

May 17, 1927.

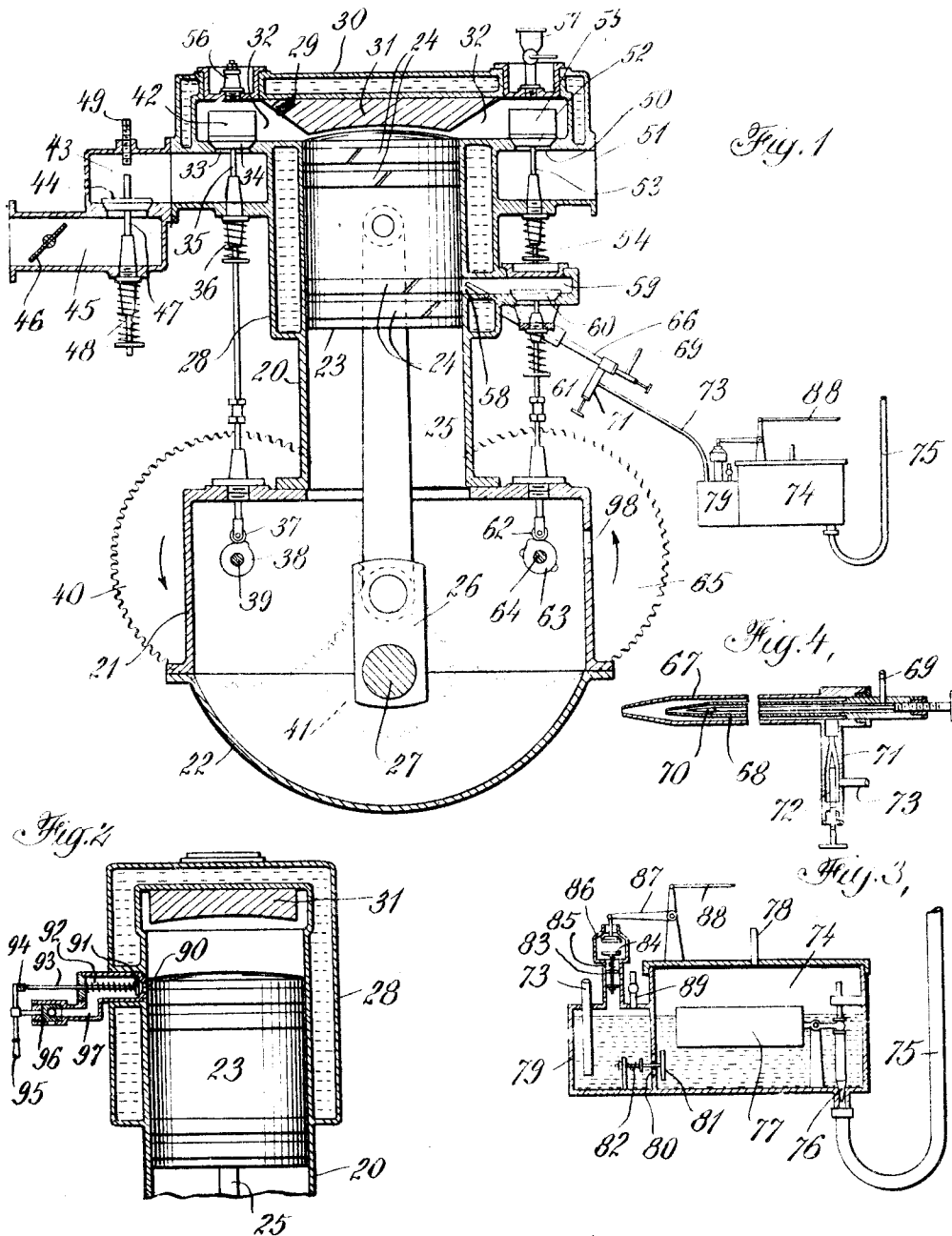
1,629,327

G. W. WALDO

INTERNAL COMBUSTION ENGINE

Filed Feb. 26, 1921

3 Sheets-Sheet 1



George W. Waldo, Inventor
By His Attorney
Walter J. Lill

May 17, 1927.

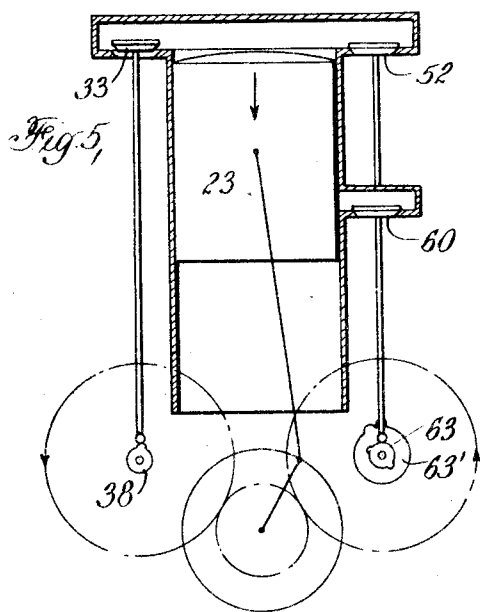
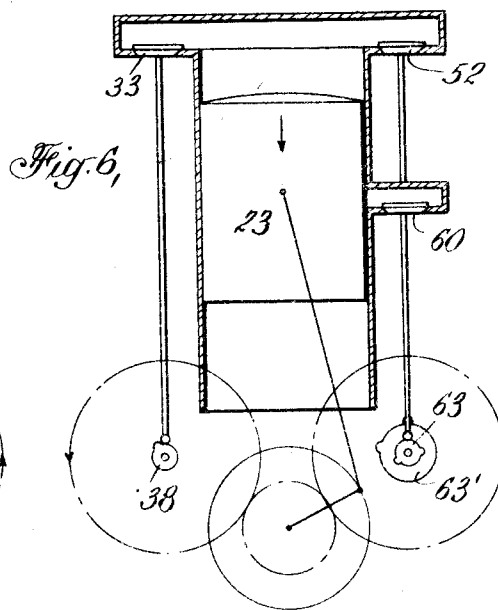
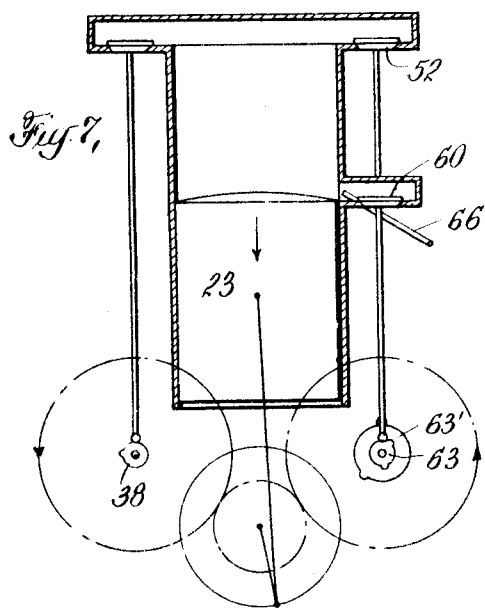
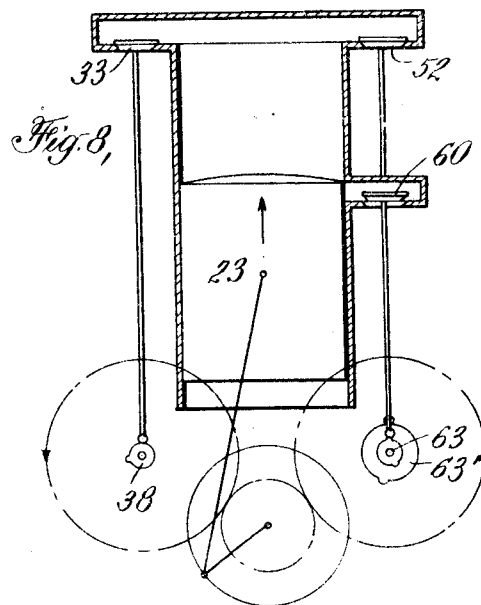
1,629,327

G. W. WALDO

INTERNAL COMBUSTION ENGINE

Filed Feb. 26, 1921

3 Sheets-Sheet 2



George W. Waldo Inventor
By his Attorney Walter J. Gill

May 17, 1927.

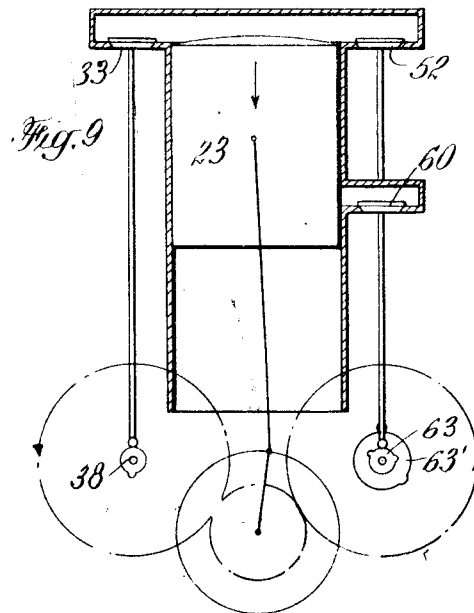
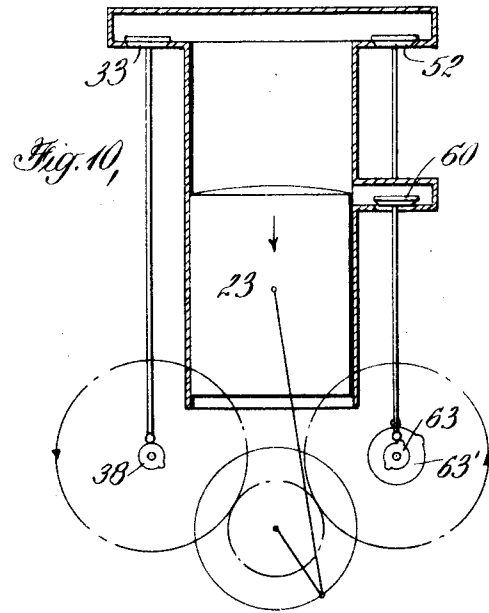
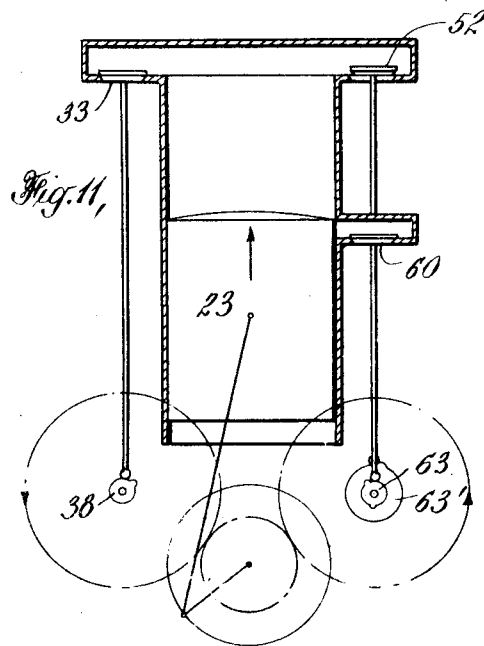
1,629,327

G. W. WALDO

INTERNAL COMBUSTION ENGINE

Filed Feb. 26, 1921

3 Sheets-Sheet 3



George W. Waldo, Inventor
By his Attorney
Walter J. Gill.

Patented May 17, 1927.

1,629,327

UNITED STATES PATENT OFFICE.

GEORGE W. WALDO, OF BROOKLYN, NEW YORK.

INTERNAL-COMBUSTION ENGINE.

Application filed February 26, 1921. Serial No. 448,034.

This invention relates to internal combustion engines and particularly to engines of the four-cycle type.

This application is a continuation in part of my copending application Serial No. 298,895, filed May 22, 1919 which has been merged herewith.

The action of four-cycle internal combustion engines of the types at present in use, in which gasoline and kindred fuels are burned, does not permit of the maximum economy of fuel because the mixture of air and fuel cannot, after ignition, be properly expanded within the available space within the cylinders. This is due to the fact that the entire cylinder space is filled with the fuel mixture at atmospheric pressure before compression and ignition take place. Such a quantity of gas after compression and ignition requires a much larger space in which to expand efficiently, and the rate of change of volume, due to movement of the piston, must also be an efficient proportion of the natural and unrestricted rate of expansion of the gas, otherwise a large proportion of the expansive power of the gas is delivered as a dead blow upon the piston and a large percentage of the heat energy of the gas is expended in heating the cylinder walls.

Most carbureters and mixing devices in use at the present time depend upon the action of a current of air passed across a small jet supplied with fuel from a small constant level reservoir usually located in such a manner as to furnish a slight head to assist the issue of fuel from the jet which is controlled by some form of needle valve. The amount of liquid which issues from the jet depends upon the opening of the needle valve and the suction action of the air current over the jet. After issuing from the jet, the liquid is carried along and mixed with the air current, becoming more or less vaporized according to the grade of fuel used and the temperatures obtaining.

If an exceptionally volatile liquid fuel is used in a carbureter or other mixing device, it will be found that a fairly close regulation can be obtained in supplying suitable quantities of fuel for the formation of a dry vapor within the air current passing through the carbureter into the engine. It should be noted, however, that the formation of vapor takes place within the air during its passage into the engine. It is doubtful if any vapor is formed in the car-

bureter itself. If the proper quantity of fuel is injected into the air current, a dry vapor mixture will be formed, which, if of sufficient quantity, will constitute an explosive and efficient mixture for use within the engine. Since a dry vapor cannot be condensed under conditions met in gas engine practice as to temperature and pressure changes, it follows that such a mixture will undergo compression without liquefaction of any of the fuel content.

Consider, now, the lower grades of fuel passing through a carbureter or other mixing device. It is found that it is very difficult, even if at all possible, to obtain a dry vapor mixture for use in the engine. This is due to the lower vapor pressure of the fuel at atmospheric temperature and pressure and to the inadequate means of the carbureter for injecting the fuel into the air current in proper quantity. Various plans have been proposed for obviating this difficulty, such as heating the carbureter from the exhaust manifold, or breaking up the jet or spray into fine particles. With such methods, however, there is no positive way of assuring the production of a dry vapor because there is no means of ascertaining that the particular fuel has been supplied at a sufficient temperature to remain in vapor form in the original quantity throughout the compression stroke of the particular engine. That this condition exists is borne out by the formation of carbon deposits in all gasoline and kindred engines regardless of the most careful carbureter adjustment, such formation being undoubtedly due to combustion of fuel in liquid instead of in vapor or gaseous form.

It appears from the foregoing considerations that internal combustion engines of the types at present in use require radical departure, not only as to the means of expanding a heated gas, but as to carbureters and mixing devices, and also as to the methods of forming the vapors in order that the existence of a dry vapor will be definitely assured at all times. Particularly is this the case on account of the low vapor tensions of present day liquid fuels at the intake pressures and temperatures obtaining in practice. I have found that it is possible to reduce the pressure of the air within the cylinders of an internal combustion engine to such a point that if a given quantity of fuel be injected, or admitted in liq-

uid form in suspension, the vapor pressure of the fuel will allow a dry vapor mixture of air and fuel to be formed, provided the fuel be accurately metered to prevent saturation pressure and other conditions from being realized. A gaseous mixture will thus result which, after combustion, can be most efficiently expanded within the engine. This reduction of pressure may be obtained by expanding a given quantity of air alone or air with fuel in liquid suspension, within the cylinder of the engine, or within a suitable auxiliary cylinder, to a pressure suitable for mixture with the particular fuel to be used. Preferably the fuel should be injected when the greatest reduction of air pressure obtains and where movement of the piston may be utilized for metering, that is, at the end of the intake stroke. The greater the reduction in air pressure, the more rapidly will the particular quantity of fuel projected into the cylinder, or present in suspension in the air, become dry vapor.

It is accordingly an object of the present invention to provide a cylinder space wherein a most efficient rate of change of volume may be possible and in which the heated gas may be expanded to or slightly below atmospheric pressure. In accordance with the invention, this is accomplished by closing the intake valve during a certain proportion of the intake stroke of the piston so that only that quantity of air will enter the cylinder which, when compressed and heated by the fuel combustion, will be capable of the most efficient expansion rate. The heated gas should be expanded to a point somewhat below the pressure of the atmosphere in order that air may be admitted to the cylinder just previous to and during the movement of the piston on its explosion stroke past a port having communication with the atmosphere through a suitable valve. The air thus entering the cylinder is transferred to the clearance space of the engine by the piston on its exhaust or scavenging stroke, thus permitting a much more efficient condition of clearance space than would otherwise obtain.

It results from the above construction that the exhaust from the engine will be practically noiseless in so far as would obtain from the release of gas at high pressures such as are now used in gas engine practice, the release of the gas, in accordance with the present invention, being entirely accomplished by the movement of the piston on its scavenging stroke and in no sense by the excess of pressure obtaining within the cylinder when the exhaust valve is opened.

In considering the action which occurs during the exhaust stroke of the engine, it will be seen that the gases discharged from the cylinder which were originated from a

partial vacuum will immediately cool to atmospheric temperature and hence to the original pressure of the partial vacuum, the gases within the cylinder thereby tending always to expand and cool to the initial pressure and temperature of the partial vacuum from which they originated, or to the original volume at atmospheric pressure and temperature. Thus a stroke which, in the usual construction of internal combustion engines, is an idle stroke against a back pressure, has, in the engine of the present invention, been converted into a power stroke, with the result that the engine may be considered to have two power strokes—a major one due to the combustion of the fuel, and a minor one due to the effect of the air pressure acting upon the exterior of the piston against a partial vacuum within the cylinder, which has a tendency to exist throughout the entire exhaust stroke.

The present invention is not, however, confined to a noiseless engine or to one in which the gas is expanded to the limits referred to above, but it also provides for the augmentation of the vaporizing tendencies of various more or less volatile liquid fuels by providing a construction wherein a suitable partial vacuum is provided for vaporizing fuel to the extent that the fuel may be injected directly into the cylinder and vaporized without special provision for preheating and in quantities desirable for an efficient combustion, such as low grade gasoline, kerosene, alcohol or other similar fuels, by merely injecting a suitable quantity into the cylinder during any part of the intake stroke, the amount of liquid injected being regulated by the piston movement past a port, hence by the width of the port, or by the piston movement during the time when injection of fuel takes place, and by timing the movement of fuel to the spraying device so that just the proper amount of fuel is admitted by both means which will give the proper quantity of dry vapor necessary for the amount of air within the cylinder. This timing is accomplished by the change of level of a fuel reservoir or by the air pressure upon the surface of the fuel within the reservoir, or by both means. By spraying fuel into a partial vacuum I obtain a dry fuel vapor which readily mixes with the air in the cylinder and cannot be condensed to liquid form while undergoing compression and other pressures.

The invention also provides an internal combustion engine in which the compression may be varied in accordance with different operating conditions due, for instance, to the kind or grade of fuel employed or the atmospheric pressure existing, but for any particular condition will remain constant so long as the condition does not change.

Other objects and advantages of the inven-

tion will appear more clearly from a description of a preferred embodiment as shown in the accompanying drawings in which

5 Fig. 1 is an elevation in section of one cylinder of an engine constructed in accordance with the invention,

Fig. 2 is a sectional view of the cylinder taken at right angles to Fig. 1,

10 Fig. 3 is a sectional view of the fuel reservoir,

Fig. 4 is a sectional view of the fuel nozzle,

15 Figs. 5, 6 and 7 are diagrammatic views showing the position of the parts at the beginning, an intermediate point and the end, respectively, of the intake stroke,

Fig. 8 shows the position of the parts shortly after the beginning of the compression stroke,

Fig. 9 shows the position of the parts at the beginning of the working stroke,

25 Fig. 10 shows the position of the parts near the termination of the working stroke, and

Fig. 11 shows their position shortly after the beginning of the exhaust stroke.

Referring to the drawings in which similar reference characters denote similar parts throughout the several views, 20 is one of the cylinders of the engine, which is mounted upon a suitable base 21 which also serves as a portion of the crank case, the latter being completed by means of a member 22 30 attached to the bottom of the base. Within the cylinder is a piston 23 provided with suitable packing rings 24 and connected by means of a rod 25 with a crank 26 attached to a crank shaft 27 which is mounted in suitable bearings at the end of the crank case. The cylinder is surrounded by outer walls 28 40 forming a chamber within which, if desired, a cooling liquid may circulate in accordance with the usual construction of internal combustion engines, or the engine may be air cooled instead. The cylinder head 29 is also provided with an outer wall 30 forming a chamber within which cooling liquid may circulate. In case the clearance space at 50 the top of the cylinder is too great, as may be the case if the invention is applied to engines of ordinary design, a member 31 of suitable shape may be immovably attached to the inside of the cylinder head to fill up the central portion of the clearance space 55 leaving an annular chamber 32. This chamber is provided at one side with a port 33 which is closed by a valve 34 the stem 35 of which is normally drawn down by means of a spring 36 and is provided at its lower end with a roller 37 or the like resting upon a cam 38 on a cam shaft 39 carrying a gear 40 meshing with a gear 41 on the crank shaft 27. The valve 34 may be provided 65 with a detachable member 42 by which the

free space within the chamber 32 above the valve may be altered by the substitution of members of different volumes in case it should be desired to alter an engine to accomplish the cycle herein described. The 70 intake port 33 communicates with a chamber 43 having a valve 44 between it and a conduit 45 leading to the external atmosphere or to an intake manifold and provided with a throttle valve 46 if desired. The 75 stem 47 of the valve 44 is surrounded by a spring 48 which normally holds the valve on its seat. In order to limit the upward movement of the valve and thus restrict the opening between the chamber 43 and the 80 conduit 45, there is provided an adjusting screw 49 adapted to be engaged by the upper end of the valve stem 47 when the valve is in open position.

The annular chamber 32 is provided with 85 an exhaust port 50, preferably arranged diametrically opposite to the intake port 33, and communicating with a passageway 51 connected to the exhaust manifold of the engine, or opening directly to the atmosphere. The port 50 is controlled by an exhaust valve 52 the stem 53 of which is provided with a spring 54 for holding the valve 90 on its seat. The exhaust valve may be provided with a detachable member 55 by which the free space above the valve may be altered. It will be understood that the valve stem 53 is extended and provided at its lower end with a roller adapted to engage a cam driven from the crank shaft, the arrangement being similar to that shown 100 in connection with the intake valve.

The cylinder is provided with a suitable spark plug 56, preferably placed above the intake valve 34, and, if desired, a priming device 57 of an appropriate construction may be placed above the exhaust valve 52, or in any other suitable position.

The cylinder 20 is provided with a port 58 at the inner end of a passage 59 having 110 communication with the external atmosphere through a valve 60, the stem 61 of which is provided with a roller 62 bearing upon a cam 63 on a cam shaft 64 which carries a gear 65 meshing with a gear on the crank shaft 27, such, for instance, as the gear 41. The stem of the exhaust valve 52 may conveniently be operated from the cam shaft 64. The lower portion of this stem, its roller and actuating cam do not appear 120 in Fig. 1, but the roller and cam are shown in the diagrammatic views Figs. 5 to 11, the cam being designated 63'.

Extending into the chamber 59 and terminating near the port 58 is a nozzle 66 125 preferably inclined at a slight angle and having the construction shown most clearly in Fig. 4. This nozzle comprises a casing 67 having a pointed inner end. Within the outer casing is a tube 68 having an exten- 130

sion 69 communicating with the atmosphere or other source of air supply. The tube is provided with a needle valve 70 by which the amount of air admitted to the nozzle may be controlled. The casing 67 is provided with an extension 71 having a valve 72 for controlling the supply of fuel from a pipe 73 leading to the fuel reservoir shown most clearly in Fig. 3.

This reservoir comprises a main tank 74 into which suitable liquid fuel may flow through a pipe 75 leading to a supply tank not shown in the drawing. The flow of fuel from the pipe 75 into the tank 74 is controlled by a valve 76 adapted to be operated by a float 77 to maintain a substantially constant level of liquid within the tank. The main tank is provided with an air vent 78 of any suitable construction. Associated with the main tank 74 is an auxiliary tank 79 having communication with the main tank through ports 80 adapted to be closed by a valve 81 controlled by a spring 82. The top of the auxiliary tank is provided with an extension 83 within which is a valve 84 normally held off of its seat by a spring 85. The top of extension 83 is open to the atmosphere through a port which is controlled by a valve 86 connected to a bell crank lever 87 adapted to be operated by a controlling rod 88. The auxiliary tank is also provided with a suitable check valve 89 which allows the escape of air from the tank, but prevents it from flowing into the tank.

The cylinder 20 is also provided with a relief port 90 (see Fig. 2) located at a suitable distance below the top of the cylinder for a purpose which will hereinafter appear. The relief port is provided with a valve 91 held normally against its seat by means of a spring 92 surrounding its stem. Cooperating with the outer end of the stem 93 is a cam 94 upon the end of a handle 95 which is connected to the outer end of the stem of a rotary valve 96 in a conduit 97 communicating with the relief port. The parts are so arranged that under normal conditions with the valve 96 closed the cam 94 will hold the valve 91 locked on its seat, but if the handle 95 is turned to open valve 96 the cam will release the stem of valve 91 to permit the latter to be opened by pressure within the cylinder.

The operation of the engine will appear most clearly from the diagrammatic views Figs. 5 to 11 inclusive. Commencing with the intake stroke the parts will occupy positions substantially as shown in Fig. 5, with the piston 23 having just passed over its upper dead center point and the intake valve 34 having just been opened by cam 38. The downward movement of the piston on its intake stroke will draw air into the cylinder through the manually controlled throttle valve 46, conduit 45, adjustable throttling

valve 44 which is lifted by the air entering the cylinder, chamber 43, and port 33. When the piston 23 has completed approximately one third of its downward movement on the intake stroke, the intake valve 34 will have completed its opening and closing movement and the parts will be in the positions substantially as shown in Fig. 6. Further movement of the piston downward will permit the air previously drawn into the cylinder to expand. This expansion will continue until the parts are in position substantially as shown in Fig. 7. The air will then have been expanded to the limit of the cylinder volume provided and as far as possible with the parts shown. A partial vacuum will therefore exist within the cylinder at this time.

At the instant when port 58 is uncovered by piston 23 on its downward movement, a flow of fuel may take place from auxiliary tank 79 through pipe 73, and nozzle casing 67 into the cylinder, since full or any part of full atmospheric pressure may be caused to obtain in the air space over the liquid in tank 79 by admitting air or restricting the admission of air through manually controlled valve 86. The valve 84 is held open by its spring 85 to permit entrance of air to the auxiliary tank. Air at atmospheric pressure will also enter the cylinder through air jet tube 68, the amount of this air being controlled by needle valve 70. Since both air and fuel must enter the cylinder through the same port the fuel entering the cylinder, if in liquid condition, will be in the form of fine spray. However, it is possible that the fuel, due to its vapor pressure will become vaporized directly at the needle valve and will be drawn into the cylinder as fuel vapor mixed with air at the end of the air jet 68. From the foregoing it will be readily seen that a mixture of air and liquid fuel spray, or of air and fuel vapor or, assuming jet 68 to be eliminated, liquid fuel alone or fuel vapor alone may enter the cylinder at any particular time or during all of the time that the port 58 is uncovered by the piston, and that any liquid fuel entering the cylinder will, due to its vapor pressure, become vaporized and will mix with the air in the cylinder in direct proportion to the pressure of the air and the particular vapor pressure of the fuel. It will also be seen, considering the proportion of fuel to air for efficient combustible mixtures, that if the fuel supply is suitably regulated a dry fuel vapor will be obtained within the cylinder, which cannot be condensed under any pressure to which it may be subjected while in the cylinder.

Referring to Fig. 4 and assuming a liquid level as shown, it will be seen that in order to reach the needle valve 70 of nozzle 66 the liquid will have to travel a definite dis-

tance through pipe 73 and that for a given pressure on the surface of the liquid in the tank 79, the liquid will accomplish the travel to the needle valve 70 in a proportionate length of time. If the volume of the air space over the surface of the liquid is properly proportioned and the air permitted to enter in a properly regulated amount, the travel of the liquid can be regulated to supply just the amount of fuel required for any engine speed. The regulation can also be accomplished by raising and lowering the reservoir, using flexible pipe connections to the nozzle, or by a combination of both these means. In designing the fuel system, consideration should be given to the size of pipe 73 and to the location of tank 79 so that the travel and amount of movement of liquid out of the tank will cause a change of volume of the air space over the liquid in the tank such as will give a sensitive control due to the change in air pressure in this space caused by the change of volume due to the movement of the liquid out of the tank.

The flow of fuel from the supply tank through the pipe 75 to the main tank of the reservoir will be controlled by float valve 76. The check valve 81 is held open normally by spring 82, the force of which is just sufficient to overcome the liquid head of the fuel in main tank 74, thus permitting normal passage of liquid for a proper quantity in auxiliary tank 79. Any considerable flow of liquid such as might be caused by air pressure on the surface of the liquid in tank 74, or by suction from auxiliary tank 79, will result in closing the check valve 81 and stopping communication between the two. The auxiliary tank is provided with an air space above the liquid which is of such proportions that any movement of liquid out of the tank will result in considerable change of volume of this space. Air is admitted freely to the main tank 74 by means of pipe 78 so as to permit liquid to flow freely in and out of this tank. Air is admitted to the auxiliary tank 79 through the manually controlled valve 86 located in the entrance to the air space. The check valve 84 is normally held off of its seat by light spring tension sufficient to hold the valve open under normal conditions to permit the passage of air admitted through valve 85, but in case of a sudden change of liquid flow out of tank 79, such as might be caused by slowing down of the engine speed due to abnormal conditions, the pressure of air entering through valve 85 will cause the check valve to close and thus automatically restrict the pressure exerted on the top of the fuel, such pressure being due primarily to the partial vacuum obtaining within the cylinder. Air may escape from tank 79 by means of check valve 89. Such escape of air is necessary in order that normal liquid level may be estab-

lished in tank 79. Assuming valve 86 to have been previously opened to admit air pressure to this tank and change of liquid level caused therein, and then closed for regulating purposes, it will be seen that the original volume of air in the tank has been increased and the liquid could not reestablish its former level when relieved from the suction of the jet, unless means were provided for the escape of air previously admitted to the tank. This is accomplished through the check valve 89 should the valve 86 have been closed after admitting air.

Considering now the subsequent operation of the engine, the piston 23 will move upward on its compression stroke, and just as its upper edge coincides with the upper edge of the port 58, as shown in Fig. 8, or at such other suitable time as practice may demonstrate to be most efficient, valve 60 will be opened by its stem 61 having been lifted by cam 63. Such opening of valve 60 will continue for an interval sufficient to establish atmospheric pressure in chamber 59, thus stopping further flow of fuel through nozzle 66, since no difference of pressure will then obtain between chamber 59 and the air space in auxiliary tank 79. Or under certain operating conditions, supposing valve 86 remained closed, an excess of pressure will exist in chamber 59 and such excess pressure will act to force the liquid back down pipe 73 until normal level obtains in tank 79 and pressure equilibrium is established between chamber 59 and air space in this tank. Continuing upward on its compression stroke the piston will compress the mixture of air and fuel into the clearance space provided by annular chamber 32, which is proportioned to give suitable compression to the quantities of air and fuel which have previously entered the cylinder. Air will have been supplied through intake port 33, and also through port 58 from chamber 59 in limited amount, while fuel will have been supplied by nozzle 66. Ignition takes place in the usual manner from spark plug 56 and may be suitably controlled by either advancing or retarding the spark in the usual manner. Since a partial vacuum of considerable degree exists within the cylinder at the end of the intake stroke, the compression may be carried to a high degree as the piston is very near the end of its upward movement when compression begins. Fig. 9 represents the position of the parts after the fuel mixture is ignited. The piston will then be driven down on its power stroke, and during this movement cam 63 will operate to open valve 60, or this cam may be surfaced to retain the valve in open position from the time of opening previously described in connection with the fuel intake. Just before again uncovering port 58 the burned or exploded mixture will have expanded to or slightly below

atmospheric pressure so that when port 58 is uncovered on this stroke (see Fig. 10), valve 60 being held open by cam 63, air at atmospheric pressure will enter the cylinder, such entrance of air continuing during the further movement of the piston to its lower dead center. Upon reaching its lower dead center cam 63 will have operated to close valve 60 and exhaust valve 52 will be opened by cam 63'. Fig. 11 represents the position of the parts just after the exhaust stroke has begun. Upward movement of the piston will expel the products of combustion from the cylinder and transfer the air previously admitted through valve 60 and port 58 to the clearance space, thus leaving the latter in a better condition for the next intake stroke. The exhaust stroke of the engine amounts to a minor power stroke since the exhaust gas as discharged is immediately cooled to atmospheric temperature and thus substantially to the pressure of the partial vacuum obtaining within the cylinder at the end of the intake stroke, the whole exhaust stroke being accomplished with the aid of air pressure acting on the bottom of the piston from the crank case which is open to the atmosphere through a port 98. Thus the exhaust stroke, which in ordinary engines is an idle stroke against a back pressure, is in this engine converted into a minor power stroke, with consequent advantages of operation.

After the exhaust stroke has been completed, the piston passes over its upper dead center point and the parts again occupy the position shown in Fig. 5 at the beginning of the next intake stroke.

With an engine designed for operation with different grades and kinds of fuel, it is desirable to change the compression pressure making it greater or less according to the fuel used. Referring to Fig. 1, the adjustable throttling valve 44 permits of the above to a certain extent by adjusting the stop 49 so that the amount of opening of valve 44 will permit a predetermined amount of air to enter the engine on its intake stroke, the stop 49 being adjusted according to the compression desired for the particular fuel to be used. However, the use of this valve together with the cut off point of the intake valve 34 must be co-ordinated in the engine design so as not to endanger the degree of vacuum required for properly vaporizing the fuel to be used and for expanding the gas in the cylinder after ignition and combustion. It is also desirable to vary the compression according to the atmospheric pressure obtaining, so that an engine may operate at full efficiency at high altitudes where a considerable reduction in atmospheric pressure is encountered. The adjustable throttling valve permits of this in the manner as above described for fuels of different grades.

It is the present practice to control the speed of internal combustion engines, other than the Diesel and semi-Diesel types, by the use of an arrangement similar to the butterfly valve 46, either manually or automatically operated. With such a method of speed control, a loss of efficiency occurs at low speeds due to decrease in compression pressure. With the engine herein embodied, variation in speed is accomplished by regulating the amount of fuel supplied and adjusting the ignition point accordingly by advancing or retarding the same, thus varying the combustion or explosion pressures, the object being to supply an amount of fuel required by the particular load and to adjust the ignition to give the maximum combustion pressure for the amount of fuel used. Since the compression pressure remains the same at all engine speeds, a very desirable condition is obtained in this engine, due to the fact that a maximum efficiency is thus obtained for all engine speeds.

If an engine of the kind described were stopped with the piston 23 in the position shown in Fig. 7, air would enter the cylinder through the air jet tube 68, or leak past the piston rings, until the partial vacuum within the cylinder was destroyed. To start the engine under the above condition would require considerable power, for the piston 23 would immediately commence to compress air from atmospheric pressure, and since the clearance space is proportioned for the compression of a much smaller volume of air at atmospheric pressure, the effort required to complete compression or to turn the engine over might require power in excess of that required for the ordinary starting of gas engines. To obviate this difficulty, the combined relief valve and stop cock, shown in Fig. 2, is located at the point in the cylinder from which compression from atmospheric pressure should normally begin. The operation is as follows: Upon starting the engine, handle 95 will be turned to open valve 96 and release stem 93, thus permitting valve 91 to be opened by the pressure within the cylinder due to the movement of the piston from the position shown in Fig. 7. Air will therefore escape from the cylinder through port 90, conduit 97, and valve 96 to the atmosphere. After the engine has taken up its cycle, the valve 96 may be closed by movement of handle 95, and at the same time the stem 93 will be locked down to prevent further opening of valve 91. Even if the valves should be left open no air can enter the cylinder, because, during the intake stroke, the spring 92 will seat valve 91 and atmospheric pressure will be exerted on the outer surface of this valve to aid the spring in holding it closed.

While in the embodiment of the invention shown and described a single fuel nozzle has

been shown, it will be understood that additional nozzles may be provided, some or all of which may be used according to the demands upon the engine. These nozzles may be supplied from a common fuel reservoir or from separate reservoirs. The engine may consist of any desired number of cylinders, the several valves of which will be operated in timed relation in accordance with the usual arrangements for this purpose. While in the embodiment of the invention shown and described a special form of fuel system has been used, it will be understood that a carbureter may be used for supplying a mixture of fuel and air through the inlet port in the usual manner, but with distinct advantages as to vaporizing the fuel and without lessening the other advantages of the invention. It will also be understood that various other changes may be made in the details of construction of the engine without departing from the principle of the invention as defined in the appended claims.

I claim:

1. The method of charging a cylinder provided with a movable piston with a combustible mixture which consists in supplying air to the cylinder during a portion of the stroke of the piston, maintaining the cylinder out of communication with the air supply during substantially the remainder of the stroke of the piston to permit the air in the cylinder to expand to a pressure below that of the supply and at the end of the stroke injecting liquid fuel into the cylinder and vaporizing it therein by the effect of the low pressure in the cylinder.

2. The method of charging a cylinder provided with a movable piston with a combustible mixture which consists in supplying air to the cylinder during substantially one third of the stroke of the piston, maintaining the cylinder out of communication with the air supply during substantially the remainder of the stroke of the piston to permit the air in the cylinder to expand to a pressure below that of the supply and at the end of the stroke of the piston injecting liquid fuel into the cylinder and vaporizing it therein by the effect of the low pressure in the cylinder.

3. The method of operating a four-cycle internal combustion engine which consists in supplying air to the cylinder during a portion of the intake stroke of the piston, maintaining the cylinder out of communication with the atmosphere during substantially the remainder of the intake stroke to permit the air therein to expand to a pressure below that of the supply, injecting liquid fuel into the cylinder and vaporizing it therein at the end of the intake stroke by the effect of the low pressure in the cylinder, compressing and igniting the charge of air and

vaporizing fuel and supplying air at atmospheric pressure to the cylinder at the termination of the working stroke to aid in discharging the products of combustion therefrom.

4. The method of operating a four-cycle internal combustion engine which consists in supplying air to the cylinder during a portion of the intake stroke of the piston, maintaining the cylinder out of communication with the atmosphere during substantially the remainder of the intake stroke to permit the air therein to expand to a pressure below that of the supply, injecting liquid fuel into the cylinder and vaporizing it therein at the end of the intake stroke by the effect of the low pressure in the cylinder, compressing and igniting the charge of air and vaporized fuel and cooling the exhaust products of combustion to reduce their pressure below that of the atmosphere in order that external pressure may be effective upon the piston during the exhaust stroke.

5. The method of charging a cylinder provided with a movable piston with a gaseous mixture which consists in admitting a gas to the cylinder during a part of the stroke of its piston, maintaining the cylinder out of communication with the gas supply during substantially the remainder of the stroke of the piston to permit the gas in the cylinder to expand to a pressure below that of the supply and at the end of the stroke of the piston injecting a liquid into the cylinder and vaporizing it therein by the effect of the low pressure in the cylinder.

6. The method of charging a cylinder with a combustible mixture which consists in supplying a predetermined quantity of air to the cylinder, increasing the free space within the cylinder while maintaining it out of communication with the air supply to permit the air in the cylinder to expand to a pressure less than that of the supply and supplying liquid fuel to the cylinder and vaporizing it by the low pressure therein.

7. In an engine, the combination of a cylinder provided with an intake port communicating with a source of supply, a piston in the cylinder, means for maintaining the cylinder out of communication with the source of air supply by closure of the port after the piston has performed a part of its intake stroke to permit the air in the cylinder to expand during the remainder of the intake stroke to a pressure less than that of the air supply and means whereby at the end of the intake stroke liquid fuel may be supplied to the cylinder and vaporized by the effect of the low pressure in the cylinder.

8. In an engine, the combination of a cylinder provided with an intake port communicating with a source of air supply, a piston in the cylinder, means for maintaining the cylinder out of communication with

the source of air supply by closure of the intake port when the piston has performed substantially one third of its intake stroke to permit the air in the cylinder to expand during the remainder of the intake stroke to a pressure less than that of the atmosphere and means whereby at the end of the intake stroke fuel may be supplied to the cylinder and vaporized by the effect of the low pressure in the cylinder.

9. In a four-cycle internal combustion engine, the combination of a cylinder provided with a fuel supply port and an inlet port communicating with a source of air supply, a piston in the cylinder adapted to uncover the fuel supply port when it approaches the end of the stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of such stroke to maintain the cylinder out of communication with the source of air supply to permit the air in the cylinder to expand during the remainder of the stroke to a pressure less than that of the atmosphere and means for supplying liquid fuel to the cylinder through the fuel supply port and vaporizing it by the difference in pressure between the interior and exterior of the cylinder.

10. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port, an exhaust port, and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, means for supplying liquid fuel to the cylinder through the fuel supply port and vaporizing it by the difference in pressure between the interior and exterior of the cylinder, means for opening the exhaust port at the beginning of the exhaust stroke, and means whereby air may be admitted to the cylinder through the supply port when it is uncovered by the piston on its working stroke to aid in driving out the products of combustion during the following exhaust stroke.

11. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, means for injecting fuel into the cylinder through the fuel supply port by the difference in pressure between the interior and the exterior of the cylinder, and

means for equalizing the pressure upon the fuel after the piston has closed the fuel supply port on its compression stroke.

12. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port communicating with a source of air supply, a valve for the port, a piston in the cylinder, means for opening the valve at the beginning of the intake stroke and for closing it after the piston has performed a part of such stroke to maintain the cylinder out of communication with the source of air supply to permit the air in the cylinder to expand during the remainder of such stroke to a pressure less than that of the source of supply, an adjustable automatic valve for controlling the admission of air from the source of supply to the inlet port and means whereby at the end of the intake stroke fuel may be supplied to the cylinder and vaporized by the effect of the low pressure in the cylinder.

13. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port communicating with a source of air supply, a valve for the port, a piston in the cylinder, means for opening the valve at the beginning of the intake stroke and for closing it after the piston has performed a part of such stroke to maintain the cylinder out of communication with the source of air supply to permit the air in the cylinder to expand during the remainder of such stroke to a pressure less than that of the source of supply, an adjustable automatic valve for controlling the admission of air from the source of supply to the inlet port and manually controlled means for determining the amount of air supplied to the automatic valve and means whereby at the end of the intake stroke fuel may be supplied to the cylinder and vaporized by the effect of the low pressure in the cylinder.

14. In an internal combustion engine, the combination of a cylinder provided with an inlet port, an exhaust port, a relief port and a fuel supply port, a valve for the relief port, means for locking the relief valve in closed position, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of this stroke to permit the air in the cylinder to expand during the remainder of the stroke, and means for drawing fuel into the cylinder at the termination of the intake stroke by the suction effect of the low pressure therein.

15. In an internal combustion engine, the combination of a cylinder provided with a relief port, a valve for the relief port, a conduit communicating with the relief port, a valve in the conduit, and means for simul-

taneously locking the relief valve in closed position and closing the valve in the conduit.

16. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, a nozzle extending into the supply port, means for causing fuel to be supplied to the nozzle by the difference in pressure between the interior and the exterior of the cylinder and means for supplying air to the nozzle to mix with the fuel as it is injected into the cylinder.

17. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, a nozzle extending into the supply port, a reservoir adapted to contain liquid fuel, a conduit between the reservoir and the nozzle, and means for admitting air to the reservoir above the fuel therein to force fuel through the conduit and nozzle into the cylinder by the pressure of the air admitted to the reservoir.

18. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, a nozzle extending into the supply port, a reservoir adapted to contain liquid fuel, a conduit between the reservoir and the nozzle, means for admitting air to the reservoir above the fuel therein to force fuel through the conduit and nozzle into the cylinder by the pressure of the air admitted to the reservoir, and means for controlling the amount of air admitted to the reservoir.

19. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a

part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, a nozzle extending into the supply port, a reservoir adapted to contain liquid fuel, a conduit between the reservoir and the nozzle, a port in the top of the reservoir for admitting air above the fuel therein to force fuel through the conduit and nozzle into the cylinder by the pressure of the air admitted to the reservoir, a valve for controlling the port to regulate the amount of air admitted to the reservoir, and an automatic valve between the port and the reservoir adapted to close when the pressure of air in the reservoir is reduced to a predetermined point.

20. In a four-cycle internal combustion engine, the combination of a cylinder provided with an inlet port and a fuel supply port, a piston adapted to uncover the supply port when it approaches the end of its stroke, means for opening the inlet port at the beginning of the intake stroke and for closing it when the piston has performed a part of its stroke to permit the air in the cylinder to expand during the remainder of the stroke, a nozzle extending into the supply port, a tank adapted to contain liquid fuel, a conduit between the tank and the nozzle, means for admitting air to the tank above the fuel therein to force fuel through the conduit and nozzle into the cylinder by the pressure of the air admitted to the tank, a supply tank communicating with the first named tank, a check valve for controlling communication between the tanks, and means for maintaining a substantially constant level of fuel in the supply tank.

21. The method of reducing air pressure to a degree whereby fuels of low vapor pressure may readily become vaporized to mix with air in quantities suitable for the production of a mixture consisting of a dry fuel vapor mixed with air, which consists in admitting a limited quantity of air from a source of supply to a confined space, increasing the volume of the space while maintaining it out of communication with the source of air supply to permit the air to expand to a pressure less than that of the source of supply and thereafter placing the space in communication with a source of fuel supply whereby fuel may be supplied to the space and vaporized by the effect of the low pressure of the space.

22. The method of reducing air pressure to a degree whereby fuels of low vapor pressure may readily become vaporized to mix with air in quantities suitable for the production of a mixture consisting of a dry fuel vapor mixed with air, which consists in admitting air at atmospheric pressure to a confined space, cutting off all communication between the space and the atmosphere, increasing the volume of the space to permit

the air to expand to a pressure considerably below that of the atmosphere and placing the space in communication with a source of fuel supply in order that fuel may be supplied to the space and vaporized by the effect of the low pressure therein.

23. The cycle of operation of an internal combustion engine comprising an inlet stroke during the initial period of which air is admitted to the cylinder of the engine from a source of supply and thereafter allowed to expand to a pressure less than that

of the source of supply during the remainder of the stroke which is performed without communication with the source of supply and at the termination of which fuel is supplied to and vaporized in the cylinder by the effect of the reduced pressure therein, a compression stroke, a working stroke and an exhaust stroke at an early period of which air is supplied to the cylinder to aid in driving out the products of combustion.

In testimony whereof I affix my signature.

GEORGE W. WALDO.