March 28, 1939. J. E. FULLER 2,152,037

INTERNAL COMBUSTION ENGINE

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FIG. 1.

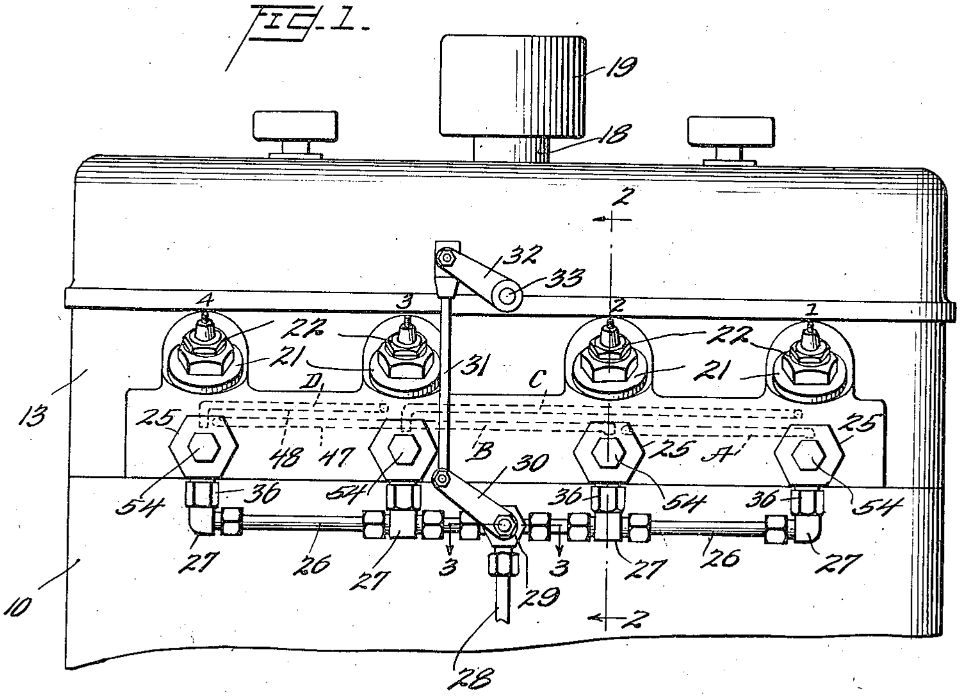


FIG. 3.

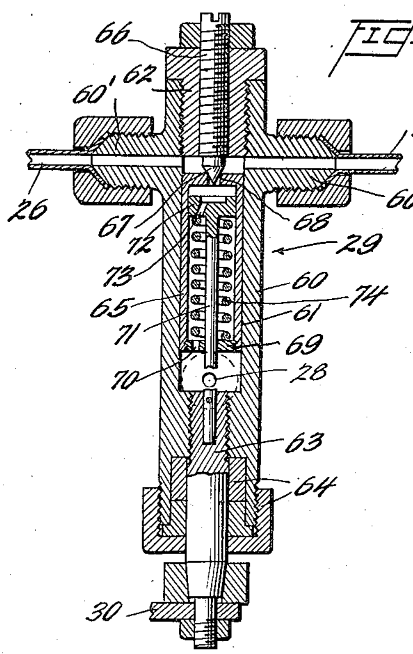
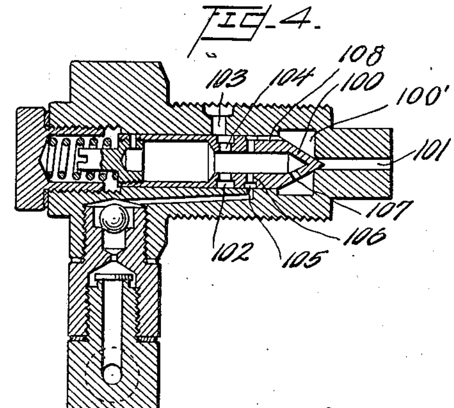


FIG. 4.



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INTERNAL COMBUSTION ENGINE

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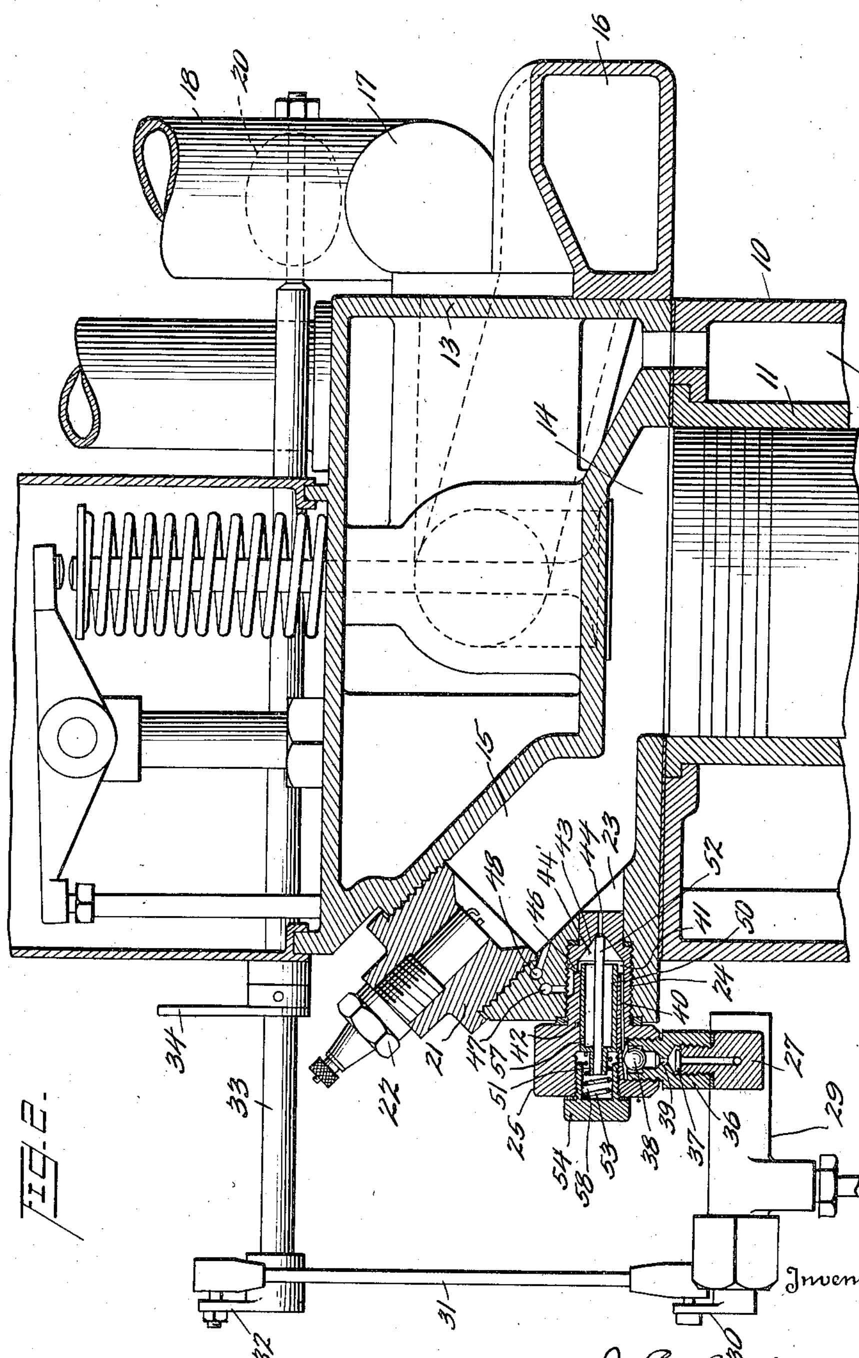

FIG. 2.

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INTERNAL COMBUSTION ENGINE

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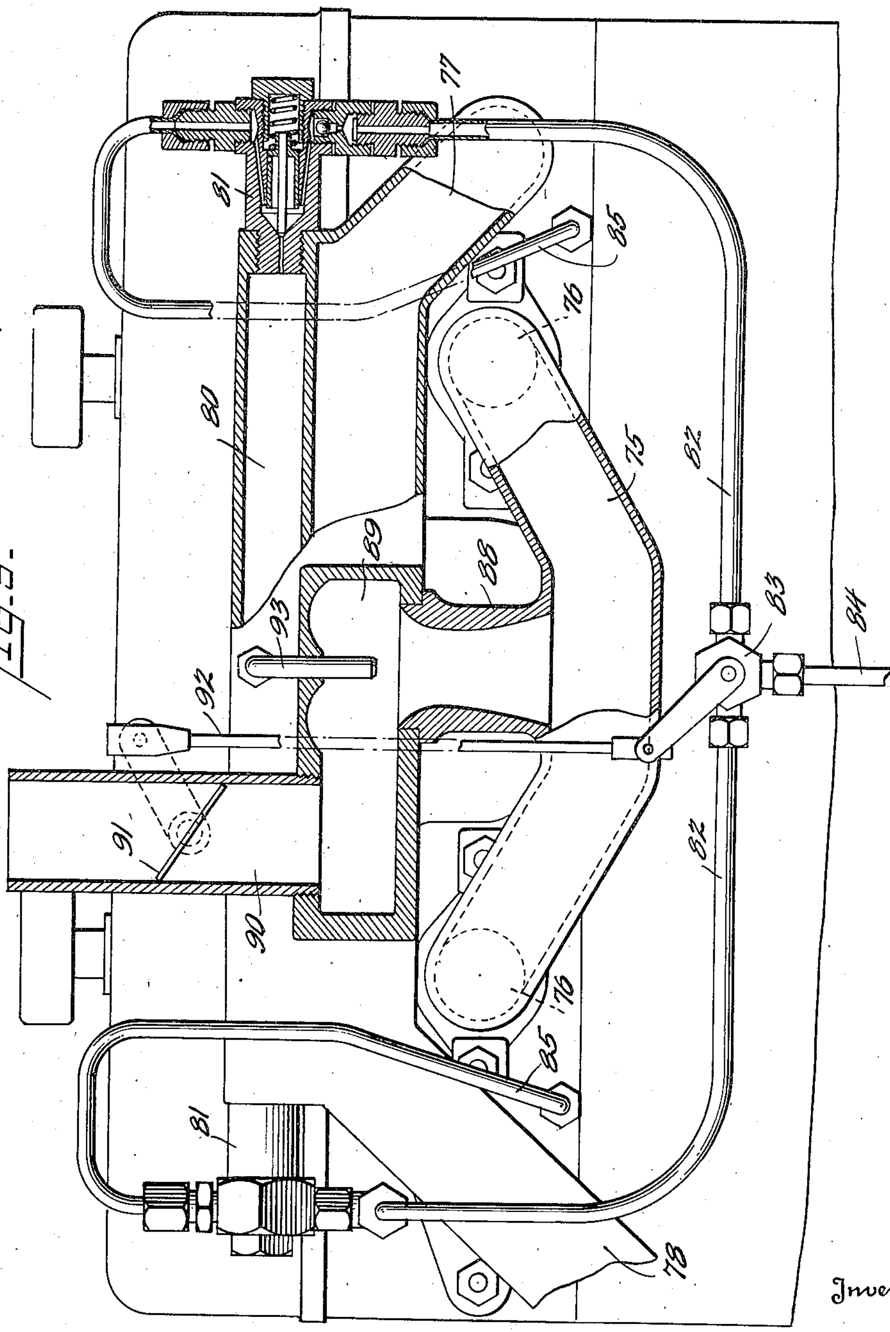
FIG. 5.



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UNITED STATES PATENT OFFICE

2,152,037

INTERNAL COMBUSTION ENGINE

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Application November 18, 1936, Serial No. 111,472

8 Claims. (Cl. 299—107.7)

This invention relates to engines of the internal combustion type and more particularly to such engines as receive their fuel by injection rather than by carburization, and the invention deals especially with the methods of and apparatus for injecting fuel into the cylinders of such engines.

It is a general object of the present invention to provide novel methods and apparatus for fuel injection for internal combustion engines.

More particularly, it is an object of the invention to provide a method of and means for delivering fuel to the combustion chambers of internal combustion engines by means of the suction of and compression or explosion pressure of certain cylinders.

An important feature of one embodiment of the invention consists in the provision of a fuel injector for the combustion chamber of each cylinder, together with means to associate this injector with a source of fuel and the suction and pressure of a previously operating cylinder for charging the injector with fuel and for discharging the fuel into the combustion chamber.

An important feature of a second form of the invention consists in the provision of an exhaust heated chamber for partially vaporized fuel, an injector for supplying liquid fuel and gas to said chamber and means for associating said injector with a source of fuel and a source of cylinder suction and pressure for charging the injector and discharging the fuel into said chamber.

A further feature of this embodiment comprises a discharge jet leading from the exhaust heated chamber to the intake manifold in such a manner as to increase the rate of air flow in the manifold while mixing the charge therewith.

A further important feature of both embodiments of the invention resides in the combined regulation of the air inlet and the fuel supply in accordance with the load demand of the engine.

Another important feature of both embodiments of the invention resides in the structural arrangements and operating methods for the fuel injectors whereby pressure developed in a cylinder of the engine, when on compression or explosion, is caused to discharge and atomize the fuel from the injector into the cylinder then associated therewith, which fuel in predetermined quantity is drawn into the injector by the suction pressure of the first mentioned cylinder.

Other and further features and objects of the invention will be more apparent to those skilled in the art upon a consideration of the accompanying drawings and following specification wherein are disclosed two embodiments of the main invention and two embodiments of the fuel injector, it being understood, however, that these disclosures are only exemplary and that such changes, combinations, and variations may be made therein as fall within the scope of the appended claims, without departing from the spirit of the invention.

In said drawings:

Fig. 1 is a side elevation of the upper portion of the cylinder block and head of an internal combustion engine fitted with apparatus in accordance with the first embodiment of the invention;

Fig. 2 is a transverse vertical section taken on line 2—2 of Fig. 1;

Fig. 3 is a section on an enlarged scale taken on line 3—3 of Fig. 1 and showing the fuel regulating valve in detail;

Fig. 4 is a sectional view on an enlarged scale of a modified form of fuel injector, the view being similar to that of the preferred form of injector shown on smaller scale in Fig. 2; and

Fig. 5 is a view similar to Fig. 1, but showing in vertical, longitudinal section the manifolds and fuel injection means of a second embodiment of the main invention.

Internal combustion engines may in accordance with one classification be divided into two groups, first those in which the fuel is prepared outside of the cylinders into a vapor by the admixture therewith of all of the air necessary for combustion. Such engines are by far in the largest proportion and make use of a carburetor or similar device for vaporizing the fuel and mixing it with air. The second group of engines makes use of fuel injection, where the fuel is delivered directly into the cylinders or inlet manifold adjacent the cylinders in a liquid form. Such engines are commonly but improperly known as Diesel engines, this term being properly applied to only certain types of fuel injection engines where the fuel in liquid form is delivered into the cylinder at the end of the compression stroke and is ignited spontaneously from the heat of the compression of the air therein.

The present invention falls into the second group but is not of the Diesel type, for in one embodiment the fuel is sprayed into the cylinders during the suction or compression stroke of the piston therein, and in the other is sprayed into a chamber communicating with the inlet manifold.

In engines of the Diesel type or so-called solid fuel injection, i. e., without air, the fuel is supplied under high pressure by the operation of one or more pumps and great difficulty is experienced in supplying the exact required quantity of fuel to each cylinder. Because of the high pressure against which the fuel must be delivered, the pumps and injectors wear rapidly and are costly to build and repair. In another form of engine the fuel is injected by the use of air under high pressure, and since this air must be at a higher pressure than the maximum compression pressure in the cylinder, it is difficult to supply and requires a costly pump. In accordance with the present invention, fuel is supplied without the use of extraneous pump equipment but the feeding of fuel to one cylinder is obtained by making use of the nominal changes in pressure in another cylinder, and thus all separate pump equipment is done away with and the engine materially simplified. When the fuel is injected on the suction stroke of each cylinder, it is not delivered against any pressure and light weight, simple parts can be used. Sometimes it is an advantage, however, to inject the fuel during the compression stroke which can readily be done with the type of engine now to be described.

The invention is applicable to engines of any multiple number of cylinders and to either the two stroke or four stroke cycle type. For convenience in illustration the invention is disclosed in connection with the four cylinder, four stroke cycle type vertical engine as commonly used for automotive and industrial purposes.

Referring now to Figs. 1 and 2 for an illustration of the invention, there is shown the engine cylinder block **10** having the inset cylinder sleeves **11** providing the water jackets **12** for cooling in the customary manner. The cylinder head **13** contains the usual water chambers, the combustion chambers **14**, the precombustion chambers **15** and suitable valve-in-the-head mechanism of conventional form, the passages from the valves in each cylinder leading respectively to the exhaust manifold **16** and the intake manifold **17** provided with a suitable intake pipe **18** leading from the air filter **19**. An air throttle valve **20** is provided in the pipe **18**.

Each precombustion chamber is fitted with a closure plug **21** receiving the spark plug **22** for firing the charge. The exact form of the combustion chamber and precombustion chamber plays no part in the present invention. A passage **23** in the wall of each precombustion chamber is threaded as at **24** to receive the threaded end of an injector **25** kept tight by suitable gaskets. The several injectors are connected by suitable conduits or manifolds **26** and fittings **27**, to a common fuel supply line **28** through the interposed fuel regulating valve **29** shown in detail in Fig. 3, to be later described. The operating arm **30** on this regulating valve is connected by a link **31** to an operating arm **32** on the shaft **33** of the air throttle valve **20** whereby the two can be operated in unison, for instance, by a linkage connected to the arm **34** also on the throttle valve shaft. Operation of this arm permits simultaneous adjustment of the quantity of fuel and quantity of air admitted to all of the cylinders.

Fuel is delivered to the line **28** from any suitable reservoir by gravity feed or it can be lifted through a reasonable distance by the operation of the engine as will appear as the description proceeds. The regulating valve **29** may be only a needle valve, although it is shown as a more complex structure for determining the quantity of fuel to be delivered. From the manifold **26** the fuel flows to each injector through a fitting **27** into a check valve assembly **36**. This includes a double check, first the flat valve **37** and second the ball valve **38**, the operations of which are so obvious as to need no description here. Between the checks is the metering passage **39**. After passing these two checks in quantity determined by the passage **39** and other factors, the fuel enters the passage **40** in the body of the injector which leads to the annular fuel chamber **41** associated with the hollow interior **42** of the injector, the tapered end **43** of which leads to the nozzle **44** through which the fuel is sprayed into the precombustion chamber **15**.

The fuel chamber **41** in the injector is connected by a passage **46**, and its extensions, to a longitudinal bore **47** in the cylinder head. This, plus a companion bore **48**, parallel thereto, extend for convenience in manufacture substantially in full length of the cylinder head and are tapped and plugged at appropriate intervals to produce passages which connect the combustion chamber of one cylinder to the annular fuel chamber **41** of the injector of the cylinder next in firing order.

The engine shown has the more or less conventional firing order 1—3—4—2 so the passages **47** and **48** are divided into portions best shown in Fig. 1 where the cylinder numbers are indicated just above the spark plugs. The passage **47** is divided into the following parts: A, leading from the combustion chamber of cylinder **2** to the fuel chamber of the injector of cylinder **1**, which fires just after cylinder 2, and B, leading from the combustion chamber of cylinder **4** to the fuel chamber of the injector of cylinder **2**. The passage **48** is divided likewise into two parts, C leading from the combustion chamber of cylinder **1** to the fuel chamber in the injector of cylinder **3**; and D leading from the combustion chamber of cylinder **3** to the fuel chamber of the injector of cylinder **4**. In this manner each injector fuel chamber is connected to the combustion chamber of the cylinder prior to it in firing order.

The chamber **42** of each injector is cylindrical and fitted with a reciprocable piston **50** closed at the rear and open at the forward end. The closed end includes a rearwardly extending tubular portion **51** closed by and rigidly supporting the valve rod **52** which normally closes the nozzle **44**, in valve chamber **44'**, as shown in Fig. 1, under the action of spring **53** extending between the end of the piston and the rear wall of the hollow plug **54** for the chamber in the injector body.

In operation, the engine is cranked for starting purposes with the fuel and air control valves partially open, and a limited quantity of air is drawn in through the intake pipe and intake valve, for instance, to cylinder **1** creating a suction in its combustion chamber in the well-known manner, and this suction is communicated through passage C to the fuel chamber **41** in the injector associated with cylinder **3**. This suction pressure being lower than the fuel pressure, fuel enters through the fuel check valves and the interposed metering passage and the passage **40** to the annular fuel chamber **41**, filling this chamber and possibly part of the bore **42** to an extent dependent on the opening of the fuel valve etc.

As rotation of the engine continues the piston in No. 1 cylinder moves up on compression and this pressure or the still higher pressure of explosion is carried through the passage C to the fuel chamber 41, overcoming the spring 53, driving the piston rearwardly and opening the nozzle 44. The gases coming through the passage C effectively discharge all of the fuel from the chamber 41 and atomize the same through the nozzle 44 into the precombustion chamber of cylinder No. 3 which is now on its suction stroke.

The pressure of the gas in passage C is sufficient to move the piston rearwardly until it is stopped by abutting the annular end of the cap 54. This brings the equalizing port 57 in the wall of the piston back to a position permitting gases within the piston to pass into the equalizing chamber 58 in the cap 54 so that the pressure in this chamber becomes the same as the pressure on the front of the piston. As the pressure in passage C is reduced, on opening of the exhaust valve in cylinder No. 1, the gases in the back pressure chamber 58 of cylinder No. 3 become of higher pressure than those in front of the piston 50 and the fuel valve closes under the action of these gases and its spring, leaving the gases trapped in the back pressure chamber at somewhat near the maximum cylinder pressure on compression or explosion. These gases together with the spring maintain the valve closed, until the following cycle, against whatever pressure may develop during explosion in the cylinder associated with the injector because this explosion pressure acts through only the small area of the nozzle 44.

The gases trapped in the back pressure chamber behind the piston of the injector will expand as the valve closes and after closing a certain amount of radiation loss and slight leakage will reduce the pressure behind the piston to a lower value of say about 75% of the maximum pressure under the piston when the valve is open. This permits the valve to lift on the following cycle. The percentage of pressure remaining behind the piston can be adjusted in designing the engine by changing the volume behind the piston in relation to the displacement of the piston and thereby the beginning and duration of the fuel delivery period in relation to the piston position and crank angle can be regulated.

Since the maximum pressure of combustion usually occurs when the piston is a few degrees past top dead center, the injector will open about at top dead center of the piston stroke of the cylinder which is operating it. This times the injection near bottom dead center at the end of the intake stroke of the cylinder being charged. The fuel valve will start to close a few degrees of rotation after the maximum combustion pressure is communicated to the underside of its piston. The gas pressure falls faster than the gases can flow back through the equalizer port, so with the aid of the spring the valve will begin to close and cut off the equalizer port to hold the gases in the back pressure chamber to tightly close the valve. The whole action is very rapid and all of the moving parts are light so that quick opening and a quick sharp cut off are obtained.

As the load and speed of the engine vary each cycle produces an increment of change of pressure in the equalizing chambers so that the back pressure is maintained in balance with the cylinder combustion pressure. If desired, the valve spring can be omitted entirely since it is not essential to the operation. The proportioning of the various parts can be effected to give a longer or shorter period of injection as desired.

The injector parts are subject to high temperature and would become over-heated except for the continual cooling by the fresh fuel being fed thereto and the partial vaporization of this fuel serving to rapidly lower the temperature. The fuel also acts as a lubricant and seal for the piston and valve.

The cycle of operations described above in connection with cylinders 1 and 3 is repeated for each pair of cylinders in sequential relation so that the engine operates in the proper firing order and with the possibility of properly regulating the power to the load. Because of the adequate regulation of both the fuel and air, idling and low speed or power operation is perfectly feasible.

Although the flow of fuel can be regulated simultaneously with the regulation of the air by the use of a needle valve in the fuel line 28 operated by the link 31 connected to the air valve stem, it is, nevertheless, preferred to use a special form of fuel governing valve, such as shown in Fig. 3, which is interposed between the fuel line 28 and the fuel manifold 26. This valve 29 includes an elongated casting 60 having a central bore 61 closed at one end by a bushing 62 and at the opposite end by a threaded stem 63 rotatable for adjustment by means of the arm 30 previously mentioned which is attached to the exterior portion thereof as shown in the lower portion of Fig. 3, so as to permit such adjustment thereon as may be needed. This stem 63 is kept leak-proof by means of a suitable packing gland and nut 64. The bushing 62 is longitudinally bored and threaded to receive the stem 66 of the needle 67 forming a portion of the valve. This stem is adjustable and locked into position as shown. The fuel pipe 28 communicates with the bore 61 at the inner end of the stem 63 and the fuel manifolds are connected to the extensions 60′ drilled to intersect the bore 61 adjacent the inner end of the needle stem 66. The portion of the bore between the fuel inlet and fuel outlet reciprocally mounts the hollow piston 65, one end of which is provided with the opening 68 cooperating with the needle 67 to regulate the flow of fuel. The opposite end is closed by a disc 69 perforated at 70 to permit fuel to flow to the inside of the piston and having a central opening for the passage of the rod 71 which is secured in the stem 63 and equipped with a head 72 loosely fitting the bore of the piston and perforated at 73 for the passage of the fuel to the opening 68. Fitted between the back of the head 72 and the inner side of the disc 69 is the helical spring 74 adjustable by rotation of the stem 63 so that the normal position of the piston in respect to the needle can be adjusted in unison with the adjustment of the air supplied to the cylinders.

This fuel governing valve regulates the amount of fuel fed to the injectors according to the air throttle opening and the air pressure in the cylinders served by the injectors. As the air throttle valve is opened the stem 63 is rotated and the head 72 on the rod 71 compresses the spring and retracts the piston, opening the needle valve in proportion to the opening of the air valve.

When the engine is running, the pressure differential between the fuel in the chamber behind the piston and that in the fuel manifold 26 tends to close the valve in accordance with the loading on the spring. The pressure existing in the fuel manifold 26 is the mean pressure on the intake stroke of all of the cylinders as communicated from the combustion chambers through the various passages to the annular fuel chambers 41 in the injectors. This provides a balanced condition between the fuel pressure, the fuel feed through the needle valve and the spring. On heavy loads the velocity of flow of the fuel through the orifices in the piston 67 tends to create a closing action thereon but because of the wide open position of the air valve required during heavy loads, the control stem 63 will be near its extreme open position and will supply enough compression to the spring 74 to counteract this closing force. Adjustment of the stem 66 sets the needle initially to suit idling conditions and the particular fuel being used. The fuel valve is of particular importance in properly proportioning the fuel to the air in accordance with the demand of the engine.

Under certain conditions, it is simpler and cheaper to inject the fuel into the intake manifold instead of directly into each cylinder or its precombustion chamber, and in Fig. 5 is shown a structure for that purpose. Here again the engine is of conventional form and shown as a four cylinder, four stroke cycle type provided with the inlet manifold 75 leading to a pair of siamesed intake ports 76. The exhaust manifold 77 delivers the exhaust gases from the four exhaust valves to the exhaust pipe 78, and preferably cast integral with the straight upper portion of the exhaust manifold is the fuel chamber 80.

In the present instance, this chamber is equipped with a pair of injectors 81 of the type already described. One is fitted at each end, although it may be possible to use a single injector or in extreme cases several, sometimes one for each cylinder. These injectors receive their fuel from the fuel manifold 82 under the control of the fuel adjusting valve 83 of the type previously described which receives its fuel from the line 84. Suction and pressure for operating the injectors is taken from an adjacent cylinder through a pipe 85.

The intake manifold has a lateral neck 88 preferably of Venturi form which connects it to a chamber 89 connected to the atmosphere by a tube 90 containing the air throttle valve 91 connected to operate in unison with the fuel valve 83 by the link 92 as in the preferred embodiment. The chamber 89 is supplied with fuel from the chamber 80 by means of the nozzle 93 axially disposed to the venturi but not extending into it.

In operation the governing valve and injectors operate in the manner already described and a mixture of fuel and gases from the cylinder supplying the power is discharged from the injector or injectors into the fuel chamber 80 which is well heated by the exhaust manifold. The fuel is thus further vaporized in this chamber and remains under some pressure depending upon the compression in the engine, the time the injector is held open, the sizes of the fuel nozzles and of the jet 93. The fuel-gas mixture discharges from the chamber 80 through the jet nozzle 93 into the throat of the venturi 88 in the air intake to the manifold. The velocity of air flow through this venturi is increased by the stream of gases expanding into it from the nozzle 93 and thus the density of the cylinder charge is increased. The fuel-gas mixture is thoroughly incorporated with the intake air in passing through the venturi and intake pipe. It is found that there will be sufficient storage of compressed gas-fuel mixture in the chamber 80 to charge all of the cylinders even though the injectors are operated by but part of them.

If desired the injectors can be attached directly to and inject the fuel-gas mixture into the intake pipe instead of the chamber. Under these conditions any desired number of injectors may be used, up to one per cylinder in which case they would be connected for suction and injection pressures as in the construction of Fig. 1.

In Fig. 4 is shown an alternative form of fuel injector suitable for either embodiment of the invention, which in its main aspect is similar to that shown in Fig. 1. The only difference resides in the piston which is extended to have a hollow conical end 100 received in the mixing chamber 100′ cooperating with the spray nozzle 101 to form the valve. The walls of the piston are thickened near this end and provided with an exterior annular recess 102 which always registers with the port 103 connected in the manner of Fig. 1 to the combustion chamber of the previously operating cylinder. Passages 104 connect this chamber 102 with the interior of the piston. The annular fuel chamber 105 has access to the interior of the piston through ports 106 and the discharge port 107 allows the fuel and gas mixture which accumulates in the chamber 105 and in the reduced end of the piston to be driven out into the nozzle 101. Furthermore, the fuel can be forced along the longitudinal passage 108 leading from 105 to 100′. In this construction the suction in the passage 103 draws fuel into the reduced end of the piston through the ports 106 and then as the valve opens by the movement of the piston discharges it through the passage 107 into the atomizing nozzle 101.

Although the invention has been shown as applied to an engine of the spark ignition type, it is obvious that it can equally as well be applied to engines of the compression ignition type.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. For use with an internal combustion engine, an injector comprising a body, a nozzle projection on said body, a chamber in said body, a valve for separating said nozzle and chamber, a piston carrying said valve and mounted for reciprocation in said body chamber, a fuel line connection, a fuel inlet therefrom to the chamber between the valve and piston, a check valve in said inlet, a fluid passage to the body chamber between the valve and piston for connection to a source of intermittent pressure, and means to normally hold said valve closed.

2. For use with an internal combustion engine, an injector having a body, a nozzle projection on said body, a chamber in said body, a valve for separating said nozzle and chamber, a piston controlling said valve and mounted for reciprocation in said body chamber, a fuel connection, a fuel inlet therefrom to the chamber between the valve and piston, a check valve in said inlet, means supplying intermittent fluid pressure waves to the body chamber between the valve and piston, a chamber behind said piston, and a passage between said chambers opened only when the first chamber is open to said nozzle.

3. For use with an internal combustion engine, an injector having a body, a nozzle projection on said body, a chamber in said body, a valve for said nozzle, a piston carrying said valve and mounted for reciprocation in said body chamber, means for connection to a source of fuel, a fuel inlet therefrom to the chamber between the valve and piston, a check valve in said inlet, a gas passage to the body chamber be-

tween the valve and piston for connection to a source of intermittent fluid pressure, a chamber behind said piston, a passage between said chambers opened only when the valve is open to said nozzle and a spring in said second chamber acting to hold said valve closed.

4. A fuel injector for operation by intermittent gas pressure waves comprising in combination, a body having a nozzle and a cylindrical chamber, a seat in said nozzle, a piston operable in said chamber, a valve carried by said piston to cooperate with said seat to close off said nozzle, a spring to normally close said valve, means to supply fuel to the space around the nozzle seat, means to apply said pressure waves to said space, and means to equalize the pressure on the two sides of said piston when the valve is opened under increased pressure from one of said waves.

5. A fuel injector for operation by intermittent gas pressure waves comprising in combination, a body having a nozzle and a cylindrical chamber, a seat in said nozzle, a piston operable in said chamber, a valve carried by said piston to cooperate with said seat to close off said nozzle, a spring to normally close said valve, means to supply fuel to the space around the nozzle seat, means to apply said pressure waves to said space, means to equalize the pressure on the two sides of said piston when the valve is opened under increased pressure from one of said waves, and means to maintain the increased pressure on the valve closing side of the piston when the valve closes and the pressure wave subsides.

6. A fuel injector for operation by intermittent gas pressure waves comprising in combination, a body having a nozzle and a cylindrical chamber, a seat in said nozzle, a piston operable in said chamber, a valve carried by said piston to cooperate with said seat to close off said nozzle, a light spring to normally close said valve, means to supply fuel to the space on the piston side of said valve, means to apply said pressure waves to said space, means to admit the pressure to the opposite side of said piston when the valve is opened, said means isolating the pressure behind the piston when the valve is closed to assist the spring.

7. A fuel injector for operation by intermittent gas pressure waves comprising in combination, a body having a nozzle and a cylindrical chamber, a seat in said nozzle, a piston operable in said chamber, a valve carried by said piston to cooperate with said seat to close off said nozzle, a light spring to normally close said valve, means to supply fuel to the space on the piston side of said valve, means to apply said pressure waves to said space, means to admit the pressure to the opposite side of said piston when the valve is opened, said means isolating and slightly reducing the pressure behind the piston when the valve is closed whereby the following stroke of the valve takes place only near the maximum of the pressure wave.

8. A fuel injector for use with internal combustion engines and adapted for operation by intermittent gas pressure waves comprising in combination, a body having a nozzle bore at one end thereof and a coaxial cylindrical chamber, a hollow piston operable in said chamber and having a valve portion to close said bore, a light spring biasing said piston to close said bore, a check valved fuel passage extending through the wall of said chamber, a channel in said piston registering with said passage and connected to the interior of the piston near the valve end thereof, a gas pressure passage through the chamber wall, a corresponding channel in the piston connected to the interior thereof more remote from the valve end, a spray opening from the valve end of the interior of the piston to adjacent the valve portion, a closed chamber behind said piston, a passage in the piston wall, normally closed, said passage cooperating with the chamber wall to connect the interior of the piston to said closed chamber only when the valve is open for the purpose described.

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