# GAS ENGINES and PRODUCERS

MARKS - WYER

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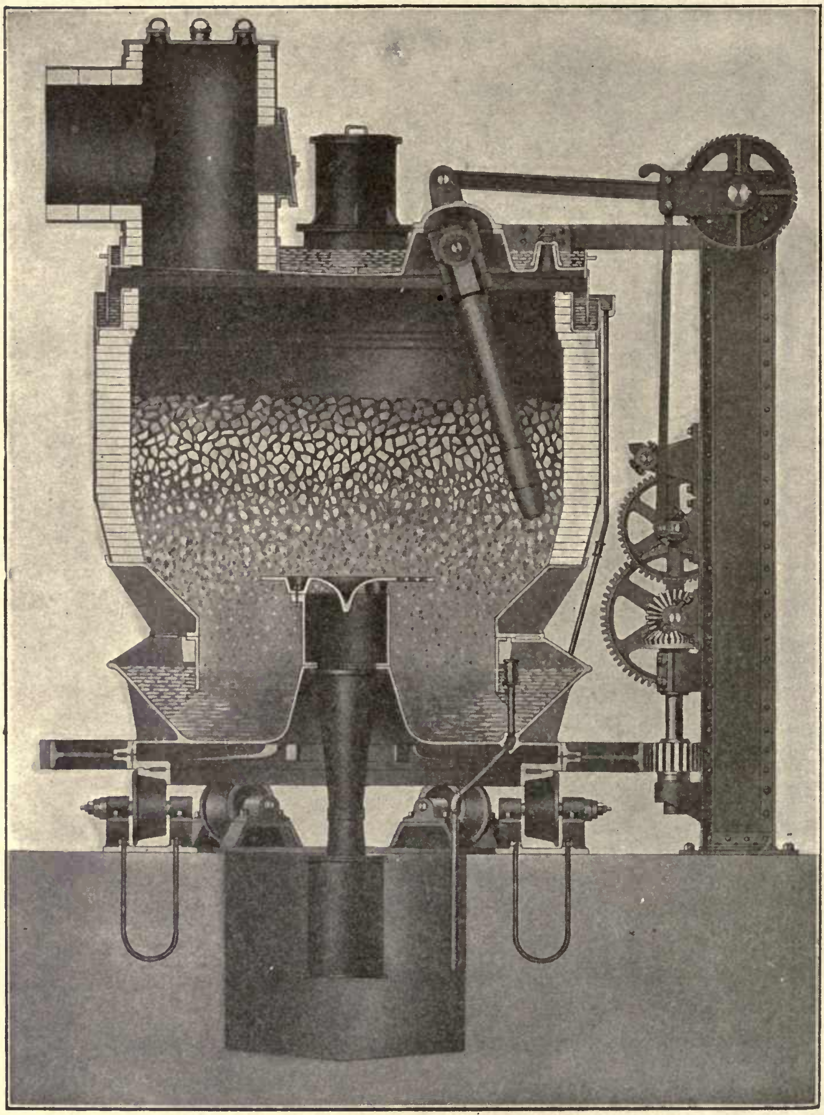

**SECTIONAL VIEW OF HUGHES PATENT MECHANICALLY-POKED CONTINUOUS GAS PRODUCER**

Standard Size is 10 ft. Diameter Inside of Fire Brick Lining, and 11 ft. 6 in. Outside of Shell

# Gas and Oil Engines

*and*

# Gas-Producers

*A Treatise*

ON THE MODERN DEVELOPMENT OF THE INTERNAL-COMBUSTION MOTOR
AND EFFICIENT METHODS OF FUEL ECONOMY
AND POWER PRODUCTION

## PART I—GAS AND OIL ENGINES

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## PART II—GAS-PRODUCERS

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of Producer-Gas."



ILLUSTRATED

CHICAGO
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# Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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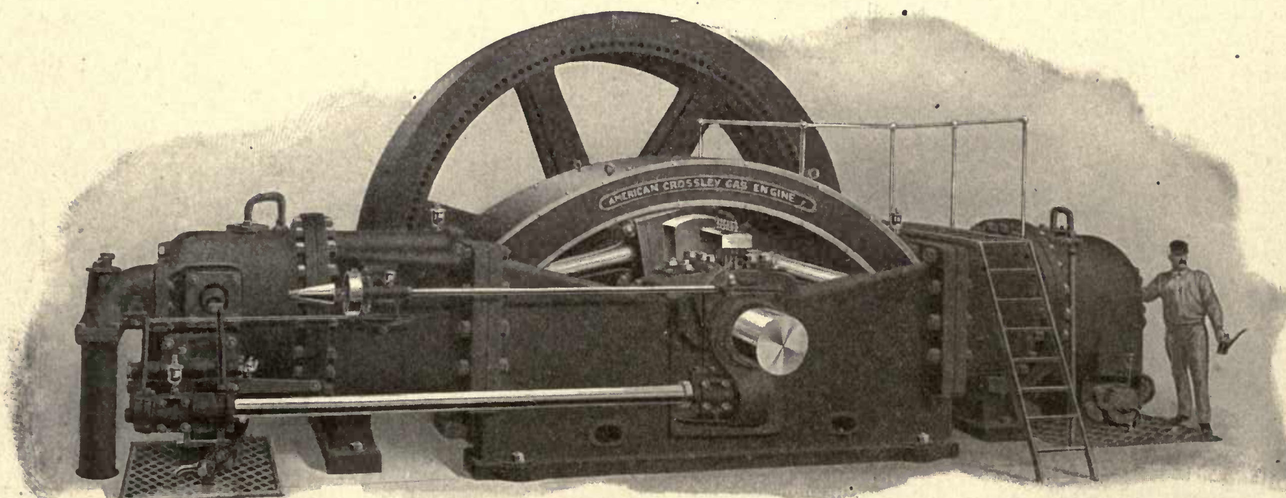



AMERICAN CROSSLEY GAS ENGINE.
Power and Mining Machinery Co.

# GAS AND OIL ENGINES.

The heat engine is at present the most important of all the available generators of power. Its purpose is to convert the heat of combustion of some fuel into work. Existing heat engines may be divided into two classes, according to where the combustion of the fuel takes place. In one class the combustion takes place entirely outside the working cylinder, and the heat of combustion is transmitted by conduction through the walls of a containing vessel to the substance which does the work Such engines may be called *external combustion motors.* The most common example of this class is the steam engine; another example, which is but little used, is the hot-air engine. If the combustion takes place inside the engine itself, or in a communicating vessel, so that the products of combustion act directly on the engine, we have an engine of the second class—the so-called *internal combustion motors.* Gas and oil engines are the common examples of this type of motor.

## THE EXTERNAL COMBUSTION MOTOR.

Engines of the second class have certain inherent advantages over external combustion motors. In the steam engine, practically the most perfect of the external combustion motors, the heat of combustion which is generated in the furnace passes through the plates of the boiler to the water on the other side. During this process about twenty-five per cent of the heat is wasted by radiation and by loss up the chimney in good modern plants. The water in the boiler is heated to a temperature which does not exceed 400° F. because at that temperature it has a pressure of nearly 250 lb. per square inch. If the water were heated to a much higher temperature, the pressure would be too great (for example, at 500° F. the pressure would be 700 lb.), requiring boilers and engines stronger than are at present practicable. The products of combustion in the furnace have a temperature which is seldom less than 2,000° F. There is consequently a very large necessary drop of temperature as the heat passes through the boiler plates. The proportion of the total heat going to an engine that can be converted by the engine into work depends chiefly upon the temperature range of the working substance, and in the steam engine this range is made comparatively small—not exceeding 300° F.—because of the corresponding pressure limits. Consequently a steam plant not only loses much of its heat up the chimney, but also is able to convert but a small part of the heat that goes to the engine into work. In the best modern steam engines about twenty per cent. of the heat going to the engine is converted into work, and about sixteen per cent. of the heat of combustion of the fuel is converted into work in the best modern steam plants. The ordinary steam engine does not convert into work more than from six to ten per cent. of the heat of combustion of the fuel. An economical steam plant consists not cnly of boilers and engines, but also has a large number of auxiliaries, such as feed pumps, air pumps, condensers, feed water heaters, economizer, coal conveyers and steam traps. It requires considerable time and fuel to raise steam in the boilers before the plant can be put in operation after shutting down; or, if the fires are kept banked, so as to keep up steam pressure while the engines are not running, a not inconsiderable amount of fuel will be used for this purpose, without any corresponding work being done.

## THE INTERNAL COMBUSTION MOTOR.

In the internal combustion motor where the fuel is a gas or volatile oil, there is no apparatus corresponding to a boiler and no losses corresponding to the boiler losses. If the fuel is coal, it has to be converted into gas before it can be used in an internal combustion motor, and thus necessitates the use of a gas producer in which some heat will be lost, though not so much as is usual in a boiler. The fuel being burned in the engine gives there a temperature of from 2,000° F. to 3,000° F., so that the temperature range in the engine is very large, and consequently the engine can be more efficient—that is, can convert a larger proportion of the heat of combustion into work than in a steam plant. The high temperatures are not necessarily accompanied by high pressures because it is air and not water which is heated to that temperature. In practice the best internal combustion motors have converted thirty-five per cent. of the heat of combustion into work, or twice as much as the best steam engines, and the ordinary small gas engine will convert from fifteen to twenty per cent. of the heat of combustion into work. The internal combustion plant is also much simpler, having but few auxiliaries. The number of men necessary to run a large gas engine plant is small, the plant is ready to start up at a minute's notice, and the standing losses are very small or nothing. When a liquid fuel is used, the absence of boiler or other auxiliaries makes the internal combustion motor lighter, more compact, and more easily portable than any other motor. The absence of a boiler also does away with the risk of a disastrous explosion, and consequently there is no inspection required by law, no license for running the plant, and lower rates for insurance. The internal combustion motor is comparatively recent in its practical use. The last five years have brought about great improvements in its operation, a big increase in its use and large extension in its application. The internal combustion motor is less uniform in its speed of rotation, and is more liable to derangements than the steam engine, but these difficulties are rapidly being overcome, so that modern gas engines are used for electric lighting and have a reliability but little short of that of the steam engine.

The fuels that are used in external combustion motors may be solid, liquid or gaseous. In internal combustion motors, though, theoretically, the fuel may be in any of these three forms, the solid fuels are not practicable because the incombustible matter or ash present in them would rapidly destroy the rubbing surfaces in the cylinders. The actual fuels used are either gaseous or liquid, and the latter may be sent into the cylinder either as a vapor or as a liquid. There is no essential difference between engines using gas and those using oil; the cycle of operations occurring in the cylinder is the same with both kinds of fuel; the only differences are slight structural differences, with the addition of special apparatus for vaporizing the oil. The same engine can be, and often is, converted from a gas to an oil engine by merely changing valves.

In this paper whatever there is of thermodynamic theory applies to both gas and oil engines. The special features of oil engines are treated after the discussion of the gas engine.

## HISTORY OF THE INTERNAL COMBUSTION MOTOR.

The history of the internal combustion motor begins with the invention of cannon. A gun is a motor in which the working substance is the gas resulting from the combustion of the powder and in which work is done on the projectile, giving it kinetic energy. Such a motor is not continuous in its action, but it offers possibilities of a practicable engine if the powder charge is small and the projectile or piston on which the gases act is restricted in its movement. The earliest internal combustion motors devised for doing useful work were intended to use gunpowder. The first of these was suggested by Abbé Hautefeuille in 1678, and was followed shortly by others, none of which were practically realizable in the then state of the mechanic arts.

It was not till the discovery by Murdock, near the end of the eighteenth century, that a combustible gas could be obtained from coal by a process of distillation, that a practical internal combustion motor was possible. As soon as the properties and method of manufacture of coal gas became known, numerous attempts were made to use it in engines. Until the year 1860 many engines were devised, patented, and in several cases constructed, operated and sold. None of these engines can be said to have been satisfactory. They were irregular in action, noisy, wasteful of fuel, and generally had practical defects.

**The Lenoir Engine,** which appeared in 1860, was the first really practical gas engine. Hundreds of these engines were made and sold, and the greatest interest in this type was aroused in France, where it was built, and in England, where it was largely used.

In general appearance the engine resembles a double-acting horizontal steam engine. The cylinder, shown in horizontal section in Fig. 1, has a separate admission port *a* and exhaust port *b* at each end. The valves are simple slide valves driven by eccentrics, and so designed that the inside edges alone uncover the ports. The valve G is used for the admission of the explosive mixture, which consists of air entering the valve cavity from *d* and gas coming through one of the branches *r* of the gas pipe and passing through the hole *i* in the valve. The air and gas enter the port *a* through a number of small holes in which they are thoroughly mixed, and the mixture is exploded in the cylinder, when desired, by an electric igniter *n*. The exhaust is through the port *b* and the cavity in the exhaust valve H to the atmosphere. As the cylinder rapidly becomes very hot, it is provided with a water jacket.

The series or cycle of operations which takes place in this engine is as follows: During the first part of the stroke the admission valve G uncovers the port *a* so that a mixture of air and gas enters the cylinder, filling the space behind the piston. At

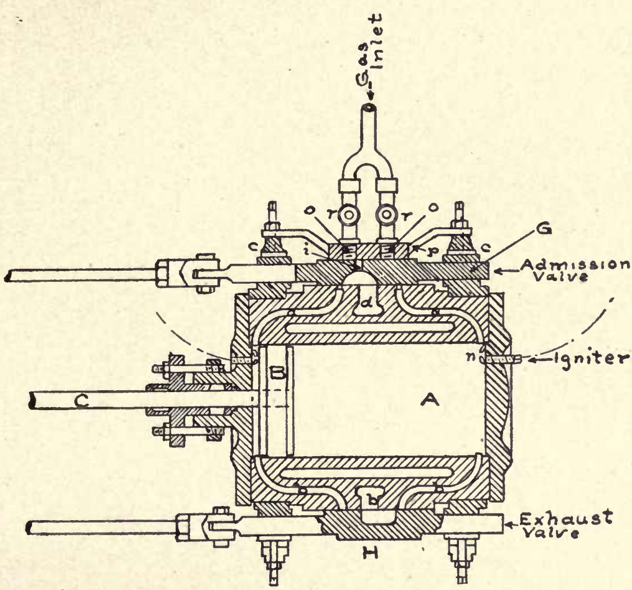



Fig. 1. Longitudinal Section of Cylinder of Lenoir Engine.

half stroke the valve closes the port and a spark from an induction coil passes between the terminals *n* of the electric igniter, exploding the mixture and raising its pressure to 60 or 70 lb. per square inch. The piston is then forced to the end of its stroke, the products of combustion expanding behind it. At the end of the stroke the valve H uncovers the exhaust port and keeps it open throughout the whole of the return stroke so that all the products of combustion are expelled to the atmosphere. A similar cycle of operations occurs on the other side of the piston. In Fig. 1 the valve G is just opening the port at the left so that admission may take place there, and the valve H is just opening the port at the right so that exhaust may occur from the other end of the cylinder. A reproduction of an indicator card from this engine is shown in Fig. 2.

This engine gave considerable trouble in many cases, but the principal reason for the falling off in its use was the large amount of gas it required. It used from 60 to 70 cubic feet of coal-gas per I. H. P. per hour, or from three to four times as much as a modern gas engine, so that it did not compare very favorably with the steam engine in its running costs.

**The Otto Cycle.** In the year 1862 it was pointed out by a French engineer, Beau de Rochas, that in order to get high economy in a gas engine certain conditions of operation were necessary. The most important of these conditions is that the explosive mixture should be compressed to a high pressure before ignition. In order to accomplish this he proposed that the cycle of operations should occupy four strokes or two complete revolutions of the engine, and that the operations should be as follows:

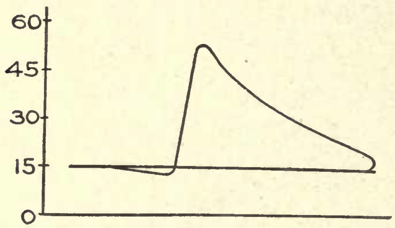


Fig. 2. Indicator Card of Lenoir Engine.

1. *Suction* or *admission* of the charge of gas and air throughout the complete forward stroke.

2. *Compression* of the explosive mixture during the whole of the return stroke so that it finally occupies only the clearance space.

3. *Ignition* of the charge at the end of the second stroke and *expansion* of the exploded mixture throughout the whole of the next forward stroke.

4. *Exhaust* beginning at the end of the forward stroke and continuing throughout the whole of the last return stroke.

This cycle was not actually used till 1876, when Dr. Otto adopted it in his engine and thereby produced the modern gas engine. The four-stroke cycle of Beau de Rochas is now universally known as the *Otto cycle.* In the past twenty years several other cycles, some of great merit, have been devised and used, but at the present day an overwhelming majority of the existing internal combustion motors use the Otto cycle. The engines using this cycle are accordingly treated of first and at greatest length.

## THE MODERN GAS ENGINE.

The construction of a modern gas engine using the Otto cycle is illustrated in the sectional elevation, Fig. 3, of a vertical engine. As in practically all Otto cycle engines, the engine is single-acting and has a long trunk piston which acts as a crosshead and also permits the use of several piston rings by which leakage past the piston is prevented even with the high pressure obtained by the explosion. The engine is made single-acting because the cylinder would get too hot for continuous running if it were double-acting; and moreover, a piston rod and stuffing box give great trouble if exposed to the high temperature of the burning gases. Since the cycle occupies two revolutions, the valves and igniter have to operate once in two revolutions, and therefore the cams which drive these parts are mounted on shafts running only half as fast as the main shaft.

Referring to Fig. 3, A is the shaft which carries the exhaust valve cam, and is driven by gears from the main shaft. The exhaust cam works against a roller carried on the free end of the guide lever G. The exhaust valve E has a long stem projecting downward and resting on a hardened steel plate on the upper side of the guide lever G. The spring surrounding the stem serves to bring the exhaust valve back to its seat and to keep the stem in contact with the guide lever. From the exhaust cam shaft A a horizontal shaft with bevel gears leads to the opposite side of the engine, engaging with a vertical shaft which in turn drives the upper cam shaft B. Incidentally, the vertical shaft carries the governor. The upper cam shaft carries two cams. One engages against a roller on the end of the horizontal lever C. As the throw side of this cam comes uppermost, the opposite end of the lever C depresses the stem of the inlet valve J, opening the latter for the admission of the mixture of gas and air. A spring on the stem of the inlet valve furnishes a means for closing it and keeping the cam and roller always in contact with each other. Immediately adjacent to the inlet valve cam is the igniter cam, which at the proper instant operates a horizontal plunger working through the guide D to break the electric current through the wire S at the terminals of the igniter F.

The cylinder heads and the upper end of the cylinder are thoroughly water-jacketed, as, owing to the extreme heat to which

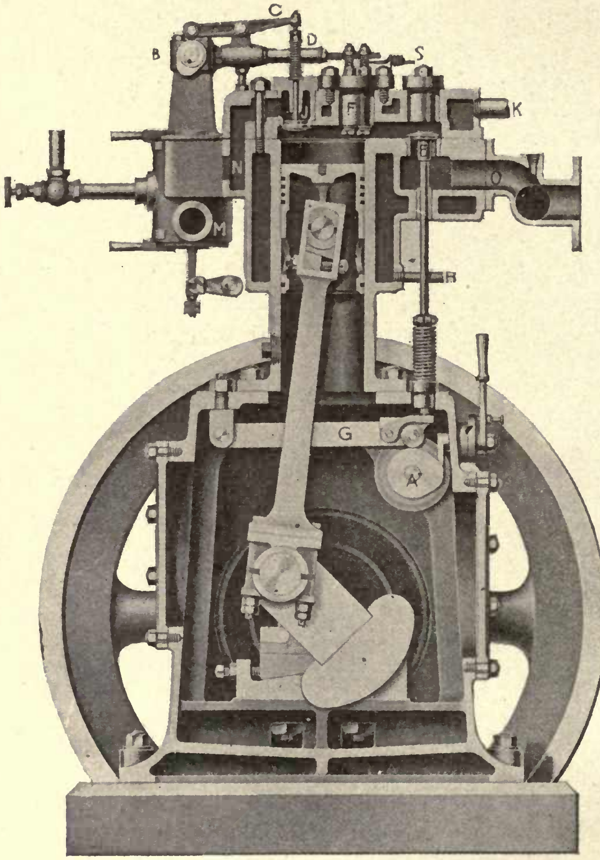



**Fig. 3. Westinghouse Gas Engine.**

these parts are subjected, they would soon become red-hot if no means were provided for keeping the temperature down. The cooling water enters at H and is discharged at K.

The gas and air enter the mixing chamber M by separate inlets, in proportionate amounts which can be regulated, and the mixture is conducted through a distributing chamber to the port

N leading to the cylinder head in which the inlet valve is located. The exhaust gases escape through O.

The operation of this engine is illustrated in the accompanying illustrations. The admission of the charge of air and gas takes place during the first downward stroke of the engine (Fig. 4). The exhaust valve E is closed and the admission valve J is open, and closes only when the piston is at the end of the stroke and the cylinder is full of the explosive mixture. During the return stroke (Fig. 5) both valves are closed and the charge is compressed till at the end of the stroke it occupies only the clearance space. Shortly before the end of the stroke the igniter cam has brought the igniter terminals into contact, completing an electric circuit. When the crank is nearly on its dead center the igniter terminals are separated by the action of a coiled spring in the guide D, and as they fly apart the circuit is broken and a spark passes between the terminals (Fig. 6), igniting the charge. An immediate

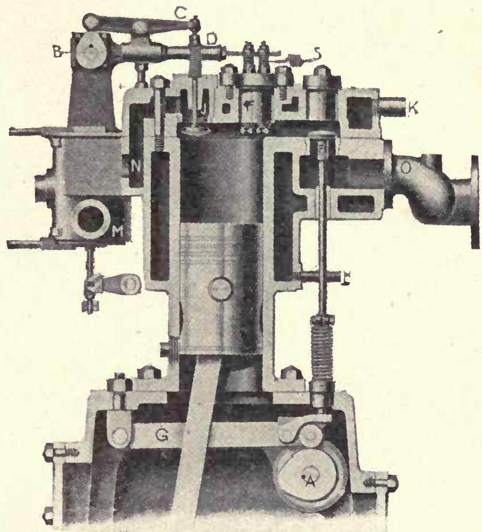


Fig. 4. Admission of the Charge.

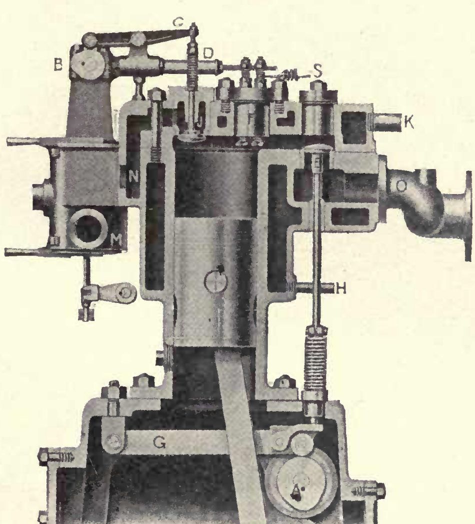


Fig. 5. Compression.

rise of pressure occurs and the piston is forced downward, both valves remaining closed until just before the end of the down stroke, when the exhaust valve E opens.

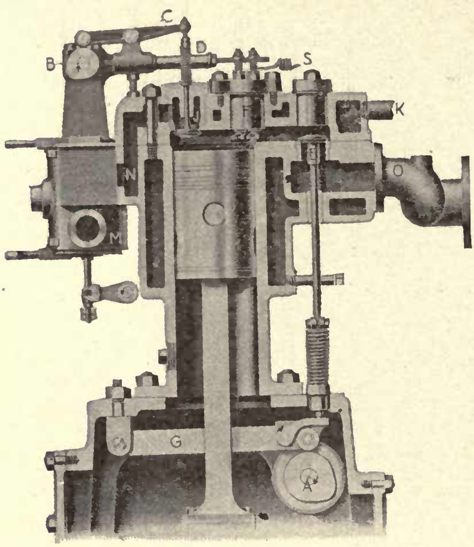



Fig. 6. Ignition.

During the whole of the last return stroke (Fig. 7) the exhaust valve E remains open and the products of combustion are forced through O to the atmosphere. The exhaust valve closes as the piston completes the stroke, and everything is in readiness to recommence the cycle.

Another form of vertical engine using the Otto cycle is shown in vertical section in Fig. 8. In this engine there are three valves—the inlet valve *b* for the gas, the inlet valve *a* for the explosive mixture, and the exhaust valve. All three valves are operated from the shaft *c* which is driven from the main shaft by spur gearing, reducing the speed to one-half that of the main shaft. A cam on the shaft *c* lifts the pivoted lever *d* at the end of which is the long spindle of the valve *a* through which the charge is admitted. The spindle carries an arm *e* which comes in contact with a short link on the

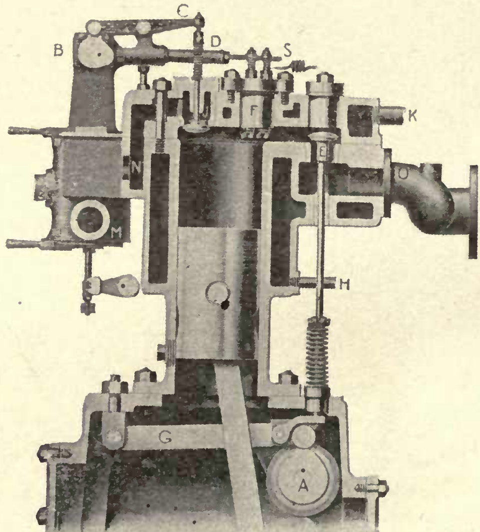
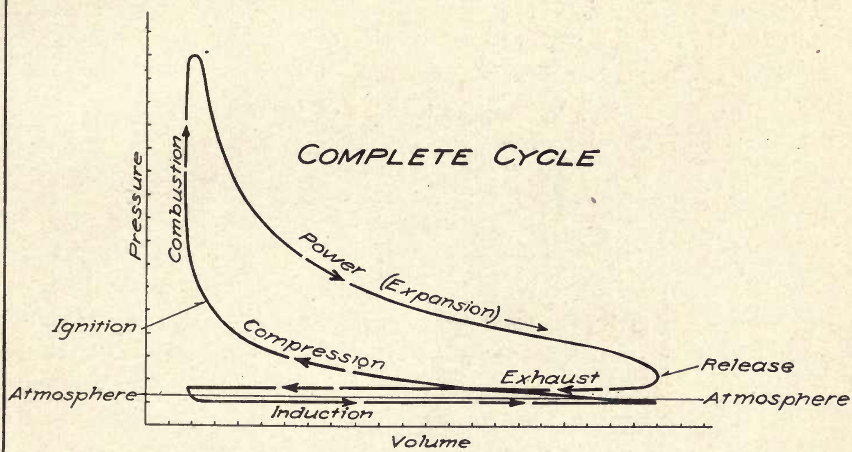
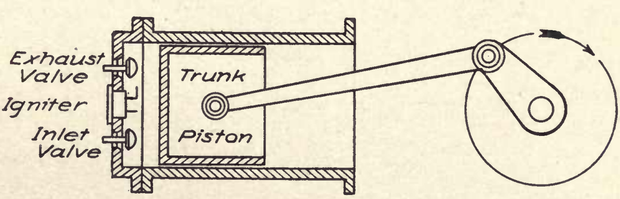



Fig. 7. Exhaust.

# DIAGRAM SHOWING OPERATIONS OF THE FOUR STROKE CYCLE

(Lower part of diagram near atmosphere exaggerated)




| | | | | |
|---|---|---|---|---|
| 1st CYCLE | POWER | ⟶ | 1st STROKE | 1st Revolution |
| | Exhaust | ⟵ | 2nd " | |
| | Induction | ⟶ | 3rd " | 2nd Revolution |
| | Compression | ⟵ | 4th " | |
| 2nd CYCLE | POWER | ⟶ | 5th STROKE | 3rd Revolution |
| | Exhaust | ⟵ | 6th " | |
| | Induction | ⟶ | 7th " | 4th Revolution |
| | Compression | ⟵ | 8th " | |

stem of the gas admission valve *b* whenever an explosive charge is required, so that both the valves *a* and *b* are open at the same time. The space *g* behind the valve *a* and around the valve *b* is in free communication with the atmosphere. With *a* open and the piston decending, air is drawn in and thoroughly mixed with the gas

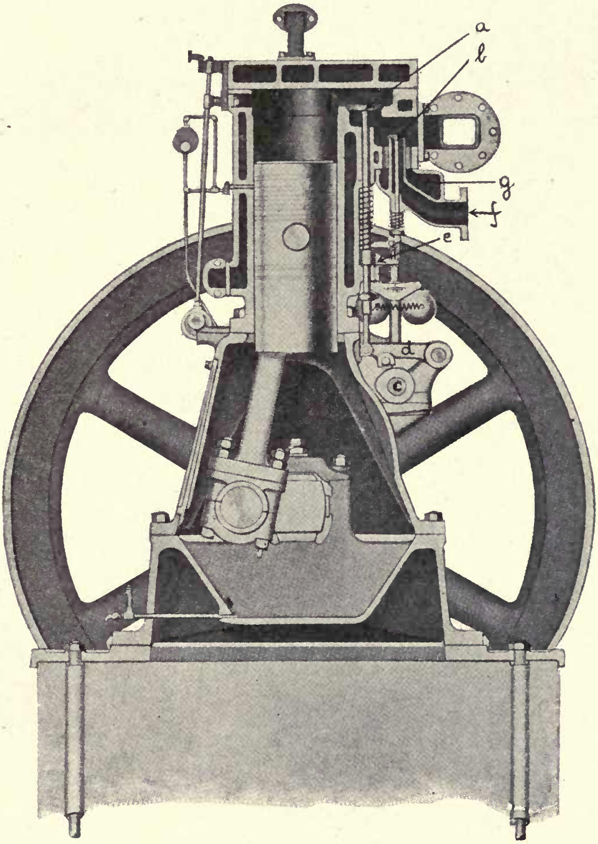



Fig. 8. Nash Gas Engine.

while passing through *a*. If the governor throws the short link to one side, the arm *e* does not come in contact with it, the gas valve does not open and air alone is taken into the cylinder during the admission stroke. The exhaust valve is behind the admission valve but is not shown in the diagram.

An example of the horizontal form of gas engine is given in Fig. 9, which is a vertical cross section through the cylinder and valves. The valve *a* for the admission of the explosive mixture acts automatically, opening when the pressure in the cylinder falls below the atmospheric pressure. The exhaust valve *b* is opened at the proper time by the action of the cam *c*, which, acting on a roller *d* at the extremity of one arm of the bell crank lever fulcrumed at *e*, pulls the rod *f* to the left and through the bell crank lever fulcrumed at *g* lifts the exhaust valve as shown. The cam *c* is mounted on a shaft which is driven through the spur wheel *k*

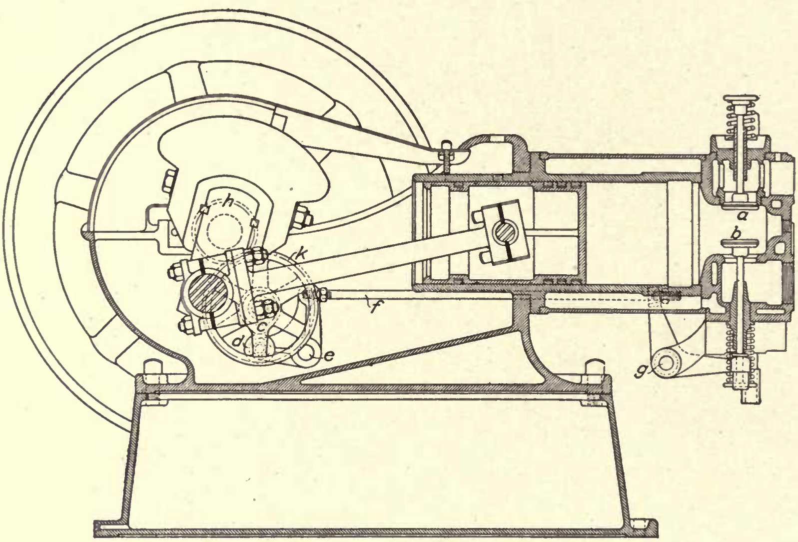



Fig. 9. Olds Engine.

by the spur wheel *h* (dotted) on the crank shaft. The wheel *k* has twice as many teeth as the wheel *h*, and consequently the cam shaft revolves only half as fast as the main shaft.

Another horizontal engine is illustrated in Figs. 10, 11 and 12. In this case the admission valve B and the exhaust valve D are both horizontal, a position which can be used satisfactorily only for engines of small size. The air goes to the admission valve through the pipe N, and is shown as taken from the base of the engine. The gas mixes with it at H (Fig. 10), entering through a nozzle. The amount of gas entering is controlled by the throttle valve A (Fig. 11), and the time at which it enters is determined by the valve G, which is opened at the desired time through the action of the cam P (Fig. 11). The cam P coming in contact with the roller Q at the end of the lever fulcrumed at R, gives a movement to the rod S which is transmitted to the valve through the levers best seen in Fig. 12. The admission valve B is automatic in its action. The exhaust valve D is opened by the action of the cam T (Fig. 10) acting on the roller U at the end of the valve rod W. The valve rod is supported near its free end by the lever X. Both the cams P and T are on a shaft driven from the crank shaft by spur wheels. The governor (Fig. 12) is of the fly-wheel type

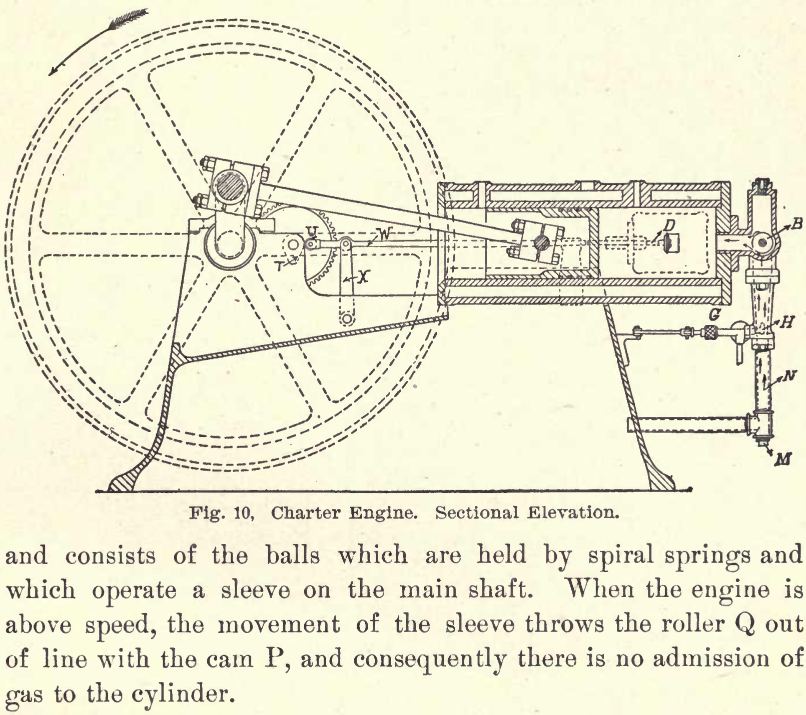



Fig. 10, Charter Engine. Sectional Elevation.

and consists of the balls which are held by spiral springs and which operate a sleeve on the main shaft. When the engine is above speed, the movement of the sleeve throws the roller Q out of line with the cam P, and consequently there is no admission of gas to the cylinder.

*The inlet and exhaust valves* in gas engines are nearly always *poppet* or *mushroom* valves similar to those shown in Figs. 4 to 11. The exhaust valves are nearly always mechanically operated; the main inlet valves are often automatic. The automatic valve is similar to a pump suction valve and is kept on its seat by a weak spring (*a*, Fig. 9) and only opens when the pressure in the cylinder is sufficiently less than the atmospheric pressure to permit the latter to overcome the resistance of the spring. Consequently the suction or admission pressure in the gas engine is necessarily low when automatic inlet valves are used. The effect is to decrease the work done by the engine and also its efficiency; the only advantage is the greater simplicity. Most small gas engines have automatic inlet valves.

A positively actuated admission valve is shown in Fig. 13. The valve is lifted by a cam *a* on the side shaft *b* through the lever fulcrumed at *c*. The valve closes by its own weight, assisted by a spring, and is guided in its motion by a long sleeve. The valve chest is completely water-jacketed.

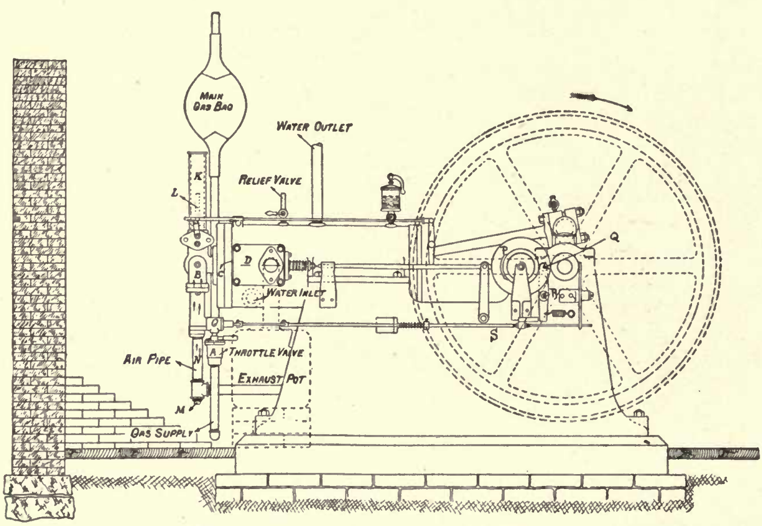



Fig. 11. Charter Engine. Side View.

The pressure in the cylinder when the exhaust valve opens is generally from 25 to 45 lb. above the atmospheric pressure, and the exhaust valve has to be lifted against this pressure. With a mushroom valve 4 in. in diameter, and with 40 lb. pressure per square inch at the end of expansion, there would be a total pressure of about 500 lb. on the valve at the time when it is to be lifted. It is desirable to reduce the strain on the valve and valve mechanism, and in large engines this is sometimes done by balancing the valve. A balanced exhaust valve *e* of the piston valve type is shown in Fig. 14 in its valve chest or housing. The connection with the cylinder is at *d* and the valve seat is the conical seat *a*. A hole *f* through the valve ensures the existence of atmospheric pressure on top of the valve, and the exhaust gases escape through *g* to the atmosphere. To prevent excessive heating of this valve water is circulated through it, entering at *b* and leaving at *c*.

In smaller engines the pressure on the exhaust valve just prior to its opening is sometimes relieved by the escape of the gases through an auxiliary exhaust port (P, Fig. 15) in the cylin-

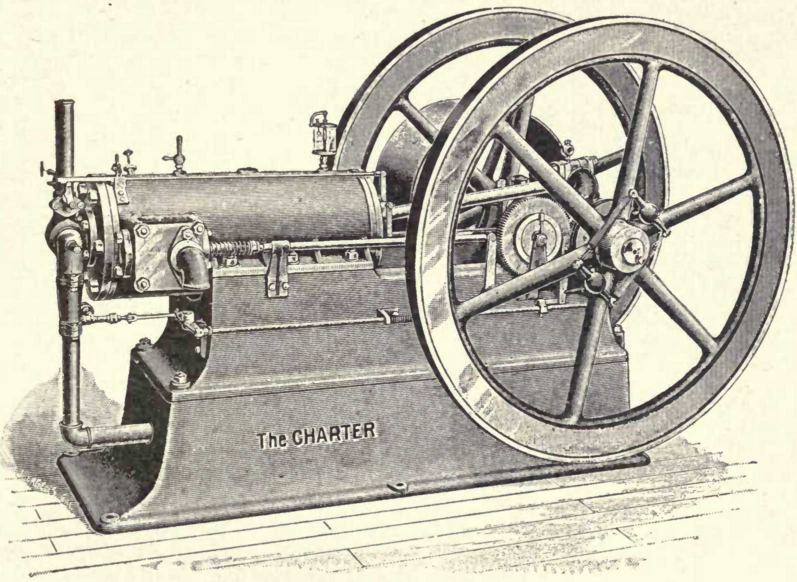



**Fig. 12. Charter Engine.**

der which is uncovered by the piston just before it reaches the end of its outstroke. Soon after it starts on the return stroke the piston covers the auxiliary port, and the exhaust for the remainder of the stroke is through the regular exhaust valve. As the regular valve (not shown in the figure) is not opened till after the uncovering of the auxiliary port, there is practically only atmospheric pressure on it when it lifts. An objection to this device is that the same auxiliary port is uncovered again near the end of the admission stroke, and as the pressure in the cylinder is then less than atmospheric pressure, some of the exhaust gases enter the cylinder, mixing with the charge and diluting it. At the beginning of the return or compression stroke part of the contents of the cylinder is forced out to the exhaust until the piston has again covered the auxiliary port, and consequently some of the charge is lost.

**Valve Gearing.** The valves are most commonly operated by cams. Cams are preferable to eccentrics for this purpose, because they can be designed to give very prompt opening and closing. The cams are mounted upon a *lay shaft*, or *side shaft*, or *cam shaft*. The cam shaft is driven in different engines either by spur gears, bevel gears, or skew gears. The spur gear (see Fig. 12) can

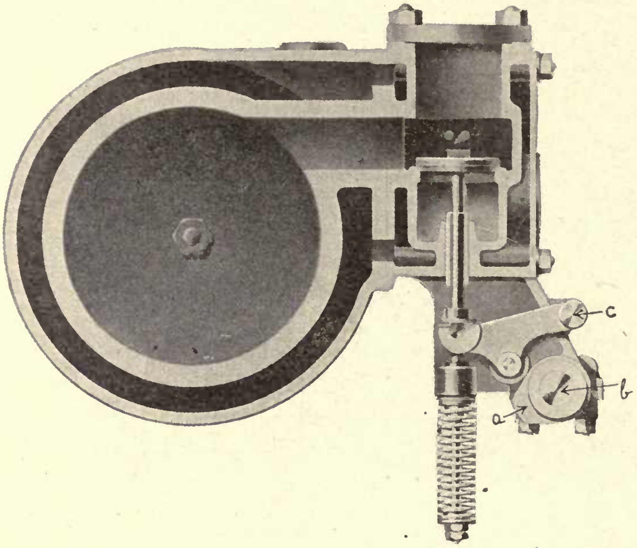



Fig. 13. Buffalo Engine. Cross-Section of Cylinder and Valve Chest.

be used only for parallel shafts, the bevel gear for shafts which are in the same plane but are inclined to one another, and the skew or spiral gear (Fig. 16) for shafts which are not parallel and do not lie in the same plane. To reduce the speed of the cam shaft the spur and bevel gears must have the gear on the cam shaft twice the size of that on the main shaft. With the skew gear there is no necessary relation between the diameter of the two gears, and generally the gear on the cam shaft is smaller than that on the main shaft. The skew gear has great advantage over the other two in its quietness of operation.

## THERMODYNAMICS OF THE OTTO CYCLE.

In internal combustion motors the explosive mixture in the cylinder consists of air mixed with a comparatively small volume of the gaseous or liquid fuel. For instance, if the engine uses gas from the city mains, the mixture will average about eight or nine parts of air to one of gas and should never have less than about six parts of air to one of gas. This mixture can be regarded up till the time when explosion takes place as if it were pure air. Also, the products of combustion, after the explosion is completed, have physical properties but very slightly different from those of air, and consequently the working substance in the cylinder can be regarded without serious error as consisting entirely of air. In the following discussion of what occurs in the engine cylinder, it is assumed throughout that the substance in the cylinder is air.

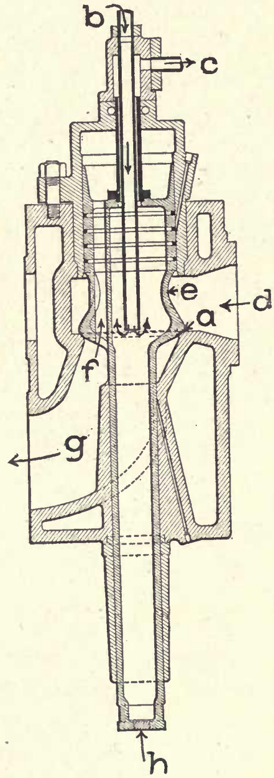


Fig. 14. Balanced Exhaust Valve.

The processes taking place in the engine cylinder are best represented on a pressure-volume diagram. At the beginning of the cycle of operations the piston is at the end of its path and is about to begin its out-stroke. The clearance space is full of products of combustion at atmospheric pressure because it has been in communication with the atmosphere through the exhaust valve which has just closed. The condition existing in the cylinder at this instant is represented in the diagram, Fig. 17, by the point 1, which is at a horizontal distance from the vertical axis representing the clearance volume, and at a vertical distance above the horizontal axis representing the atmospheric pressure of 14.7 lb. per square inch. As the piston makes its out-stroke the admission valve opens admitting the charge to the cylinder throughout the stroke, and as the cylinder is in communication with the outside air through the air admission valve, the pressure in the cylinder remains atmospheric pressure throughout the stroke. On the diagram the admission is represented by the line 1 2, which is at the constant height representing the atmospheric pressure and whose length represents the volume of the charge taken in, which is the same as the volume through which the piston moves. The point 2 represents the condition at the end of the first stroke. The admission valve now closes and the piston makes its return stroke. Since all the valves are closed,

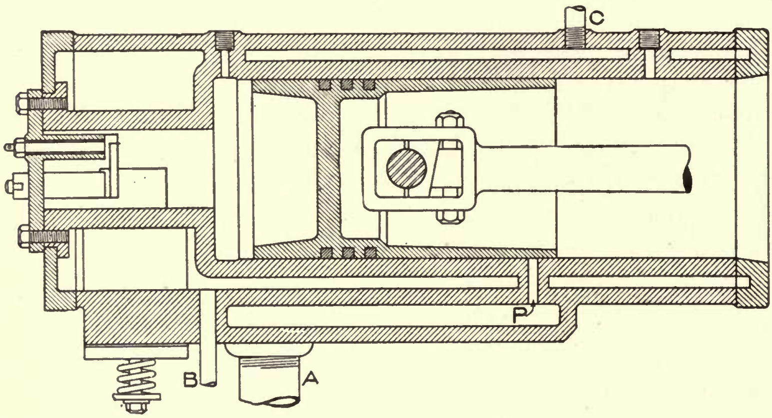



Fig. 15. Section Through Cylinder, Columbus Engine

the charge cannot escape and is crowded into a smaller volume while its pressure rises. The process continues till the piston reaches the end of its stroke, at which time the whole charge is compressed into the clearance space. This process is represented by the line 2 3, which shows the rise in pressure resulting from the compression. A compression of this kind, occurring without the addition or the abstraction of heat from the gas, is called an *adiabatic* compression. It causes not only an increase in the pressure but also in the temperature of the gas. It is the process that takes place in the working of an ordinary bicycle pump and which causes its rise in temperature. The relation between the pressure of air and its volume when subjected to adiabatic compression is

$$PV^{1.405} = \text{constant}$$

(Note carefully that in this equation P means the absolute pressure and not the pressure shown by a gauge). When the charge has reached the conditions represented by the point 3, it is ignited, and the heat generated by the explosion raises the temperature and consequently the pressure of the mixture. The combustion occurs so rapidly that the piston has not time to start on the out-stroke before the combustion is completed and the rise of pressure occurs, as is shown by the line 3 4, while the volume of the gas is constant. The hot products of combustion at the pressure $P_4$ now force the piston out and, expanding behind it, they fall in pressure. This expansion, occurring without communication of heat to or from the gas is *adiabatic expansion*, and is consequently accompanied by a fall in temperature of the gas. The expansion curve 4 5 is similar to the compression curve 2 3, and has the same equation.

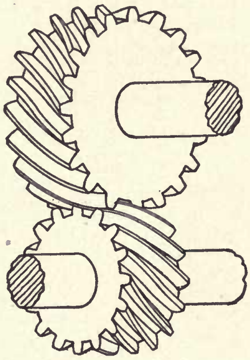


Fig. 16. Spiral Gear.

At the point 5 the piston is at the end of the stroke and no more expansion is possible. The exhaust valve opens and the pressure in the cylinder falls immediately to atmospheric pressure, as shown by the line 5 2 in the diagram. Throughout the last return stroke, 2 1, the exhaust valve remains open so that the pressure in the cylinder remains atmospheric pressure. The completed diagram, Fig. 17, shows the whole series of pressure and volume changes occurring in a gas engine, and is such a diagram as would be taken by an indicator from a perfect engine. The area 2 3 4 5 enclosed by the diagram represents the work done by the engine per cycle.

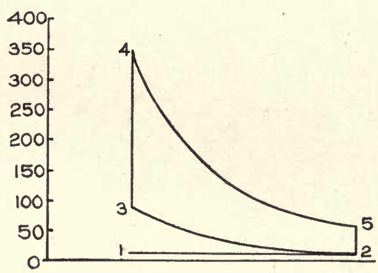



Fig. 17. Ideal Indicator Card of Otto Cycle.

**The Pressures and Temperatures** of the working substance and the amount of work done in an engine which exactly follows the Otto cycle can be readily calculated. Starting at the point

2 (Fig. 17), there is present in the cylinder a volume $V_2$ at atmospheric pressure $P_2$ and at the temperature $t_2$, which will be assumed to be the temperature of the air as it came into the cylinder. The working substance is compressed adiabatically till it fills only the clearance volume $V_3$. The consequent rise in pressure can be calculated from the formula already given, but it is more simply obtained from the curve, Fig. 18, which gives the relation between the changes of volume and of pressure in adiabatic expan-

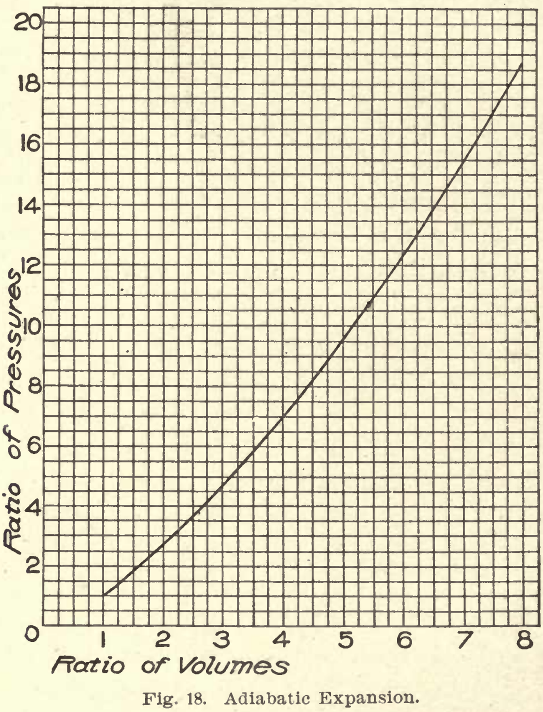



Fig. 18. Adiabatic Expansion.

sion or compression. The horizontal scale in this diagram is the ratio of expansion or compression, and the vertical scale shows the corresponding ratio of the pressures at the beginning and end of the expansion or compression. If, for example, the working substance expands adiabatically to five times its original volume, the pressure (which varies inversely as the volume) is shown by the curve to fall to $\frac{1}{9.67}$ of its original value. Conversely, if the working substance is compressed to $\frac{1}{5}$ the original volume, the pressure rises to 9.67 times its original value. Consequently, the pressure at the point 3, Fig. 17, can be found by the use of this curve.

*Example.* A gas engine with $33\frac{1}{3}$ per cent clearance takes in its charge at 14.7 lb. per sq. in. pressure. What is the pressure at the end of the adiabatic compression?

*Solution.* The clearance volume $V_3$ is $33\frac{1}{3}$ per cent of the volume, $V_2 - V_3$, through which the piston moves, or

$$V_3 = \frac{33\frac{1}{3}}{100}(V_2 - V_3)$$

$$\therefore \quad 3V_3 = V_2 - V_3$$

$$\text{and} \quad \frac{V_2}{V_3} = 4$$

From the curve, Fig. 18, if the ratio of compression is 4, the corresponding ratio of pressures is 7.06, so that the pressure at the end of compression is 7.06 times the pressure at the beginning of compression. Therefore the pressure at end of compression, $P_3 = 7.06 \times 14.7 = 103.8$ lb. per sq. in. abs.

*The temperature at the end of the adiabatic expansion* can be found from the equation for a perfect gas. This may be stated in the form

$$PV = wRT$$

where $w$ is the weight of the gas, R is a constant for any perfect gas and has the value 53.2 for air, P is the pressure in lb. per sq. ft. abs., and T is the absolute temperature of the gas. The weight of the gas is constant throughout the adiabatic compression, and can be found from the point 2 if $P_2$, $V_2$ and $T_2$ are known. The temperature at 3 can then be found from the equation

$$P_3V_3 = wRT_3$$

*Example.* Assuming the conditions of the previous problem and supposing the temperature of the air to be 60° F., what is the temperature of the charge at the end of the compression?

*Solution.*

$$P_2V_2 = wRT_2$$

$$\therefore \quad wR = \frac{P_2V_2}{T_2} = \frac{14.7 \times 144 \times V_2}{60 + 461}$$

Also

$$T_3 = \frac{P_3V_3}{wR}$$

$$= P_3 \frac{V_3}{V_2} \times \frac{60 + 461}{14.7 \times 144}$$

and

$$\frac{V_3}{V_2} = \frac{1}{4}$$

$$\therefore \quad T_3 = 103.8 \times 144 \times \frac{1}{4} \times \frac{521}{14.7 \times 144}$$

$$= 919.6^\circ \text{ abs.}$$

and

$$t_3 = 458.6^\circ \text{ F.}$$

*The rise in temperature during explosion* depends on how much heat is generated which in turn depends on the strength of the explosive mixture and the heat of combustion of a cubic foot of the fuel. Let H be the heat of combustion of a cubic foot of the fuel in B. T. U., and let the mixture consist of 1 part of gas to $n$ parts of air. The total volume of the charge taken into the cylinder each admission is

$$V_2 - V_1 \text{ cu. ft.}$$

the volume of fuel in this charge

$$\frac{1}{n+1}(V_2 - V_1)$$

and the heat of combustion of this fuel is

$$Q = H \frac{V_2 - V_1}{n + 1} \text{ B.T.U.}$$

This heat is utilized in raising the temperature of the gas from the known temperature $T_3$ to another temperature $T_4$. The rise in temperature can be found when the heat necessary to raise one pound of air one degree in temperature is known. This amount of heat is called the *specific heat.* It is represented by the symbol $C_V$ (indicating that the volume is unchanged while the temperature rises), and is equal to .169 B.T.U. for air. With a weight of $w$

lb. the heat necessary to raise the gas one degree in temperature is

$$wC_V \text{ B.T.U.}$$

To raise the temperature $T_4 - T_3$ degrees the heat supply is

$$w\ C_V\ (T_4 - T_3) \text{ B.T.U.}$$

and the heat of combustion is used entirely in raising the gas from $T_3$ to $T_4$.

$$\therefore\ H\frac{V_2 - V_1}{n+1} = w\ C_V\ (T_4 - T_3)$$

$$= \frac{P_2V_2}{RT_2} C_V\ (T_4 - T_3)$$

$$T_4 - T_3 = \frac{H}{n+1} \times \frac{RT_2}{P_2} \times \frac{1}{C_V} \times \frac{V_2 - V_1}{V_2}$$

*Example.* In the previous problem if the charge taken in consists of 1 part of gas to seven parts of air and the heat of combustion of the gas is 640 B.T.U., per cu. ft., find the temperature at the end of explosion.

*Solution.*

$$\frac{V_2 - V_1}{V_2} = \frac{V_2 - \frac{1}{4}V_2}{V_2} = \frac{3}{4}$$

$$T_4 - T_3 = \frac{640}{8} \times \frac{53.2 \times 521}{14.7 \times 144} \times \frac{1}{.169} \times \frac{3}{4}$$

$$\therefore\ T_4 = 4649 + T_3$$

$$= 5568.6^\circ \text{ abs.}$$

$$\therefore\ t_4 = 5107.6^\circ \text{ F.}$$

If a perfect gas is raised in temperature while its volume is unchanged, the absolute pressure will increase in exact proportion to the rise of absolute temperature,

or

$$P_4 : P_3 :: T_4 : T_3$$

$$\therefore\ P_4 = \frac{T_4}{T_3} P_3$$

*Example.* What is the pressure at the end of explosion in the preceding problem?

*Solution.*

$$P_4 = \frac{T_4}{T_3} P_3$$

$$= \frac{5568.6}{919.6} \times 103.8 \text{ lb. per sq. in. abs.}$$

$$= 628.6 \text{ lb. per sq. in. abs.}$$

*The pressure and temperature at the end of the adiabatic expansion* can be found most simply, after the other pressures and temperatures are known, by making use of a relation which exists between the pressures and temperatures at the points 2, 3 4. 5.* These relations are

$$\frac{P_2}{P_3} = \frac{P_5}{P_4}$$

and

$$\frac{T_2}{T_3} = \frac{T_5}{T_4}$$

*Examples.* What are (a) the pressures and (b) the temperatures at the end of the adiabatic expansion in the preceding problem ?

(a) $P_5 = \frac{P_2}{P_3} \times P_4 = 89$ lb. per sq. in. abs.

(b) $T_5 = \frac{T_2}{T_3} \times T_4 = 3155°$ abs.

$= 2694°$ F.

*The work done* by any heat engine is equal to the difference between the heat that goes to the engine and that which is rejected by the engine, because whatever heat disappears cannot have been destroyed and must have been converted into work. In the Otto cycle the heat taken in has been seen to be

$$Q = wC_V(T_4 - T_3) \text{ B.T.U.}$$

Heat is rejected from the engine only during the process represented by the line 5 2, because when the charge gets back to the condition 2, it has returned to its original volume and pressure

* The ratio of the pressures $\frac{P4}{P5}$ can be obtained from the curve, Fig. 18, since the ratio of the volumes $\frac{V5}{V4}$ is known. But $V_5 = V3$, therefore $\frac{V5}{V_4} = \frac{V_2}{V3}$ and $\frac{P3}{P2} = \frac{P_4}{P5}$

and consequently to its original temperature. The heat rejected is then

$$Q_R = wC_v\,(T_5 - T_2)\ \text{B.T.U.}$$

And consequently the work done per cycle is

$$\begin{aligned} W &= Q - Q_R\ \text{B.T.U.} \\ &= 779\,(Q - Q_R)\ \text{ft. lb.} \end{aligned}$$

*The efficiency of the cycle*, that is, the fraction of the heat supplied that is converted into work is

$$\begin{aligned} E &= \frac{W}{Q} = \frac{Q - Q_R}{Q} \\ &= 1 - \frac{Q_R}{Q} \\ &= 1 - \frac{T_5 - T_2}{T_4 - T_3} \end{aligned}$$

And since, as already stated,

$$\frac{T_5}{T_4} = \frac{T_2}{T_3}$$

we get
$$\frac{T_5 - T_2}{T_4 - T_3} = \frac{T_2}{T_3}$$

therefore
$$E = 1 - \frac{T_2}{T_3}$$

*Example* Find the efficiency of the cycle in the preceding problem.

$$\begin{aligned} E &= 1 - \frac{T_2}{T_3} \\ &= 1 - \frac{521}{919.6} \\ &= 1 - .567 = .433 \end{aligned}$$

The work W done per cycle can be calculated from the efficiency, without knowing the heat rejected

$$E = \frac{W}{Q}$$

or
$$\begin{aligned} W &= E \times Q\quad \text{B.T.U.} \\ &= 779\,E \times Q\quad \text{ft. lb.} \end{aligned}$$

*Examples.* If the cycle discussed in the previous examples takes place in a cylinder of 12 in. diameter and 18 in. stroke, what will be the work done per cycle? If the engine makes 250 revolutions per minute, what will be its indicated horse-power?

*Solution.*

$$W = 779\ E \times Q \quad \text{ft. lb.}$$

$$Q = \frac{H}{n+1}(V_2 - V_1) \quad \text{B.T.U.}$$

$V_2 - V_1$ is the volume through which the piston moves in cu. ft., and is the product of the cross section area of the cylinder in sq. ft. by the stroke in ft.

$$\therefore \quad V_2 - V_1 = \frac{\pi}{4} \times \left(\frac{12}{12}\right)^2 \times \frac{18}{12}$$

$$= 1.178 \text{ cu. ft.}$$

$$\therefore \quad Q = 94.25 \text{ B.T.U.}$$

$$\therefore \quad W = 40.81 \text{ B.T.U.}$$

$$= 31791 \text{ ft. lb.}$$

Since this engine requires two revolutions to complete a cycle, the number of cycles per minute is only half the number of revolutions per minute; therefore the work per minute

$$= W \times 125 \quad \text{ft. lb.,}$$

and the horse-power

$$= \frac{31791 \times 125}{33000},$$

$$= 120.4 \text{ I.H.P.}$$

## EXAMPLE FOR PRACTICE.

(a) A gas engine using the Otto cycle has 25 per cent clearance and takes in its charge at 14.7 lb. per sq. in. and at 60° F. What is the pressure at the end of the compression?

Ans. 141.1 lb. per sq. in. abs.

(b) What is the temperature at the end of compression?

Ans. 539° F.

(c) If the charge consists of 1 part of gas to 9 parts of air and the heat of combustion of the gas is 600 B.T.U. per cu. ft. what is the temperature at the end of explosion? Ans. 4258° F.

(d) What is the pressure at the end of explosion?

Ans. 665.9 lb. per sq. in. abs.

(e) What are the pressure and temperature at the end of the expansion? Ans. 69.4 lb. per sq. in. abs. 1997° F.

(f) What is the efficiency of the cycle? Ans. .479.

(g) If the cylinder diameter is 18 in. and the stroke is 24 in., and the engine makes 150 revolutions per minute, what is the I.H.P.? Ans. 180 I.H.P.

An examination of the equation for the efficiency of the Otto cycle.

$$E = 1 - \frac{T_2}{T_3}$$

brings out certain important results. The efficiency is seen to depend only on the ratio of the temperatures at the beginning and end of the compression, and not at all upon the temperature and pressure at the end of explosion. Since the ratio of the temperatures at the beginning and end of compression depends only upon the ratio of compression, and since further, the charge is always compressed till it occupies the clearance volume, the efficiency is seen to depend only upon the percentage clearance. In other words, in engines with the same percentage clearance using the Otto cycle, the percentage of the heat liberated in the cylinder that is converted into work is always the same whatever be the size of the engine or the strength of the charge. The effect of the clearance on the efficiency is exhibited in table I, where it is seen that the smaller the clearance the greater is the efficiency of the engine. The pressures at the

**TABLE I.**

| Percentage Clearance of Otto cycle engine. | Pressure at the end of compression lb. per sq. in. abs. | Efficiency of Otto cycle. | Efficiency of cycle with increased expansion, but with the same compression pressure as the Otto cycle. |
|---|---|---|---|
| 20 | 183.3 | 51.6 | 60.9 |
| 25 | 141.1 | 47.9 | 58.4 |
| 30 | 115.4 | 44.8 | 55. |
| 35 | 98. | 42.1 | 52.5 |
| 40 | 85.5 | 39.8 | 50.4 |

end of compression are also given in the table, and are calculated on the assumption that the atmospheric pressure is 14.7 lb. per sq. in. abs.

## OTTO CYCLE WITH INCREASED EXPANSION.

The pressure at the end of expansion is seen in the example worked out to be 89 lb. per sq. in. abs. In ordinary practice it is commonly found to be from 50 to 60 lb. abs. It is evident that if the gas were permitted to expand further it would do more work and consequently would increase the efficiency of the cycle. The indicator card, Fig. 19, shows one method used for obtaining more expansion. The charge enters at atmospheric pressure from 1 to 2, when the admission is cut off. The piston continues moving forward to the end of its stroke, but as no more admission takes place the charge expands adiabatically to 3, while its pressure falls. On the return stroke the charge is compressed adiabatically, retracing the expansion path along 3 2 and continuing till the whole charge is compressed into the clearance space at 4. The rest of the cycle is unchanged. The diagram 1 2 4 5 8 2 represents the ordinary Otto cycle, and the shaded area 8 6 7 2 represents the increase in work due to the increased expansion. The efficiency of this cycle can be easily calculated and the results of such calculations are given in table I. They are made on the assumption that the charge is admitted for only one-half the stroke and that the heat combustion is 80 B.T.U. per cu. ft. of the charge. An inspection of the table shows the increase in efficiency which results from the increased expansion for engines which have the same pressures at the end of compression and indicates that in order that a gas engine of this type should be of high efficiency, it should compress the charge to a high pressure, and then should expand the products of combustion to a volume considerably in excess of the original volume of the charge.

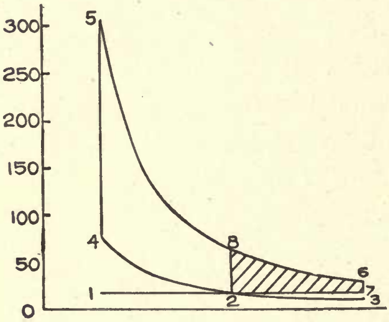


Fig. 19.

## THE IDEAL AND THE REAL OTTO CYCLES.

The calculations in the preceding pages are made on the assumption that the gas engine follows the Otto cycle exactly, in which case the engine is called an *ideal* engine. The *real* engine does not exactly follow the Otto cycle because of certain practical difficulties. Differences between the real and the ideal engines occur in each part of the cycle. During admission (Fig. 20, line 1 2) the pressure in the cylinder is actually a pound or more below the atmospheric pressure, that difference being necessary to open the air admission valve (when automatic), and to cause the air to flow in with sufficient velocity. The charge, moreover, is heated by contact with the cylinder walls and with the hot gases remaining in the clearance. The compression is not adiabatic because it occurs in a cast iron cylinder which takes heat from the gas while it is being compressed and so makes the final temperature and pressure less than that calculated on the assumption of adiabatic expansion. The difference, generally, is not very great.

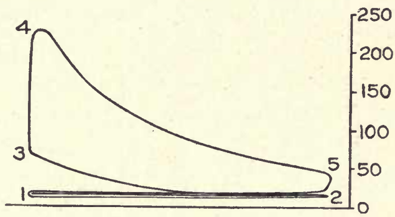


Fig. 20. Indicator Card from Otto Cycle Engine.

The explosion in the real engine is neither instantaneous nor complete. It approximates more closely to the ideal explosion when the compression is considerable and when the explosive mixture has only a small excess of air present. With weaker mixtures the explosion becomes slower and less complete, as shown in Fig. 21, till, with the weakest explosive mixture, the process is really one of slow combustion taking place throughout the whole of the expansion period, and some of the charge may be still unburned when exhaust takes place. Even under the best conditions the rise of temperature, and consequently of pressure, during the explosion is only about six-tenths of that occurring in the ideal engine. This, it will be seen, makes the power of the real engine considerably less than that of the ideal. The water jacket around the cylinder, without which the cylinder would be too hot to be properly lubricated, is one of the

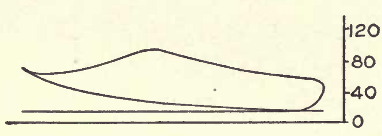


Fig. 21. Indicator Card with Weak Mixture.

important causes of the difference between the real and ideal cycles, as the jacket absorbs usually about forty per cent of the total heat of the combustion.

The expansion curve is above the adiabatic in real engines because the cylinder walls that have been heated by the explosion give back some heat to the gases and also because the combustion still continues and liberates more heat. This last effect is especially marked when the explosive mixture is weak.

Finally, the exhaust, as in the steam engine, begins a little before the end of the expansion stroke so as to give plenty of time for the escape of the gases, and the pressure in the cylinder during the exhaust stroke is necessarily higher than that of the atmosphere into which the gases are rejected.

The total effect of all these differences between the real and the ideal engine is that the work done in an actual engine in good condition is only from five-tenths to six-tenths of that which the ideal engine would do, and the efficiency of the real engine is only from five-tenths to six-tenths of that of the ideal engine.

*Example.* What are the probable actual efficiency, horse-power and gas consumption of the engine whose ideal performance has been worked out in the preceding examples? Assume the real engine to have $\frac{6}{10}$ the efficiency of the ideal engine.

The ideal efficiency was found to be .433.

$\therefore$ The probable real efficiency $= .6 \times .433 = .26$.

The ideal horse-power was found to be 120.4,

the probable real H. P. $= .6 \times 120.4 = 72.2$.

The gas consumption is expressed in cu. ft. per I.H.P. per hour. In the ideal engine the volume of gas taken in per cycle was

$$\frac{V_2 - V_1}{n+1} = \frac{1.178}{8} = .147 \text{ cu. ft.}$$

The number of cycles per minute was 125.

$$\begin{aligned} \therefore \text{ the gas used per minute} &= .147 \times 125 \text{ cu. ft.} \\ &= 18.4 \text{ cu. ft.} \\ \therefore \text{ the gas used per hour} &= 18.4 \times 60 \text{ cu. ft.} \\ &= 1104. \text{ cu. ft.} \end{aligned}$$

And the probable real I.H.P. is 72.2.

$$\therefore \text{ the gas used per I.H.P. per hour} = \frac{1104.}{72.2} = 15.3 \text{ cu. ft.}$$

## EXAMPLE FOR PRACTICE.

What are the probable actual efficiency, I.H.P. and gas consumption of the engine whose ideal performance has been worked out in the previous examples for practice.

Answers: .287 efficiency.
108 I.H.P.
14.71 cu. ft. gas consumption.

**Ignition.** For satisfactory action of a gas engine the ignition of the explosive mixture must be certain and must occur at a definite predetermined time. In *timing* the ignition it has to be recognized that the explosion is not instantaneous but requires the lapse of a not inconsiderable period of time before the maximum pressure is reached. The actual duration of the explosion depends on the strength of the explosive mixture and on the amount of compression to which it is subjected. The ignition should have *lead*, that is, should begin a little before the end of the return or compression stroke, when the crank is about 15° from its dead center, so that the maximum pressure is reached when the crank has just passed the dead center. The indicator card, *a*, Fig. 22, is with properly timed ignition. If the ignition is later than this, indicator cards similar to *b* or *c* will be obtained, and the engine will do less work and be less efficient. If the ignition is too early, the maximum pressure will be obtained (Fig. 23) before the crank has reached its dead center and will tend to reverse the engine. This causes great shock to the engine, its rapid deterioration and low-

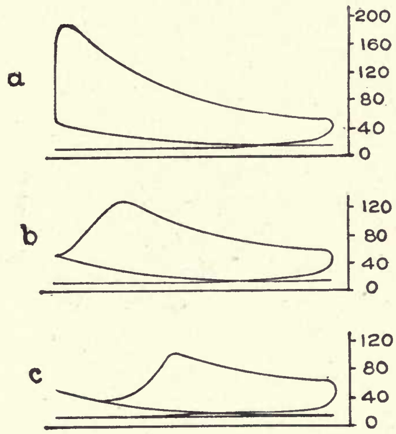


Fig. 22.

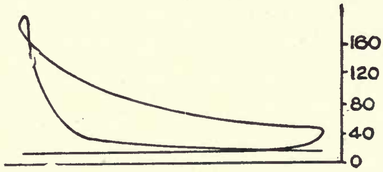


Fig. 23.

ered efficiency. The immediate external evidence of too early or premature ignition, from whatsoever cause, is a violent pounding noise in the engine.

*Two methods of ignition* are in common use in engines using the Otto cycle. The first is by bringing the explosive mixture into contact with some surface which is kept at a temperature sufficiently high to cause ignition; the second is by means of an electric arc. A hot tube is the common device when the first method of ignition is used. The tube E (Fig. 24) is closed at the upper end and communicates at its lower end through the port B with the cylinder A. It is heated by an external flame from the Bunsen burner C, and is maintained at a full red heat. The chimney around the tube is lined with asbestos and keeps the flame in good contact with the tube. During the admission stroke the tube is filled with products of combustion at atmospheric pressure remaining from the previous explosion. As compression goes on, the non-explosive products of combustion are crowded into the upper part of the tube while part of the explosive mixture in the cylinder is compressed into the lower part of the tube. The length of the tube and the position of the flame are adjusted by experiment so that the explosive charge will just reach the hot portion of the tube and be ignited at the moment when ignition is desired. Shortening the tube makes the ignition come earlier. With this device the actual time of ignition is not very definite. It depends on the temperature of the tube, the position of the Bunsen flame, the strength of the

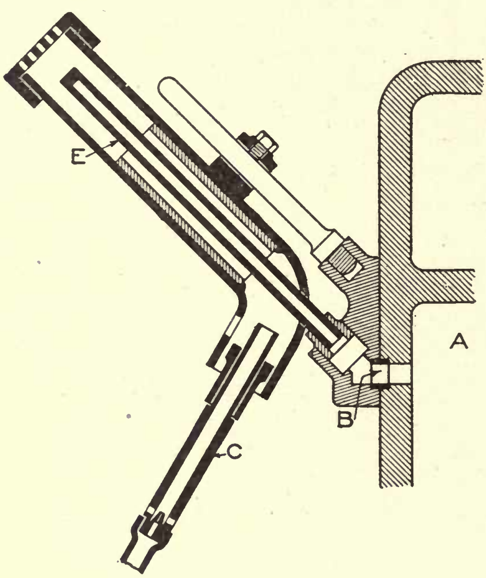


Fig. 24. Hot Tube Igniter.

mixture and the amount of compression. As these last two quantities are purposely varied by the governor in some engines, irregular timing would result from its use in such cases.

The irregularity of timing with the hot tube igniter can be partly remedied by the use of a *timing valve*. The timing valve B (Fig. 25) is held on its seat by a spiral spring D until ignition is desired, when by a movement of the bell crank lever E the valve opens and the compressed charge in the cylinder A gets access to the hot tube C. The valve B is kept open till the end of the exhaust stroke. The tubes are preferably made of nickel alloy or of porcelain, but the latter is very brittle and apt to break when being fastened in place. Iron tubes are used sometimes, but they burn out rapidly and are unreliable.

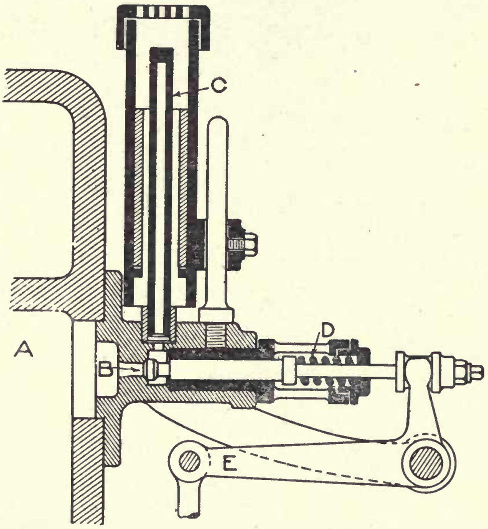


Fig. 25. Hot Tube Igniter with Timing Valve.

Even when provided with a timing valve the hot tube does not give very satisfactory ignition; and, moreover, some time is consumed in heating the tube before the engine can be started. Accurate timing can be obtained best by electric means, and *electric ignition* is consequently used more than any other. The method is to make a spark pass at the instant when ignition is desired between two terminals situated in the clearance space of the engine. The most common way of forming the spark is to separate two contact points through which a current has been flowing. An electric arc will then pass between the separating contact points. In order to ensure that the temperature of the arc is high enough and its duration is sufficient to ignite the explosive mixture through which it passes, a *spark coil* is generally inserted in the circuit. A spark coil consists merely of a bundle of soft iron wires surrounded by a coil of insulated copper wire, through which the current goes. The contact points of the igniter must be brought together to re-establish the current before another spark can be obtained. A device of this nature is known as a *make-and-break* igniter; and when the contact points do not slide across one another, it is called a *hammer break* contact.

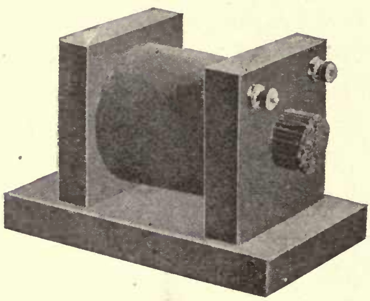


Fig. 26. Spark Coil.

One of the common forms of hammer break igniter is illustrated in Fig. 27, which shows an igniter plug removed from the cylinder head. The movable electrode *b* is at the end of an arm which is fastened to the spindle *c*. When the interrupter lever *d*, which is loose on the spindle *c*, and is connected to it through a coiled spring, is lifted by an arm from the cam shaft of the engine, it rotates the spindle *c* so as to bring *b* into hard contact with the stationary and thoroughly insulated electrode *a*. This completes a circuit and permits a current to flow from *a* to *b*. When ignition is desired the lever *d* is tripped and flies back, carrying with it the shaft *c*, abruptly breaking the contact and causing an electric arc to form between *a* and *b*. The contact points are generally made of platinum, as this does not oxidize or corrode, but other metals are also used. The passage of the spark takes minute particles of the material from one terminal and deposits them on the other, the action following the direction of the current. By reversing the direction of the current, the material may

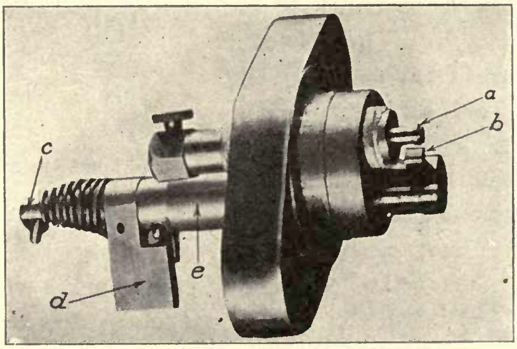



Fig. 27. Otto Engine Igniter Plug.

be returned to the terminal from which it was taken, and the durability of the contact points considerably increased.

The current is generally taken from a primary battery, consisting of about five cells. The Edison-Lalande cell, made up of two zinc plates and a plate of compressed copper oxide immersed in a strong solution of caustic soda, is perhaps the most largely used. Other sources of electricity can be used. Current is sometimes taken from a direct current lighting or power circuit, but this is objectionable because the circuit is grounded every time the igniter terminals are in contact. The practice is growing of using a small special dynamo for the exclusive purpose of supplying the current for ignition. This makes the ignition spark more certain and of more uniform strength than when a battery is used, as the latter deteriorates and weakens with use.

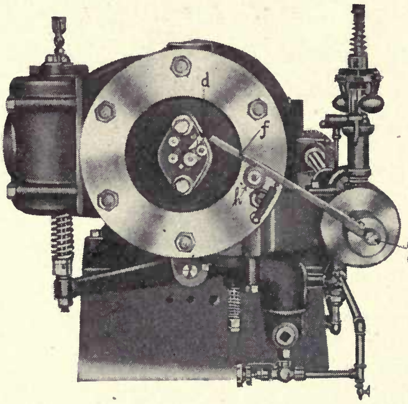


Fig. 28. Igniter Gear of Root and Van Dervoort Engine.

A make-and-break contact is sometimes obtained by sliding one contact point over the other until it slides off completely. This is known as a *wipe break.* The method ensures a good contact, produces a very hot spark, keeps the contact points clean, but wears them out quite rapidly. Provision must be made for adjustment, otherwise the timing will alter with the wear of the points. The rubbing surfaces can be of iron.

The igniter gear of an engine with hammer break ignition is shown in Fig. 28. The igniter rod *f*, which is supported on the reel *h*, receives a reciprocating motion from a crank *g* at the end of the side shaft. During the exhaust or admission stroke the end of the rod *f* comes in contact with the interrupter lever *d* (compare with Fig. 27) and establishes the contact of the electrodes. The vertical component of the movement of the end of the rod *f* sets free the lever *d* at the moment when ignition is desired.

A switch (Fig. 29) should always be included in the electric circuit and should be thrown out when the engine is not running, so as to prevent the short-circuiting and consequent exhaustion of the batteries.

Another way of obtaining electric ignition is known as the *jump spark* method. In this system the terminals are stationary, generally from one-sixteenth to one-eighth of an inch apart, and the spark is made to spring across the gap between them by putting the terminals in the secondary circuit of a Ruhmkorff or *induction coil.* This coil consists of a core of soft iron wire around which is wound a relatively coarse insulated wire, the *primary circuit*, through which the current from the source of energy flows. A relatively fine insulated wire coil, the *secondary*

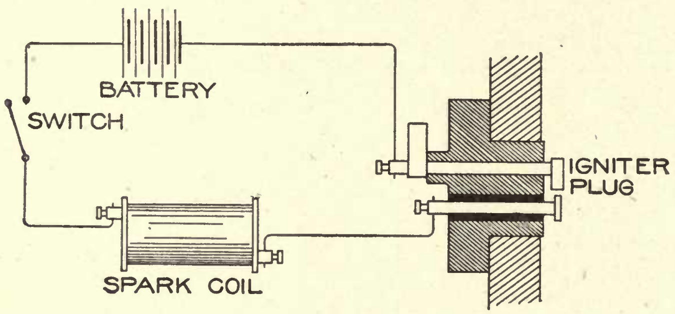



Fig. 29. Diagram of Igniter Circuit.

*circuit*, is wound around the primary coil, but has no metallic contact with it. If the current flowing through the primary circuit is varied in strength, it creates or induces a current in the secondary circuit. Generally the Ruhmkorff coil is provided with a magnetic vibrator (similar to that used in an electric bell), which makes and breaks the primary circuit with great rapidity and induces a considerable alternating current in the secondary circuit. If the two ends of the secondary coil be brought close to one another, but not quite in contact, a spark will jump across the gap at each make and break of the primary current, the spark at the break being the more powerful. For ignition of the explosive mixture in a gas engine it is not necessary to use a vibrator; the cam shaft of the engine breaks the primary circuit at the instant when explosion is desired. The spark passing on the subsequent remaking of the primary circuit is not strong enough to ignite the charge. The connections for jump spark ignition are shown diagrammatically in Fig. 30. The primary circuit is shown there as being completed through a cam on the side shaft of the engine. As soon as the side shaft has moved from the position shown, the contact with the upper flat spring is broken and the primary current is interrupted, thereby inducing sufficient current in the secondary circuit to make a spark pass across the air gap between the terminals of the spark plug. These terminals are completely insulated, so that the only path for a current between them is across the air gap.

The jump spark method has as its great advantage the absence of moving parts inside the cylinder. This is offset by the fact that the spark is liable to fail as a result of the formation of

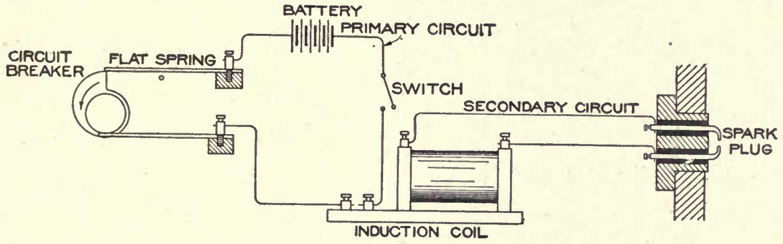



Fig. 30. Diagram of Jump Spark Igniter and Connections.

deposits of rust or corrosion on the points, the liability to this being much greater than in either of the make-and-break methods. The difficulty of obtaining satisfactory insulation is also greater.

**Governing.** The governing of an engine means the control of the power which it is developing so that its speed is maintained practically constant. If the engine develops more power than is required, the engine will speed up; if the power delivered to the crank shaft is less than the resistance there, the engine will slow down. The governing of a gas engine, like that of the steam engine, is effected by utilizing small variations of engine-speed resulting from change of engine load. The controlling mechanism, or the governor proper, does not differ from that used on the steam engine, but there is a considerable difference in the way in which it controls the work done by the engine. There are two general methods in use in gas engines for varying the power; one by varying the number of explosions or impulses per minute, which is known as the *hit-and-miss* system, and the other by varying the magnitude of the impulse while keeping the number per minute constant, which may be called the *variable impulse* system.

**The Hit-and-Miss System.** The omission of the explosion or impulse can be obtained in several ways. The most common method is to keep the gas admission valve closed so that air alone is taken in during the admission stroke, and consequently there is no explosion. A method of accomplishing this is to be seen in Fig. 31, in which a loaded centrifugal governor is shown driven by bevel gearing from the cam shaft. In the position shown, the gas admission cam *d* will come under the reel *c*, and will start to lift it at the beginning of the admission stroke. The reel *c* is loose on a spindle at the end of the horizontal lever *e*, and the vertical rise of the spindle due to the action of the cam opens the gas valve by a system of levers not shown in the figure. If the engine speeds up, the rise of the governor balls raises the sleeve on the governor spindle, lifts the horizontal arm of the bell crank lever fulcrumed at *a* and shifts the forked end *b* of the vertical arm to the right, carrying the reel *c* with it, so that the cam no longer engages it and no gas is admitted.

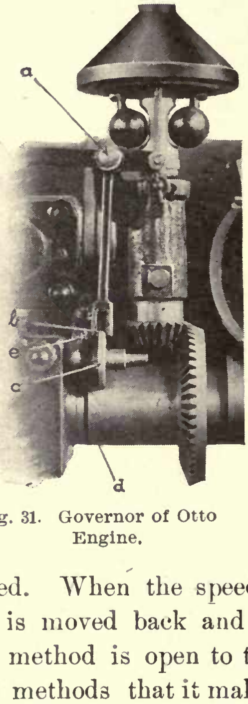


Fig. 31. Governor of Otto Engine.

When the speed comes down to the normal speed, the reel is moved back and the admission of gas again takes place. This method is open to the objection common to all the hit-and-miss methods that it makes the speed of the engine very irregular at any other than full load. Even at full load, with the Otto cycle occurring in a single acting cylinder, there is only one motive stroke or impulse in four strokes instead of one every stroke as in a double acting steam engine. If the engine governs by the hit-and-miss method and is running at half load, half the explosions will be omitted and there will be but one motive stroke in eight; at one-third load, there is but one motive stroke in twelve; and at quarter load, one in sixteen. Running at quarter load, the engine will be speeded up during the motive stroke and will slow down during the succeeding fifteen strokes till it gets to normal speed again. The actual variation in speed at low loads can be reduced by the use of heavy fly wheels, but with this method of governing it is too great for use when close regulation is necessary, as for electric lighting. There is an incidental advantage in the use of this method in that, during the idle cycles, the cylinder is flushed out by the *scavenging* charge of air, which makes the next explosion more powerful.

The omission of an explosion is sometimes effected in engines which have an automatic admission valve by the action of the governor in keeping the exhaust valve open throughout the cycle. The free communication between the cylinder and the outside through the exhaust valve prevents the pressure in the cylinder from falling sufficiently below the atmospheric pressure, during the admission stroke, to cause the inlet valve to open. The cylinder contains only products of combustion, substantially at atmospheric pressure, so long as the exhaust is open, and consequently no explosion can occur.

**The Variable Impulse System.** The amount of work done in a given gas engine depends on the strength of the charge, on its amount, on the timing of the ignition, and on several other factors. The engine can be governed by the variation of *any one* of these, and the three specifically mentioned are all in regular use for this purpose.

If the governing is effected by *varying the strength of the charge*, the control has to be such that the mixture is always an explosive one. With each kind of gas used in an engine there are both higher and lower limits to the amount of air with which it may be mixed if it is to remain an explosive mixture. If the ratio of air to gas should be outside these limits, the mixture sent to the exhaust would be unburned and valuable gas would be lost. Conseqently, if the engine goes above normal speed when admitting the weakest explosive mixture, the power of the engine has to be further reduced by omitting the admission of gas entirely. In Fig. 32 is shown a device for governing in the manner just described. The governor *d* is driven from the cam shaft *c* through the bevel gears shown in section. Gas is admitted by raising the end of the lever on which is a reel *b* similar to *c* in Fig. 31. The sleeve *a* is free to slide on a feather on the cam shaft *c*, its exact position being controlled by the governor through the bell-crank lever *e*. On the sleeve *a* is a series of cams of the same throw but of different circumferential lengths. The duration of the admission of gas is varied by shifting the sleeve so as to bring different cams into engagement with *b*. In the position shown the engine is above normal speed, and the sleeve is at extreme position to the right and no gas is being admitted. As the speed of the engine falls, the sleeve travels to the left, admitting gas for a definite period for each engine speed. With full load on the engine, the reel engages with the longest cam and the strongest mixture is admitted to the cylinder.

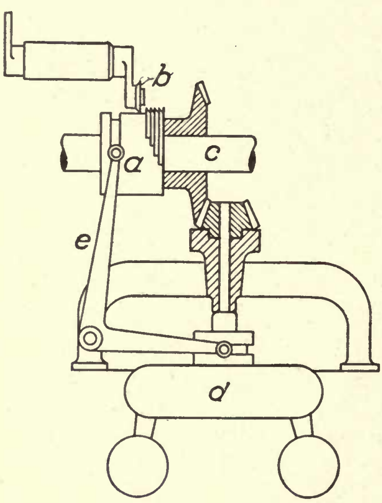


Fig. 32. Diagram of Governor.

With this method of governing, the same amount of the mixture is always taken into the cylinder, and consequently the pressure at the end of compression is always the same. The explosion, however, becomes weaker as the mixture is "leaner" and requires a longer time for its completion. A comparison of the areas of Figs. 20 and 21 shows the effect of a weaker mixture on the power of the engine.

It is found in practice that there is a certain strength of the explosive mixture which gives the most economical running of the engine. It is obviously desirable to run the engine with a mixture of this strength, and that can be done when a hit-and-miss governor is used. When it is desired to have an impulse every cycle, a constant strength of mixture can be maintained if the power of the engine is controlled by varying the *amount of the mixture* taken in. An example is shown in Figs. 33 and 34 of the actual mechanism used for this purpose. Gas from the passage

G enters a port in the cylindrical valve A and meets air which enters from D through similar ports. The mixture passes out of the valve through a large port near the top and goes through C to the cylinder when the inlet valve D is open. The relative amounts of gas and air are regulated by the two levers H H, which are connected to entirely independent cylindrical shells inside the valve A and which can rotate them so as to cover up more or less of the lengths and therefore of the areas of the gas and air ports respectively. With the two levers in constant positions the areas for admission of gas and air to the cylindrical valve A will be fixed, and consequently the strength of the mixture will be constant. The actual amount of the mixture entering the cylinder is controlled by the governor B, which works an internal cylindrical valve in such way as to throttle the discharge port of the valve A when the speed increases.

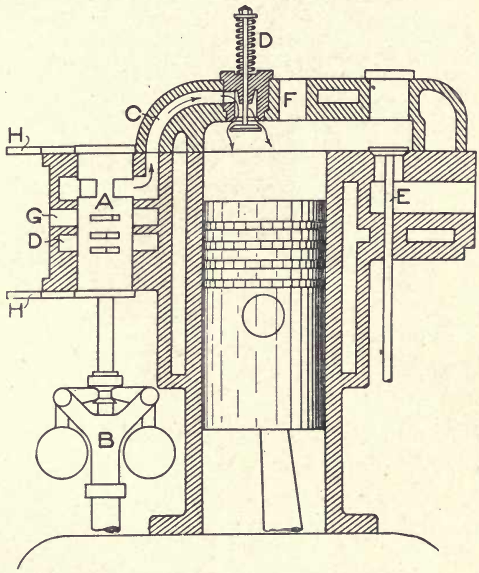


Fig. 33. Mixing Valve of Westinghouse Engine.

This method of governing permits a perfect adjustment of the work done in the cylinder each cycle, and consequently gives more uniform speed of the engine than any of the methods so far described. The throttling of the mixture imposes extra work upon the engine during the admission stroke, as the piston has to move out with a vacuum behind it. At the end of the admission the pressure in the cylinder will be less and less as the load on the engine becomes smaller, and consequently the pressure in the cylinder at the end of compression is less as the load decreases. With decreased compression the combustion of the mixture is slower. This is well shown in Fig. 35, which gives a series of indicator cards taken at different loads from an engine using a strong mixture and a throttling governor.

Another method of accomplishing the same result is to admit a mixture at atmospheric pressure for part of the admission stroke only, the duration of the admission being determined by the governor. This method of governing gives an indicator card similar to Fig. 19. The difference between an engine governing in this way and one governing by the throttling method is similar to that between a Corliss steam engine and a throttling steam engine. The advantage of *cut-off* governing is in the decreased work done by the engine in drawing the charge into the cylinder. The use of a partial charge, whether obtained by throttling or by cutting-off, permits the expansion of the exploded mixture to a lower pressure than is possible in an engine admitting a full charge and having the same pressure at the end of compression. This is the practical method of obtaining the increased expansion, the advantage of which has been already pointed out.

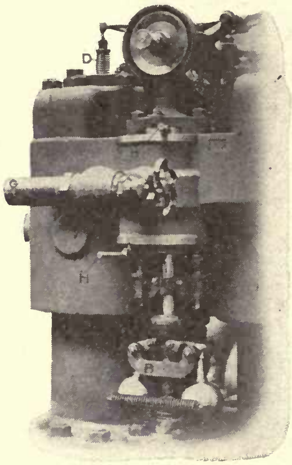



Fig. 34. Governor of Westinghouse Engine.

When economy is not of the greatest importance, as, for instance, in automobile practice, the power of the engine may be controlled by *varying the point of ignition.* It has been shown already (Fig. 22) that the power of the engine decreases as the lead of the ignition becomes less. If the ignition occurs after the beginning of the stroke, the lead is said to be negative, and the power is greatly decreased. If the lead is increased (Fig. 23), there still results a decrease of power. The

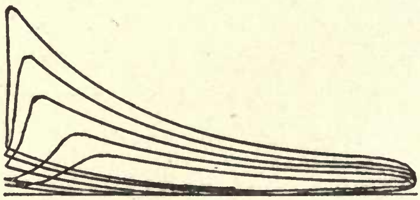
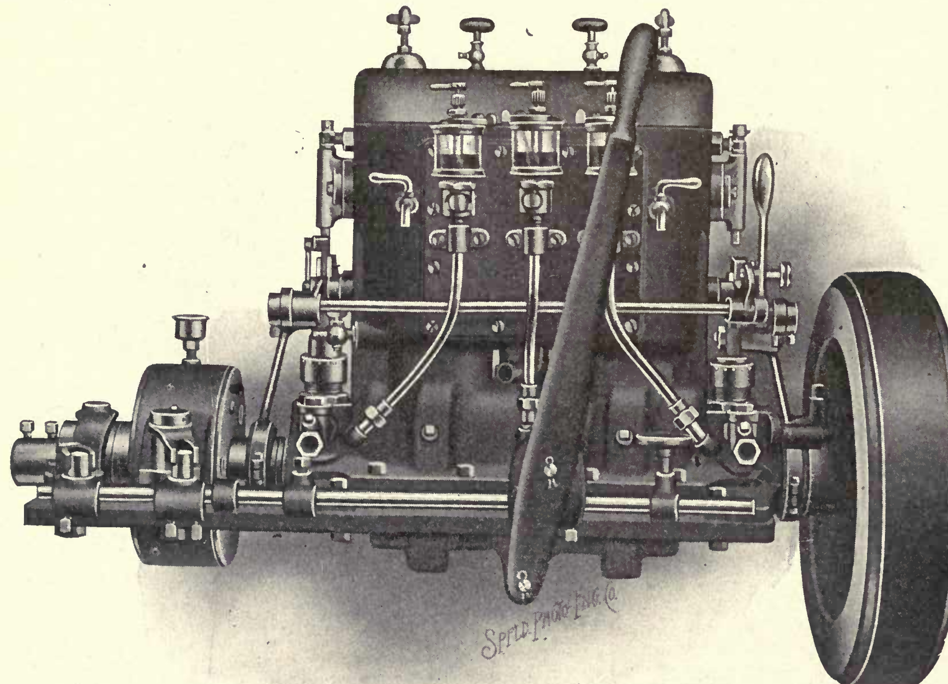


Fig. 35.




**TOQUET MARINE MOTOR.**
Starboard Side with Reverse Gear.

control of the power by varying the ignition is always uneconomical, but the method is one of extreme simplicity.

**Starting.** A gas engine will not start itself in the way a steam engine does when steam is turned on. It is necessary to get the engine in motion by means of some special source of power before it can take up its normal cycle of operations. Generally this special source of power is not adequate to get the engine moving rapidly when it is connected to any considerable load; it is always preferable and generally necessary to throw the load completely off the engine till it gets under way.

In the normal running of an engine the ignition of the charge occurs before the end of the back stroke, and if the time of ignition is kept the same when starting there is a danger, or often the certainty, that the high pressure of the explosion acting on the piston before the crank has got to its dead center, will overcome the inertia of the engine, which is small because of its low speed, and will reverse its direction of rotation. If the starting power is small, the ignition has to be retarded by some special device so that it will not occur till after the crank has passed its dead center —that is, there must be negative lead. An example of a device for retarding the ignition is given in Fig. 36. The igniter rod A (compare with *f*, Fig. 28) which is worked by a crank on the side shaft B, is supported during normal running on the reel C, which is loose on the fixed spindle D. In the position shown it is just about to trip the interrupter lever E on the spindle which moves the movable electrode. When starting, the reel C is slid along the spindle D so that the igniter rod A rests, as shown in the dotted lines, directly on D, consequently the tripping occurs so much later.

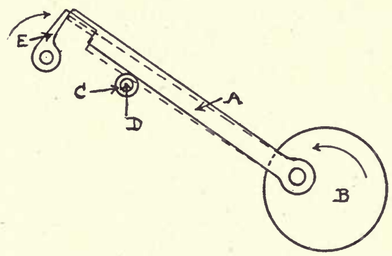


Fig. 36.

There are several general methods of starting gas engines. If the engine is small, not exceeding 10 H. P., and can be disconnected from its load, it is common to start it by turning it over by hand for a few revolutions till an explosive mixture is admitted and ignited. As it is difficult to pull the engine over when the charge is compressed for the whole back stroke, most engines are provided with an extra exhaust cam which is put into action while starting, and which not only opens the exhaust valve during the exhaust period but also opens it again during the first part of the compression period, so that some of the explosive mixture is forced out of the cylinder and the amount of compression is decreased. The explosion of this diminished charge after the crank has passed the dead point, starts the engine going, and after operation under these conditions for several cycles, the engine will come up to speed if it is not loaded heavily, and the compression and ignition may then be changed back to the normal running conditions.

With large engines it is impracticable to start by hand, and other devices have to be used. One of the most simple and certain is to start the engine by the admission of compressed air, which acts on the piston just as steam does in a steam engine. This method is especially desirable in an engine with several cylinders, in which case one cylinder is used as a compressed air cylinder to run the engine till the other cylinders take up their normal cycle of operations; and then the compressed air is shut off and the first cylinder is put into normal action. If the engine has only one cylinder, it can be brought to a good speed by the admission of compressed air, and then, after the compressed air is shut off, it will continue to revolve by its own inertia until an explosive mixture is taken in and exploded.

An arrangement for starting a multicylinder engine with compressed air is illustrated in Figs. 3 and 37. A compressor (Fig. 37), which is driven by a belt from the engine, forces air into a storage tank and brings it to a pressure of about 160 lb. In case of need the compressor can be operated by hand. When the engine is to be started, the compressed air can be admitted to one of the cylinders. The cam B (Fig. 3) on the upper shaft is first thrown out of action by a special device, so that the inlet valve J cannot open. The hand lever on the outside of the crank case near the cam A is thrown over, putting the ordinary exhaust cam A out of action, but bringing into action a double cam which keeps the exhaust valve E open throughout every up-stroke of the engine. Another cam on the same shaft is brought into action at the same time, and operates a starting valve (not shown) on the pipe from the compressed air reservoir, admitting compressed air to the cylinder on every down stroke. The cylinder then acts as a compressed air engine till the explosions begin in the other cylinders, when the cams B and A are brought back to their normal positions and the starting cylinder functions normally. In other engines compressed air is admitted to the cylinder during the expansion stroke by manual operation of a special valve. After two or three admissions during successive cycles, the engine will attain speed enough to permit the opening of the gas valve and the commencement of the cycle.

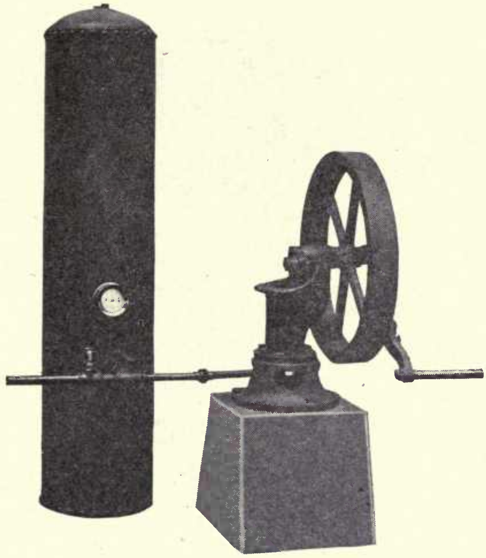


Fig. 37. Air Compressor.

With engines up to 100 H.P. a common method of starting is to ignite a charge which has been drawn into the engine by turning it over by hand. The engine is brought to the beginning of the expansion stroke, and a definite amount of gasoline is put into a cup which connects with the cylinder through a valve which is opened. The engine is then pulled over till the piston has made half its forward stroke, air being drawn in and forming an explosive mixture with the gasoline which enters at the same time. The gasoline valve is then closed and the engine is turned quickly in the opposite direction, the charge is compressed as much as possible, and is then ignited. The ignition is brought about by tripping the electric igniter by hand, or by the use of a special detonator, or even, in some cases, by striking a match inside the cylinder by means of a special device. It is not possible with a loaded engine to compress the charge much by hand, so that this method is only applicable to engines of moderate size which can be disconnected from their starting load.

If the engine has to start under moderate load, it is generally necessary to supply the engine with a charge which has been compressed to a high pressure. This can be accomplished by setting the engine with the crank about ten degrees past the dead center on the expansion stroke, and then pumping an explosive mixture into the cylinder (Fig. 38) till the piston begins to move. At that instant the charge is ignited, and the work done by the expansion of the exploded charge will be enough to start the engine on its cycle of operations. Another method of accomplishing the same

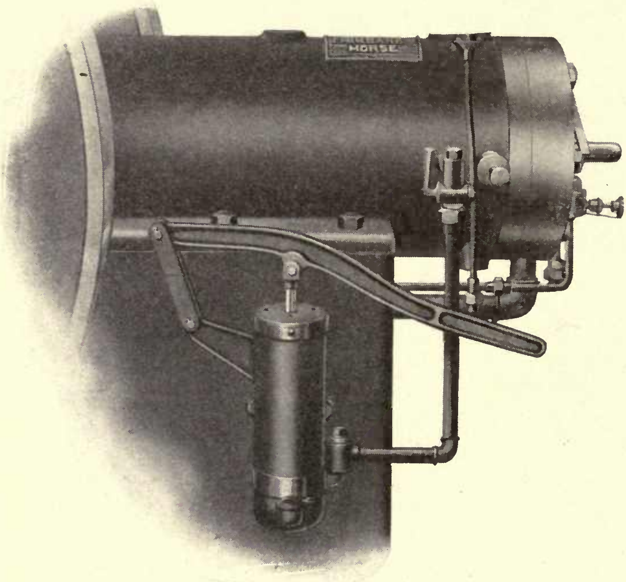



Fig. 38. Starting Gear of the Fairbanks-Morse Engine.

thing is to connect the cylinder E (Fig. 39) with a special starting chamber D. When the engine is being shut down, the special inlet valve A is lifted from its seat, so that at each suction stroke air is drawn through the chamber D by way of the valve F. The chamber D, the cylinder, and the connecting pipe are thus filled with pure air at atmospheric pressure. When the engine is to be started the gas cock C is opened and gas flows both into the chamber D and into the cylinder, a cock on the cylinder being opened. A pilot light burns across the opening above the valve F, and after a short time a combustible mixture of air and gas issues and catches fire. If the cock C is then closed, the flow of the explosive mixture stops and the flame consequently shoots back past the valve F and ignites the mixture in D, closing the valve F against an upper face by the force of the explosion. The flame proceeds to the cylinder, the contents of which will have been compressed by the explosion in D, and causes an explosion there. In large plants a special starting engine is customary.

**Water Jacket.** In all the preceding sectional views of gas engine cylinders it will be seen that the cylinder barrel and the cylinder head have double walls and in every case provision is made for the active circulation of water through the space between the two walls. Without the use of a *water jacket*, or some equivalent device, the engine would be inoperative, because the high temperature to which the cylinder would be raised by the explosions would not only vaporize the lubricating oil and cause the rapid destruction of the cylinder, but also the entering mixture would be exploded before its time by contact with the hot metal. The necessity for effective cooling is greater in the larger engines; it is often necessary to water-jacket the exhaust valve in large engines that it may not be warped out of shape by the high temperature, and may not be hot enough to ignite the entering charge. The cooling arrangement for a balanced exhaust valve is shown in Fig. 14, the water entering the valve through the tube *b* and escaping after circulating at *c*. In some large engines the pistons also are water-jacketed. In very small engines

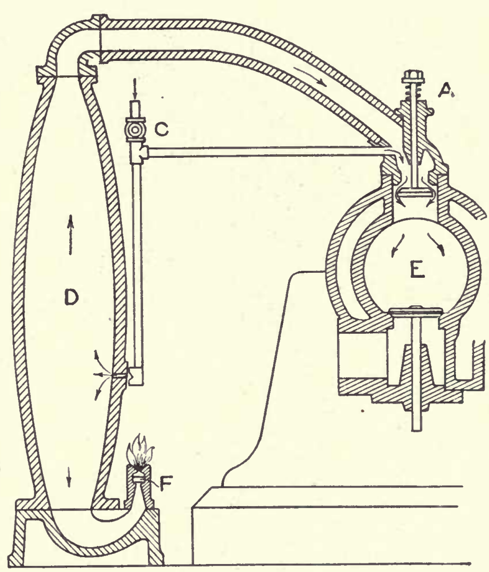


Fig. 39.

it is possible, when the engine is placed in a strong current of air, to replace the water jacket by a system of thin metal ribs (Fig. 40), or points, on the external surface of the cylinder. The current of air can be obtained either from a fan driven by the engine, or, as in bicycle motors, by the movement of the engine itself. When the engine is water-jacketed it is often practicable with small engines to use the same cooling water over and over again, and there is a distinct economy in so doing when the water must be paid for. The usual arrangement (Fig. 41) consists of a vertical galvanized iron water tank of considerable capacity connected at its bottom to the lower part of the jacket, and near its top to the upper part of the jacket. The water in the jacket being heated, rises and flows to the upper part of the tank, where it cools by contact with the air and with the sides of the tank. Cold water from the bottom of the tank flows to the cylinder jacket to take its place. A continuous circulation is maintained by the difference of density between the cold and the heated water.

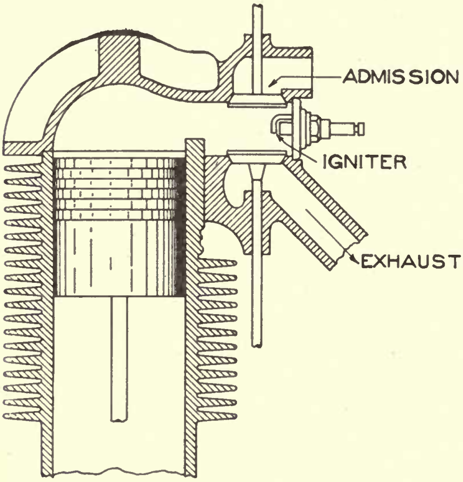


Fig. 40. Arrangement of Cylinder for Air Cooling.

In large engines when a large amount of water must be circulated, this method is generally too cumbrous and the water is taken from some constant source of supply, such as the city mains. The piping and valves are always so arranged that it is possible to draw the water from the jacket.

**The Explosive Mixture.** The air used in the engine may be taken from the engine room or from the outside. The inrush of air to the air pipe makes a noise which is often objectionable in the engine room, but which can be greatly reduced if the air is taken from a large chamber, as in Fig. 10, where it is taken from the base of the engine.

If the gas is taken from the city mains, the intermittent action of the engine in admitting gas will cause considerable fluctuation of pressure in the supply pipe, which is not only undesirable in that it makes variable the amount of gas admitted, but also causes flickering of any lights supplied from the same pipe. To reduce this fluctuation it is usual to insert in the gas supply pipe a rubber bag (see Fig. 11), which collapses partly during the admission stroke and fills out again during the other strokes. Any enlarge-

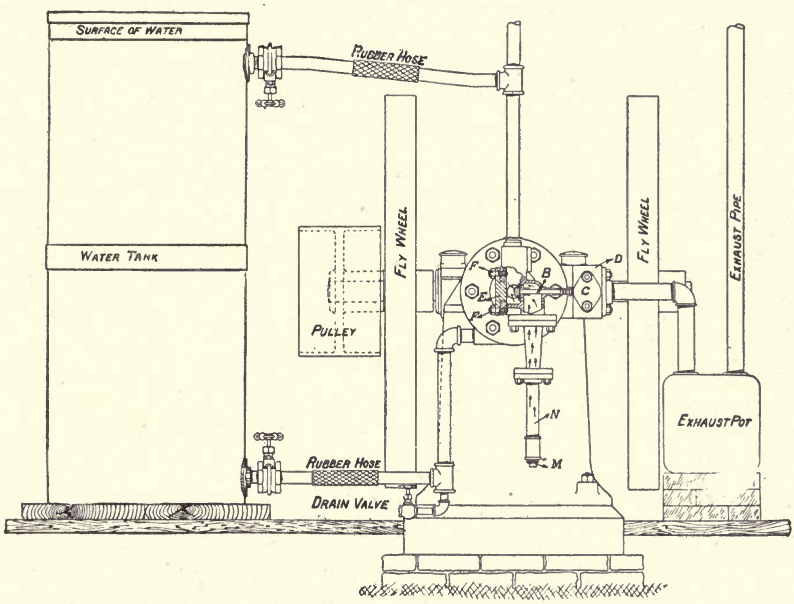



Fig. 41. Arrangement of Water Circulation for Jacket.

ment in the gas supply pipe will serve the same purpose, but the flexible rubber bag is more effective than a mere enlargement.

The air and gas should be mixed as thoroughly as possible on their way to the cylinder. This is satisfactorily accomplished if the air and gas have to pass through a common admission valve after they are mixed, as in Figs. 8, 10 and 33. The strength of the mixture is adjusted by throttling the gas supply, the air supply being left uncontrolled.

**The Exhaust,** if allowed to escape direct from an exhaust pipe of uniform cross section, is generally a source of annoyance by reason of the loud noise which it makes. This noise is greatly reduced if the pipe discharges into an exhaust chamber or pot (see Fig. 41) before going to the air. The injection of water into the exhaust pipe is also useful in reducing the noise in large engines. To make the noise nearly imperceptible a good plan is to have the pipe discharge near the bottom of a pit filled with large stones.

**Modifications of the Otto Cycle.** Although the gas engine using the Otto cycle will give a higher efficiency than any steam engine, it is nevertheless desirable to increase its efficiency as much as possible. Its efficiency has been shown to depend on the amount of compression, and the obvious way of increasing the efficiency is to decrease the clearance and thereby increase the compression pressure. The amount of compression that can be used is limited by two considerations. The first is that it is not commercially practicable to construct engines which will work properly under very high pressures rapidly imposed by explosions. With an engine compressing the charge to 100 lb. pressure and using a strong explosive mixture, the pressure in the cylinder rises suddenly to about 350 lb., and this is at present about the practicable limit. If the explosive mixture is weak, the compression may be increased; with very weak mixtures a compression to 200 lb. is sometimes used, and results in a maximum pressure of about 300 lb.

The second objection to the use of high compression is that the rise in temperature of the mixture resulting from the compression may easily be sufficient to explode the mixture before the piston has reached the end of its stroke. Such pre-ignition of the charge, tending to force the piston back, gives rise to a great shock and is very destructive to the engine, besides reducing its efficiency, and is consequently to be avoided. Pre-ignition may occur even with low compression if any part of the clearance is not water-jacketed, or if there is any metallic projection into the clearance space. Such unjacketed parts, or projections, not being properly cooled, are liable to be raised to a temperature high enough to cause the ignition of the charge. This often forces water-jacketing of the exhaust valve and of the piston in engines of large size.

Another method of increasing the efficiency is by what is known as *scavenging* the cylinder. In the ordinary Otto cycle the charge which is compressed consists of a mixture of fresh air and gas with the burned gases remaining in the clearance space from the previous cycle. If these burned gases are expelled from the cylinder by a charge of fresh air before the admission of the explosive charge, the force of the explosion and the efficiency are increased. The clearing out or scavenging of the cylinder with fresh air has been accomplished in several ways. The simplest method is by the use of an exhaust pipe of such length that the gases exhausting from the cycle with great velocity create a vacuum in the cylinder near the end of the exhaust stroke. This vacuum causes the automatic air admission valve to open and the consequent rush of air from the air valve to the exhaust port flushes out the cylinder, especially if the air and exhaust valves are on opposite sides of the clearance space. Occasional scavenging is obtained in engines governing on the hit-and-miss principle, each idle cycle flushing out the cylinder with the result that the succeeding explosion is of greater force than the normal explosion.

It has been pointed out already that the pressure at the end of the expansion in the Otto cycle is high, and that the efficiency of the cycle can be increased considerably if the gas is expanded more completely. Ordinary steam engine practice suggests that the more complete expansion can be obtained by *compounding*, but attempts so far to make a satisfactory compound gas engine have not proved very successful. The practical method of obtaining more complete expansion is to take into the cylinder a diminished charge. The two methods of accomplishing this have been discussed already. The only fundamental difference between engines using these two methods is that in one case the governor controls the amount of the opening of the admission valve, while in the other case it determines the instant at which the admission valve shall close.

One of the main objections urged against the Otto cycle is that it requires two revolutions of the engine for its completion, so that the expansion or motive stroke comes but once in four strokes. There results from this a very irregular driving effort, making large fly wheels necessary if the main shaft is to rotate uniformly, or else requiring the use of several engines working on the same shaft. The motive efforts can be made twice as frequent if the cylinder is double acting, with admissions and explosions occurring on both sides of the piston. Many large engines are now being made double acting, but the practical troubles in keeping the piston, piston rod, cylinder and stuffing box cool enough for satisfactory working have prevented the use of double-acting cylinders in engines of small size.

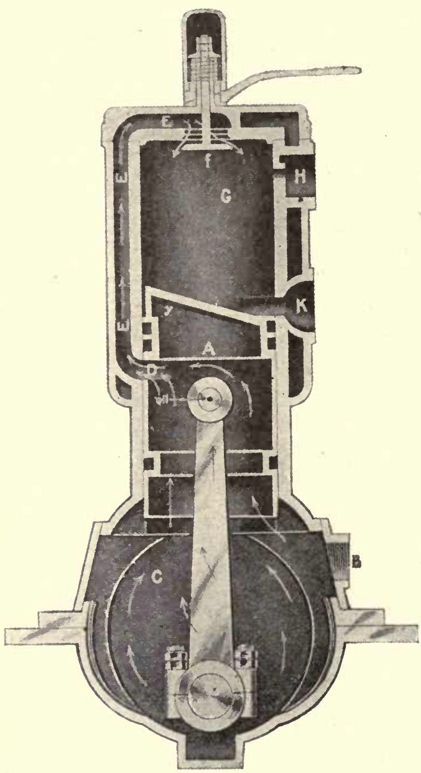


Fig. 42. Smalley Two-Cycle Engine.

An increased frequency of the expansion or motive stroke can be obtained by a slight modification of the Otto cycle which results in the cycle being completed in two strokes, and which is consequently called the *two-cycle* method. Engines using the two-cycle method give an impulse every revolution, and consequently not only give greater uniformity of speed of rotation of the crank shaft, but also develop nearly twice as much power as *four-cycle* or Otto cycle engines of the same size. Moreover, they are generally of great simplicity, having fewer valves than the four-cycle engines. An example is shown in Figs. 42 and 43 of a two-cycle engine of small size; Fig. 42 is a vertical section showing the piston at the bottom of its stroke, and Fig. 43 is a vertical section in a plane at right angles to the previous section plane and showing the piston at the top of its stroke. As the trunk piston A makes its upward stroke, it creates a partial vacuum below it in the closed crank chamber C, and draws in the explosive charge through B. On the downward stroke the charge below the piston is compressed to about 10 lb. pressure in the crank chamber C, the admission through B being controlled by an automatic valve which closes when the pressure in C exceeds the atmospheric pressure. When the piston reaches the lower end of its stroke, it uncovers the exhaust port K and at the same time brings the admission port D in the piston opposite the by-pass opening E E E, and permits the compressed charge to enter the cylinder G through the automatic admission valve *f* as soon as the pressure in the cylinder falls below that of the compressed charge. The return of the piston shuts off the admission through E and the exhaust through K and compresses the charge into the clearance space. The charge is then exploded (Fig. 43) and the piston makes its down or motive stroke. Near the end of the down stroke, after the opening of the exhaust port K, the admission of the charge at the top of the cylinder sweeps the burned gases out, the complete escape being facilitated by the oblique form (Fig. 42) of the top of the piston. The engine is so designed that the piston on its return stroke covers the exhaust port K just in time to prevent the escape of any of the entering charge. The processes described above and below the piston are simultaneous, the upstroke being accompanied by the admission below the piston and compression above it, while the down stroke has expansion above the piston and a slight compression below it. The very short interval of time between the beginning of the exhaust and the admission of the new charge (which enters as soon as the pressure in the cylinder has fallen enough to permit the admission valve to open), makes premature ignition of the charge, or *back firing*, of not infrequent occurrence. If

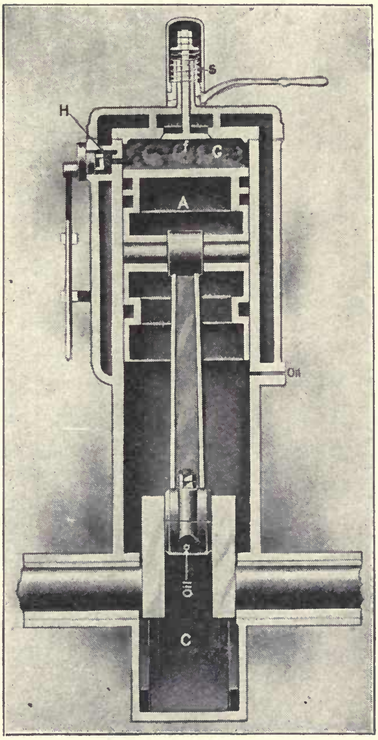


Fig. 43. Smalley Two-Cycle Engine.

the mixture is weak, or the speed is very high, so that the charge is still burning when the exhaust opens, or if the frequency of the explosions bring any part of the cylinder to a red heat, the charge will be ignited on entering, and the explosion then travels back through E E E to the crank case, which has to be made strong enough to resist it. In large engines the charge is compressed by a separate pump and not in the crank case. A modification of this engine makes the construction even more simple, so that the only valve on the engine is the automatic valve admitting the charge to the crank case. In this engine (Fig. 44) the series of operations is precisely similar to that just described. The only difference is in the by-pass connection E, which has no valve between it and the cylinder. The exhaust is made to open a little earlier than the admission, so as to make sure that the pressure in the cylinder shall have fallen below the pressure of the slightly compressed charge when the admission port opens. If the opening of the exhaust and admission ports were simultaneous, as in the engine just described, some of the exhaust gases would force their way through E to the crank case, igniting the charge there. The piston is so shaped that the entering charge is directed to the top of the cylinder, forcing out the burned gases before any of the charge can escape through the exhaust port.

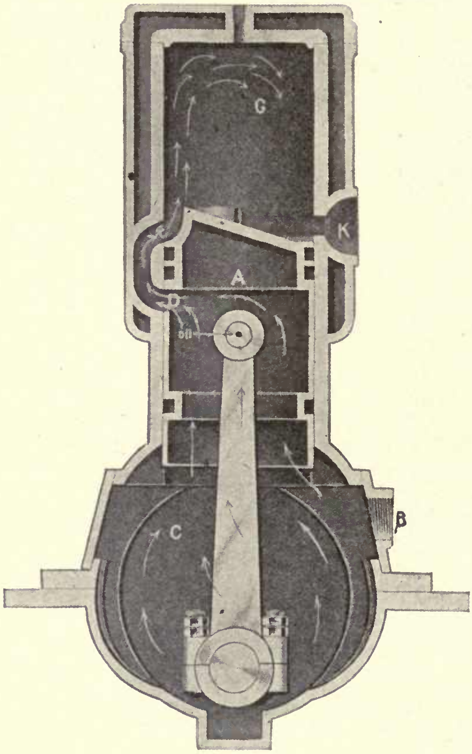


Fig. 44. Smalley Two-Cycle Engine.

The fact that the exhaust port is open while admission is taking place makes it always possible in a two-cycle engine that some of the charge may be lost through the exhaust. If the exhaust closes early, so as to diminish the probability of such loss, it will cause the retention in the cylinder of an unnecessarily large volume of burned gases, with consequent decrease in power and efficiency. The two-cycle engine may then be regarded as a modification valuable from the point of view of the more uniform turning movement, compactness and simplicity, but it is always likely to be inferior in efficiency. In some large engines the air and the gas are compressed separately; air alone is admitted at first, expelling the exhaust gases, and then the gas valve opens, admitting gas with the air. In this way the cylinder can be thoroughly scavenged and the exhaust be closed before any of the explosive charge reaches it.

**Gas Engine Fuels.** The fuels used in gas engines are very variable in origin, in composition, and in heat value. They consist almost entirely of various compounds of the chemical elements of carbon, hydrogen and oxygen, diluted with more or less nitrogen. In those regions where *natural gas* occurs, that fuel is used almost exclusively in the gas engine; but in most regions the gas has to be made either from solid or from liquid fuels. The use of liquid fuels will be considered later in connection with the discussion of the oil engine. In most towns of moderate size there is available *illuminating gas* made from coal. The illuminating gas is made by one of two processes giving either *coal gas* or *water gas.*

**Coal Gas** is made by heating the coal in a retort away from contact with the air, so that no combustion takes place. The hydrocarbon gases in the coal are driven off by the heat, and after undergoing various purifying processes, are collected in a holder. The non-volatile part of the coal remains as coke. The gas consists mainly of hydrocarbons and has a high heating value.

**Water Gas** is made from a non-gaseous fuel such as anthracite coal or coke, by an intermittent process. Air is blown through a bed of coal several feet thick until the coal is incandescent, the products of combustion being permitted to escape. Then a jet of steam is blown through the incandescent fuel, and is thereby broken up into its constituent elements—hydrogen and oxygen.

The oxygen combines with the carbon of the fuel to form carbon monoxide, CO; the hydrogen goes off unchanged. The passage of the steam quickly cools the coal, and air has to be blown through again. The only gas collected is that generated during the steam blow; it consists principally of hydrogen and carbon monoxide, and has a much lower heating value per cubic foot than coal gas. The whole of the coal is consumed in this process.

Both coal gas and water gas are excellent fuels for use in a gas engine, but as they have gone through certain processes for cleansing them and increasing their illuminating power, which increase the cost of the gas but do not add materially to its value for gas engine use, and since also the cost to the consumer is considerably greater than the cost of production, they are not economical fuels. Such fuels should be used only when the engine is very small or its operation very infrequent.

For engines of 50 H.P. or over, which are in regular operation, it is practically always more economical to generate the gas in a special *gas producer* than to use illuminating gas. In the gas producer either air alone, or generally both air and steam, are sent through a thick bed of coal. The oxygen of the air on first striking the zone of the incandescent coal combines with the carbon to form carbon dioxide, $CO_2$, but this on passing through the burning coal above, is reduced to carbon monoxide, CO, which escapes with the hydrogen and carbon monoxide resulting from the action of the steam on red hot coal, and with the nitrogen which came in with the air. The resulting gas therefore consists almost entirely of carbon monoxide, hydrogen and nitrogen. The large amount of nitrogen in the air (79 volumes in 100) makes the producer gas contain fifty per cent or more of that inert gas, and consequently gives it a low heat value.

A good example of a gas producer is shown in Fig. 45 under working conditions. The bed of coal, several feet thick, rests on a bed of ashes of about equal thickness, the ashes being supported on a solid circular table *a*. The blast pipe *b* terminates near the top of the bed of ashes, the blast being discharged radially so as not to concentrate the combustion. The blast is generally produced by a steam jet blower, but sometimes a fan blower is used. In the latter case steam is mixed with the air in the blast pipe so as to keep down the temperature of the producer and to soften any clinkers that form. Fresh coal is supplied by a continuous automatic feeding device on top of the producer, which spreads the coal in a uniform layer over the upper surface. In many producers the coal is merely dumped in from above at intervals, and has to be spread by hand. The intermittent charging has the disadvantage that it causes considerable variation in the condition of the fire, and consequently in the composition of the gas generated. The bed of ashes is maintained of the desired depth and the surplus ashes removed by rotating the grate *a* by means of gears worked through the crank *c*. As the grate is placed at some distance below the conical casing or *bosh*, the ash discharges uniformly around its periphery when it is revolved. This causes a uniform settling of the bed of ash, and also lets the bed of fuel settle so as to close up any channels in it which have been formed by the blast.

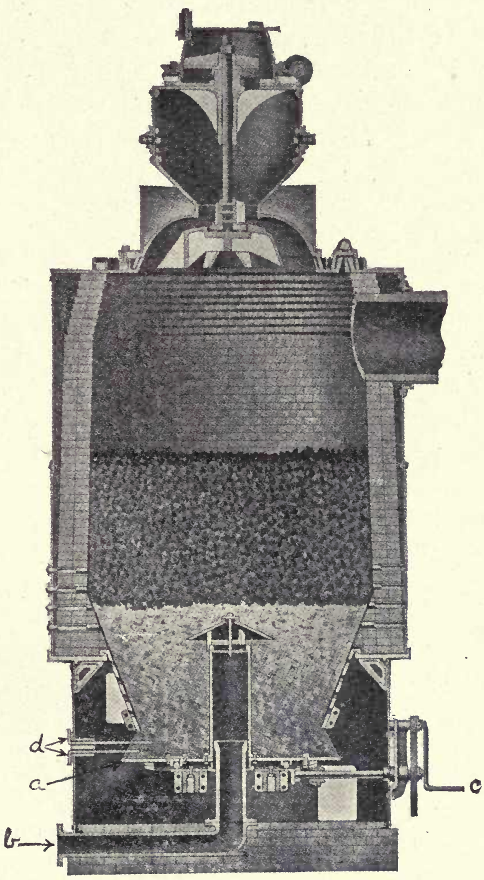


Fig. 45. Taylor Gas Producer.

The scrapers *d*, projecting a short distance into the ash bed, help the discharge of ash from the grate. The depth of the bed of ashes ensures that the ash is completely burned and cooled before it is finally discharged.

**Producer Plants** are of two kinds, according as the flow of air through the producer is caused by air being forced in from below or by a partial vacuum being created above the fuel. The former is called a *pressure plant*, the latter a *suction plant*.

The general arrangement of the *pressure type* of producer gas plant is shown in Fig. 46, in which the arrows indicate the direction of flow of the gas. A small boiler supplies steam to the blower. The gas escapes from the producer at a high temperature and goes to an economizer, where it gives up much of its heat either to fresh air, which is about to be forced through the producer, or else to water, the vapor from which mixes with the air. The gas then passes to the scrubber, where it meets a spray of cold

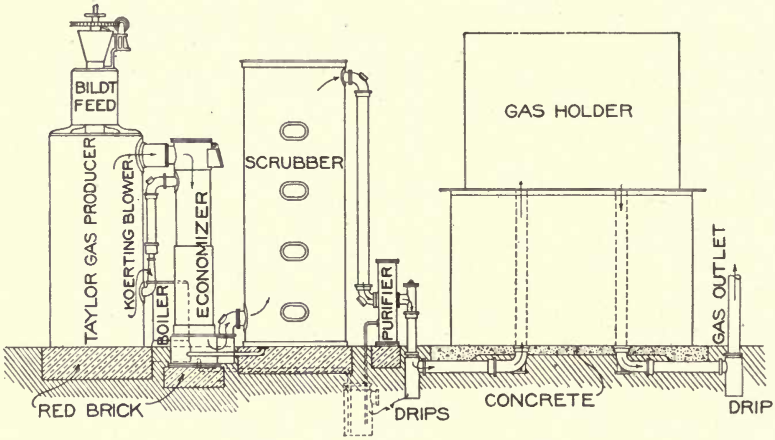



Fig. 46. Producer Plant—Pressure Type.

water, which further cools it and takes from it dust and solid impurity, after which it goes to the purifier for the extraction by chemical process of certain undesirable components and for the completion of the removal of solids, and thence to the gas holder. If anthracite coal or coke are used, very little chemical purification is necessary; if bituminous coal is being burned, the cleaning is somewhat more complicated, as the tar and other troublesome substances in the gas have to be extracted before it can be used.

The *suction type* of gas producer plant can be used only when the operation of the engine is continuous for long periods. It has considerable advantage over the pressure type in compactness, but is rather troublesome to start. The flow of air and vapor through the fuel in the producer or generator (Fig. 47) is dependent on the sucking action of the engine each time it takes in a charge, so that no boiler is needed to produce the blast. The volume of gas generated is always equal to the amount that the engine uses, so that no gas holder is required between the producer and the engine, its place being taken by a small gas tank. To start the producer working, a small hand or belt-driven blower is used, and the products of combustion are sent past a by-pass valve directly to the atmosphere until the escaping gas will burn steadily. The by-pass valve is then closed, and the gas is forced through the scrubber

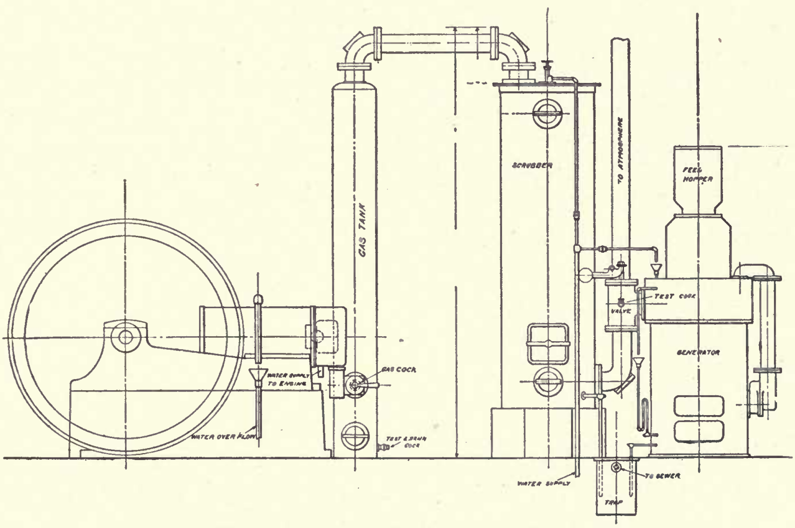



Fig. 47. Producer Plant—Suction Type.

and purifier into the gas tank and the whole apparatus is filled with gas. When good gas appears at a test cock near the engine, the engine is put in operation and the blower is stopped, its function being performed thereafter by the engine. The hot gases escaping from the generator go first through an economizer or vaporizer (not shown in Fig. 47), and the steam formed there is conducted to the under side of the grate of the producer and is sucked through with the air.

Owing to the resistance offered by the fuel, scrubber, and other parts of the plant to the passage of the gas, its pressure on reaching the engine is considerably below the atmospheric pressure. This causes a decrease in the weight of the charge taken to the engine, and so makes the power of the engine less than when pressure gas is used. In order to get the high compression which is necessary to ensure ignition with a weak gas supplied at a low pressure, the clearance in the engine using suction gas is smaller than in other engines using the same cycle. It is not safe to use such an engine with illuminating gas, as the pressures resulting from explosion would be excessive. When in some cases illuminating gas is used to start the engine, a special device is used to exhaust some of the charge during the compression period, and so to reduce the compression pressure.

An efficient producer of either the pressure or suction type will waste not more than fifteen to twenty per cent. of the heat of combustion of the coal in converting it into gas—that is, the gas on burning will give up eighty to eighty-five per cent. of the heat of combustion of the coal. Its efficiency exceeds that of a steam boiler. If the gas produced is a weak one, it is produced in greater volume, and it has to be mixed with a much smaller volume of air than is required for illuminating gas. For example, ordinary coal gas must have at least six parts of air to one of gas, whereas producer gas requires a minimum of about one-and-a-quarter parts of air to one of gas.

The heat liberated by the combustion of a cubic foot of each of the gases discussed is as follows:

| | | |
|---|---|---|
| Natural gas | 900 – 1000 | B.T.U. |
| Coal gas | 650 – 700 | " |
| Water gas | 300 | " |
| Producer gas | 120 – 150 | " |

The power which can be developed in an engine does not depend upon the heat of combustion of a cubic foot of the fuel but on the heat of combustion of a cubic foot of the explosive mixture. The difference in the amounts of air necessary for combustion with the different gases makes the heats of combustion per cubic foot of the explosive mixture much more nearly equal than the heats of combustion per cubic foot of the fuel. Thus, when mixed with just sufficient air for complete combustion, natural gas, coal gas, and water gas will all give up about 90 B.T.U. per cu. ft. of the explosive mixture, while producer gas gives up about 65 B.T.U. An engine will consequently develop about the same power whether using natural gas, coal gas or water gas; with producer gas it will develop considerably less power.

**Blast Furnace Gas.** Besides the gases produced from solid fuels for illuminating or power purposes, there are waste gases escaping in many industrial processes (notably in the production of pig iron) which have considerable heat value. These gases have been utilized by burning them under a boiler for the generation of steam, but they are generally satisfactory, after cleansing, as fuels for a gas engine, and when so used give three or four times more power than when used for steam generation. The gases escaping from a blast furnace have a heat value of about 100 B.T.U. per cubic foot. Even when the gas is so poor that it will not burn under a boiler, it can be made to burn satisfactorily in a gas engine because of the high compression to which it is subjected.

**The Care of a Gas Engine.** For the successful operation of a gas engine intelligent care and accurate adjustment are necessary, and also an understanding of the processes going on in the cylinder. It sometimes happens that the engine fails to start, although the ordinary starting operations have been carried out faithfully. The most common causes of this difficulty are incorrect strength of mixture, failure of ignition and leakage of the charge. The setting of the gas valve which gives a satisfactory mixture one day may give a non-explosive mixture on the following day as a result of variation of pressure of the gas or other change. The strength of the mixture should be varied in case of failure to start. If this is ineffective, the ignition should be tried. The batteries may have run down as a result of much use or of short circuiting, and should be tested by short circuiting momentarily, when they should give a bright spark. Too strong a current is undesirable, as it burns the contact points rapidly. It is well to have on hand a spare set of cells for putting in circuit. There should always be a switch in the battery circuit, which should be thrown out when the engine is shut down, so as to prevent short circuiting. If the battery is in good condition, the trouble may be with the electrodes, either by their having become fouled or wet, or, in the make-and-break system, by a gumming of the spindle of the moving electrode which makes it sticky and slow in action. The igniter plug should be withdrawn and the electrodes examined. The whole igniter circuit should be examined for short circuits.

If the trouble is not with the igniter it may be caused by leakage of the charge. To test this, the engine, if not too large, is pulled over by hand. The resistance to turning on the compression stroke should be very considerable. If the resistance is not very great, or decreases, the compressed charge is escaping. The leakage may be either past the piston, the igniter plug or the valves. If the leakage is past the piston, it is either due to the wearing of the cylinder or to the sticking of the piston rings. The latter is very liable to occur after a while, especially if the cylinder has been permitted to get very hot, and can be remedied by taking the piston out and loosening and cleaning the rings with kerosene. A leakage past the valves is due either to gumming of the valves or to other deposit which keeps the valve off its seat, to wearing of the valve, or to sticking of the valve stem in its guide as a result of imperfect lubrication. The gumming and wear of the exhaust valve is the most common of the causes of leakage and may be remedied by grinding the valve on its seat with flour of emery and oil.

The presence of water in the cylinder, which has leaked in from the jacket through imperfect joints, sometimes causes the electrodes to become wet and prevents the engine starting. In some engines the possibility of this particular trouble is avoided by a special design of the jacket which has no joints communicating with the inside of the cylinder.

The cylinder oil that is used in steam engines cannot be used in gas engines, as it carbonizes at the high temperature of the explosion, and forms a deposit in the cylinder and on the exhaust valve. A much lighter oil is used, and even this if supplied in excess causes a gradual accumulation of hard deposit in the cylinder which must be cleared out occasionally. Apart from its interference with the action of the igniter and exhaust valve, it is liable to cause premature ignition by being raised to incandescence.

Cold water must be kept circulating through the jackets whenever the engine is running, being started as soon as the cylinder warms up. A stoppage of this flow, even for a comparatively short time, is liable to have a disastrous effect upon the cylinder. A gradual accumulation of sediment may occur in the water jacket, with a consequent reduction in its efficiency. On shutting down, it is always better to drain the jacket, which not only prevents the possibility of its freezing up in winter, but also tends to clear it of deposit of sediment. Generally, however. the jackets are drained only in cold weather.

In the running of a gas engine—especially under light loads—very loud and alarming explosions are sometimes heard in the admission pipe or in the exhaust pipe. The *back firing* in the admission pipe nearly always results from a leaky admission valve. The explosions in the exhaust, indicating as they do the presence of explosive gases in the exhaust pipe, are caused either by the use of a mixture which is too weak or by faulty ignition. If the mixture is too weak, the charge taken in just after an explosion may fail to ignite because it is mixed with the products of the previous explosion, while the next charge taken in may explode because it does not mix with burned gas but with the weak charge in the clearance. The hot exhaust gases ignite the weak mixture which was rejected unburned to the exhaust at the previous cycle. If the ignition is imperfect, a good mixture may fail to explode and be exhausted, and then ignited in the exhaust pipe by the next exhaust of hot gases.

**Large Gas Engines.** A very rapid development has taken place in the size to which gas engines are built until they are now made as powerful as the largest steam engines. To obtain large powers and to get the desired uniformity of crank shaft movement, multi-cylinders and multi-cranks are commonly used. When double-acting cylinders are used, the piston being subjected to high temperatures on both sides, becomes too hot unless there is a circulation of cooling water within it. If the piston is to be water-cooled, the piston rod is made hollow and is furnished with an internal tube. A water pipe is attached to the piston rod near the crosshead, by means of swing joints, and a current of water flows through the internal tube to the piston, circulates through it in a regular path, returns along the annular space around the internal tube in the hollow rod and escapes through other pipes with swing joints.

To obtain an impulse each stroke from a single cylinder engine (Fig. 48) a two-cycle double-action engine may be used. In this engine the exhaust occurs by the uncovering of the ports in the middle of the cylinder when the engine is near the end of its stroke. The air and gas that are to be admitted are compressed separately in the cylinders B and A respectively. When in consequence of the opening of the exhaust, the pressure in the cylinder falls below that to which the air is compressed, air enters

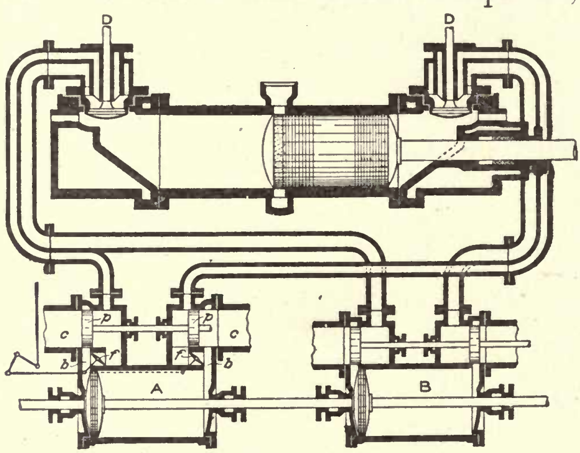



Fig. 48. Koerting Gas Engine.

through the automatic valve D at the top of the cylinder, and rushing toward the exhaust port, sweeps the cylinder clear of burned gas. The gas admission valve opens immediately afterwards, and an explosive charge enters; but before this can get to the exhaust port, the return of the piston stops the exhaust. In this way the cylinder is kept clear of burned gases without the loss of any of the entering charge. The propagation of the explosion in the cylinders of large engines is comparatively slow, so that two or more igniters are sometimes used so as to start the explosion in several places simultaneously.

**Fuel Consumption.** The consumption of fuel in a gas engine running at its rated load when natural gas is used, is from 13 to

17 cu. ft. per B.H.P. per hour; with coal gas 15 to 19 cu. ft. per B.H.P. per hour, and with producer gas about $1\frac{1}{4}$ lb. of coal per B.H.P. per hour. These are average good results; large engines show higher economy than smaller engines and have given a B.H.P. with a consumption of 1 lb. of coal per hour.

**Oil Engines.** The fuel used in oil engines is generally *crude petroleum* or some of the oils derived from it by the process of refining. Crude petroleum is not a simple chemical substance, but is a mixture of a very large number of different hydrocarbons having widely varying properties. If crude petroleum is slowly heated, it gives off as vapor its various constituent elements, the more volatile being given off at the lower temperatures, and the residue becoming continuously more dense and more viscous. In the refining of petroleum the vapors given off at various temperatures are condensed and collected separately, and the names given to the various products are an index chiefly to the temperature at which they give off their vapors. The most volatile of the ordinary products contains all the elements that vaporize at a temperature below 160° F., and is called *gasoline*. It gives off some of its lighter vapors at the ordinary temperature of the air, and as these vapors are highly combustible, gasoline is quite dangerous. When mixed with from eight to twenty parts of air, it forms an explosive mixture, which gives a more rapid explosion and consequently higher pressure than mixtures of equal heat value used in the gas engine. When exposed to the air, the lighter vapors escape, leaving behind a heavier and less volatile oil.

If petroleum which has been heated for some time at 160° is slowly raised in temperature to 250° F., a new and heavier series of vapors will be given off, which, when condensed and collected, are called *benzine* or *naphtha*. On still further raising the temperature from 250° F. to 350° F., a still heavier series of vapors is given off, forming the oil known as *kerosene*. Kerosene will not give off inflammable vapors till it is heated to about 120° F., so that it is comparatively safe and also will not change or deteriorate when stored under ordinary conditions. It is more difficult to burn satisfactorily than is gasoline, and when subjected to a high temperature with insufficient air for its combustion, it decomposes and deposits its carbon as a hard cake on the walls of the containing vessel. The dense petroleum which remains after the kerosene has been driven off is called *fuel oil.* If the fuel oil is subjected to still higher temperatures other and denser vapors are driven off, giving when collected *lubricating oils*, *cylinder oil* and *paraffine wax*, leaving finally a dense sticky mass which is known as *residuum.* The various oils can be distinguished in a general way by their densities, that is, their weights as compared with the weight of an equal volume of water. The density of gasoline is about .65, of kerosene about .80, of fuel oil about .82, of lubricating oils up to .92. If it is stated that an engine uses .76 kerosene, it means that the density of the kerosene is $\frac{76}{100}$ of that of water.

Crude petroleum, gasoline, kerosene and fuel oil are all used in oil engines. The cycle of operations through which the engine goes and the general structure of the engine may be the same for all these oils as for the gas engines already discussed; the only essential difference is in the addition of devices for supplying the oil to the cylinder and for its preparatory treatment.

Oil engines may be divided into two classes:

1. Those that convert the oil into a fine spray or a vapor before admitting it to the cylinder.

2. Those that deliver the oil to the cylinder in the liquid form.

**Gasoline Engines.** When gasoline is used, the vaporization is brought about by passing a current of air over or through the oil; the air escapes enriched with vapor of gasoline, and is said to be *carbureted.* The vessel in which the process takes place is called a *carburetor.* The carbureted air is too rich in fuel to be explosive, so that a further addition of air is necessary at the cylinder. The vaporization of part of the oil results in a lowering of temperature of the main body of the oil, and this reduces its volatility. In order to carry out the process satisfactorily with a uniform quality of the carbureted air, it is customary to heat the carburetor. This may be effected by making use of the heat either of the exhaust gases or of the escaping jacket water. The latter is more common with gasoline. A further advantage of moderate heating of the carburetor is that the denser constituents of the gasoline then become more volatile, so that the passage of the air through the oil does not result in depriving it of its lighter constituents and in leaving a residue too dense to be used.

The carburetor shown in Fig. 49 consists of a vertical cylinder surrounded by a water jacket. Gasoline is pumped to the top of the cylinder and, passing through a spraying device, falls in a finely divided state. It meets an upward current of air drawn in through inlets at the bottom by the suction of the engine cylinder. The carbureted air goes from the top of the carburetor to the engine, while any unvaporized gasoline drains to the suction side of the gasoline pump and is returned later to the carburetor. The water jacket has circulating through it some of the heated jacket water from the cylinder. The actual temperature of the jacket is controlled by a thermostat which varies the amount of water circulating.

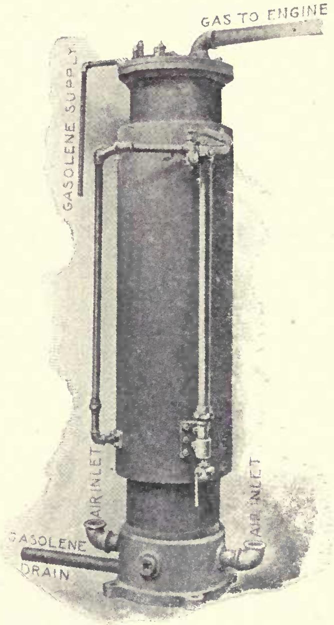


Fig. 49. Westinghouse Carburetor.

Gasoline is very fluid and atomizes completely when injected into a pipe through which a current of air is passing. The air in that case carries the gasoline with it, partly in the form of a mist and partly vaporized. This process is largely used in gasoline engines, and is illustrated in Fig. 50, which shows the whole arrangement of a gasoline plant. The gasoline tank is buried below the floor level and outside the building, so as to reduce the danger in case of fire or explosion, and also so that there can be no leakage of gasoline from the pipes when the engine is not running. The gasoline is taken through a strainer near the bottom of the tank and through the suction pipe by the action of a gasoline pump, which is worked from the cam shaft. It is then forced through the control valve A and is sprayed into the air pipe N through the jet H whenever the fuel admission valve G opens. A vertical branch of the discharge pipe from the gasoline pump has an overflow connecting with the tank. The pump always delivers more gasoline than is required, the excess being returned to the tank through the

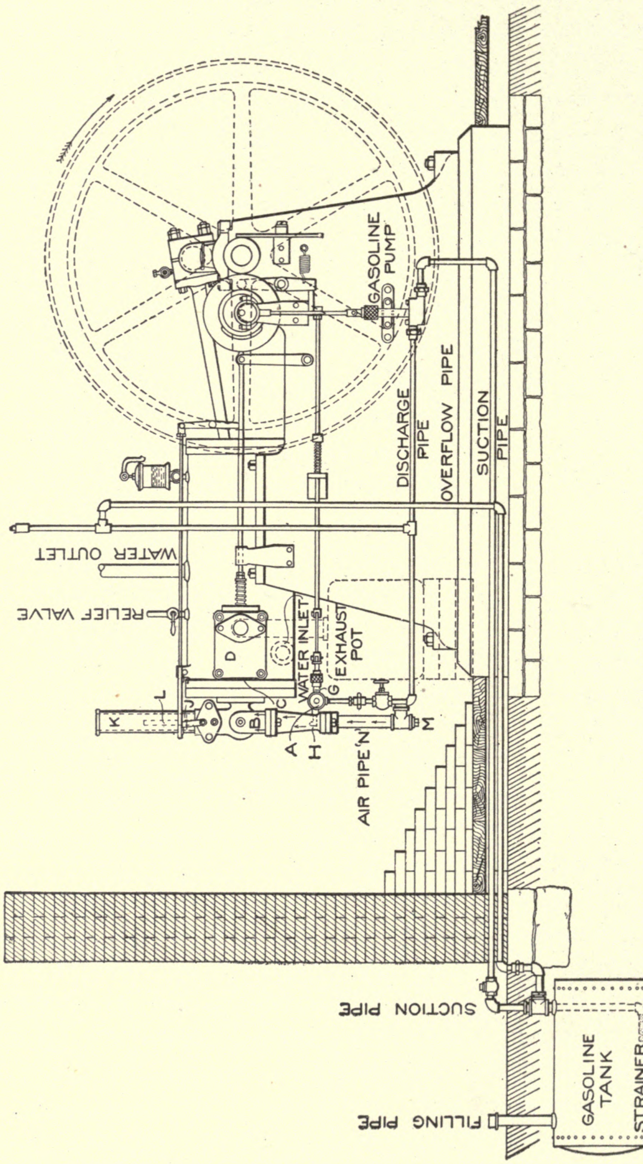



Fig. 50. Charter Gasoline Engine.

overflow pipe. This maintains a constant pressure of the gasoline depending only on the constant overflow level. With a given opening of the control valve A and a constant head on the gasoline, the amount of gasoline admitted each time remains constant.

An engine using gasoline is usually provided with a clearance space somewhat larger than that used in a gas engine, so as to prevent excessive pressures during explosion. The indicator card, Fig. 51, shows the rapidity and force of the explosion in a gasoline engine.

**Kerosene and Crude Oil Engines.** When kerosene or heavier oils are to be burned, different methods from those described for gasoline must be used. The kerosene is generally broken up in the carburetor into a fine spray or mist by a current of air; it is then sent to a vaporizer before being admitted to the cylinder. In the vaporizer the carbureted air is raised to a high temperature, the heat of the exhaust gases being utilized for this purpose, and the kerosene is converted into a vapor. Unless the kerosene is completely vaporized before admission to the cylinder, it is difficult to ensure its complete combustion. Some of the liquid kerosene in the cylinder *cracks* or breaks up into its elements as a result of the very high temperature to which it is subjected, and the carbon deposits itself on the piston and walls of the clearance space as a hard coating. The temperature in the vaporizer is not sufficient to crack the oil.

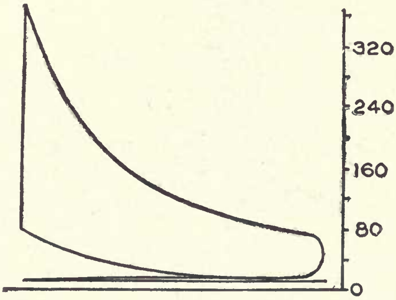


Fig. 51. Indicator Card of Gasoline Engine.

In some cases the carburetor or spraying device is omitted and the oil is pumped directly into a vaporizer or generator which converts the liquid into a vapor. A device of this kind for burning heavy crude oil, such as is found in the Texas oil fields, is shown in Fig. 52. The generator G is placed close to the engine so that the hot exhaust gases coming through the pipe N shall not be cooled before reaching it. The oil pumped by the engine goes through the pipe F to the small reservoir R on top of the generator, any excess returning by the overflow pipe O to the main supply tank. The amount of oil entering the generator is controlled by the throttle valve T at the reservoir R. The oil trickles down over surfaces which are heated by the exhaust gases and is partly or completely vaporized. Any unconsumed residue drains off through the cock D at the bottom of the generator. The temperature in the generator is regulated by a heat valve E, which may be set so as to circulate all or any part of the exhaust gases

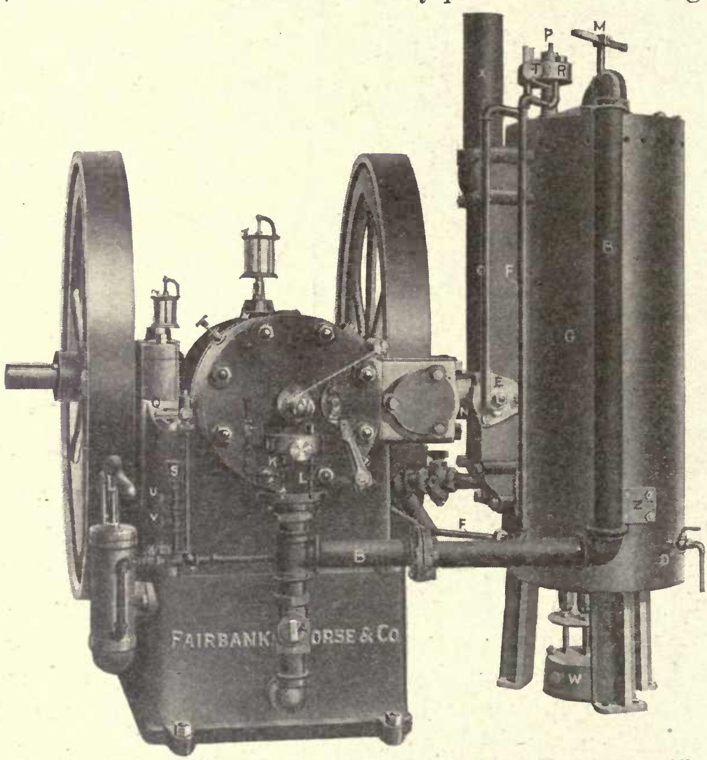
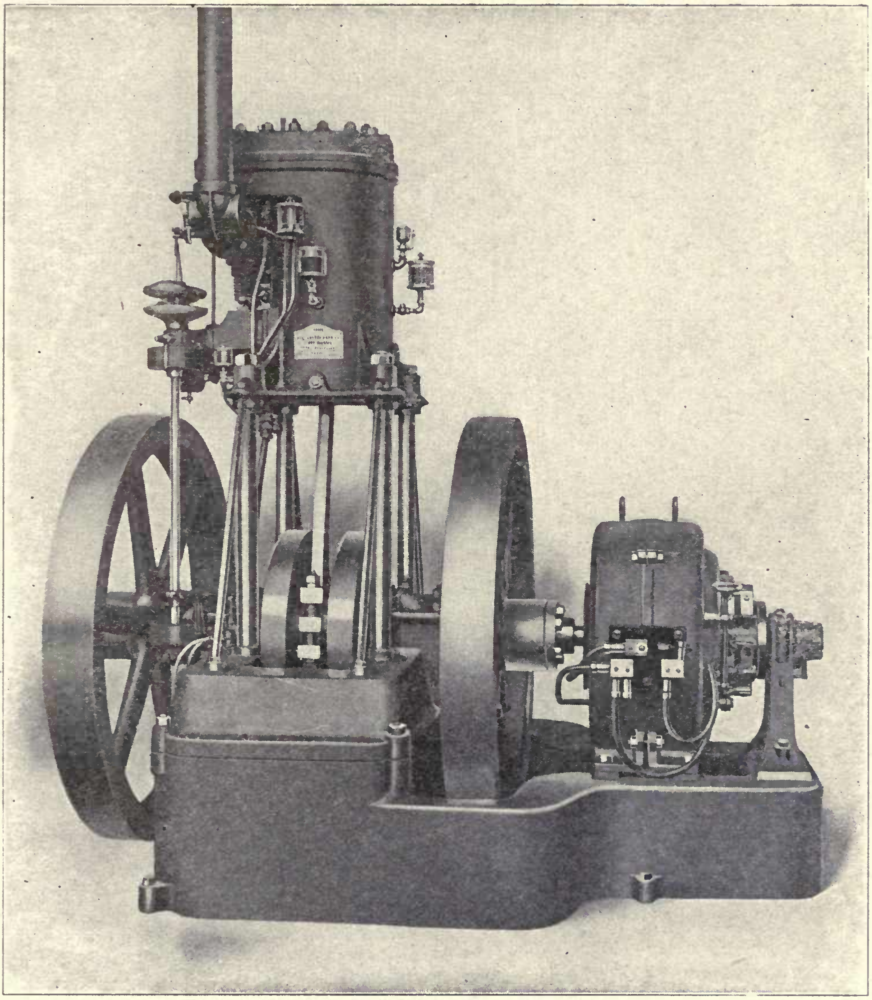



Fig. 52. Fairbanks-Morse Engine Arranged for Burning Heavy Crude Oil.

through the heating coil of the generator, the rest being sent directly to the exhaust pipe X. Air is drawn into the lower part of the generator through the pipe C, and the mixture of air and vapor leaving the top of the generator by the pipe B, meets a fresh supply of air arriving through the valve A before being admitted to the cylinder. When kerosene is to be used, the generator is very much smaller, but the general arrangement is similar



**15 KILOWATT, 250 LIGHT.**
Secor Oil-Electric Generating Plant.

Kerosene and the heavier oils can be used in oil engines without preliminary vaporization. One of the methods of accomplishing this is illustrated in Fig. 53, which is a longitudinal section of an engine using kerosene or crude oil. A combustion chamber or vaporizer A is attached to the end of the cylinder and communicates with it through a narrow neck B. The outer part of the vaporizer is unjacketed, and consequently is kept at a good red heat by the successive explosions. The engine follows the usual four stroke cycle. During the admission stroke air alone is admitted to the cylinder, while oil is injected into the combustion chamber and is vaporized there. During the return stroke the air is

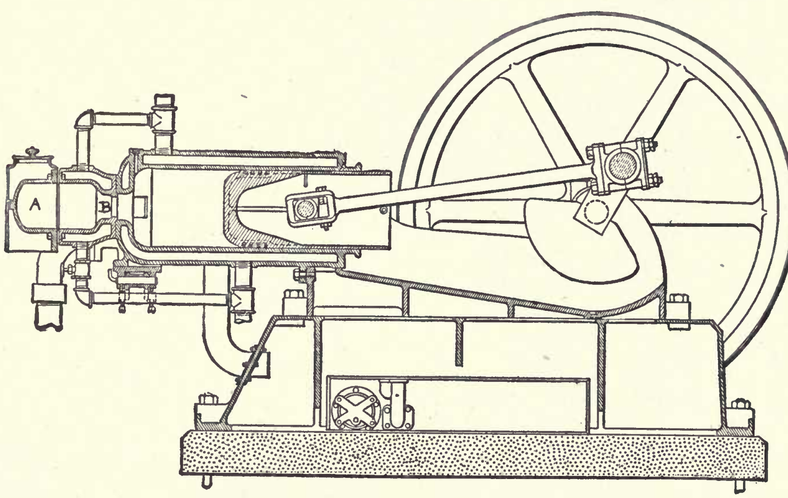



**Fig. 53. Hornsby-Akroyd Oil Engine.**

compressed into the vaporizer, mixes with the oil vapor and forms an explosive mixture which is ignited by the hot walls of the combustion chamber. The proportions of the combustion chamber are designed so that the explosion does not occur till near the end of the compression stroke. The fuel supply is regulated by the governor, which controls a by-pass permitting part of the discharge from the pump to return to the suction side. Before starting the engine the combustion chamber must be raised to a bright red heat by an external heater; but after starting, it is maintained in that condition by the explosions. The engine is of great simplicity since it dispenses with both igniter and mixing valve. The combustion chamber becomes coated with a deposit of carbon resulting from the cracking of the oil at the high temperature, but it is easily removed for cleaning.

**The Diesel Cycle.** All the engines discussed so far have operated on the Otto cycle or some modification of that cycle. There is coming into use for crude oil or fuel oil engines another cycle of operations, known as the Diesel cycle, which merits attention because of its high efficiency. The cycle will operate equally well with gas or gasoline, but is naturally used with the cheaper fuels. The Diesel cycle resembles the Otto cycle in requiring four strokes for its completion. The first out stroke draws into the cylinder a charge of pure air alone, without any admixture of the fuel. On the return stroke the air is compressed; and since the clearance in this engine is only about seven per cent of the cylinder volume, the pressure at the end of compression rises to about 500 lb. per sq. in., and the temperature of the air to about 1,000° F. As the high pressure is reached gradually, it does not cause a shock to the engine, such as an explosion to the same pressure would give. At the beginning of the second out-stroke the oil admission valve opens and a charge of oil is blown into the cylinder in the form of a fine spray by a small quantity of air which has been compressed by a special compressor to about 550 lb. The moment the entering oil meets the highly heated air in the clearance space, it ignites and burns. The combustion goes on so long as the fuel is being blown in, usually for about one-tenth of the forward stroke; and since there is no large quantity burning at any instant, there is nothing in the nature of an explosion. Usually the heat generated by the combustion is not sufficient to prevent the pressure in the cylinder falling while the admission is taking place, so that the admission line on the indicator card falls below the constant pressure line as seen in the indicator card, Fig. 54. The method of burning is really essentially similar to that of an ordinary gas burner, and not to that of an explosive mixture, and consequently the oil will burn with any

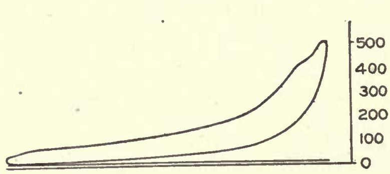


Fig. 54. Indicator Card—Diesel Engine.

excess of air present. After the admission valve has closed, the charge expands and then is exhausted on the return stroke. The indicator card, Fig. 54, shows the cycle of operations.

The general structure of the engine and a detail of the valves are shown in Figs. 55 and 56. The movement of the fuel admis-

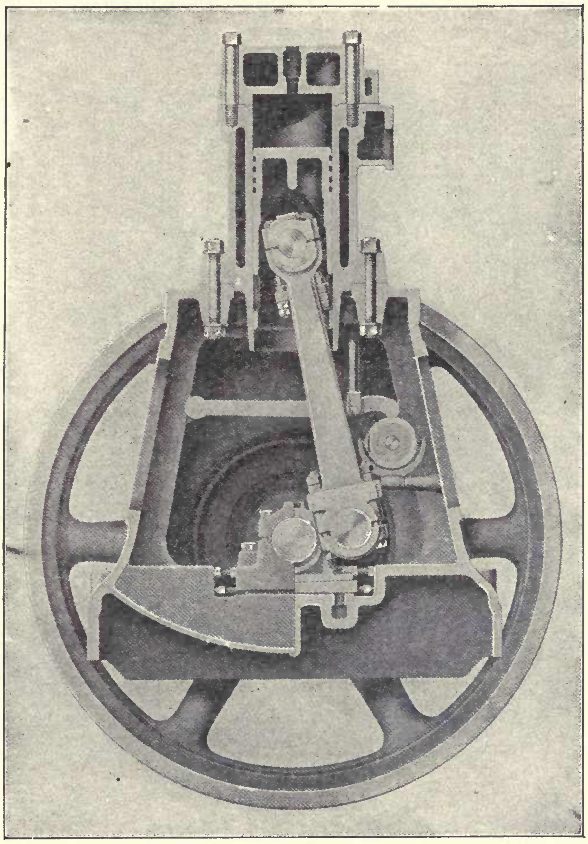


Fig. 55. Sectional View—Diesel Engine.

sion valve is very slight, giving a narrow annular opening for the entry of the oil. Surrounding the valve spindle is a series of brass washers perforated parallel to the spindle by numerous small holes. The oil is pumped into the space around the valve spindle near its middle, and by capillary action finds its way between the washers and into the perforations. The air for fuel injection is admitted through another pipe into the same space, but behind the oil, and because of its high pressure blows the oil into the cylinder when the valve opens. The amount of oil admitted is regulated by the governor which controls the time of opening of a by-pass connecting the discharge and suction sides of the oil pump. At light loads the oil is pumped to the fuel valve for part only of the admission period, and air alone will enter past the valve for the rest of the period. The method of slow combus-

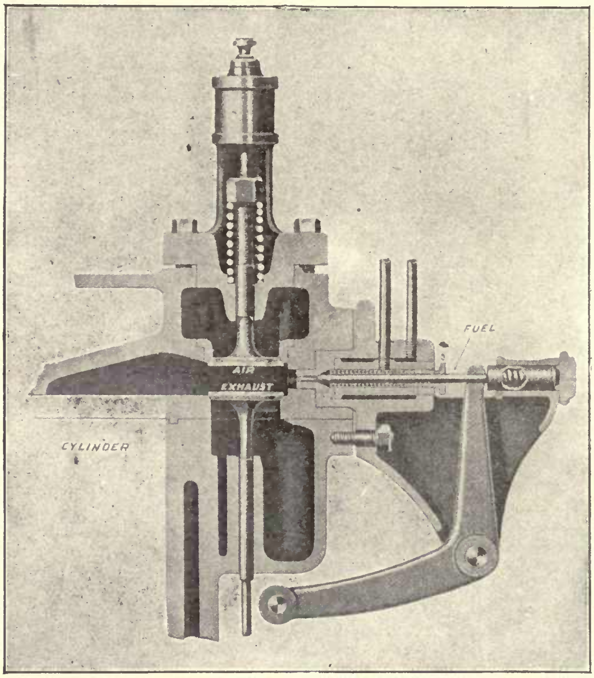



Fig. 56. Valves of Diesel Engine.

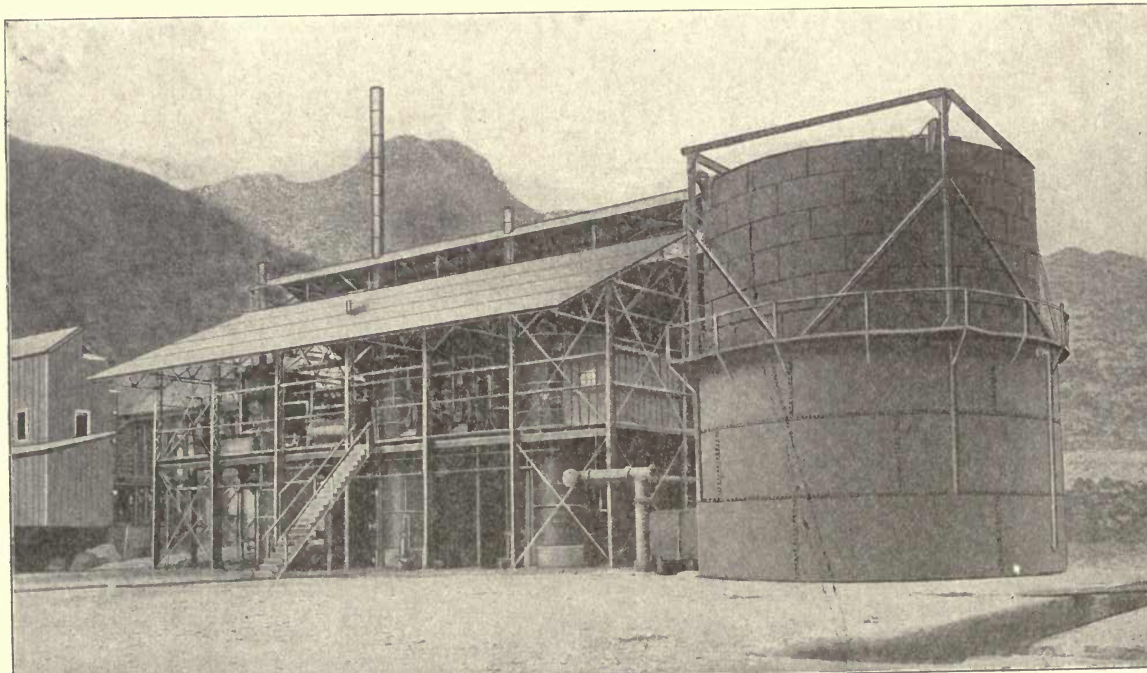
tion in a large excess of highly heated air ensures very complete combustion even with the heaviest oils, so that there is no chance for the accumulation of a carbon deposit in the cylinder. The engine is started by compressed air from an auxiliary reservoir, a special starting valve being used for the purpose. Diesel engines have, under test, converted more than 35 per cent of the heat of combustion of the oil into work done in the cylinder.

**The Care of the Oil Engine.** The same general precautions are necessary in running an oil engine as in running a gas engine, and the same troubles are liable to occur. The starting by hand of a gasoline engine of small size has been described already. If the engine fails to start, it will probably be because either too much or too little gasoline was admitted. The amount admitted for starting must be varied with the temperature of the cylinder. In cold weather about twice the normal amount must be used, while on the other hand, if the engine has been running and has been shut down for a short time only, a considerable diminished charge is necessary.

Great care must be taken by the use of suitable strainers that no solid foreign matter gets into the oil supply pipe, otherwise there is great liability to the obstruction of the flow. Owing to its more rapid explosion and to the greater richness of the explosive charge, a gasoline engine will develop more power than a gas engine of the same size, even when the latter uses natural gas.

**Oil Consumption.** The consumption of gasoline in an engine of small size averages about one-tenth of a gallon per brake horse power per hour. In the Diesel motor the average consumption of crude oil per brake horse power per hour is less than one-tenth of a gallon.

The field for the use of the oil engine is very extended. It is the most compact of the heat engines, requiring nothing equivalent to boiler or gas generator, and consequently is inherently the most suitable for purposes of transportation. Its extensive adoption for driving automobiles and motor boats is being followed by its application to locomotives and to large vessels. The absence of boiler and of heat generator losses makes it both potentially and actually the most efficient of all heat engines. The relative cost of power developed by oil, gas and steam engines depends on the cost of the oil and of coal, and this varies with the locality and the kind of oil or coal. In refining petroleum not more than ten per cent of the oil can be collected as gasoline, so that this oil, which is the most easy to use, is not available in as large quantity, and consequently has a considerable higher cost than the heavier oils. Kerosene forms twenty-five to fifty per cent of the crude oil, and is consequently cheaper. Fuel oil and crude oil are the cheapest, but are also the most difficult to burn satisfactorily.



LOOMIS-PETTIBONE GAS GENERATING PLANT, OF 3000 H. P. CAPACITY

# GAS-PRODUCERS

## INTRODUCTION

Gaseous fuel has long been a desideratum, and many modern industries demand it for their successful operation. Where nature has not supplied it, man has been compelled to make it. The intelligent appreciation of the method of manufacture and of the advantages of gaseous fuels in general, and producer gas in particular, necessitates a clear understanding of certain fundamental facts.

Gases may be divided into three classes: *Elementary, Compound,* and *Mixtures*. Elementary gases consist of one element only—as oxygen, for instance. Compound gases are composed of two or more elements in chemical combination—as marsh gas, for instance, in which carbon and hydrogen are combined. Mixtures are not definite compounds, but consist of two or more elementary or compound gases simply mixed together without any chemical affinity existing between any of the constituents. Producer gas belongs to the class of mixtures. Table 1 shows the composition of a representative sample of producer gas:

**TABLE I**

**Typical Producer-Gas Analysis**

| | | | |
|---|---|---|---|
| Combustible | Hydrogen | 8.0 | per cent |
| | Marsh gas | 3.0 | " " |
| | Olefiant gas | 0.5 | " " |
| | Carbon monoxide | 24.0 | " " |
| Condensible | Tar | 1.0 | " " |
| | Water vapor | 1.0 | " " |
| Diluents | Carbon dioxide | 3.0 | " " |
| | Oxygen | 0.5 | " " |
| | Nitrogen | 59.0 | " " |
| | | 100.0 | |

The proportion of each constituent present will depend upon the nature of the raw fuel, the type of producer, and the method of operation. Water vapor and tar, although generally present, are not usually determined and given in the analysis, since both will nearly always condense within a short distance from the producer. It is evident that the properties of producer gas will be determined by its constituents. That is, the presence of certain desirable or undesirable constituents will give the gas desirable or undesirable properties, and these properties will be proportional to the relative percentage present of the constituents in question. Hence it is desirable to know the properties of each constituent so that its effect on the gas as a whole may be determined.

Hydrogen is the lightest known substance, is colorless, odorless, non-poisonous, very combustible, non-luminous, and burns with a pale blue flame.

Marsh gas, also called methane, is odorless, colorless, has a high calorific power but slow rate of combustion, and burns with a slightly luminous flame.

Olefiant gas, also called ethylene or ethene, has a high calorific power, is colorless and odorless, and burns with a very luminous flame. It is sometimes spoken of as an "illuminant."

Carbon monoxide, also called carbonic oxide, is a deadly poison, colorless, odorless, insoluble in water, and burns with a blue flame.

Carbon dioxide, also called carbonic anhydride or carbonic acid, is soluble in water, odorless, colorless, and non-combustible.

Oxygen is colorless, tasteless, odorless, and its presence in producer gas decreases the amount of oxygen that must be furnished for combustion.

Nitrogen is odorless, colorless, non-combustible, and has no effect on producer gas except to act as a diluent.

Water vapor comes from undecomposed steam passing through the fuel. On account of its high specific heat, it may cause a large heat loss.

The tar in producer gas comes directly from the fuel; it will condense quite easily and will then be precipitated in the pipes.

A fixed or permanent gas is one that will not precipitate any condensible constituents when the gas is cooled. Producer gas should be composed of fixed gases only. The gas will always be cooled after leaving the producer; and, if it contains any condensible constituents, these will be deposited in the pipes; not only will this cause a heat loss but will also give trouble from the clogging of the pipes.

The volume of a gas varies with the temperature and pressure. In order to secure comparable results from different analyses, it is necessary that some definite standard be used. This is known as the *standard condition,* and is taken as 32 degrees Fahrenheit and a pressure of 29.92 inches of mercury—or its metric equivalent, 0 degrees Centigrade and a pressure of 760 millimeters of mercury.

The *specific gravity* of a gas is the ratio of the weight of a unit volume of the gas to the weight of a unit volume of another gas taken as a standard, and at the same standard condition. Hydrogen and air are the standards usually used. With reference to air, the specific gravity of producer gas is about .86.

The *thermal capacity* of a substance is the heat required to raise the temperature of a unit weight of it one degree. The *specific heat* of a gas is the ratio between the thermal capacities of equal weights of the gas and water.

The *sensible heat* of a gas is the heat that it carries by virtue of its temperature. It is equal to the product of the volume of gas and its specific heat per unit of volume.

**TABLE II**

**Combustion Data**

| | Name | Symbol | Atomic Weight | Specific Heat per Cu. Foot | Specific Gravity Air = 1 | Weight per Cu. Foot in Pounds | B. T. U. Evolved per Cu. Foot | Combustion Product |
|---|---|---|---|---|---|---|---|---|
| Combustible Gases | Hydrogen ... | H | 1 | .0194 | .069 | .0056 | 346 | $H + 2O = H_2O$ |
| | Marsh gas... | $CH_4$ | | .0264 | .559 | .045 | 1070 | $CH_4 + 4O = CO_2 + 2H_2O$ |
| | Olefiant gas.. | $C_2H_4$ | | .0289 | .967 | .078 | 1670 | $C_2H_4 + 6O = 2CO_2 + 2H_2O$ |
| | Carbon monoxide.. | CO | | .0193 | .967 | .078 | 342 | $CO + O = CO_2$ |
| Diluent Gases | Carbon dioxide ... | $CO_2$ | | .0265 | 1.529 | .123 | | |
| | Oxygen ..... | O | 16 | .0194 | 1.105 | .089 | | |
| | Nitrogen .... | N | 14 | .0192 | .972 | .078 | | |
| | Water vapor at 212° F.. | $H_2O$ | | .0173 | .469 | .036 | | |
| | Carbon ..... | C | 12 | 1 lb. evolves 4,450 B. T. U. when burned to CO | | | | |
| | Carbon ..... | C | 12 | 1 " " 14,500 " " " " $CO_2$ | | | | |

The *British thermal unit* (B. T. U.) is the amount of heat required to raise one pound of water one degree Fahrenheit. The Centigrade unit (C. U.) is the amount of heat required to raise one pound of water one degree Centigrade.

The calory is the amount of heat required to raise one kilogram of water one degree Centigrade.

The *gram-calory* is the amount of heat required to raise one gram of water one degree Centigrade.

The *calorific power*—or, which is the same thing, the *heating power*—of a gas, is the number of heat units evolved by the complete combustion of a unit volume of the gas.

Gas firing requires that the fuel bed be *thick* and *compact* enough to permit only a partial combustion of the fuel, so that a stream of combustible gas will be given off at the surface of the fuel. Direct firing requires that the fuel bed shall be sufficiently *thin* and *porous* to permit enough oxygen to get through the interstices in the fuel bed to produce vigorous combustion at the surface of the fuel.

## GASEOUS FUELS

A proper understanding of producer gas requires a clear conception of the other well-known gaseous fuels with which it is frequently associated.

*Retort gas* is made by the destructive distillation of coal—*i. e.*, by heating coal in retorts without access of air. The gases are drawn off by an exhauster; the residual coke, which is a by-product, is removed at intervals and replaced by a charge of fresh fuel. The principal use of this gas is for illumination purposes. "Bench," "coal," "city," "illuminating," and "artificial," are some of the terms sometimes applied to this gas.

*Coke-oven gas* is evolved in the manufacture of coke in by-product ovens, and is quite similar in composition and method of manufacture to retort gas. The method of manufacture differs in this respect, that the gas is the by-product and the coke the main product, which is the reverse of retort gas.

*Water gas* is made by bringing steam in contact with incandescent carbon. It consists essentially of hydrogen and carbon monoxide. The fuel is first blown up by an air blast, and then steam is introduced for a short time; this will cause the fire to cool rapidly and necessitates frequent reblowing. As a result, the process is intermittent.

*Carburetted water gas* consists of ordinary water gas into which some hydrocarbons, such as oil or naphtha, have been injected to make the gas luminous.

*Oil gas* is made by vaporizing oil passed through highly heated tubes.

*Blast-furnace gas* is the waste gas evolved in the ordinary blast furnace, which is simply a huge gas-producer. The gas is quite similar to producer gas.

*Producer gas* is the gas resulting from the gasification of solid fuel where the heat required in the process is obtained by a partial combustion of the fuel itself.

From the preceding, it will be seen that producer gas has several competitors. Yet it is the most extensively used artificial fuel gas in existence.

A large amount of experimental and inventive work has been done on the manufacture of gaseous fuels. The path has been strewn with failures, and this field of industrial development has become the graveyard of abandoned fuel-gas processes and shattered hopes of immature and visionary enthusiasts who have not understood the problem in all its phases. There is no such thing as chance or luck in the inventive world. All results are the consequence of the operation of definite laws. The supremacy of one system of fuel-gas manufacture over its competitors must be due to certain definite causes and effects. The proper appreciation of the advantages of producer gas requires that we should know the real reasons why it has been able to surpass all the other fuel-gas processes in the race for commercial supremacy.

A successful fuel-gas process must be *simple, efficient, continuous,* and *flexible.*

Natural gas is restricted to such a limited territory that its extensive use is out of the question. Retort gas requires a definite quality of coal, and a large, complicated plant, and makes a residue which must be disposed of. Coke-oven gas can be made only in a large, complicated plant, and requires the attention of a skilled chemist, and a ready market for the coke. The water-gas process is intermittent, complicated, and not very efficient. The carburetted water-gas process, in addition to having the disadvantages of the straight water-gas process, requires oil for the carburetting. Oil gas is restricted to a very limited territory, since it can be used commercially only where the cost of oil is very low. Blast-furnace gas can be obtained only in connection with the operation of large iron works; hence it cannot be adapted to many localities or conditions.

Producer gas combines simplicity, efficiency, continuity, and flexibility in one compact and harmonious unit. Gas-producers for the manufacture of producer gas are simple in construction; can be used through a large range of sizes; are efficient; do not make a residue to be disposed of; can be used with almost any available fuel; and can be operated continuously. The reasons just given account for the supremacy of the producer-gas process over its competitors.

There has been an unusual demand for a gaseous fuel within the last few years, and this has given the producer-gas industry an unprecedented growth. This demand, and the resulting growth, are due to the advent of the gas engine, the appreciation of the value of gaseous fuel for ceramic and metallurgical operations, and the constant diminution of the natural gas supply. The gas engine, on account of its high efficiency, has many advantages over the reciprocating steam engine or the steam turbine. A gas-engine power plant will give more power from a given amount of fuel than is possible to obtain from a steam power plant. Yet, to be able to compete with the steam engine, the gas engine must be supplied with a suitable and inexpensive gaseous fuel such as we have in producer gas. The highest and most easily controlled working temperatures, perfect combustion—thus eliminating the smoke nuisance—and high fuel economy, are possible only by the use of a gaseous fuel. Since many ceramic and metallurgical operations require such conditions for successful operation, it is evident that an adaptable fuel gas like producer gas has an extensive use in such work. Many industries which in the past have used natural gas for fuel, have started to use producer gas because in many cases the cost of the natural gas has become prohibitive as the supply has diminished.

## HISTORY OF PRODUCER GAS

About 1834, Faber du Faur, a German engineer, began using blast-furnace gas for heating furnaces at a German iron works.

This gave such good results that the demand for the gas was greater than the supply furnished by the furnaces. From this he reasoned that it would be desirable to build a low type of blast furnace, omitting the charge of iron and using the furnace only for the production of gas to supply the increased demand. Circumstances prevented Faber du Faur carrying this idea into practice; but he announced it at that time, and several contemporary engineers began working on the problem. The first gas-producer was probably built by Bischof in 1839. It is shown in Fig. 1, and resembles a small blast furnace. A is the ash-pit under grate B; C and D are cleaning doors, the former being made with openings to admit the air; E is the body of the producer; F and G are doors for charging the producer with fuel; H is the gas exit; I shows a peep-hole for examining the condition of the fire. The producer was connected to a furnace, from which it received the necessary draught.

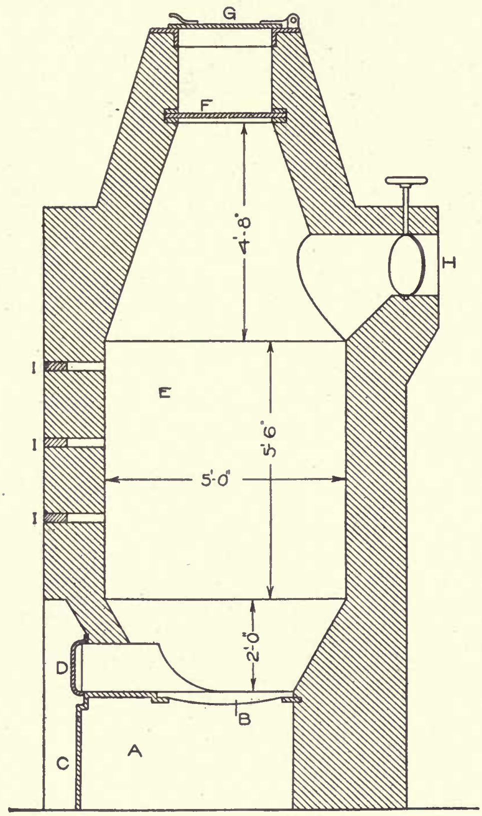


Fig. 1. First Gas-Producer.

Ekman in Sweden, Wedding in Germany, Ebelmen in France, and Siemens in England, were also working on the problem between 1840 and 1860; and they all built certain types of producers. Ebelmen anticipated several present-day types of producers.

The first producer to be used to any extent was the Siemens, which was introduced in England about 1860. This forms the commercial starting point of the producer-gas industry. Dowson, in 1878, was the first to use producer gas for power purposes. The suction gas-producer was introduced on a commerical scale by Benier in France, in 1895.

## MANUFACTURE OF PRODUCER GAS

**Introduction.** The simplest form of producer gas consists of a mixture of nitrogen and carbon monoxide. That is, when a bed of charcoal or coke is blown with a dry air-blast, the fuel bed will soon be at a white heat, when the following reaction will take place:

$$C + \underbrace{(O + N)}_{\text{air}} = CO + N. \qquad (1)$$

In case carbon dioxide is formed, it should be immediately converted into the monoxide, on account of the excess of incandescent carbon. Thus:

$$CO_2 + C = 2CO. \qquad (2)$$

The heat required for gasification is that which is evolved in burning the carbon to carbon monoxide. The heat available in the gas is that which will be evolved when the carbon monoxide is burned to carbon dioxide. The heat loss by this method is very high, as is shown by the following example:

| | | | | |
|---|---|---|---|---|
| 1 lb. C burned to $CO_2$ evolves | 14,500 | B. T. U. | = | Heat in fuel |
| 1 lb. C " " CO " | 4,450 | " | = | " lost |
| | 10,050 | " | = | Available heat in gas (about 70 per cent). |

On account of the high heat loss, the use of simple producer gas is now obsolete. The judicious use of steam will not only curtail this loss, but will also increase the heating value of the gas, and will eliminate some of the difficulties of producer operation. Thus a small amount of water gas is made along with the producer gas. In some producers, the fuel undergoes a partial destructive distillation before going onto the fuel bed proper. Hence, modern producer gas is nearly always made in a trinity of processes, the best features of the retort, water, and producer-gas processes being combined into one simple, continuous, and efficient process. This combination of the best elements of other systems is the secret of the extensive present-day use of producer gas.

**Gas-Producer.** This term is applied to the apparatus in which producer gas is made. It is not, however, very satisfactory, since it fails to be mutually inclusive and exclusive, which is the fundamental requirement of a satisfactory descriptive name. The term is frequently applied to apparatus that is used for making gases other than producer gas. Although evidently unsatisfactory, the term has been in use so long that it is now impossible to replace it with a more rational one.

**Typical Producer.** A typical producer is shown in Fig. 2. It consists essentially of a steel jacket A; fire-brick lining B; support C;

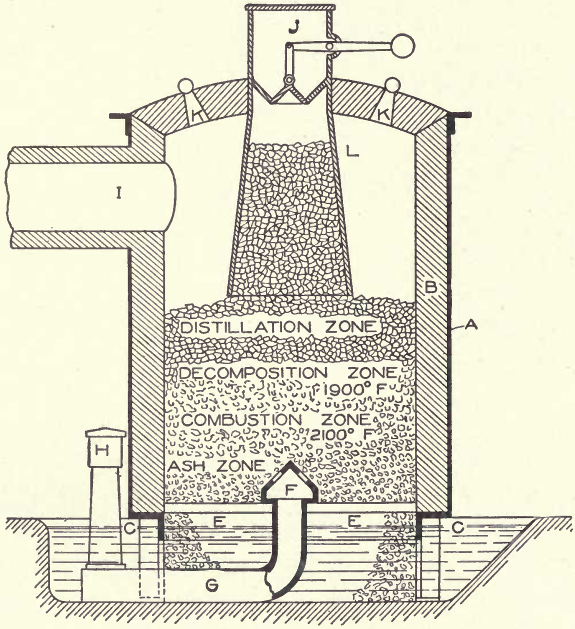



Fig. 2. Typical Gas-Producer.

grate E; tuyère F; air blast H; charging hopper J; poke-hole K; and retort L. In American types, L is usually omitted; but it is used quite extensively in European types. Frequently the grate is omitted and the fuel rests directly on the ash-pan bottom.

**Steam Blowers.** The steam and air should be introduced together so as to secure a thorough admixture. In a large number of producers, the air is forced into the producer by a steam blower, which is simply an air-injector. Since a small quantity of steam must carry in a large quantity of air, the area of the surface of contact between the two should be as large as possible, for "the quantity of air delivered per minute by a steam jet depends upon the surface of contact between the air and the steam, irrespective of the steam pressure, up to the limit of exhaustion or compression that the steam jet is capable of producing." To secure this, the steam jet should be very thin and of annular form. There are two general types of steam blowers—the *solid-jet* type, shown in Fig. 3; and the *annular-jet* type, shown in

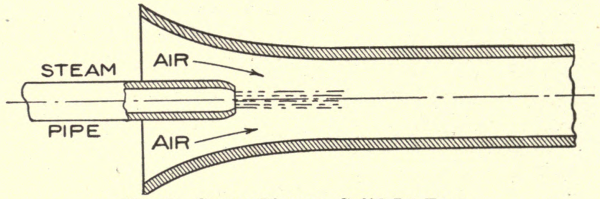



Fig. 3. Steam Blower—Solid-Jet Type.

Fig. 4. Referring to the former, it will be seen that there is a very small area of surface contact between the air and steam; and as a result, this form of blower is very efficient. The annular type will

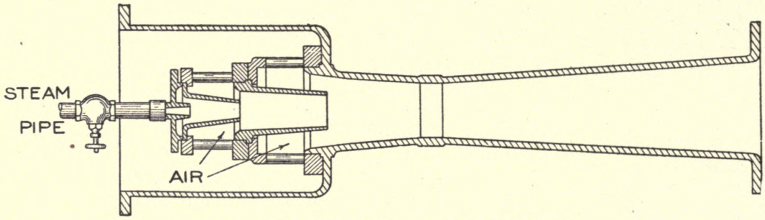



Fig. 4. Steam Blower—Annular-Jet Type.

deliver several times as much air with a unit quantity of steam as the solid-jet type.

**Chemical Action in Gas-Producer.** This is not complicated, and will be understood more readily by considering each successive step. Fig. 2 shows the fuel bed divided into four zones. In practice, the line of demarcation between the different zones is not always distinct, and they sometimes overlap one another.

No reactions take place in the *ash zone*, but it serves to protect the grate from the intense heat of the upper zones, and also preheats the air-blast.

The *combustion zone* receives its name from the fact that the heat required for gasification is generated there by the combustion of the carbon, which burns to carbon dioxide. Thus:

(3) $C + 2\,O = C\,O_2$.

The intense heat generated there keeps the superimposed zone at its proper working temperature.

The *decomposition zone* receives its name from the fact that the steam from the blast, and the carbon dioxide from the combustion zone, are there decomposed. Thus:

(4) $H_2O + C = 2H + CO$.

$(2 + 16) + 12 = 2 + (12 + 16)$ atomic weights.

$(1 + 8) + 6 = 1 + (6 + 8)$ proportion of atomic weights.

(5) $C\,O_2 + C = 2CO$.

The zone must contain an excess of incandescent carbon, and must be kept above 1,800 degrees Fahrenheit, in order that these reactions may take place. Since the decomposition of the steam will absorb a large quantity of heat, it is evident that only a limited amount may be used, if the operation of the producer is to be continuous. By equation 4, 6 lbs. of carbon will be burned to carbon monoxide, evolving $6 \times 4{,}480 = 26{,}880$ B. T. U.; 1 lb. of hydrogen will be separated from 8 lbs. of oxygen, the two being in the form of 9 lbs. of steam, and this will absorb exactly the same amount of heat that would be given off in the combustion of 1 lb. of hydrogen—namely, 62,100 B. T. U. The heat absorbed by the reaction will equal $62{,}100 - 26{,}880 = 35{,}220$ B. T. U. for every 9 lbs. of steam decomposed, or 3,913 B. T. U. for every lb. of steam.

The *distillation zone* is so named because the heat from the lower zones effects a partial distillation of the fresh fuel in that zone. The addition of a charge of fresh fuel will always lower the temperature, and this will change the composition of the resulting gas. High temperatures in this zone are conducive to the formation of fixed gases, while low temperatures will be sure to produce a large yield of tar.

**Working of Gas-Producer.** The temperature of the gas as it leaves the producer should be kept low, or else the sensible heat loss due to the cooling of the gas between the producer and the place of use will be high. This is especially true where the gas contains condensible constituents such as tar which will be deposited in the carrying pipes if the distance is considerable. This will not only mean a heat loss, but will cause trouble in clogging the pipes.

The advantages of *hot* and *cold* gas for heating purposes have been vigorously debated in the past. Both sides have certain advantages; but the conclusions are in favor of cool gas, especially if the cooling may be done in such a way as to utilize the sensible heat extracted. The producer should be so arranged that the sensible heat of the gas may be utilized for preheating either the fuel or the air. The pipes for carrying hot gas must be larger than those for cold gas, since the thermal energy of a cubic foot of gas when it is cold is distributed through about two cubic feet when the gas has a temperature of 800 degrees Fahrenheit. The valves and dampers for handling hot gas must be water-cooled to prevent warping. Further, for gas-engine work the sensible heat is of no value, and the gas should be cooled when it goes into the engine cylinder.

Preheated air will not only conserve the heat losses, but will also induce better gasifying conditions. Combustion with preheated air will be much more intense than with cold air; and as a result, higher temperatures can be obtained. The waste heat in the gas engine exhaust should be used for this purpose when a producer furnishes the gas for the engine. By such an arrangement, in many cases, the efficiency of the producer can be increased ten per cent.

The temperature of the fire is of the greatest importance. A satisfactory operation of the producer can never be secured unless the different zones are kept at their proper temperatures. Low temperatures are conducive to the formation of small amounts of carbon monoxide, and large amounts of carbon dioxide and water vapor, thus causing a heavy heat loss, since the last two are not only diluents, but also represent a certain heat loss in the producer. An excess of steam will be sure to cause a reduction of temperature. Fig. 2 shows the proper temperatures for the different zones. The effect of different temperatures on the composition of the gas, is shown in Table 3 which is taken from an actual test:

The steam acts as a *carrier* of heat energy between the producer and the chamber in which the gas is to be burned. All the heat absorbed from the producer in the decomposition of the steam and in the formation of hydrogen will be given out when the hydrogen is burned back to water. That is, when steam is used, a certain amount of sensible heat that would otherwise be wasted in the producer-gas process is locked up temporarily in the form of hydrogen, and carried over into the combustion chamber, where it becomes available. Under no circumstance can the use of steam cause a gain of heat, and the tendency will always be to chill the fire. The primary function of steam is to induce better gasifying conditions in the producer. In addition to the conservation of the heat losses in the process of gasification, the steam has a very desirable mechanical effect on the fuel bed, by softening the clinkers, preventing localized combustion and the fusing of the clinkers to the brickwork, keeping the fuel bed porous and homogeneous, and protecting the grate by keeping the intense combustion away from it.

**TABLE III**

**Effects of Temperature on Action of Steam**

| Temperature F. | Percentage of Steam Decomposed | Gas Analysis | | |
|---|---|---|---|---|
| | | $CO_2$ | CO | H |
| 1,245 | 8.8 | 29.8 | 4.9 | 65.2 |
| 1,750 | 70.2 | 6.8 | 39.3 | 53.3 |
| 2,057 | 99.4 | .6 | 48.5 | 50.9 |

This table shows the importance of keeping the temperature of the combustion and decomposition zones near 2,000 degrees Fahrenheit, if satisfactory results are to be obtained.

The producer should be supplied with all the steam that it can decompose, in order to secure a high efficiency. This maximum quantity will vary with the nature of the raw fuel, with the type of producer, and with the method of operation. Excess of steam should be guarded against, as it will cool the fire and will produce a gas with a large amount of water vapor. This water vapor, on account of its high specific heat, will cause a large heat loss when the gas is burned.

**Fuel.** Practically every known solid fuel has been successfully used for the manufacture of producer gas. The purpose for which the gas is to be used, and the type of producer, will, however, determine what fuels may be used in each particular case. Since each fuel will give the gas certain definite properties, it is evident that the producer gas made from different fuels may vary perceptibly in composition. Thus, the producer gas made from bituminous coal will be high in easily condensible hydrocarbons generally spoken of as "tar;" while that made from anthracite coal will have a low percentage of tar. Thus, some fuel with a certain type of producer might make a quality of gas that would give good results in a steel furnace; while this same gas might be worthless for use in a gas engine. Impurities in the raw fuel will in certain cases give the resulting gas certain constituents that would make it unfit for certain kinds of work. Thus, in burning certain ceramic products with producer gas made from fuel containing volatile sulphur compounds, ammonium salts, or other impurities, considerable difficulty may be experienced from the action that the gas may have on the particular product under treatment. The chemical reactions of the flame, and especially the volatile impurities, may have such a deleterious effect on the product being burned as to make the gas useless for such work. On the other hand, if a muffle-kiln—that is, one in which the combustion products do not come in contact with the ware that is being burned—is used, the impurities would not make any difference. This simply emphasizes the fact that no general rules can be laid down in regard to the kind of fuel to be used for all classes of work, but each individual case must be studied by itself.

The size and condition of the fuel are of considerable importance. A crushed coal will always give better results than coal with large lumps. When large lumps are placed on the fire, considerable time is required for the fire to disintegrate them, and they will always induce adverse gasifying conditions. Some run of mine coal is now being used in gas-producers; but it must be remembered that not all things that are possible are desirable. The use of fine dust, also, is not good practice. The fuel should be dry, since any moisture that it contains must be driven off in the producer, and this will cause a certain heat loss. Anthracite, bituminous and brown coal, peat, lignite, wood, sawdust, shavings, tanbark, and similar refuse, have all been used for making producer gas.

**Nomenclature and Definitions.** Several absurd terms have crept into use, probably due to the fact that the producer-gas industry is the result of the labors of many men covering a period of nearly three quarters of a century and working from different points of view. The prefixing of either the name or the type of the producer to the gas made therein, is positively wrong and should never be done. That is, expressions like "Siemens gas," "Dowson gas," "Mond gas," and "suction gas" should never be used. In the first three examples, the name of the designer of the producer, and in the last one, the name of the type has been prefixed to the gas. The absurdity of this becomes evident when we use similar terms in connection with steam and steam boilers. For example, the steam made in a Stirling boiler would be called "Stirling steam;" and if a return tubular were used, the steam would be called "return tubular steam"—terms so absurd as not to need further emphasis. It was originally thought that each design or type of producer would make a gas with a certain distinctive quality. It is true that the gas made in different producers will vary in composition; but this variation is due to the method of operation or to the nature of the raw fuel used, rather than to the name or type of producer.

To avoid any further ambiguity, the following definitions are given, the close observance of which will save a large amount of trouble and misunderstanding:

A *pressure gas-producer* is one which has the blast introduced under pressure; this may be done either by a steam or a power blower.

An *induced-draft gas-producer* is one in which the resulting gas is induced away from the producer; the interior of the producer is kept at less than atmospheric pressure, and the air is forced in by the pressure of the outside air. The inducing action may be obtained by a chimney, steam ejector, gas-engine piston, or exhausting fan.

A *natural-draft gas-producer* is an induced-draft gas-producer in which the inducing action is accomplished by a chimney.

A *suction gas-producer* is an induced-draft gas-producer in which the inducing action is accomplished by a gas-engine piston. That is, the gas engine draws its gas directly from the gas-producer on the charging stroke of the engine. The term "suction gas-producer" has frequently been incorrectly applied to other types of producers.

A *water-seal gas-producer* is one which is so constructed as to have a seal of water between the interior of the producer and the atmosphere.

A *continuous gas-producer* is one that may be operated continuously for a long period of time. To secure this condition, the fuel must be introduced, and the ashes removed, in such a manner as not to interfere with the process of gasification.

An *automatic gas-producer* is one that is so constructed and operated as to keep automatically a fixed supply of gas stored in a holder.

A *down-draught gas-producer* is one that removes the gas from the bottom, and introduces the air-blast at the top of the fuel bed, and in this way causes the draught and the resulting combustion to go downward. The term *inverted-combustion* is also used synonymously for *down-draught.*

A *by-product gas-producer* is one that, in addition to the regular production of gas, makes one or more auxiliary products based on certain constituents of the raw fuel or resulting gas, constituents that generally would otherwise be lost.

An *underfeed gas-producer* is one in which the fresh fuel is fed into the bottom of the producer.

## GASIFICATION LOSSES

**Efficiency.** Since producer gas is made by a partial combustion of the fuel itself, it is evident that there must always be a certain loss in the process of gasification; and, as a result, the efficiency of the gas-producer will always be less than unity.

$$\text{Efficiency} = \frac{\text{Heat units in gas from a unit weight of fuel}}{\text{Heat units in a unit weight of fuel}}.$$

With a properly designed and carefully operated gas-producer, the gasification loss should not be over 20 per cent; that is, the efficiency should be at least 80 per cent. Thus, if the fuel contained 14,000 B. T. U. per pound, and the gas evolved from a pound of that fuel contained 11,200 B. T. U., then the efficiency would be equal to $\frac{11,200}{14,000} = .8$, which is the equivalent of 80 per cent.

The heat energy in the gas will be of two forms—heat of combustion and sensible heat, by virtue of the temperature of the gas. Since the latter will be lost if the gas is cooled down to atmospheric temperature, it is evident that a gas-producer will have two efficiencies, depending upon whether the gas is used hot or cold. The former is called the *hot-gas efficiency,* while the latter is called the *cold-gas efficiency.*

Since the heat units in the gas can come only from the carbon actually gasified, evidently, if some carbon passes through the producer without being converted into gas, a certain correction must be made to get the true efficiency of the producer. The grate efficiency represents the percentage of carbon actually gasified. Thus, if the grate efficiency is 96 per cent, it means that 96 per cent of the carbon charged into the producer is gasified, and 4 per cent passes out with the ashes. The true efficiency of the producer will be the product of the grate efficiency and the efficiency as first determined. Thus, if the efficiency as first determined—or, which is the same thing, the apparent efficiency—is 80 per cent, and the grate efficiency is 96 per cent, then the true efficiency of the producer is 80 per cent × 96 per cent = 76.8 per cent.

To determine the efficiency of a gas-producer, it is necessary to have the chemical analysis and temperature of the gas, experimental determination of the calorific value of the fuel, and the percentage of carbon passing out with the ashes. The chemical work must be done by a skilled chemist, and the engineering work by a skilled engineer, if satisfactory results are expected. In brief, a careful test of the gas-producer must be made, in order to determine its efficiency.

**Testing Gas-Producer.** The correct testing of a gas-producer is of the greatest importance. In order that the results of any test may be comparable with other tests, it is desirable that all testing should be done in accordance with a fixed code. The essential points are as follows:

Before the test is begun, the producer should be examined very carefully, and a record made of all the principal dimensions. All the apparatus used in the test must be calibrated. The producer must be in operation for several hours before the test is started, so as to insure that it is heated up to its working temperature. The test, to be of value, should be continued for at least twelve hours. All the conditions during the test should be as nearly uniform as possible.

When the test is stopped, the height and condition of the fire in the producer should be as near the height and condition at starting as it is possible to have them. The sampling of the fuel, ashes, and resulting gas is of the utmost importance, since the value of the test depends primarily upon the accuracy and care with which the samples are secured. A careful record should be kept of all events connected with the test. All the readings or observations should be so secured as to make their interpretation at any future date an easy matter.

If the test is conducted along the general lines just mentioned, the data obtained from it will be valuable in that it will show whether the producer is doing its best. In many cases, by making suitable changes, the efficiency of the producer can be materially increased.

**Heat Losses.** Usually there are eleven heat losses in the process of gasification. By judicious management, each of these may be reduced to a very small quantity. It is seldom possible to reduce any one loss to zero. The principal losses will now be given.

*Sensible Heat Loss.* This is the heat carried out by the gas by virtue of its temperature. If the temperature of the exit gases is 1,000 degrees Fahrenheit, this loss will amount to about 11 per cent. If the producer gas is high in hydrogen—on account of its high specific heat—the percentage of loss will be considerably higher. The sensible heat loss is large in nearly all forms of producers, and is a strong argument in favor of a form of construction for the producer whereby the gas is cooled before it leaves the producer, thus securing a conservation of this heat energy.

*Carbon Dioxide Loss.* The loss due to the formation of carbon dioxide is frequently high; in some cases this may amount to 10 per cent.

**Heat Balance.** In order to determine just what the various losses are, it is necessary to collect considerable data during the test. In order that such data shall be of value, it must be secured with a definite end in view. The easiest and most logical way to arrange it is in the form of a balance sheet. That is, the producer is charged with all the heat units delivered to it, and credited with every heat unit that is received from it. In other words, one should run a debit and credit account with the producer; if these are correct, the two sides will balance; that is, they will be equal to each other. The following arrangement of such a heat balance is taken mainly from the author's treatise on *Producer Gas and Gas-Producers:*

| Debit Side | Credit Side |
|---|---|
| To heat per pound of fuel | By heat per pound of fuel |
| Calorific pound of fuel | Calorific power of gas |
| Heat in air-blast | Evolved in formation of CO |
| Heat in steam-blast | Evolved in formation of $CO_2$ |
| | Absorbed in decomposing steam |
| | Lost in ashes |
| | Lost in unburned carbon |
| | Lost in tar and soot |
| | Lost in sensible heat of gas |
| | Lost in heating undecomposed steam |
| | Lost in evaporating moisture in fuel |
| | Lost in volatilization of hydro-carbons |
| | Lost in radiation |
| Sum of debits = | Sum of credits |

The classification of all the losses in a balance like the one just given will show at a glance where any heat unit goes. If any loss is high, it will suggest certain changes in the construction or operation of the producer which will make it possible to curtail the loss in question. There are a large number of producers now in operation where certain heat losses are high; and in many cases this useless waste could be reduced materially by the application of this heat balance to locate the difficulty, and subsequently the utilization of engineering skill to remedy it.

## RULES

**Specific Heat of Producer Gas.** To determine the specific heat of producer gas, multiply the amount of each constituent present by its own specific heat as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the specific heat per cubic foot of the particular gas in question.

**Weight of Producer Gas.** To determine the weight per cubic foot of producer gas, multiply the amount of each constituent present by its own weight per cubic foot as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the weight per cubic foot of the particular gas in question.

**Specific Gravity of Producer Gas.** To determine the specific gravity of producer gas, first determine the weight of the gas per cubic foot. Then,

$$\frac{\text{Weight per cu. ft.}}{.0807^*} = \text{Specific gravity with reference to air.}$$

*Weight of air per cubic foot.

**Calorific Power of Producer Gas.** To determine the calorific power of producer gas, multiply the amount of each combustible constituent present by its own calorific power per cubic foot as given in Table II, page 3, and divide the sum of the products so obtained, by 100. The result will be the calorific power per cubic foot of the particular gas in question.

## CLASSIFICATION OF GAS-PRODUCERS

All gas-producers may be classified into the following groups:

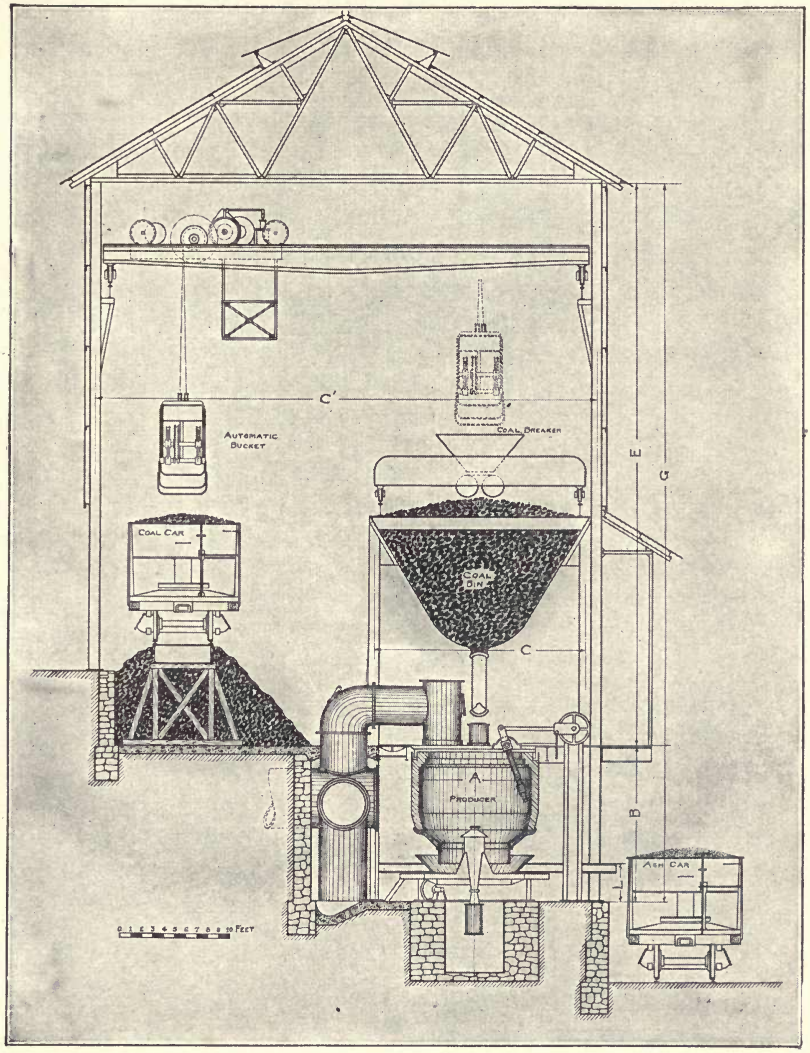
1. Pressure.
2. Induced-draught.
   - (a) Draught induced by a chimney.
   - (b) Draught induced by an exhauster.
   - (c) Draught induced by a gas-engine piston—that is, a suction gas-producer.

## REPRESENTATIVE TYPES OF GAS-PRODUCERS

**Pressure Types.** The Amsler gas-producer is shown in Fig. 5. A is the body of the producer, with charging hopper B, and gas-exit C. D is a side poke-hole, to facilitate the breaking of climbers which may adhere to the side wall. E is a steam blower which is connected to the central blast-chamber G, by the pipe F. H is the blast opening. The cross-section of the producer is circular.

The Duff gas-producer is shown in Fig. 6. The main features of this are an inverted V-shaped grate in the middle, which extends from one wall to the other, vertical openings in this grate so as to give the blast a vertical direction, and a rectangular cross-section for the producer. The usual form of water-seal ash-pan is used.

The Swindell gas-producer is shown in Fig. 7. H is a charging hopper; N is the gas-exit; G is an inclined grate; C is a cleaning door. The blast is introduced by the usual form of steam blowers, although these are not shown in the illustration, and enters the ash chamber by the pipes S. A P is the usual form of water-seal ash-pan. A careful inspection of this producer and the ones shown in Figs. 5 and 6 will reveal a marked similarity in principle of grate construction. The Duff gas-producer has an inverted V-shaped grate of rectangular




**HUGHES MECHANICALLY-POKED CONTINUOUS GAS PRODUCER**
Coal Handled from Cars by Overhead Traveling Crane with Automatic Bucket

cross-section; the Amsler gas-producer has an inverted V-shaped grate of circular cross-section; and the Swindell gas-producer has a V-shaped grate.

The Forter gas-producer is shown in Fig. 8. A is the main body of the producer and has a gas-exit B. C is the usual form of

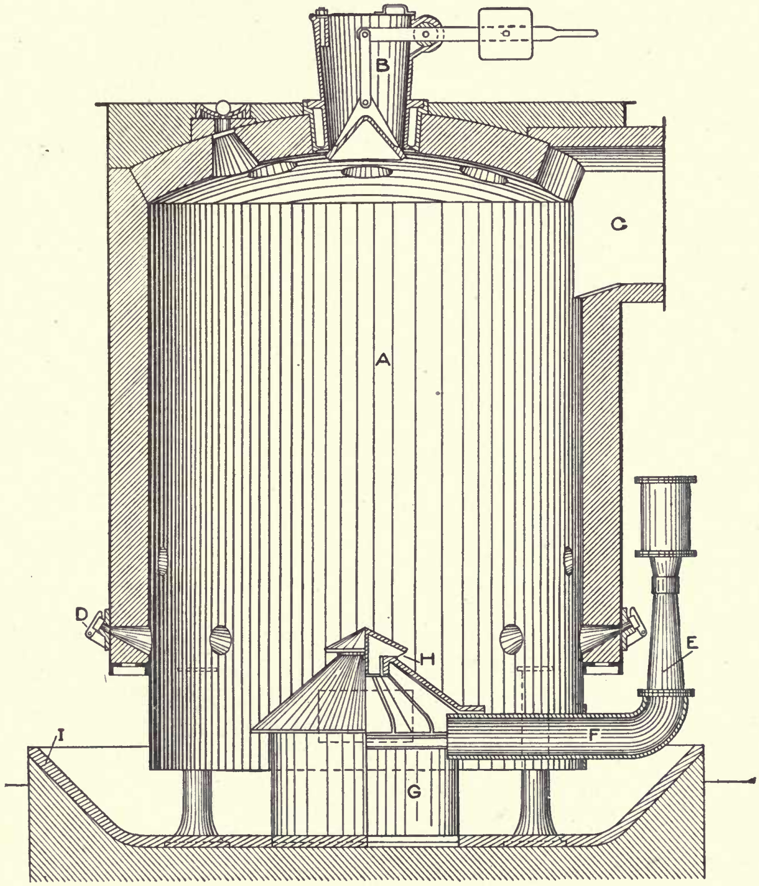



Fig. 5. Amsler Gas-Producer.

charging hopper, while D is a poke-hole. E is a leg for supporting the producer. F is an inclined bosh wall which has the blast-chamber G. H is an opening for the blast to pass from G to A. I is a door for cleaning G. K and L are steam blowers. M is the central blast pipe with hood N. J is side poke-hole.

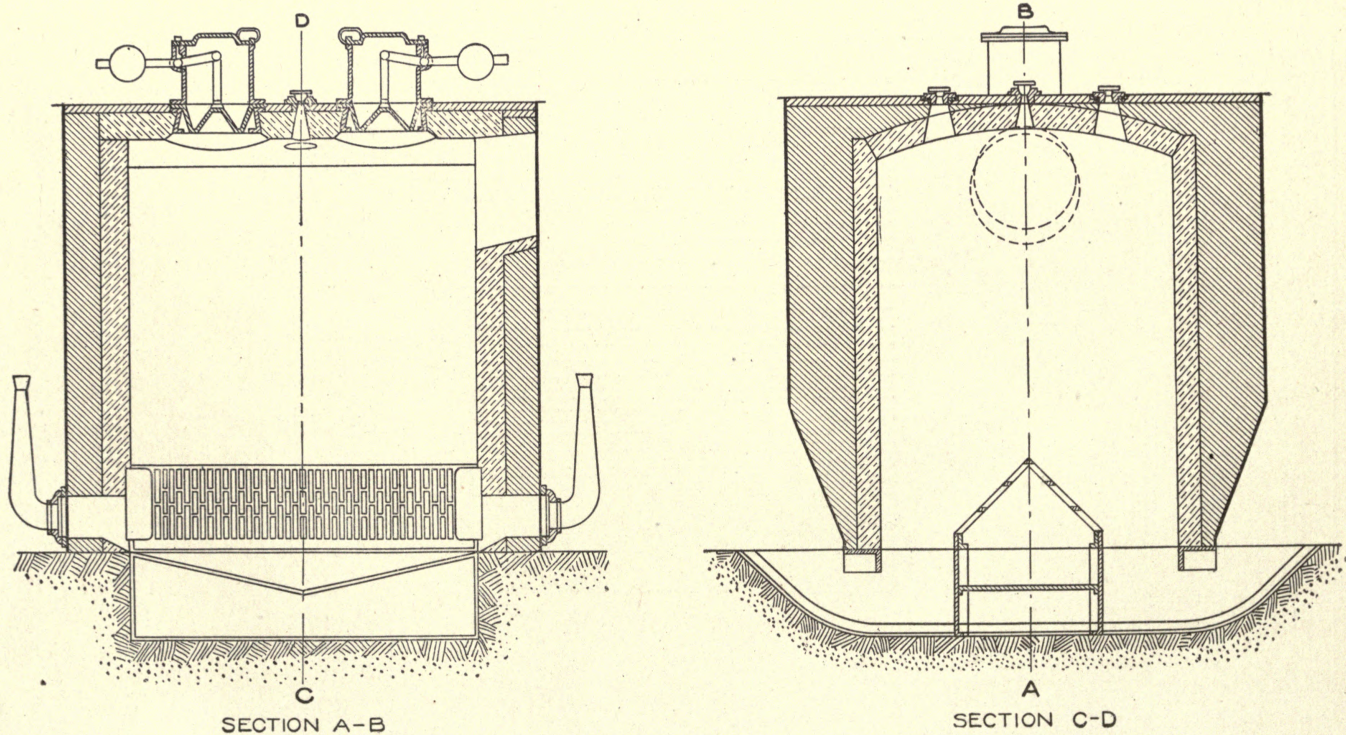



Fig. 6. Duff Gas-Producer.

The Fraser and Talbot gas-producer is shown in Fig. 9. In construction and method of operation this producer differs radically from the usual practice. The poking of a gas-producer is very laborious, and men will usually shirk it whenever possible. The primary object of this producer is to eliminate the hand-poking entirely. A is a central shaft that is operated by motor B. In addition to a slow

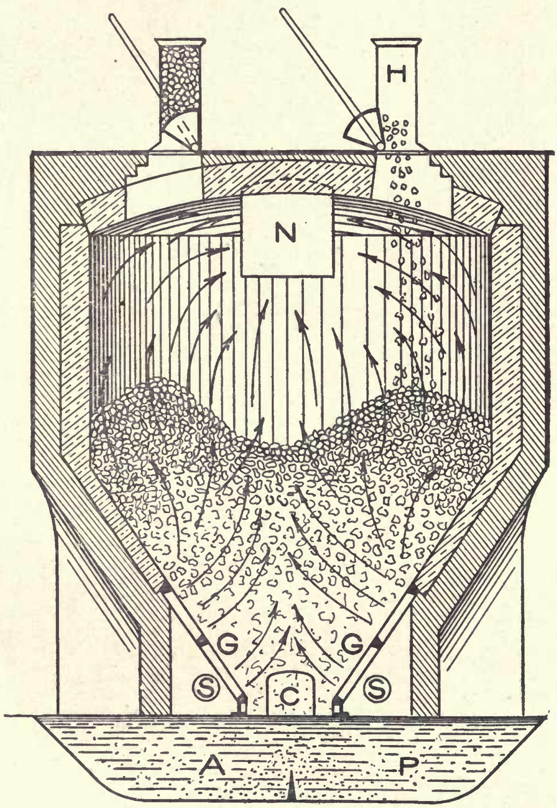


Fig. 7. Swindell Gas-Producer.

rotary motion, A is also given an up-and-down motion by crank C and connecting rod D. E is a water- or steam-cooled poking-arm that is fastened to A. The upper position of E is indicated at F. H is a frame for supporting the driving mechanism. I is the blast pipe which is supplied with air and steam by a blower on the outside. J is a bosh plate, and K is the bottom of the water-seal ash-pan. L is a coil spring so arranged that if E should strike a hard clinker, it will allow the poking arm to slide past it. In this way the danger of

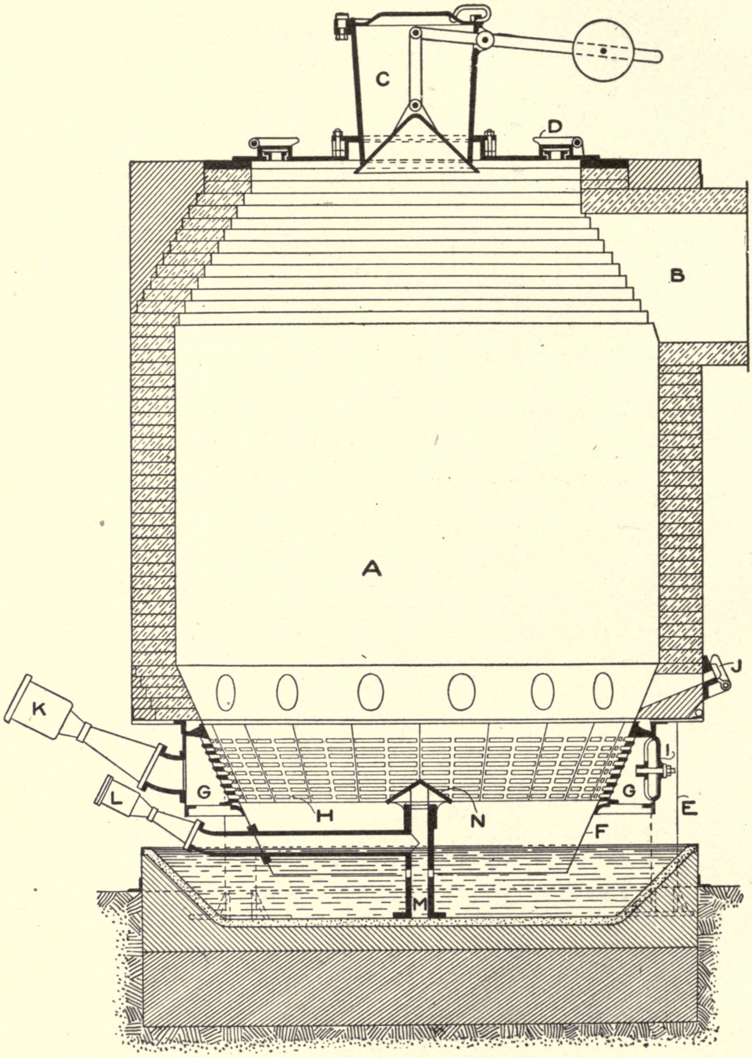



Fig. 8. Forter Gas-Producer.

the breakage of E is in a large measure eliminated. M is an ordinary charging hopper. By means of the rotary and up-and-down motion

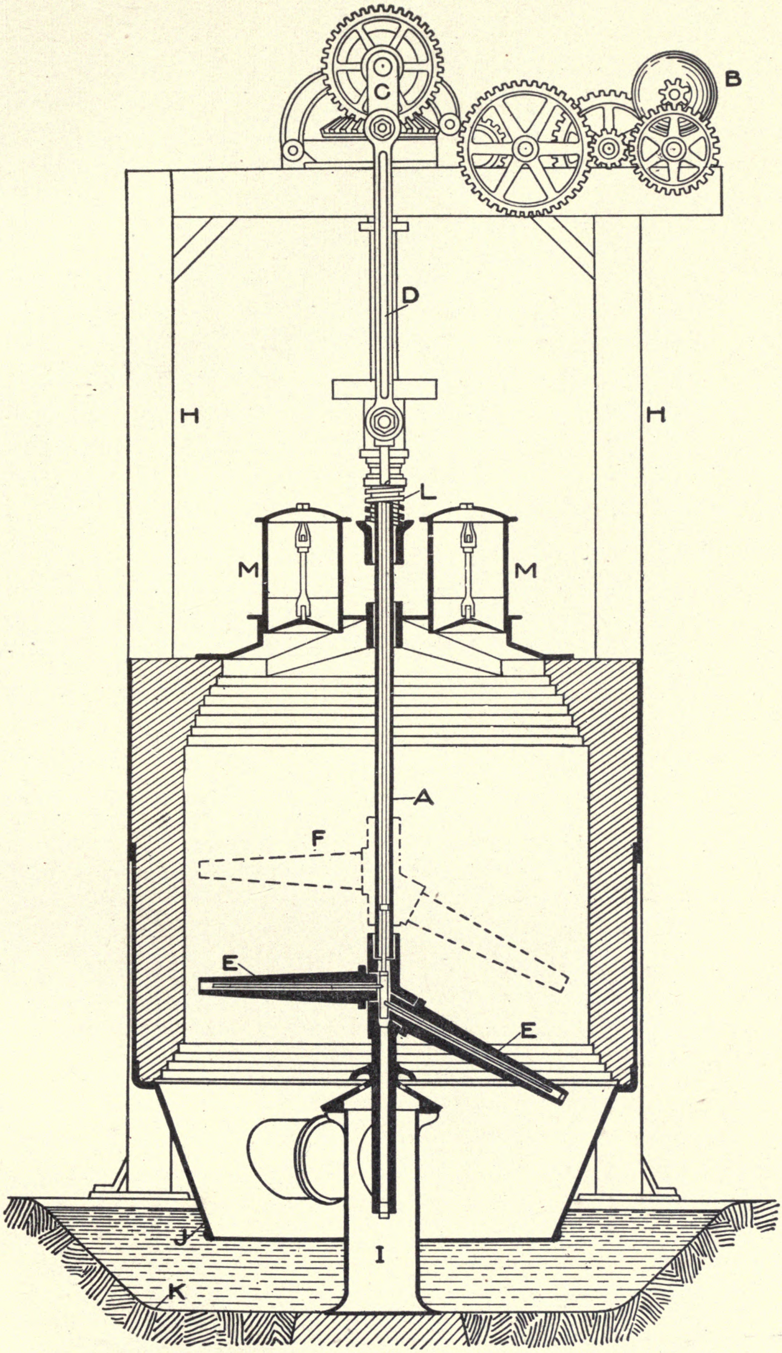



Fig. 9. Fraser and Talbot Gas-Producer.

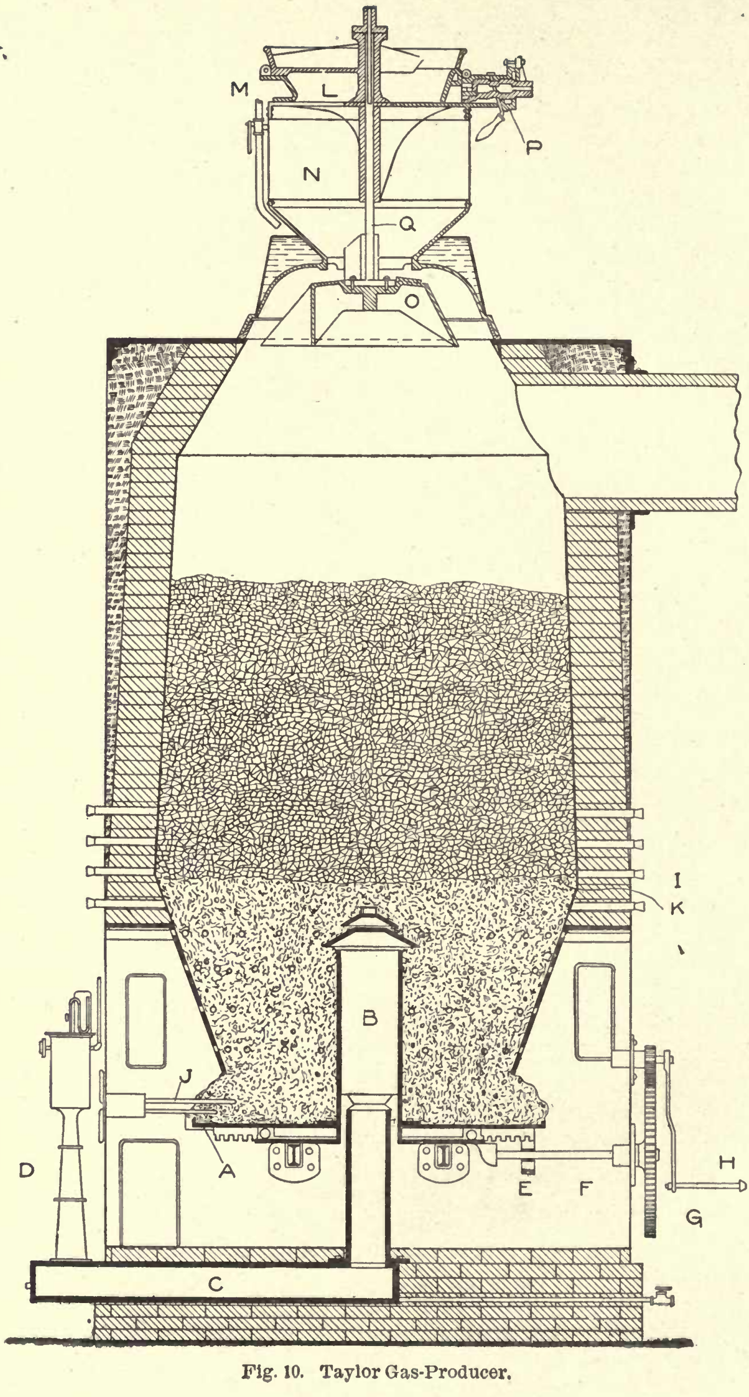



Fig. 10. Taylor Gas-Producer.

of E, a very thorough agitation of the fuel bed is secured without any hand labor.

The Taylor gas-producer is shown in Fig. 10. The essential features of this producer are a revolving grate, the use of a thick bed of ashes to prevent the burning out of the grate, and a high, central blast pipe which introduces the blast at the upper surface of the ash bed. The producer is equipped with the Bildt automatic feed, which introduces the coal in a thin, continuous stream and that without any hand labor. A is the circular grate that revolves around the central blast pipe B. C is a pipe connecting B with the steam blower D. E is a pinion on shaft F, that has the gear teeth which mesh with E, and by turning H, A will be revolved. I is a peep hole for observing the height of the ash-bed. The division between the fuel and ash-bed is shown at K. J is a finger which drags the ashes off of A as it is rotated. The Bildt automatic feed consists essentially of a hopper L into which the coal is primarily deposited, a register valve M, which controls the amount of coal going to the tank N below, and a rotating disk O. This disk has sloping sides of varying angles and is so designed as to deposit the coal evenly over the charging area. O is rotated by means of a special ratchet motion P and the vertical shaft Q. The coal is supplied to the hopper L by any convenient means and dropped into the storage tank N as needed. The tank N may be made of considerable capacity, but three hours supply is usually enough. The disk O has a slow, rotating motion and causes the coal to work out of N and fall over the edge of O. The speed of O is from 1 to 15 revolutions per hour, the different speeds being obtained by the ratchet P.

The section of the Morgan gas-producer fitted with a George automatic feed is shown in Fig. 11. The automatic feed consists essentially of coal tank and a revolving eccentric chute which spreads the coal out over the surface of the fuel as shown in the illustration. The steam blower is placed in a horizontal position as is shown in the lower left-hand corner of the illustration. Fig. 12 shows the operating floor of a battery of 52 Morgan gas-producers. A small, auxiliary coal tank is placed over and above the feeding mechanism of each producer. These tanks are filled by means of the large tank shown on the traveling crane. The plant is a good example of what may be done in the way of using labor-saving devices in a gas-producer installation. Inasmuch as every pound of coal that is used in these 52 producers is handled by mechanical means, it can be seen at once that the labor cost will be very low. Further, gas-producers that are equipped with some form of automatic feeding device will make a more uniform quality of gas and will also usually be more efficient.

The Smythe gas-producer is shown in Fig. 13. This is a radical departure from the usual type of gas-producer in that the grate is

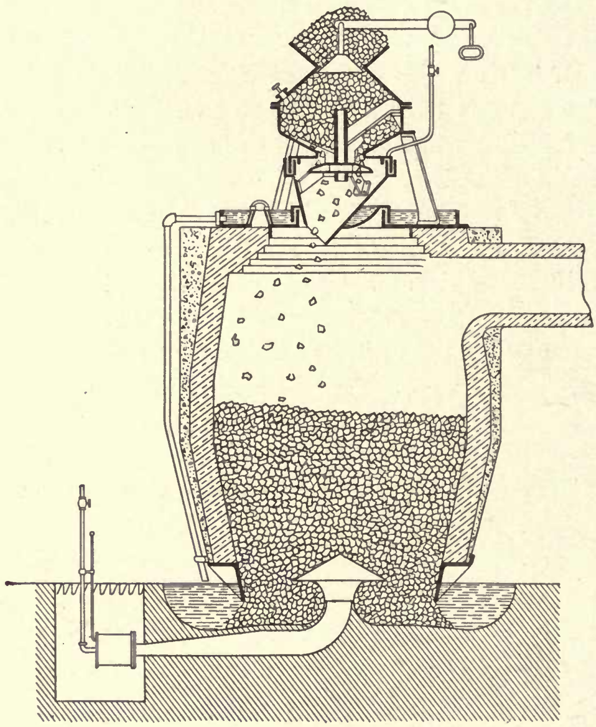


Fig. 11. Section of Morgan Gas-Producer Fitted with George Automatic Feed.

made entirely different. A is the main body of the producer with charging hopper B, poke-hole C, and gas-exit D. E is an inclined grate so positioned as to cause the ashes to work down to the lower left-hand corner of the producer and then down into the water-seal ash-pan below. The steam is introduced at a higher point than usual, and in this way it at once comes in contact with the incandescent fuel.

The Poetter gas-producer is shown in Fig. 14. The main feature in this is the use of a device to effect the destruction of the tar in the producer and make a gas with no condensible constituents. A is a retort which is supplied with fresh coal by means of the charging hopper B. The upper end of A is in communication with the ash-zone below by means of pipe C. The blast is introduced at D. E is a water-seal ash-pan, and F is the gas-exit. As the gas is given off from the surface of the fuel, it heats A and the fuel contained therein. A large part of the volatile matter or tar in the coal contained in A will be given off as vapors and then pass out through C and come up

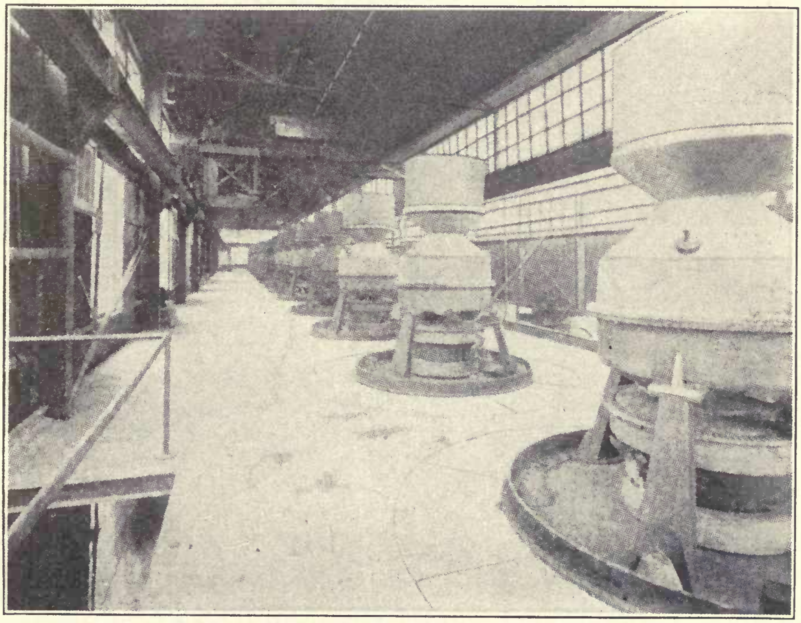


Fig. 12. Operating Floor of Morgan Gas-Producer.

through the fuel bed. When these vapors come in contact with the incandescent fuel they will be converted into fixed gases, thus eliminating all trouble from condensation after the gas leaves the producer. This type of producer will give good results when using a coal that contains a large amount of tar, and under those circumstances will make a gas suitable for gas engine use.

The Duff-Whitfield gas-producer is shown in Fig. 15. The main object of the new features in this producer is to secure the destruction of the tar in the producer itself. The unique feature is the circulation of the gases through different parts of the producer. The blast is introduced under the Duff grate A. B is the usual charging hopper, and C is the water-seal ash-pan. The gas-exit is at D. E is a small steam-blower which draws the gases given off from the surface of the fuel away at F and delivers them at the lower part of the fuel bed through opening G. H is a small steam-blower which draws off the gases from the space near the fuel surface by opening I, and delivers them through J at the bottom of the fuel bed. In each case the green gases taken from or near the surface of the fuel

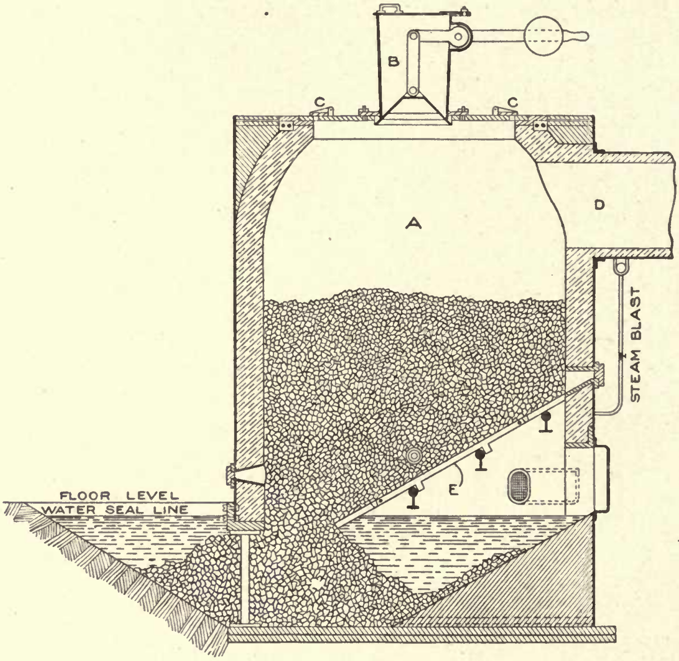



Fig. 13. Smythe Gas-Producer.

are forced up through the incandescent fuel and in this way they are converted into fixed gases. Since the producer secures the destruction of the tar, it is obviously well adapted to make a clean gas from fuel containing large amounts of tar.

**Induced-Draft Gas-Producers.** The Loomis induced-draft gas-producer is shown in Figs. 16 and 17. Under certain conditions this producer may also be used with pressure. The producers are generally installed in pairs. The producer A is shown in section, while producer B is shown in elevation. The two are connected at the top by the pipe C. D is a vertical, tubular boiler which acts as an economizer by abstracting some of the sensible heat in the gas. E and F are water-cooled valves connecting the bottom of D with B and A. G is an exhauster driven by engine H. K is a tower scrubber with a series of shelves M upon which is placed a layer of coke. L is a pipe connecting D and K, and I connects K with G. Q is a cleaning door for removing the coke from M. N and O are strain pipes for admitting steam under the fire in A and B. P is a door for charging the producers with fuel. R is a seal. S and T are delivery pipes. S goes to the producer-gas holder, and T to the atmosphere. As water-gas may also be made in this producer under certain conditions, another pipe is sometimes placed on R and is used to deliver the water-gas to the water-gas holder. The operation is as follows: The exhauster G being in operation and the valves E and F and doors P open, the air will enter at P and produce a down-draft combustion in A and B; the resulting gas will pass down and out through E and F, up through D, over to the bottom of and then up through K, out through G and then go to the mains or gas holder. Another way is to have the ash-pit door U open, doors P and valve F closed, then the air will enter at U, pass up through A, and the resulting gas will pass over to B by pipe C, and then pass downward through the fuel bed in B, then out through E and up through D. By either method it is

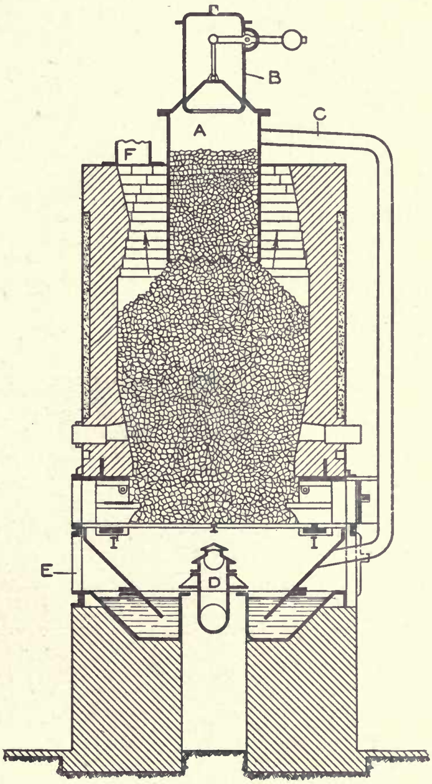


Fig. 14. Poetter Gas-Producer.

evident that all the volatile or easily condensible matter given off from the fresh coal must come in close contact with the incandescent fuel in the middle of the producer, and, as a result, the tar is broken up and converted into fixed gases. In making water-gas the fuel is first brought to the proper temperature by blasting with air and making producer gas; then steam is admitted and water-gas is made

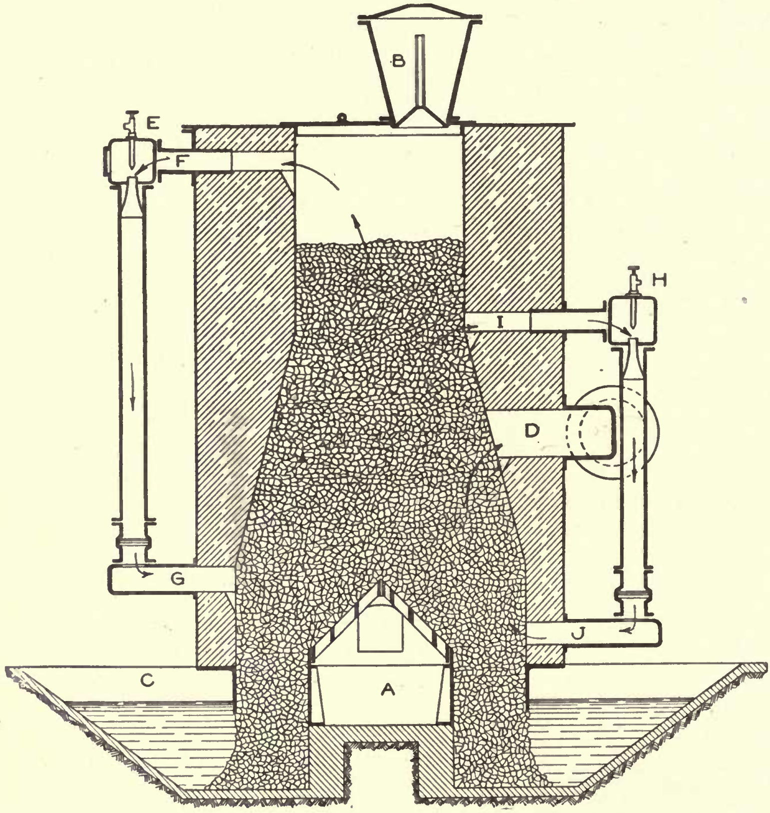



Fig. 15. Duff-Whitfield Gas-Producer.

for several minutes. When the fire becomes chilled the steam is shut off and the temperature is again raised by making producer gas.

The Capitaine underfeed gas-producer which is operated by induced draft is shown in Fig. 18. The coal is introduced at A and is then fed over to the center of the producer by spiral conveyor B which delivers the coal to the vertical spiral conveyor C; this, in turn, screws the coal up into the center of the fuel bed. The ashes are worked out through grates D, while the gas is withdrawn at E. The primary object of this design of gas-producer is to introduce the fuel in such a manner as to secure a slow agitation of the fuel bed and also compel the volatile products of the green fuel to pass up and through the mass

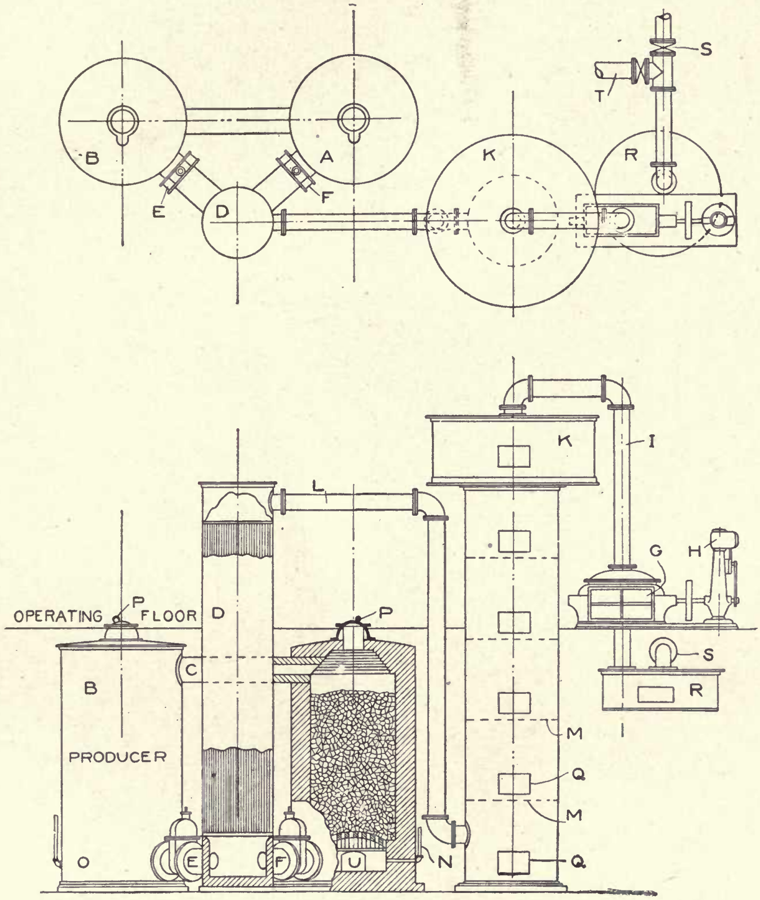



Fig. 16. Loomis Induced-Draft Gas-Producer.

of superimposed incandescent fuel; in this way the volatile matter will be converted into fixed gases. By comparison with Fig. 2 it will be seen that the distillation zone is under the fuel bed in Fig. 18.

**Suction Gas-Producers.** These are used entirely for power purposes—that is, for furnishing gas to gas engines. The chemical

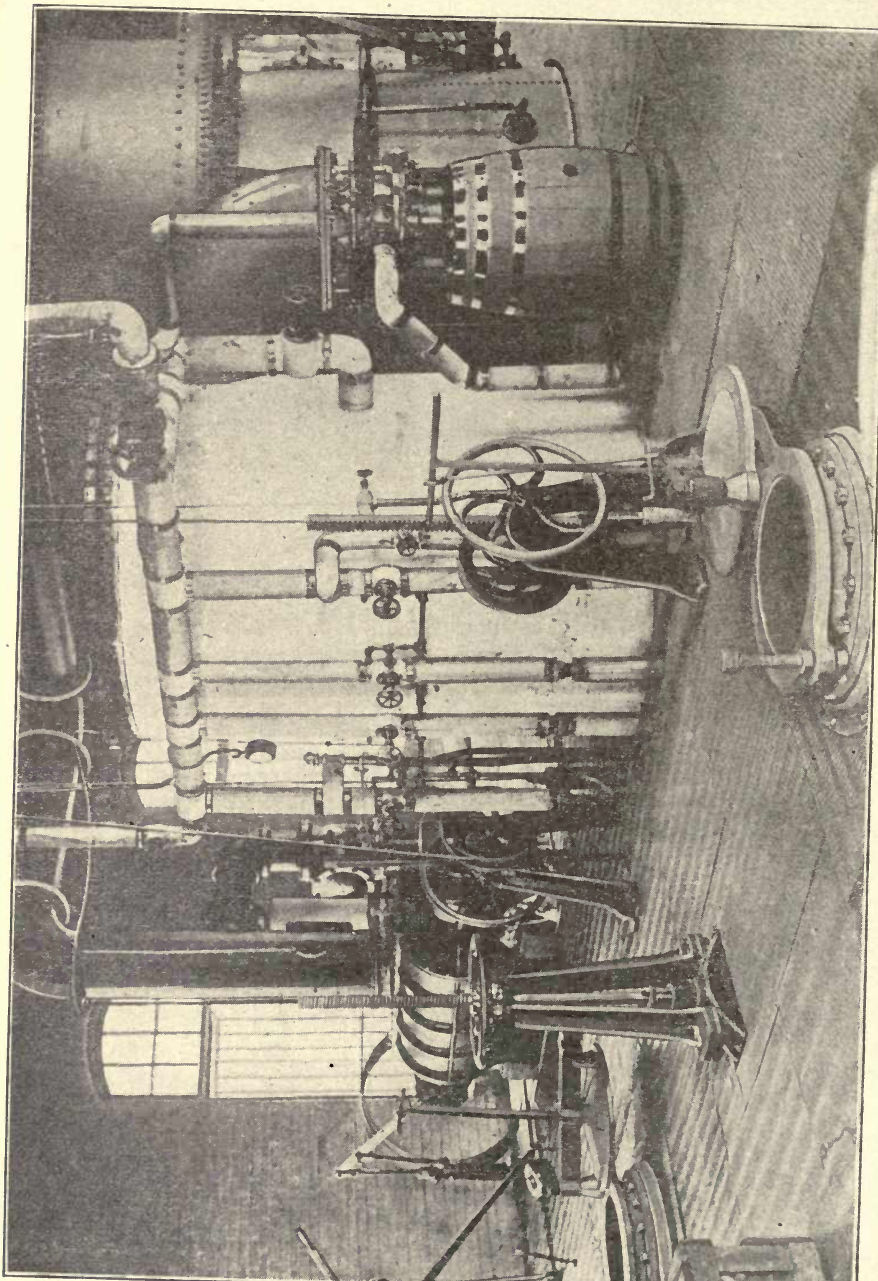


Fig. 17. Operating Floor of Loomis Gas-Producer.

reactions that take place in the manufacture of the gas are the same as for the pressure type of producer. The construction of the suction gas-producer is usually quite different from that of the other types. The two most desired requirements for suction gas-producers are that they shall be *compact* and *self-contained.* As a result each suction producer has its own steam generating apparatus. This

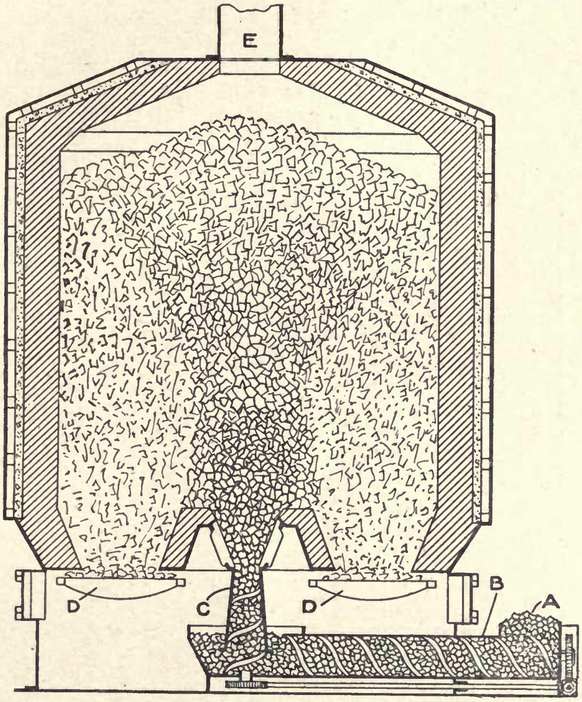



Fig. 18. Capitaine Underfeed Gas-Producer.

apparatus is usually spoken of as a vaporizer, and there are three general ways of using these vaporizers.

*First*—To have the vaporizer an integral part of the producer, as shown in Fig. 19.

*Second*—To have the vaporizer attached to the side of the producer, as shown in Fig. 20.

*Third*—To have the vaporizer entirely separate from the producer as shown in Fig. 23. In the first two cases the water is vaporized by means of the sensible heat in the gas as it leaves the producer; in the last case the sensible heat of the engine exhaust gases is used;

this may be made to return about 10 per cent of heat back to the producer. Inasmuch as the gas must be cleaned before going to the engine, some form of scrubbing apparatus is always used between the producer and the engine. In order that this scrubbing device may be kept simple, practically all suction gas-producers are operated

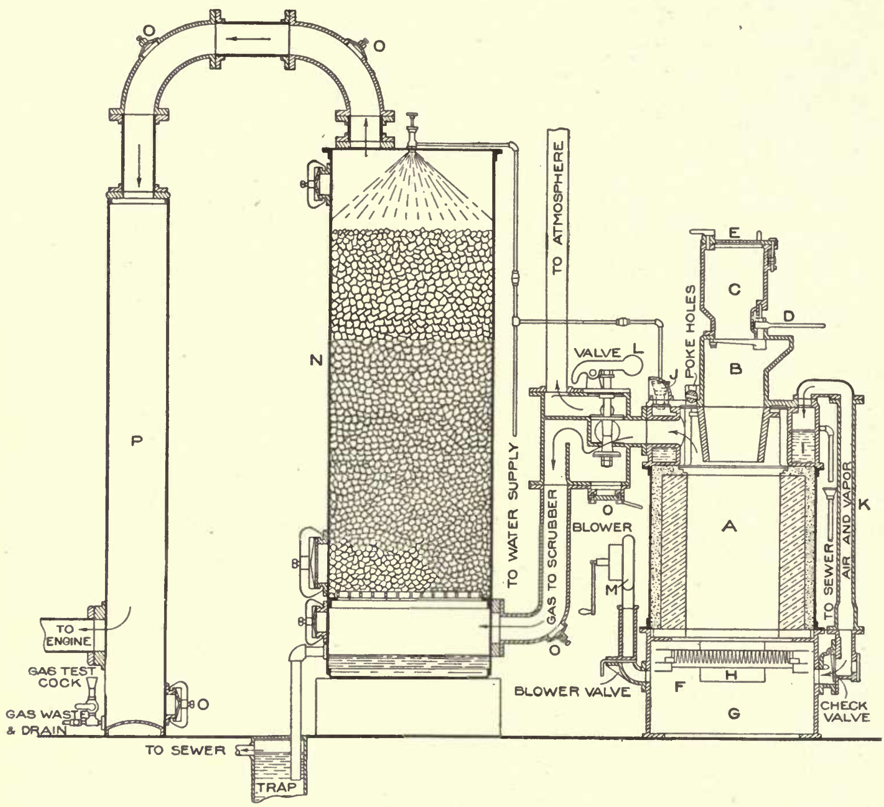



Fig. 19. Fairbanks-Morse Suction Gas-Producer.

on anthracite coal, which produces very little tar; as a result, the work of the scrubber is generally limited to the removal of fine dust only.

The Fairbanks-Morse suction gas-producer is shown in section in Fig. 19. A is the body of the producer with fuel magazine B, hopper C, fuel valve D, and hopper cover E. F is a grate bar over ash-chamber G. H is the ash-door. I is the vaporizer with air inlet J. K is a pipe connecting I with G. O is a hand-hole cover which may be removed either for inspecting the interior of the pipe or for the removal of dirt. L is a valve lever and weight. M is a hand-blower that is used in starting the fire and blasting it up to such a point that the gas evolved will be of the proper quality to use in the engine. N is a scrubber filled with coke and supplied with a spray of water at the top; as the gas comes up through the interstices of the columns of coke it comes in close contact with the water that is trickling down, and, as a result, the fine dust carried by the gas is washed down to the bottom. P is a storage tank placed near the engine. The test cock at the bottom of P is used to test the quality of the gas before starting the engine.

The method of starting a suction gas-producer will now be given. The reference will be made to the producer just described, but the principles may be applied to any other producer. First see that the vaporizer is supplied with water and that the valve under L is open to the atmosphere. To open the valve it will be necessary to turn L over 180 degrees from the position shown in the illustration; then the lower disk on the valve stem will come up against its seat, closing the passage to the scrubber, and the upper disk opening the one to the atmosphere. Place some easily inflammable material, such as oily waste or pine kindling on the grate; set fire to this and add a little coal, in the meantime keeping the ash-door open so as to produce a natural draft. Just as soon as the fire is started nicely, add more wood and coal. Close the ash-door and begin blowing the fire very slowly with the hand-blower. Care is necessary at this point or else the fire will be killed by an excessive blast. As the combustion progresses add more fuel and increase the intensity of the blast. This period of preliminary blowing will usually require about twenty minutes, and the combustion products are sent out to the atmosphere. At the end of twenty minutes, turn L back to the position shown in the illustration. A valve should be placed near the engine so that the gas may be by-passed to the exhaust pipe; have this valve open and then purge out the scrubber and pipes between the engine and the producer by further blowing the producer with the hand-blower and forcing gas out through the valve just mentioned. The quality of the gas may be judged by opening the test cock and lighting the gas. If it burns with a pale blue flame the gas is not rich enough for use in the engine and the blowing must be continued. As soon as the gas burns uniformly with an orange-colored flame, the blowing may

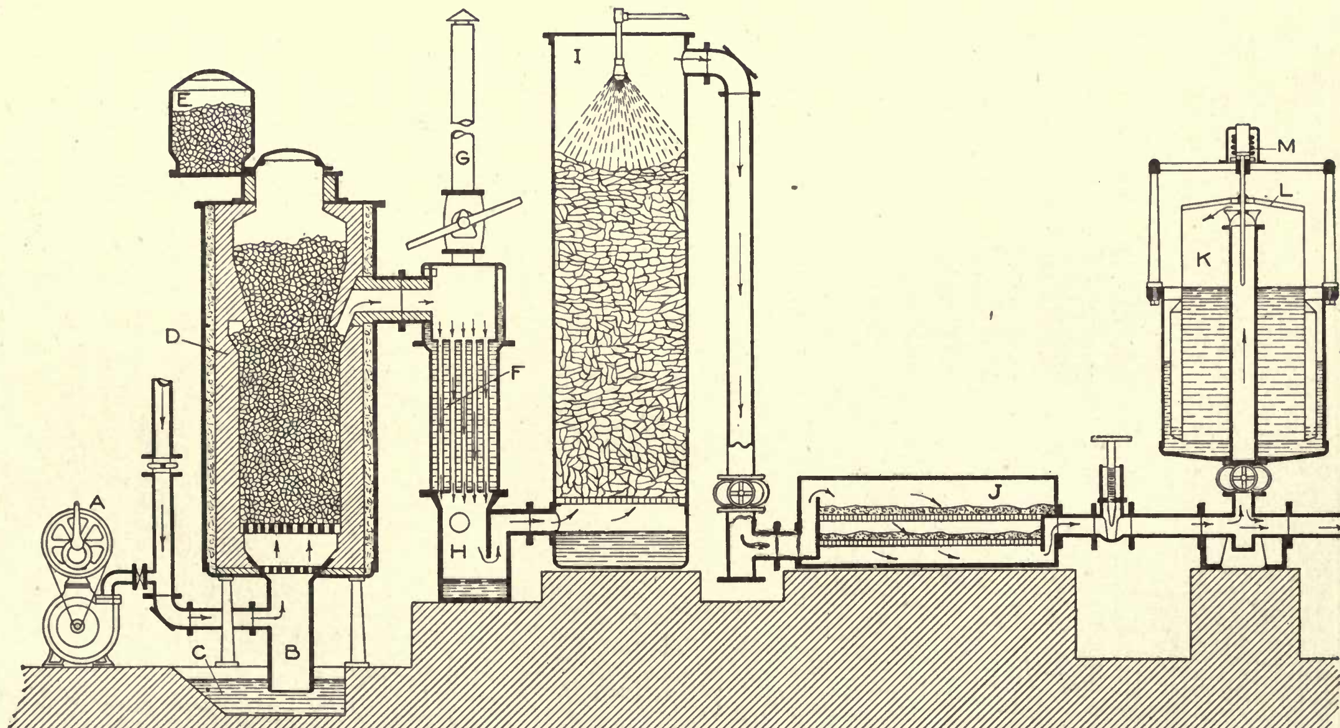



Fig. 20. American Suction Gas-Producer.

be stopped and the engine started from the producer gas. The scrubber spray must, however, be turned on before the engine is started so as to wash out the fine dust particles in the gas. In some cases it will be desirable to use the hand-blower for a few minutes after the engine has started.

The American suction gas-producer is shown in Fig. 20. A is the hand-blower. B is the ash-chamber with water-seal C. D is the body of the producer with charging hopper E. F is a tubular vaporizer above which is the vent pipe G. H is a settling chamber. The air for the producer is drawn through F, in that way absorbing the steam formed in the vaporizer, and is then taken to the ash-chamber by means of a pipe not shown in the illustration. I is an ordinary tower scrubber filled with coke and supplied at the top with a spray of water. J is a purifier; the two shelves are filled with shavings, sawdust, or some similar material; as the gas passes through this, some of the impurities are filtered out. K is an automatic regulator; it consists essentially of a tank of water containing the bell L which is supported by the spring M. The object of the device is to make the actual time of drawing gas away from the producer of longer duration than the time occupied by the gas-engine piston in charging the engine cylinder with gas. The operation is as follows: When the gas-engine piston draws gas to fill the cylinder about half will be drawn from the chamber K; as a result the exterior atmospheric pressure will cause L to move down and compress the spring M. Just as soon as the engine stops drawing gas, the spring M will draw L back of its original position, and the gas required to fill K will be drawn from the producer. In this way the process of gasification is carried on after the engine piston has filled the engine cylinder.

Any gas-producer to be operated efficiently must be supplied with the maximum amount of steam. On the other hand, no more steam must be delivered to the producer than it is able to decompose. If any excessive amount of steam is used, it will pass through the fire without being decomposed. This will chill the fire and place water-vapor in the gas. In some cases the chilling effect may be enough to stop the process of gasification. If not enough steam is used, the fire may become so hot as to make the producer very inefficient. In a suction gas-producer the quantity of gas made will be directly proportional to the load on the engine. As the latter may vary in some cases from engine friction up to full load, it is evident that the rate of gasification must also vary through a large range. As a result of the conditions just mentioned, it will be necessary to accurately proportion the amount of steam delivered to the producer to the

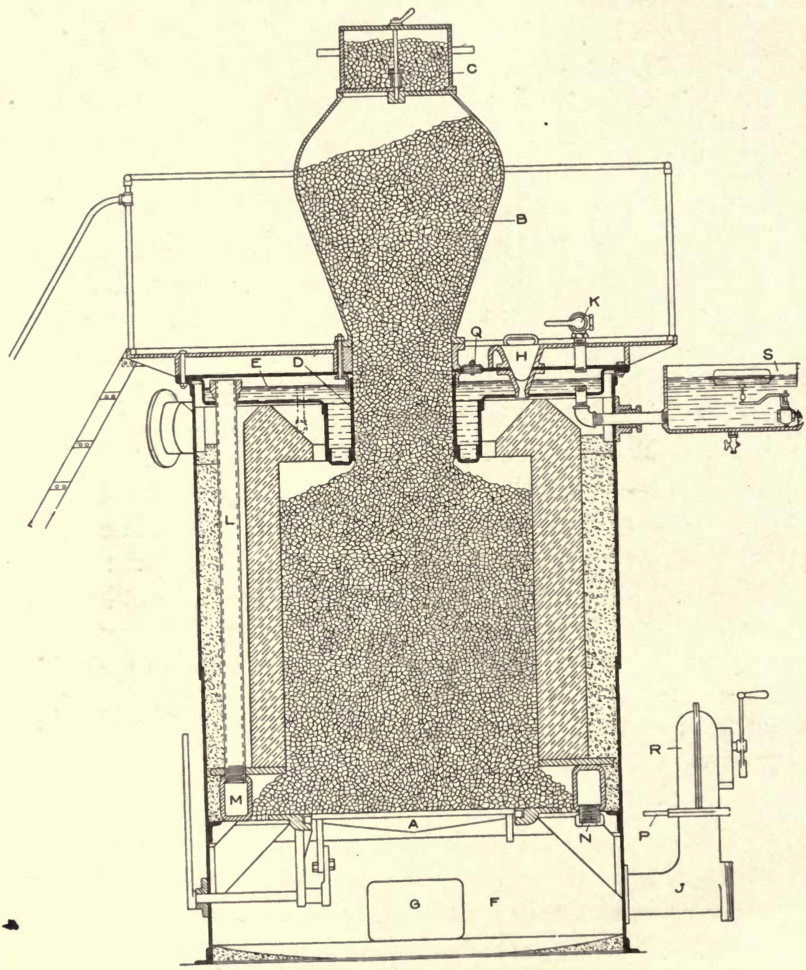



Fig. 21. American Crossley Suction Gas-Producer in Section.

amount of gas made therein. Several devices intended to accomplish this regulation will now be illustrated and described.

The American Crossley suction gas-producer is shown in section without the scrubbers in Fig. 21, and in perspective with the scrubbers in Fig. 22. A is a shaking grate which may be operated by the lever on the outside. B is a fuel magazine with charging valve C. The fuel from B goes down through the feed tube D and into producer fuel bed below. D is surrounded by a water leg or jacket which forms a part of the vaporizer E. The construction of E is such as to form a cover for the top of the producer, and heat that is radiated upwards is used in vaporizing the water. The water in E is kept at a constant level by means of the float controlled valve in the auxiliary tank S on the side. K is an air-inlet valve. H is a poke-hole. Q is

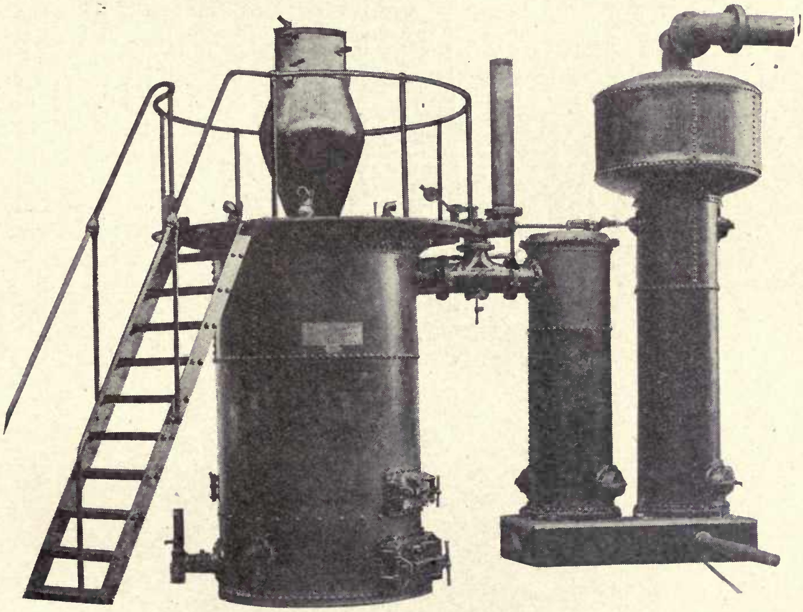


Fig. 22. American Crossley Suction Gas-Producer in Perspective.

a hand-hole for removing sediment from the water leg D. L is a pipe connecting the vaporizer E with the distributing ring M. N is a nipple for allowing the air and water vapor to pass from M to ash-chamber F. G is a cleaning door for F. R is a hand-blower with valve P and delivery pipe J. The operation of the water-regulating device is as follows:

The air for the ash-chamber is supplied from two sources. These are called the primary and secondary supply. The primary supply enters at J and passes up through the fuel bed. The secondary supply

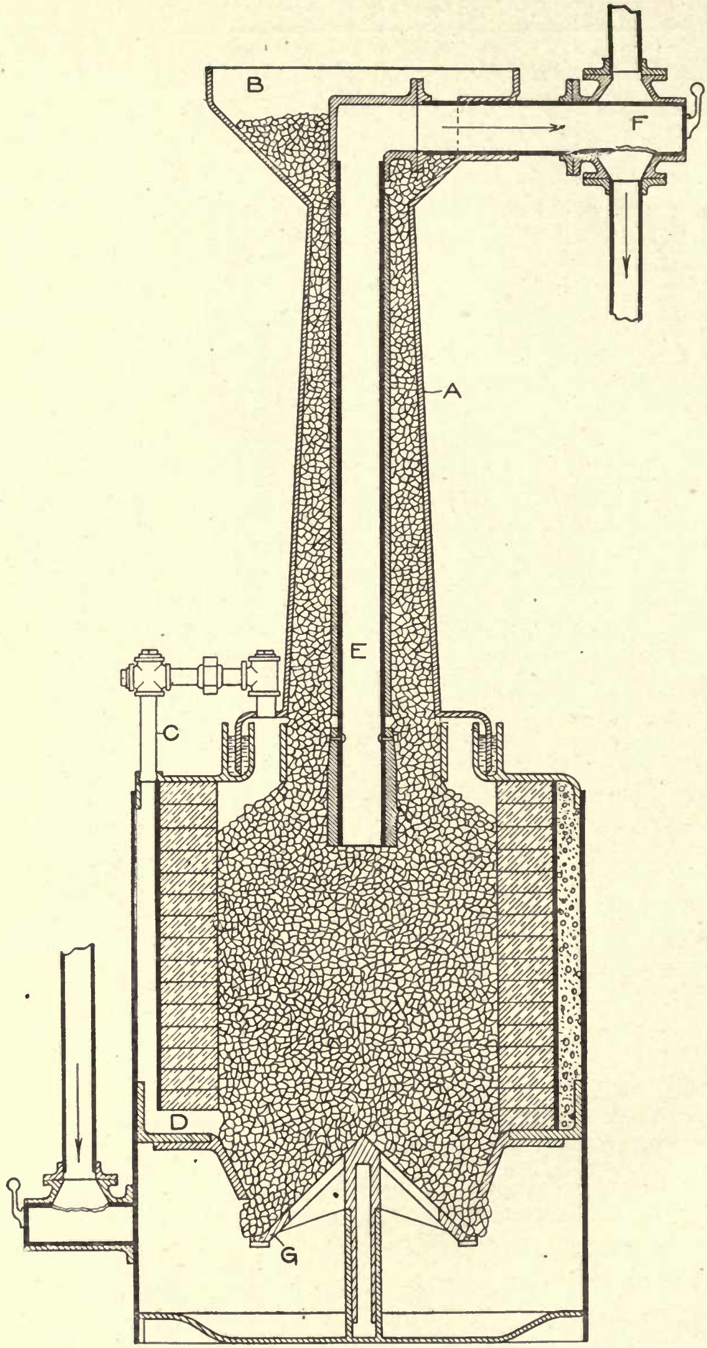


Fig. 23. Wyer Suction Gas-Producer.

enters at K, passes over the surface of the water in the vaporizer E, becoming saturated with water vapor, and then passes down pipe L into the ring M, and out into the ash-chamber F. The air entering the primary and secondary supply may be throttled by adjusting the valves P and K, so as to secure the proper proportion.

The Wyer suction gas-producer is shown in section in Fig. 23, and Fig. 24 shows its water-regulating device. Referring to Fig. 23, A is a superimposed retort with charging hopper B. The retort is connected by means of pipe C with the part D. The gas must pass around and up to the top of the retort through pipe E, and then out to valve F. In this way the gas is cooled and the fuel is preheated; that is, the sensible heat of the gas which would otherwise be lost is conserved and given back to the producers. The vapors given off in A pass to D by means of pipe C, and then go into the fire and are converted into fixed gases. G is a shaking grate which may be operated from the outside.

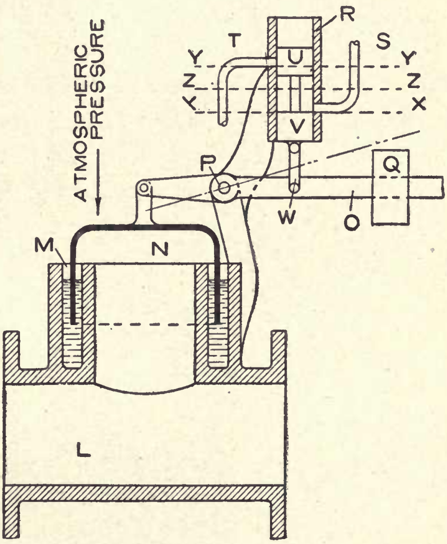


Fig. 24. Water-Regulating Device of Wyer Suction Gas-Producer.

Referring to Fig. 24, L is a pipe through which the gas passes in going from the producers to the engine; M is an annular chamber on L and is filled with water. N is a cup that is suspended in the water in M. P is a fulcrum for lever O and counter weight Q. R is a small cylinder with two pistons U and V. These pistons are connected by the small stem between them and are operated by link W and lever O. S is an inlet water port, while T is an outlet water port. From T the water goes to the vaporizer. The operation is as follows:

The weight of N is balanced by W. When the engine is drawing gas from the producer the pipe L will be at less than atmospheric pressure; as a result, the exterior atmospheric pressure on N will force it down, lift weight Q up, and move the piston V from the level X X to the level Y Y. S will be closed. T will be opened and the water contained between U and V will pass out of T and go to the vaporizer. When the engine stops drawing gas from the producer, the pressure in L increases, forces N up, closes T, and opens S. Then at the next charging stroke of the engine the same cycle is repeated. If a throttling engine is used—that is, one that proportions the amount of gas taken into the cylinder to the load on the engine—the decrease of pressure in L will be directly proportional to the gas taken into the engine cylinder, and consequently the extent of the movement of N will be directly proportional to the amount of gas used in the engine or taken from the producer. Thus, if the engine is running at half load, the movement of N will raise X X only to Z Z, and only half the amount of water contained between U and V will go out of T and to the vaporizer.

The Dowson water regulator is shown in Fig. 25. A and B are two water chambers. C is a supply pipe and D is the overflow. The

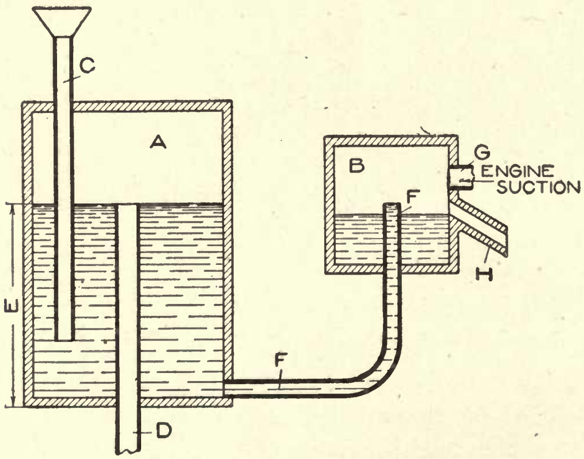



Fig. 25. Dowson Water Regulator.

height E of the water in A may be adjusted by changing the height of D in A. F is a pipe connecting A and B. G is an opening connecting B with the gas pipe going to the gas engine, so that the engine pulsations will be felt in B. H delivers the water to the vaporizer. The operation is as follows:

During the charging stroke of the gas engine a partial vacuum will be produced in B; as a result, the water from A will flow out of the top of F, the flow ceasing just as soon as the engine has completed its charging stroke. The water so delivered to B will pass out through H. The amount of water flowing out each time may be adjusted by varying the distance E.

The Wintherthur water regulator is shown in Fig. 26. A is a chamber connected with the pipe leading from the producer to the engine. D is a piston working in A. C is an adjusting screw over coil spring D. E is a spindle with a needle valve at its lower end. F is a water chamber with overflow pipe G and inlet H. I is a pipe connecting with the vaporizer. J is a port connecting the water in F with I. K is an air inlet for the underside of the piston. The operation is as follows:

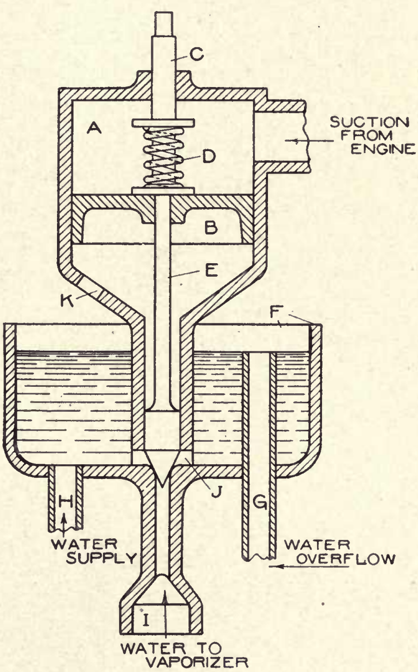


Fig. 26. Wintherthur Water Regulator.

The suction action of the gas engine produces a partial vacuum in A. As a result, the atmospheric pressure on the lower side of B raises it and E, compresses D, and opens the needle valve, allowing a certain amount of water to go to the vaporizer. When the sucking action of the gas engine ceases, the spring D will force B and E down and stop the flow of water. At the next charging stroke of the engine the same cycle is repeated. The extent of the movement of E and the resulting flow of water may be adjusted by changing the compression on spring D by means of screw C.

The Pierson water regulator is shown in Fig. 27. A is a diaphragm chamber connected with the pipe leading from the producer to the engine. B is a diaphragm. C is a needle valve connected to B by link F, levers G and H, and link I. J is a counterweight. D is the water inlet from the supply and E is the water outlet. Frequently this device is used between the vaporizer and the producer so that D becomes a steam inlet and E a steam outlet. The operation is as follows:

The sucking action of the gas engine produces a partial vacuum in A and, as a result, the exterior atmospheric pressure will cause B to move inward, raise C, and allow a certain amount of water to pass

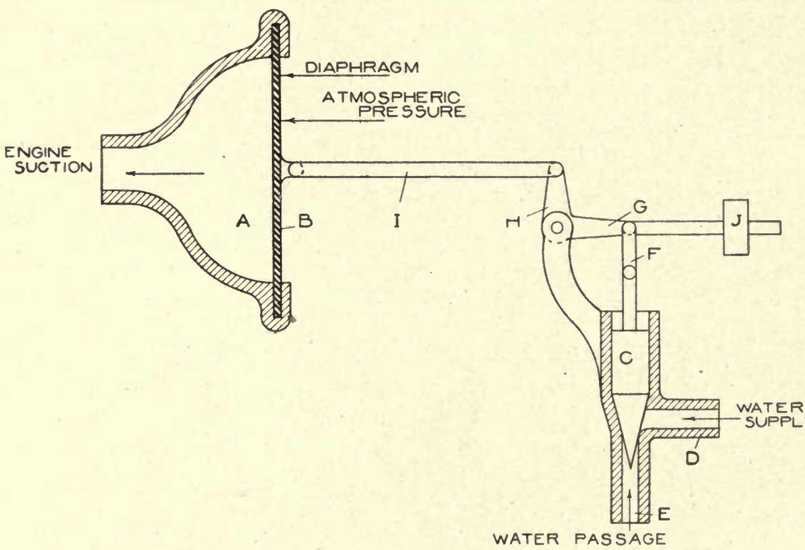



Fig. 27. Pierson Water Regulator.

through D and E. When the sucking action of the gas engine ceases, B will come back to its normal position, C will be closed, and the flow of water stopped. At the next charging stroke of the engine the same cycle is repeated. The amount of water admitted each time may be changed by adjusting the counterweight J.

The Smith water regulator is shown in Fig. 28. This also shows the heater for vaporizing the water and superheating the resulting steam and preheating the air by utilizing the waste heat in gas engine exhaust gases. A is the inlet for the exhaust gases while B is the interior of the heater. C is a thin, flat disk, around which the exhaust gases circulate and through which the air and steam pass. D is a shaft upon which the weighing vessel E is pivotally supported. F is a rod connecting E with the vane G. H is the air inlet; the curve of this is concentric with D. J is a screw for adjusting the amount of water going through the artifice I. K is the water inlet pipe, and L is the inlet valve. If more water is delivered to E than can pass out through I, the excess is drained to M by an opening not shown in the figure and then passes out through the drain N. O is a counter-

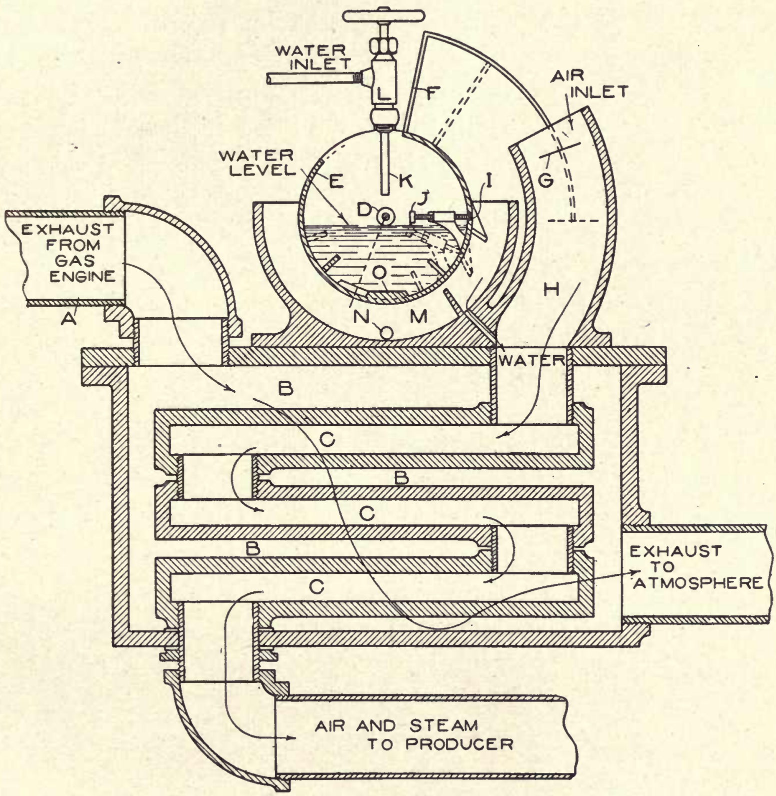



Fig. 28. Smith Water Regulator.

weight to keep E poised in the position shown in the illustration. The operation is as follows:

When the engine draws gas from the producer, outside air will rush in through H to replace the gas removed. As the air comes in past G it will cause this vane to be deflected and take the position indicated by the dotted lines; at the same time, E will be moved a corresponding amount and water will pass out of I and go down to the vaporizer below. When the sucking action of the gas engine ceases, the flow of air in H will cease and the counterweight will swing E and G back to their normal position; just as soon as I comes back to this position the flow of water will stop. The water falling down on the hot disks C is converted into steam and swept on through by the movement of the incoming air. In this passage the air becomes preheated and the steam superheated. At the next charging stroke of the engine the same cycle will be repeated. The amount of water delivered each time may be adjusted by means of the screw J.

**By-product Gas-Producers.** All by-product processes differ in detail only. They all are based on the same fundamental points; namely, a cooling of the gas after it leaves the producer, washing, and treatment with some reagent to precipitate the by-product.

Ammonia sulphate is about the only by-product that has enough commerical value to justify the additional expense required to save it, and its principal use is that of a fertilizer for certain soils. It is one of the most concentrated forms in which ammonia can be applied to the soil and gives very good results in clayey and loamy soils. It is, however, worthless for soils containing lime or chalk. The chief advantages of ammonia sulphate for fertilizing purposes are, that it is a definite product, quick acting, very concentrated, and easily mixed. Pure ammonia sulphate is a whitish crystaline salt and extremely soluble in water; the commercial article is generally grayish or brownish in color on account of small quantities of impurities. The ammonia sulphate is formed from the ammonia in the gas. Nearly all coal contains some nitrogen, usually about 1.5 per cent. From one-tenth to two-tenths of the nitrogen in the coal will go into the gas in the form of ammonia. By the use of an excessive amount of steam the yield of ammonia may be increased very much.

The gas-producer is usually of the pressure type and generally very little different from other producers. The by-product features are introduced after the gas leaves the producer proper. The scrubbing system must always be large and complicated; the by-product system is not adapted for small plants, and the additional first cost of the apparatus necessitates a large outlay of money. The operating expenses will also be higher on account of the salary of a skilled chemist required to handle the plant, reagents for the process and laboratory, and advertising of by-product. To make the plant

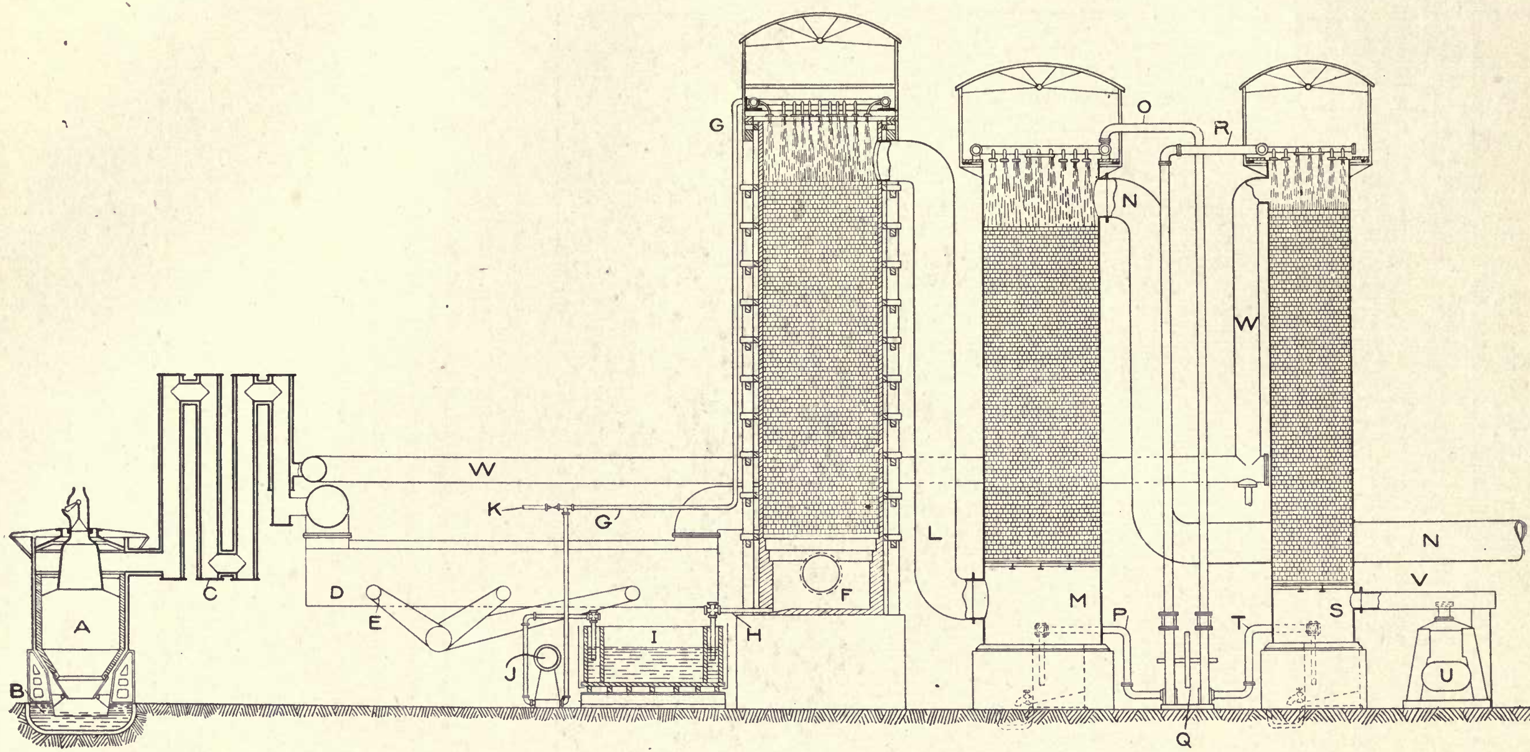



Fig. 29. Diagrammatic Section of Mond By-Product Gas-Producer.

a profitable investment the revenue from the by-product must be a considerable amount.

The Mond by-product system is the only one that has been used to any extent in this country, and it will now be described and illustrated. A diagrammatic section is shown in Fig. 29; Fig. 30 gives a general view of a Mond by-product plant, and Fig. 31 shows the producer regenerator and gas-washer. Referring to Fig. 29, A is the producer with water-seal ash-pan B. C is the air regenerator; the hot gas from the producer is passed through this and serves to pre-

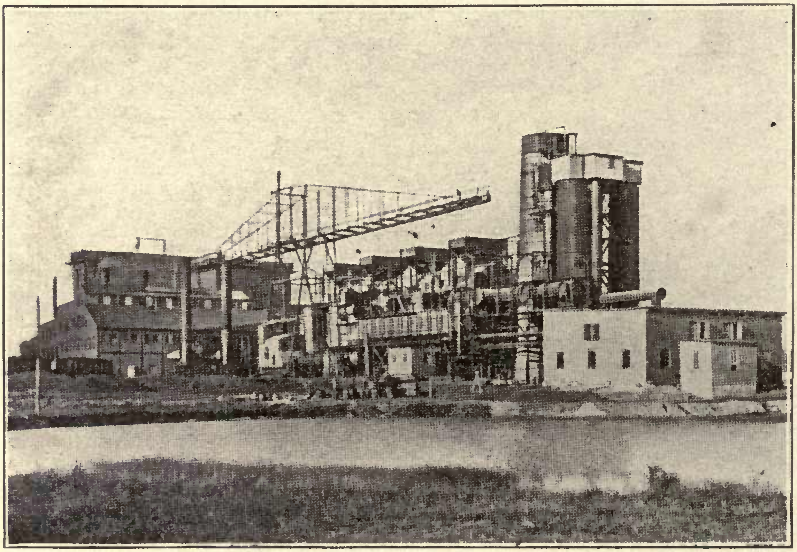


Fig. 30. General View of Mond By-Product Plant.

heat the incoming air, which passes through the outer compartment of the regenerator. D is a mechanical gas-washer. A few inches of water is in the bottom, and as the gas passes through, the rotating paddles, or dashers, E throw the water upward and secure a thorough mixture of the gas and water. In this way a large number of the impurities are washed out. From D the gas goes to the bottom of the acid tower F. This tower is filled with checker work and diluted sulphuric acid is introduced at top by the pipe G. As the gas goes upward, it is brought into intimate contact with the acid and this acts on the small percentage of ammonia in the gas, forming ammonia sulphate. The ammonia sulphate solution collects at the bottom of

F and then drains to the tank I by means of pipe H. J is a circulating pump which takes the liquor from I and delivers it to the top of F by pipe G. The liquor is circulated in this way until it reaches a certain degree of saturation; then some of it is by-passed out of the system by pipe K, and a corresponding amount of fresh acid added to the tank I. The concentrated ammonia sulphate solution is then

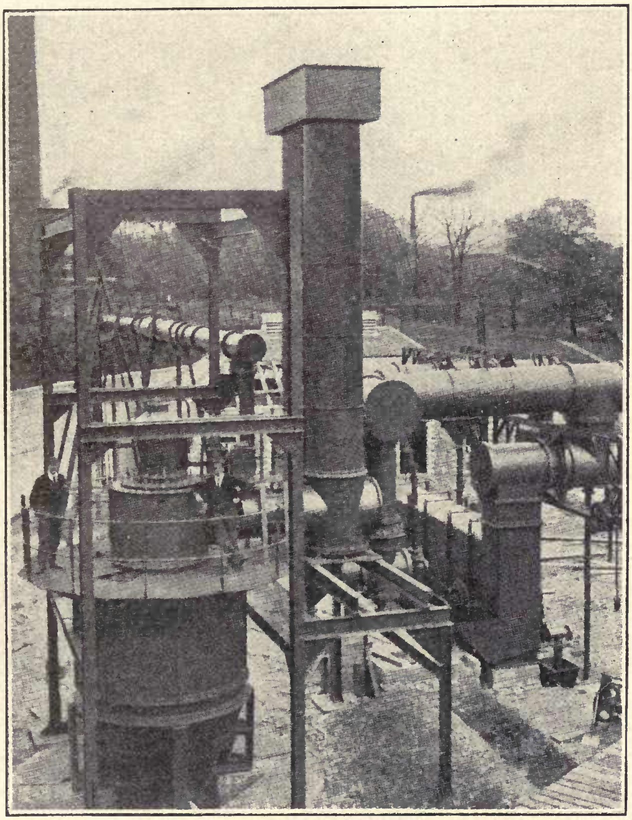


Fig. 31. Producer Regenerator and Gas Washer of Mond By-Product Plant.

evaporated and the sulphate reduced to a solid crystaline state. From the top of tower F the gas goes to the bottom of the cooling tower M by pipe L, and then goes up and out through pipe N. O is a pipe delivering cold water to the top of M. As this water trickles down through M it becomes heated by absorbing the heat from the ascending gas. The hot water from the bottom of M is withdrawn by pipe P and double circulating pump Q, and then delivered to the top of the air heating tower S. U is an air blower that furnishes the air to the producer A. V is a pipe connecting U with the bottom of S. As the cold air goes up through S, it becomes heated and saturated by the hot water from R. From the top of S the air goes to the regenerator C by means of pipe W. The cold water collecting at the bottom of S is withdrawn by pipe T and the double circulating pump Q, and delivered to the top of M. From the description just given it will be seen that the water acts as a heat carrier between the gas-cooling tower M and the air-heating tower S. Some idea of the extent and size of one of these plants may be obtained by a close examination of Figs. 30 and 31.

## GAS CLEANING

Producer gas, in addition to containing condensible constituents as shown in table 1, nearly always carries fine dust with it. Gas cleaning is used synonymously with gas scrubbing and gas washing and means either the removal of foreign constituents from the gas, or the removal of certain elements of the gas composition that are undesirable for certain uses of the gas. The idea of "washing" and "scrubbing" evidently comes from the fact that water is nearly always used in gas-cleaning processes. The object in cleaning any particular gas is simply to prepare it for some particular kind of work. No general rules can be laid for the number of constituents that must be removed or the degree of purity required. The primary requisite is that the gas shall be adapted to its specific work. The highest degree of purity is required for engine work; at the same time the additional cost of cleaning the gas up to that point might prohibit its use for heating a furnace where the impurities would not have a detrimental effect.

Gases may be cleaned by means of deflectors, liquid scrubbers, coolers, filters, and rotating scrubbers.

**Deflectors.** The deflector consists of an obstruction placed across the path of moving gas, and causes a sudden change of course. This has a tendency to precipitate the fine dust or water globules carried in suspension. It is very similar to the steam separator used near steam engines to separate the steam and water.

**Liquid Scrubbers.** Liquid scrubbers bring the gas in intimate contact with a liquid which is almost universally water. The liquid may be in the form of a seal, spray, or film.

Where a *seal* is used the gas is forced down into a mass of water and then bubbles up through it.

Where a *spray* is used the water is forced in a finely divided state out into a chamber and the gas is forced to pass through the spray, the object being to bring each particle of gas in close contact with a particle of water and in that way wash the impurities down into a chamber where they may be removed from time to time. The scrubbers shown in connection with the suction gas-producers, previously described, are of this type.

Where a *film* is used the stream of water is divided into as thin a film as possible and the gas is then zig-zaged across this a number of times.

**Cooler.** The cooler simply lowers the temperature of the gases passing through it, and in that way causes the condensible constituents to be precipitated. They are frequently used for removing the moisture or water vapor carried by producer gas made from wood.

**Filter.** The filter consists of some porous material through which the gas is passed and in so doing deposits some of its impurities in the filtering material. Shavings, excelsior, and sawdust are the filtering materials most generally used. Just as soon as the filtering material becomes saturated with impurities its usefulness as a remover of foreign matter from the gas ceases.

**Rotating Scrubbers.** Rotating scrubbers may be divided into two classes; those which are intended only to secure a thorough mixing action between the gas and some liquid, which is usually water; and those which drive the impurities out by centrifugal force. The former operate at comparatively slow speed, while the latter must be operated at a high speed in order to secure the centrifugal separation. The high speed type depends on the fact that all the impurities in the gas are heavier than the gas itself; as a consequence, when a mass of gas is rotated at a high speed the impurities will be driven out to the periphery of the apparatus.

It is very seldom that one type of gas-cleaning apparatus is used alone, but two or more types are frequently used together. In suction-producer gas plants deflectors, sprays, and seals are frequently used together. No one type is usually efficient enough to remove all the impurities.

The removal of *tar* from gas is one of the hardest problems in connection with gas cleaning. The use of a tar-laden gas in gas engines will quickly gum the valves and necessitate a stoppage of the producer and engine. This is the reason why so many gas-producers for power purposes are using anthracite coal. This particular fuel making a gas practically free from tar, makes the problem of gas cleaning an easy matter. However, there are many cases where the high cost of anthracite coal prohibits the use of producer gas for power purposes. In many instances the cost of anthracite coal is four times the cost of bituminous coal. Now, since a pound of the latter will make just as much producer gas as a pound of the former there would evidently be a decided advantage in many cases to use bituminous coal in a producer-gas power plant. The problem of the use of bituminous coal for such work is simply the problem of eliminating the tar. This may be done by the separation of the tar from the gas or the use of a device that will prevent the formation of the tar or its deposition in the gas.

Tar is a very complex substance and is one of the products of the destructive distillation of coal. It is made up of about two hundred other compounds and some of these are so complex and hard to isolate that very little is known about them. The exact composition will depend on a large number of factors, the most important of which is the temperature at which it is formed. Coal tar has a specific gravity of about 1.15, a black color, and a very marked and disagreeable odor. It condenses easily and if brought into intimate contact with incandescent carbon it may be converted into fixed gases. The last fact just mentioned forms the basis of all tar-destruction methods; that is, where the tar is broken up in the producer.

The separation of the tar from the gas may be accomplished by an extensive tower scrubber or the use of some form of centrifugal apparatus which will drive the tar out of the gas by centrifugal force. The latter method can be made very effective, but the former is adapted only for gas containing small amounts of tar. On the other hand, the centrifugal method requires close watching, and, in some cases, considerable power to run the apparatus; neither method is as satisfactory as the complete destruction of the tar in the producer.

The tar is always evolved in the distillation zone and goes directly into the distillation products. All schemes for tar destruction consist in bringing these *distillation* products into close contact with hot carbon, so that the condensible constituents will be converted into fixed gases. This may be accomplished by the use of a down-draft producer, as shown in Fig. 16; the removal of the gas in the middle of the producer or the circulation of distillation products, as shown in Fig. 15; the use of a distillation retort, as shown in Fig. 14; or underfeeding, as shown in Fig. 18. The passing of the tar through a separate chamber filled with incandescent coke has also been used.

## USES OF PRODUCER GAS

The use of producer gas now extends to a large number of industries. The following diagram taken from the author's Treatise on Producer Gas and Gas-Producers gives a classification of the various uses.

General Uses of Producer Gas.

- 1. Fuel for Gas Engines
- 2. Firing Steam Boilers
- 3. Firing Ceramic Kilns
  - Brick Kilns
  - Tile Kilns
  - Pottery Kilns
  - Muffle Kilns
  - Lime Kilns
  - Cement Kilns
- 4. Firing Metallurgical Furnaces
  - Forges
  - Steel Furnaces
  - Muffle Furnaces
  - Glass Furnaces
  - Roasting Furnaces

## PRODUCER-GAS POWER PLANTS

There are now a large number of producer-gas power plants in successful operation in America. They have many advantages over steam plants and many more will be installed in the future. To be successful, the gas-producer and gas engine must be adapted to each other. Producer gas having a lower calorific power, the engine must handle a large volume of gas, and, as a result, the ports and valves must be larger. A 100-H. P. gas engine designed to use natural gas will develop only about 80-H. P. with producer gas or a loss of

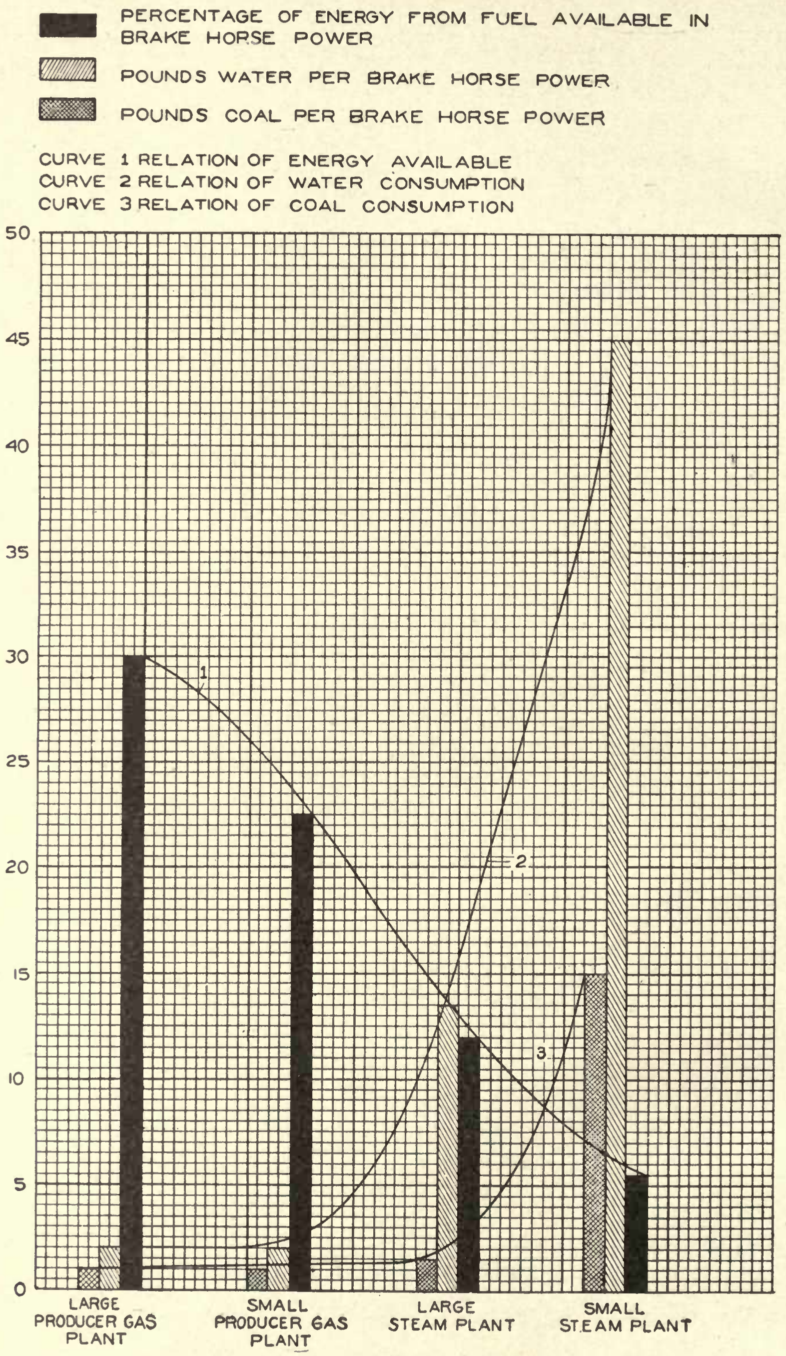



**Fig. 32. Chart Showing Relative Efficiency of Producer-Gas and Steam Power Plants.**

about 20 per cent. If a suction gas-producer is used there will be a further loss of probably 4 per cent due to the negative work of drawing the gas away from the producer.

The high fuel and water economy of the producer-gas power plant is one of its strongest advantages over the steam power plant. These points are clearly shown in Fig. 32. This arrangement of data brings out several important points. It will be seen that there is little difference in the coal or water consumption between large and small producer-gas plants. This is due to the fact that small gas engines may have practically the same thermal efficiency as large ones. As a result of this fact the small producer-gas power plant can be operated nearly as cheaply as a large plant. In other words, it is not necessary to use large units in order to get economical results. In many cases where the load fluctuation is large much better results will be obtained by installing, say four 500-H. P. gas engine units in place of one 2,000-H. P. unit. Another interesting fact shown on Fig. 32 is, that even a small producer-gas plant is more economical than a large and complicated steam plant. The economy of water of the producer-gas plant over the steam plant is always a desirable feature for the former, and in cases where water is scarce or impure so as to make it undesirable for boiler use, it is of the greatest importance.

Inasmuch as the gas-producer does not make any smoke, it is evident that the producer-gas power plant offers an ideal solution for the smoke problem. Just as soon as public sentiment against the smoke nuisance becomes crystalized into prohibitory laws, the gas-producer industry will receive a new impetus.

The labor in a producer-gas plant will generally be about the same as that in a similar steam plant. It is, however, much easier to install mechanical appliances for handling the fuel in a gas plant than in a steam plant. If a suction gas-producer is used the labor will also be decreased. The producer may be started in about twenty minutes and can be stopped instantly.

The first cost and cost of repairs will be about the same in producer-gas as in steam plants. Gas engines cost more per horse power than steam engines, but the cost of the smoke stack is eliminated. Sometimes in small producer-gas plants the cost will be about one-fifth higher than in steam plants.

In steam and producer-gas plant the steam and producer gas simply act as carriers of thermal energy. The cooling of the steam will lower and may entirely destroy its thermal energy, while the cooling of the gas will simply decrease its volume and increase the thermal energy carried per cubic foot. This last statement refers to calorific power only; since the sensible heat of the gas is of no use in the gas engine, the temperature of the gas as it leaves the producer should be very low. In other words, with producer gas the thermal energy carried by the gas *for* the gas engine will *not* be lowered if the gas is cooled. This fact makes it possible to put in central producer-gas plants with long pipe lines to distribute the gas to isolated engines.

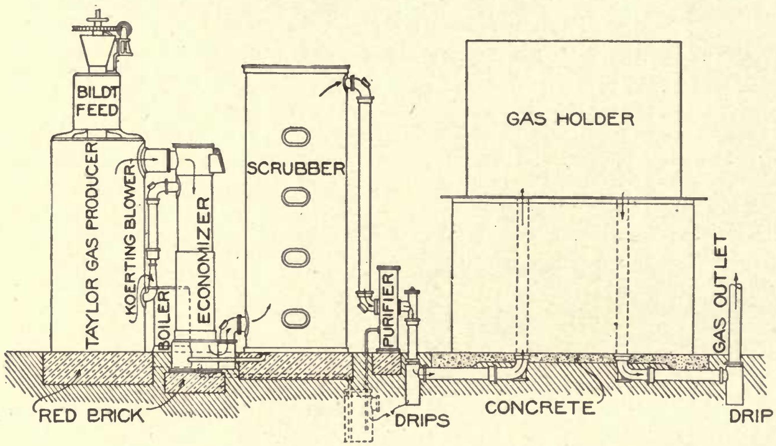



Fig. 33. Typical Producer Plant—Pressure Type.

This would mean a large saving in shafting, especially when electrical power is not available. Then too, it is entirely possible to build a large producer-gas plant at the coal mines and in place of shipping the coal to the various places of consumption simply pipe the gas to those places. This scheme if properly executed will give much better results than the shipping of coal to a large number of small plants.

The use of a gas holder for storing the gas has marked advantages in certain cases. By this means irregularities in the load may be taken care of without any difficulty. In some industries it may be desirable to have a small amount of gaseous fuel for heating furnaces, as forges, and, in such cases, the gas may be taken from the same holder that supplies the engine.

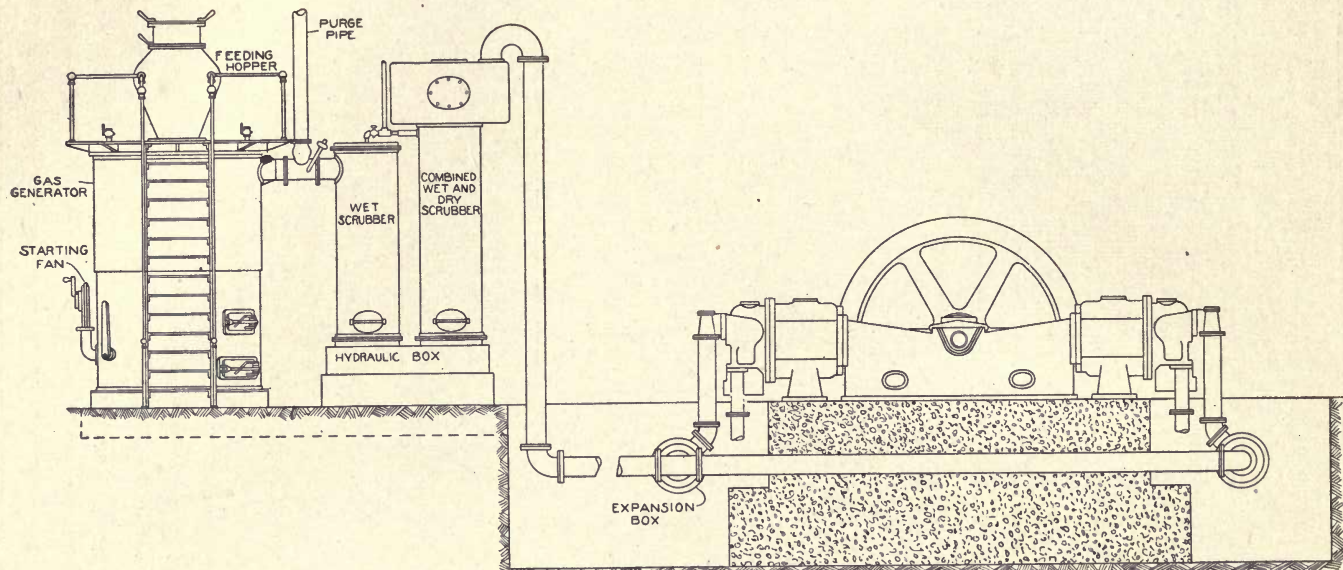



Fig. 34. Typical Suction Producer-Gas Power Plant.

Fig. 33 shows a typical producer-gas plant. The names of the various parts are given on the illustration. The holder is frequently placed farther away from the producer than shown in the illustration; in fact, it may be placed on any area that is available, regardless of immediate proximity to the producer. Fig. 34 represents a typical suction producer-gas power plant. The engine shown at the right-hand side and the names of the other parts are clearly indicated on the illustration. Fig. 35 is another view made from a photograph of the previous plant. The engines are shown in the foreground, while the producer and scrubbers may be seen beyond the open

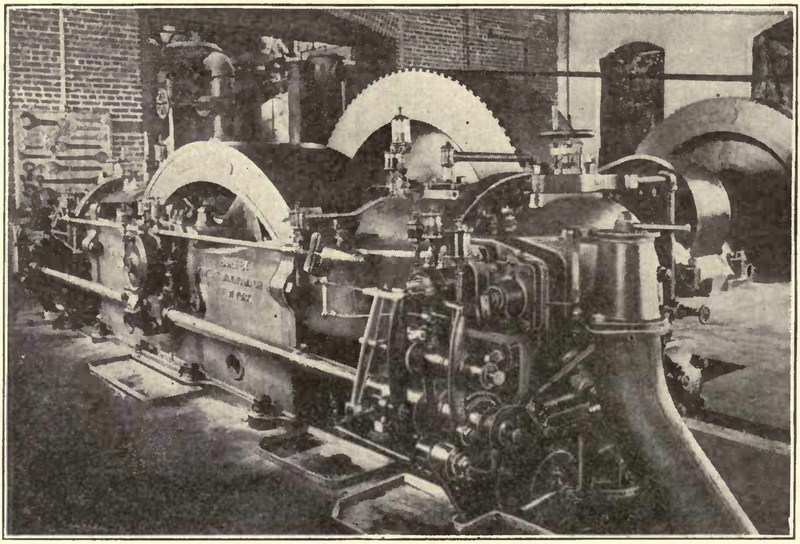


Fig. 35. View of Engine and Producer Room of Suction Producer-Gas Power Plant.

doorway. In Figs. 33 and 34 all the parts are shown in line with one another. This is done only to simplify the illustration. In nearly all installations the producer and auxiliary apparatus is arranged in more compact form.

**Firing Steam Boilers.** Producer gas has been used to a limited extent for this work in Europe. It is not very good engineering practice and should be used only in cases where steam is required in the process of manufacture; as for instance, in steaming lumber. It will be much better to eliminate the boiler entirely in other cases and use the gas directly in a gas engine. In general, no direct fuel economy will result from first gasifying the fuel in a gas-producer and then burning the resulting gas under a steam boiler.

**Firing Ceramic Kilns.** Producer gas has been used extensively in Europe for this work but until the last few years has had a very limited use in America. Several costly failures have been made in attempting to use it, but these have not been the fault of the system but rather were due entirely to the ignorance of the men who have attempted to use it. Producer gas has decided advantages for ceramic work, but great care is necessary in applying it. No generalized rules can be given for its application. Every installation must be studied in detail and all the results co-ordinated to each other in order to secure a harmonious unit. The best results will be obtained in connection with continuous kilns. The use of producer gas in kilns eliminates clinkering in the kilns, induces more uniform burning, produces better combustion, makes it possible to regulate fire more readily, secures a centralization of furnaces, and should result in fuel economy.

**Firing Metallurgical Furnaces.** This was the first, and even today, is the largest field for the use of producer gas. It has been an important factor in developing the modern steel industry and has become a commerically necessary adjunct of it. The types of producers shown in Figs. 5, 6, 7, 8, are used very extensively for this work.

## REQUIREMENTS

One of the most important requirements is that the gas-producer shall be adapted to the work it has to do. The construction of the producer should be compact and simple and so designed as to permit the easy removal of worn out parts. The feeding device should be such as to secure a uniform distribution of the fuel. The blast should be so introduced as to burn out all the carbon in the ash-zone and yet not produce localized combustion along the walls. The construction should be such as to permit the easy removal of the ashes. The entire process of gasification should be clean. The radiation loss should be low, and the producer must be efficient.

## GAS POISONING

Producer gas on account of the presence of carbon monoxide will always be poisonous. The carbon monoxide has a specific toxic effect on the human system, and when inspired enters into direct combination with the blood. The new compound formed is incapable of carrying oxygen to the tissues and is so stable that it can be broken up only with great difficulty. The action is very insidious, and if the amount that is inhaled is small, the person breathing it may be made almost helpless before they are aware of it. The symptoms are a sense of discomfort, with throbbing of the blood vessels, severe headaches, giddiness, and great debility. In case of poisoning, the first thing is to remove the patient to the fresh air and send for a physician. In handling a patient, great care must be exercised to keep the head higher than the lower part of the body.

## CONCLUSIONS

The manufacture of producer gas is an old and well-established process. The process is not complicated and the chemical reactions are simple. Originally developed as a by-product of the iron industry, its ramifications now extend to a large number of industries. In many cases its use will result in fuel economy, and in the near future producer-gas power plants will be as common as steam power plants.

# INDEX

*Part I*—Gas and Oil Engines; *Part II*—Gas-Producers