.t.u. during 51-hour test; maximum variation 11.5 per cent above and below mean. Difference between total and effective heat values, about 4⅔ per cent.

TABLE XXIII.

Normal Operating Economy.

Averages for Nine Weeks. 500-Horsepower Gas Engine Power Plant.

Number of hours per week run on load	54.4	hours.
Output	13500.0	kw.-hrs.
Average running load	248.1	kw.
Average running load per cent rating of engine	72.2	per cent.
Coal gasified (including stand-by losses)	24839.0	pounds.
Coal for new fires	2369.0	pounds.
Coal for new fires (per cent of producer coal)	9.5	per cent.
Total coal for all purposes	27204.0	pounds.
Average total coal per hour including new fires	500.00	pounds.
Coal consumed (excluding new fires) per kw.-hr	1.83	pounds.
Total coal consumed per kw.-hr	2.015	pounds.

* Lower heat value.

TABLE XXIV.

51-Hour Test of Gas Power Plant.

500-Horsepower Gas Engine. Summary of Results.

	Load. Kilowatts.	Water. Cubic Feet.	Oil. Gallons.	Coal.* Pounds.
Quantity at finish	363,550.0	94,900.0	2.875	23,775
Quantity at start	345,710.0	63,560.0	....	....
Difference	16,840.0	31,340.0	2.875	23,775
Correction	+117.3	....	....	....
Corrected difference	16,957.3	31,340.0	2.875	23,775
Elapsed time	51 hrs.	50 hrs.	48 hrs.	51 hrs.
Rate per hour	332.5	626.8	0.06	466

	Water. Cu. Ft.	Water. Gal.	Oil. Gal.	Coal. Pounds.
Rate per kw.-hr........(332.5 kw.)	1.885	14.12	0.00018	1.402
Rate per b.h.p. hr.......(482.9 b.h.p.)	1.3	9.74	0.000125	0.965
Rate per i.h.p. hr........(579.0 i.h.p.)	1.078	8.075	0.000104	0.805

* Clearfield run-of-mine — 14,321 B.t.u. per pound as fired. Average thermal efficiency of plant, 18.43 per cent; engine, 24.93 per cent; producer, 73.81 per cent. Average gasification rate, 13.36 pounds per square foot per hour.

TABLE XXV.

51-Hour Test of Gas Power Plant. 500-Horsepower Gas Engine.

6-Hour Averages. Corrected Data Only.

Period.	June 24, P.M.		A.M. June 25 P.M.				A.M. June 26 P.M.			Total Average.
	3–6	6–12	12–6	6–12	12–6	6–12	12–6	6–12	12–6	51 Hours.
Load.										
Kw. by wattmeter	303.6	358.9	347.25	333.1	320.3	354.5	338.85	322.0	319.0	332.2
Kilo-volt-amperes	306.2	354.9	352.9	336.4	306.2	335.3	338.2	317.7	310.7	328.72
B.h.p. from kw.	440.7	522.2	504.8	483.8	451.5	487.4	492.2	467.3	462.8	482.3
B.h.p. from k.v.a.	445.0	516.4	512.7	498.5	445.0	487.0	491.5	461.0	451.0	477.31
Amperes	1290.0	1412.0	1411.0	1382.0	1250.0	1341.0	1353.0	1302.0	1276.0	1335.2
Volts	237.3	251.1	250.1	243.5	245.0	250.0	250.0	244.0	243.3	246.03
Coal.										
Lbs. fired per hour	443.5	454.7	455.3	466.00	475.0	463.8	449.7	522.0	452.0	466.0
Lbs. fired per sq. ft. per hour *	12.71	13.04	13.06	13.36	13.63	13.30	12.90	14.97	12.96	13.36
Water.										
Cu. ft. per hour	613.3	594.1	613.3	595.3	592.6	653.1	652.0	651.0	677.0	626.8
Cu. ft. per kw.-hr.	2.126	1.625	1.765	1.786	1.850	1.843	1.925	2.020	2.120	1.886
Gal. per b.h.p. hr.	10.43	8.53	9.100	9.200	9.260	10.04	9.270	10.44	10.95	9.740
Av. inlet temp. — deg. Fahr.	65.00	65.50	65.00	65.40	66.30	67.00	66.00	66.60	67.30	66.01
Av. temp. rise — deg. Fahr.	42.80	54.60	47.70	48.90	49.80	46.00	46.60	43.80	43.60	47.10
Gas.										
Heat value by calorimeter †	112.3	109.16	108.0	116.7	119.4	113.5	111.8	119.3	120.9	114.56
Heat value by anal.	....	119.74	105.9	110.4	109.78	108.5	113.5	116.13	115.13	112.40
Heat value max.	123.2	122.60	122.1	125.8	125.6	117.1	116.3	122.8	126.0	126.00
Heat value min.	105.0	108.10	101.5	101.9	111.6	109.8	107.2	110.2	111.4	101.50

* Rate of gasification per square foot of fuel bed area of producers.

† Calorific values all reduced to effective at 62 deg. Fahr. 30 inch Hg.

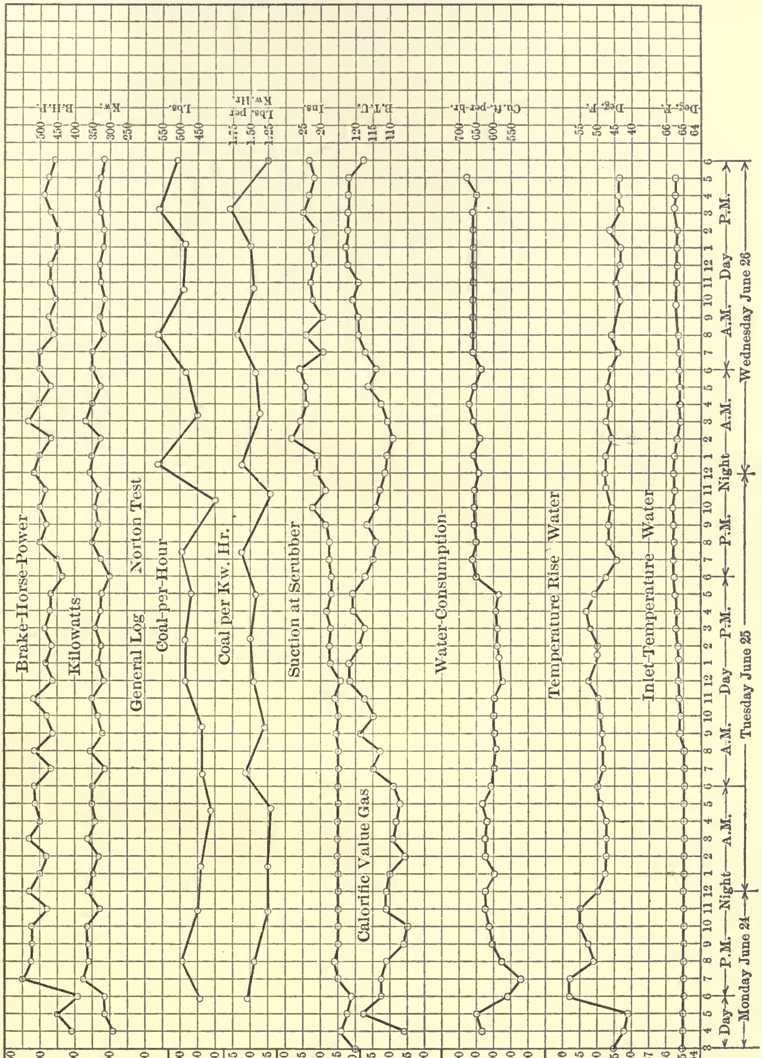

FIG. 140. General Log. of 51-Hour Test.

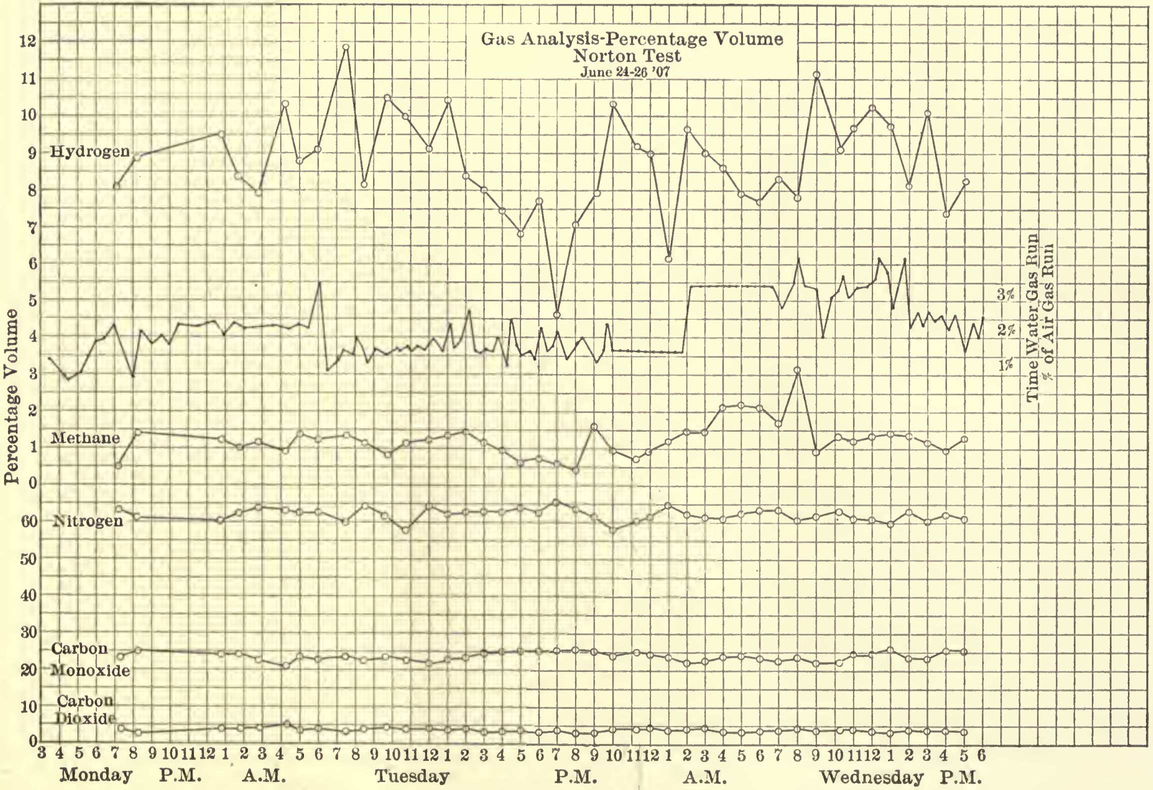

FIG. 141. Gas Analysis.

Gas Analysis, Percentage Volume. 51-Hour Test of 500-H.P. Gas Power Plant.

TABLE XXVI.

Fuel Analysis.

51-Hour Test of Gas Power Plant. 500-Horsepower Gas Engine.

Sample.	No.	Volatile Matter.	Fixed Carbon.	Moisture.	Ash.	B.t.u. per Pound.	
						Dry.	Actual.
Clearfield bituminous* used during test.	1	19.15	73.50	0.85	6.5	14313	14181
	2	20.12	73.60	1.09	5.19	14531	14360
	3	20.40	73.30	0.70	5.6	14407	14306
	4	18.30	75.40	0.90	5.4	14484	14347
	7	20.78	73.20	0.60	5.42	14531	14445
	10	20.75	71.81	0.75	6.69	14345	14236
	15	19.70	74.79	0.90	4.61	14594	14457
	18	19.30	76.40	1.00	3.30	14641	14486
	20	20.43	71.41	1.05	7.11	14232	14069
Average of 9 samples..		19.87	73.71	0.87	5.54	14450	14321
Anthracite for building fires..............		5.20	78.95	3.20	12.65	12709	12320
Ash anthracite †		....	88.25	1.15	10.6	11977	11840
from under clinker .		....	87.80	1.40	10.8	11946	11780
including ash in producer ash pits....		....	88.30	0.70	11.0	11946	11850
Averages............			88.12	1.08	10.8	11956	11823

* Sulphur in Clearfield Samples 2, 1.05 per cent; 10, 0.75 per cent; 20, 0.69 per cent. Average, 0.83 per cent.

† See section of producer bed, Fig. 116.

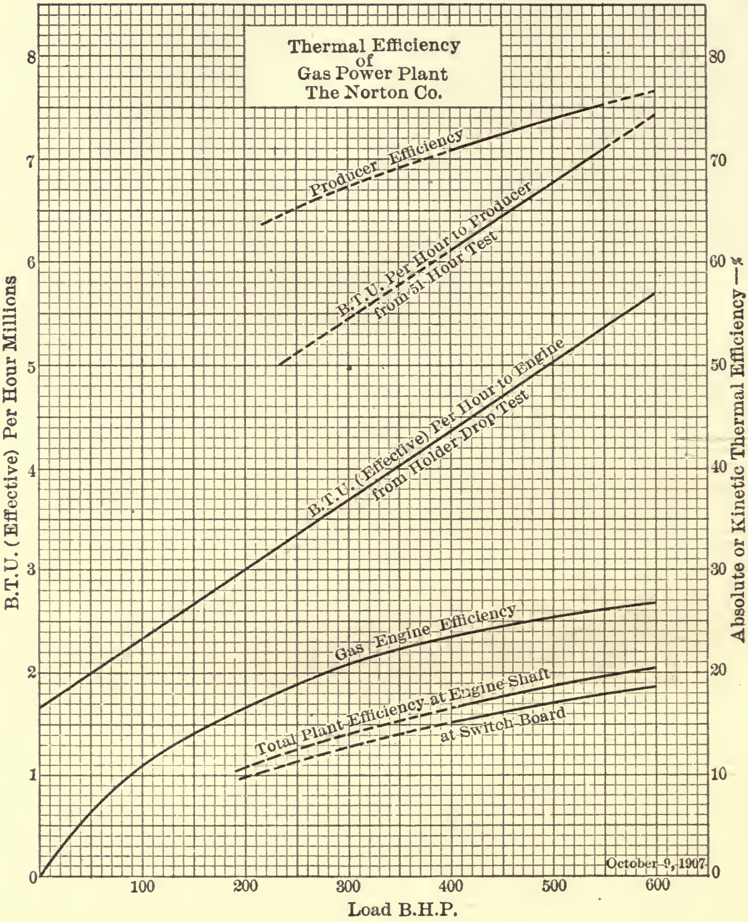

Fig. 142.

The producer efficiency shown in this chart is based on the lower (effective) heat value of the gas.

TABLE XXVII.

Distribution of Heat at Average Load of 483 B.H.P.

51-Hour Test. 500-Horsepower Gas Engine.

	Engine only.		Entire Plant.	
	Brake.	Elec.	Brake.	Elec.
Useful work	24.9	22.98	18.38	16.97
Electrical losses	....	1.92	....	1.41
Friction and pump work	4.58	4.58	3.37	3.37
Jacket absorption	34.22	34.22	25.22	25.22
Exhaust and radiation (by bal.)	36.3	36.3	26.81	26.81
Loss in producer	....	....	26.22	26.22
	100.00	100.00	100.00	100.00

TABLE XXVIII.

Speed Variation Tests. 500-Horsepower Gas Engine.

Speed, r.p.m.	155	154.0	152.0	150.0	149.0	148.0
Volts	255	255.0	257.0	258.0	258.0	257.0
Amperes	......	327.5	665.0	955.0	1303.0	1347.0
Kw.	......	86.1	170.8	246.6	336.1	346.0
B.h.p.	......	129.6	247.6	356.5	489.3	503.0
Per cent full rating	......	25.9	49.5	71.2	97.9	100.5
Speed drop, per cent ± mean	......	0.819	0.958	1.597	1.916	2.236

Instantaneous Load Test.

No load to full load, 280 volts, 1190 amperes, 345 kilowatts, 502 brake horsepower.

No-load speed	155 revolutions per minute.
Load thrown on	148 revolutions per minute.
Load thrown off	155 revolutions per minute.
Difference	7 revolutions per minute.
Speed variation	4.6 per cent of total; 2.3 per cent ± mean speed.

TABLE XXIX.

Short Tests of Gas Power Plant. (Holder Drop Tests.)

Gas consumed measured by the drop of the gas holder. No gas admitted to the holder from the producer during these tests. 500-horsepower gas engine.

SUMMARY OF RESULTS.

Test No.	A	B	C	D	E	Remarks.
Duration of run, min	11	8	10	10	10	
Load; per cent eng. rating		25.4	45.1	70.6	102.2	Circum. holder 110.33 ft.
Brake horsepower		127.0	225.5	353.0	511.5	
Kilowatts		84.1	154.3	243.5	352.0	
Speed, revolutions per minute	158.00	156.0	154.0	152.0	150.0	Barom. = 29.26″
Holder drop, ft. per hr.	16.91	24.96	32.22	39.89	51.60	Av. temp. of gas 71.6 degrees Fahr.
Cu. ft. per hr. 30″ Hg., 60° F.	15760.00	23270.00	30050.00	37280.00	48200.00	Av. gas pressure 2⅞ inches water.
Gas consumption rate:						
Cu. ft. per b.h.p. hr	(Std. gas.)	183.2	133.2	105.5	94.25	Correction factor — 0.9642
Cu. ft. per kw.-hr.		276.8	194.8	153.1	137.0	
Heat value of gas:						
Effective B.t.u. per cu. ft.	106.4	106.4	106.4	106.4	106.	Av. of all tests.
B.t.u. per b.h.p. hr.		19480.00	14160.00	11215.00	10030.00	
B.t.u. per kw.-hr.		29430.00	20720.00	16280.00	14560.00	
* Thermal efficiency brake, per cent.		13.05	17.96	22.68	25.36	
† Thermal efficiency (electrical) per cent.		11.6	16.46	20.96	23.42	

* Motor efficiency as used in text of book.

† Motor efficiency × electrical efficiency as used in text.

TABLE XXX.

Fractional Load Efficiencies of 500-Horsepower Gas Engine.

HOLDER DROP TESTS.

Nominal Load.	¼	½	¾	Full.	Over-load.
Load, brake horsepower	125.00	250.00	375.00	500.00	550.0
Gas cons.,* cu. ft. per b.h.p. hr.	190.00	127.00	105.6	95.00	92.20
Heat cons.,* B.t.u. per b.h.p. hr.	20210.00	13510.00	11240.00	10100.00	9800.00
Heat cons.,* B.t.u. per kw.-hr.	30530.00	19700.00	16340.00	14675.00	14300.00
Heat cons.,* B.t.u. per i.h.p. hr.	11180.00	10600.00	9050.00	8460.00	8295.00
† Thermal efficiency, per cent brake	12.58	18.84	21.66	25.21	25.97
‡ Thermal efficiency, per cent electric	11.16	17.32	20.9	23.25	23.85
Thermal efficiency, per cent indicated	22.75	24.1	28.14	30.1	30.7

Equivalent Coal Consumption § for Various Producer Efficiencies.
Pounds per Unit Hour.

Producer Efficiency.	Coal Consumed per	Coal, pounds.				
100 per cent	brake horse power hour	1.413	0.994	0.785	0.705	0.685
	kilowatt hour	2.13	1.376	1.141	1.025	0.999
80 per cent	brake horse power hour	1.766	1.812	0.980	0.882	0.857
	kilowatt hour	2.663	1.720	1.426	1.281	1.250
70 per cent	brake horse power hour	2.015	1.347	1.120	1.006	0.977
	kilowatt hour	3.040	1.964	1.63	1.465	1.426

* Assuming same coal used on test — 14,321 B.t.u.

† Motor efficiency as used in text of book.

‡ Motor efficiency × electrical efficiency.

§ Standard Gas — 106.4 B.t.u. (effective), 62 degrees 30 inches Hg.

HEAT UNITS.

1 British thermal unit = 0.252 calorie (French).
= $\frac{5}{9}$ of a pound-calorie.
= 778 foot-pounds.
1 Calorie (French) = 3.9683 British thermal units.
= 2.2046 pound-calories.
= 3091 foot-pounds.
1 Pound-calorie = 0.4536 calorie (French).
= 1.8 British thermal units.
= 1400.4 foot-pounds.

Molecular heat units: — To reduce French calories to molecular heat units for any substance, multiply the calories by the molecular weight of the substance. Thus, the heat of one pound of carbon burned to CO is 1128 calories. The molecular weight of carbon is 12. The molecular heat value of a pound of carbon burned to CO is therefore

$$12 \times 1128 = 13,536.$$

POWER.

1 Horsepower for 1 hour = 2545 British thermal units.
= 1,980,000 foot-pounds.
1 Horsepower for 1 minute = 42.416 British thermal units.
= 33,000 foot-pounds.
1 Horsepower for 1 second = .70794 British thermal unit.
= 550 foot-pounds.

PRESSURES.

760 mm. of mercury = 29.922 in. mercury = 14.696 lbs. per sq. in.
1 Centimeter of mercury = .19336 lb. per sq. in.
1 Inch of mercury = .4908 lb. per sq. in.
30 Inches of mercury = 14.724 lbs. per sq. in.
1 Inch head of water = .577 ounce per sq. in.
= .0361 lb. per sq. in.

THERMOMETER SCALES.

Degrees Fahrenheit $= 1.8 \times C^\circ + 32.$
Degrees Centigrade $= \frac{5}{9}(F^\circ - 32).$

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