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FUEL INJECTION SYSTEM

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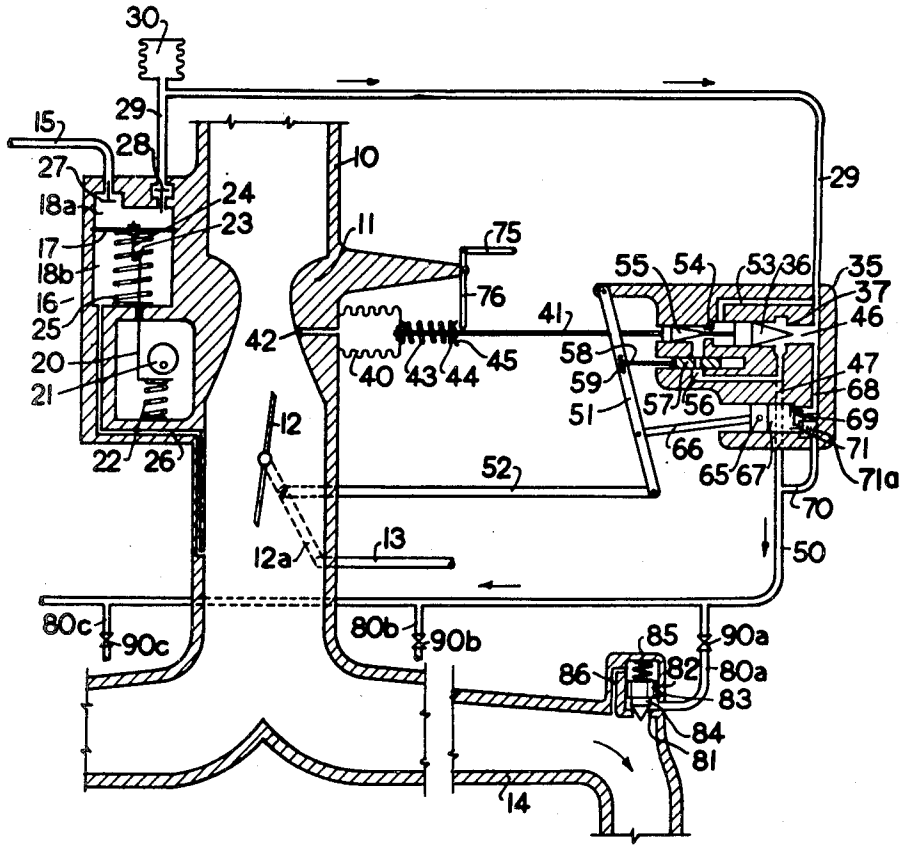


Fig. 1

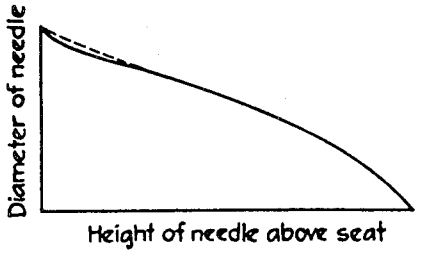


Fig. 2

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FUEL INJECTION SYSTEM

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11 Claims. (Cl. 261—34)

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This invention relates to systems for supplying fuel to combustion chambers, such as the cylinders of internal combustion engines and combustion chambers of jet propulsion and turbine engines, and pertains more particularly to an improved fuel metering or fuel flow regulating device for regulating the amount of fuel admitted to the combustion chamber. It is, further, concerned with the control of the injection of the fuel into the air stream entering the combustion chamber.

Heretofore, fuel and air mixtures have been introduced into the internal combustion engine, i. e. the cylinder, in several different ways. The simplest of these and therefore the most widely used is the introduction of a continuous stream of fuel into a continuously-flowing air stream in the central carburetor air-intake manifold, whereby a fuel-air mixture is formed, which is then divided and introduced into the several cylinders through individual intake pipes. This system has several disadvantages, foremost of which is that, since the fuel is seldom completely vaporized, and the intake manifold is not perfectly symmetrical, the individual cylinders do not receive uniform fuel-air mixtures or tetraethyl lead concentrations. Moreover, the lead scavenger, because of its lower boiling point, does not accompany the tetraethyl lead in proper proportions. These non-uniformities frequently result in loss of power and in an increase in fuel consumption, lead deposits, and detonation and preignition tendency.

To overcome this non-uniformity it has been proposed to inject fuel in separate streams to each cylinder. However, such a system requires boosting the fuel pressure to several hundred pounds and requires an expensive and complex timing and metering arrangement, which is difficult to maintain in good working condition.

Another proposed system of fuel injection comprises a primary carburetor for forming rich fuel-air mixtures and secondary carburetors for diluting the rich mixture with further quantities of air to form the lean mixtures. This system depends upon air suction for the mixing of the fuel with the air and necessarily utilizes complicated air throttling controls, etc. Further, in such a system even distribution of fuel and uniform mixtures of fuel and air are not insured. The fuel is generally supplied through a simple fuel duct to the primary carburetor, from which the fuel is drawn by air suction into the several rich mixture ducts, and hence is subject to flaws in the symmetry of the device and the vagaries

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of the air flow. Especially at nearly closed throttle, the air velocity through the primary carburetor is too low to lift fuel to the distribution lines or to insure uniform quantities of fuel to each duct. Such systems have not come into commercial use in view of their complexity, lack of uniformity of fuel-air mixtures over the full speed range and when the engine is tilted, etc.

To provide a well functioning charge forming system wherein fuel is injected continuously, directly into the air current flowing to the combustion space, such as an engine cylinder or other combustion space, it is important to provide a fuel metering unit which will regulate the flow of fuel jointly in response to the rate of air flow (which air flow may be regulated by an air throttle or by controlling the speed of operation of an air compressor, etc.), and to the will of the operator, viz., to permit the flow of an added amount of fuel when the throttle is fully opened or some other control element is set for maximum fuel flow, and which will give temporary increase in fuel flow during acceleration.

It is therefore an object of the present invention to provide an improved charge forming system, whereby uniform distribution of fuel is accomplished in a simple and efficient manner without the necessity of employing complicated or expensive devices.

It is a further object of this invention to provide such an improved charge forming system, wherein the amount of fuel introduced into each cylinder may be adjusted to the optimum value.

A further object is to provide an improved fuel flow regulating mechanism wherein the fuel flow is regulated through three parallel flow channels, one of which is automatically actuated in response to the rate of air flow into the combustion chamber; the second of which is controlled by the operator and may be connected to the throttle or similar control element to increase the fuel flow at full throttle; and the third of which boosts the fuel flow for acceleration.

Further objects reside in the particular arrangement and relationship of parts, as will be readily apparent from the following description, taken together with the drawing forming a part of this specification and illustrating one preferred embodiment of the invention as applied to a multi-cylinder internal combustion engine, wherein:

Fig. 1 is a schematic vertical sectional view; and

Fig. 2 is a diagram illustrating the approximate contour of the metering needle.

It has now been found that, contrary to expectations, undiluted fuel can be continuously injected into the discontinuously flowing air in the individual intake pipes adjacent the cylinder intake valves, whereby a uniform fuel-air mixture may be obtained in a simple and efficient manner.

Briefly, the fuel supply system comprises a source of fuel at constant pressure, e. g., a fuel supply pump discharging against a regulated back pressure, a main fuel conduit, and a metering unit having three parallel flow channels for primary flow of fuel, for added flow at full throttle, and for acceleration.

As applied to a multi-cylinder internal combustion engine, the outlet from the metering or fuel regulating unit may be connected to a fuel header and ducts for continuously injecting fuel under pressure directly into the separate intake passages or pipes, preferably thereinto at points adjacent the intake ports of the engine cylinders. As described more fully hereinafter, a particular feature of the invention resides in the provision of separate tuning valves for the several ducts for conveniently adjusting the proportionate amount of fuel injected into each intake pipe. A further feature resides in an improved spring-loaded injection device for injecting the fuel into the air intake passages having a pressure-balanced piston.

As will be more readily apparent from the following detailed description, the present charge forming system does away with carburetors dependent upon suction, the discontinuous drawing of fuel by suction into a mixing chamber, and the non-uniformities of fuel-air mixtures attendant thereto. No complicated timing mechanisms, which cause difficult maintainance problems, are required in the present system. This charge forming system avoids complex arrangements to compensate for asymmetrical parts, such as carburetor ports, mixing chambers, etc. The use of both primary and secondary carburetors and the difficulties of adjustment thereof to obtain a proper balance are obviated.

Referring to Figure 1 of the drawings, a preferred embodiment of the present invention comprises a main air intake passage or manifold **10** having a Venturi throat **11** and a throttle vane **12** provided with an actuating arm **12***a* and a throttle lever bar **13** pivotally attached thereto. The main air intake passage **10** branches into secondary air passages or intake pipes **14** which communicate with the intake ports of the engine cylinders (not shown). Fuel is drawn from the tank (not shown) through line **15** into diaphragm pump, generally designated by **16**, which comprises a diaphragm **17** dividing chamber **18** into upper and lower sections **18***a* and **18***b*. An actuating rod **20** is reciprocated by the action of an eccentric **21**, which may be operated by the engine, and of compression spring **22**. In the downward stroke of actuating rod **20** the upper hooked end **23** thereof engages the hooked rod **24** carried by the diaphragm **17**, thereby drawing down the diaphragm **17** against the upward urging of compression spring **25** and the pressure in the lower chamber section **18***b*. The pressure in chamber section **18***b*, is maintained by means of a channel **26** communicating with the main air passage **10**. Fuel from line **15** enters the upper chamber section **18***a* past inwardly-opening check valve **27** and is discharged past outwardly-opening check valve **28** into pressure conduit **29**. The compression on the spring **25** is adjusted to maintain the pressure of the discharged fuel at a predetermined value, such as 5 to 25 p.s.i. more or less above the pressure below the throttle in the main air passage **10**. A surge damping bellows **30** or the like preferably opens into pressure conduit **29**.

The conduit **29** is interrupted with a fuel flow regulating mechanism generally designated as **35**, and including, if desired, in addition to the main metering control, suitable auxiliary devices as will be hereinafter described. Since, in the present system using a pump maintaining the fuel pressure at a predetermined value above the air intake passage pressure, the pressure drop in the fuel lines is substantially constant, the main fuel control or metering can be accomplished by adjusting the area of a variable orifice formed by a contoured needle valve **36** cooperating with valve seat **37**. The needle valve **36** is preferably designed to give a fuel flow proportional to the square root of the pressure drop in the inlet air passage venturi **11** and therefore proportional to the total air flow in intake passage **10**. For example, the contour of the needle valve may be as shown in Figure 2. The curve may be approximated by the equation.

$$d^2+K\sqrt{h}=D^2$$

wherein

d=the diameter of the needle valve

k=a constant

h=the height of the needle above the valve seat

D=the diameter of the valve seat.

The upper portion of the valve does not follow the curve (indicated by dotted line) but is relieved or constructed to provide enrichment of the fuel-air mixture during idling.

The needle valve **36** is operated by an expansible bellows **40** or the like attached to the valve stem **41**. The inside of the bellows **40** is exposed through channel **42** to the pressure in the Venturi throat **11**. The expansion of the bellows **40** acts against a compression spring **43** fitted with an end plate **44** engaging stop pins **45**. The main fuel flow passes from conduit **29** through port **46** having valve seat **37** and hence past the valve **36** through exit passage **47**, into main fuel line and header **50**.

A control arm **51** is pivoted at one end of the body of the regulating mechanism **35** and pivotably attached at the other end to link **52** which is pivotably connected to manually operated control means for the engine. For example, it may be connected to the lever bar **13** through the throttle actuating arm **12***a*. Full throttle enrichment is provided by means of a secondary fuel passage **53** leading to a port **54** cooperating with valve **54** carried by the valve stem **41** of main valve **36**. This enrichment valve is preferably a needle valve of similar shape as and acts simultaneously with the main valve **36**. The exit passage **56** leading into main exit passage **47** is generally closed by a slide valve **57**, which opens at full throttle by means of a slidable attachment of its valve stem **58** with slot **59** in the control arm **51**. Acceleration enrichment is obtained by a piston **65** connected to actuating arm **51** by linkage **66** and slidably fitted in cylinder **67**, to which fuel is fed through channel **68** having an inwardly-opening check valve **69** when the piston is moved toward the left. When the piston is moved toward the right fuel is discharged to fuel header **50** through line **70** having an outwardly-

opening spring loaded check valve 71. The spring 71a of the valve 71 is sufficiently stiff to prevent the continuous flow of fuel through the passages 68 and 70 when the piston 65 is stationary. For choking, a choke lever bar 75 is pivotably attached at its end to a pivoted choke lever 76, the free end of which acts against end plate 44 to compress the spring 43, thereby tending to open needle valve 36. Likewise, other suitable auxiliaries or different types or arrangements thereof may be used, as desired.

The regulated fuel flow leaving the metering mechanism 35 passes into fuel header 50 and is proportionately divided into separate streams to each of the intake pipes 14 by means of individual fuel ducts 80a, 80b, 80c, etc. The fuel from each of ducts 80a, etc. is injected into the intake pipes 14 through an injection nozzle adapted to disperse or atomize the fuel. Preferably, the injection nozzle is adapted to close to prevent drip when the engine is not operating and to deliver fuel at a given pressure, e. g. 5 to 15 p.s.i., above the manifold air pressure. For this purpose, the injection port 81 cooperates with a valve 84 to form a spray nozzle. The valve 84 is carried by a piston 83 reciprocable in cylinder 82. The fuel pressure in duct 80a acts against the lower face of the piston 83, urging the valve 84 into open position, and a compression spring 85 together with air pressure from intake pipe 14 via channel 86 act against the upper surface of the piston, urging the valve 84 to closed position. Where the engine is occasionally tilted from the horizontal during operation or where cylinders are arranged at different heights, it is preferable that the contour of the valve 84 be designed and the spring 85 adjusted to require a relatively large change in fuel pressure for a small difference in fuel flow. When, such as in aircraft engines, superchargers are used, the injection port 81 is preferably positioned in the intake pipes 14 on the downstream side of the supercharger, and slightly higher fuel pressures may be used. Especially uniform air-fuel mixtures are obtained when the injection nozzle 81 is installed at a distance corresponding to about 2 to 4 cylinder volumes upstream from the cylinder. Injection at the usual elbow adjacent the cylinder in the intake pipe, as shown, has also been found convenient.

A special feature of the present invention is the provision of tuning valves 90a, 90b, 90c, etc., respectively, in the individual fuel ducts 80a, 80b, 80c, etc. These tuning valves, 90a, etc., which may be conveniently located to permit ready adjustment, provide means for adjusting the line resistance to give exactly equal flow through all ducts 80a, etc., or, if desired, to give a fuel distribution in accordance with the air distribution or cooling characteristics of the engine and its installation. Instead of a needle valve 90a any suitable flow-adjusting device, such as a replaceable orifice plate selected for the proper size may be used.

In operation of the above-described charge forming system, the fuel is pumped by diaphragm pump 16 through conduit 29 to regulating mechanism 35 at a predetermined pressure, such as 15 p.s.i., above the main air passage pressure, depending on the adjustment of the diaphragm spring 25. The flow of fuel through the port 46 of the regulating mechanism 35 is controlled in proportion to the total air flow through the main air passage 10 by means of pressure-operated valve 36 and associated parts, including the valve stem 41, expansible bellows 40, channel 42 in the Venturi throat 11, etc. The regulated fuel flow then passes into the fuel header 50 and therefrom into the individual ducts 80a, 80b, 80c, etc. The fuel is continuously injected from each duct 80a, etc., through an injection nozzle 81 directly into the intake pipe 14 at a predetermined pressure above the air pressure, depending on the adjustment of the spring 85. The flow resistances in ducts 80a, etc. are adjusted by means of tuning valves 90a, etc. These adjustments may be made on the carburetor testing bench or after installation on the engine.

In order to test the charge forming system of the present invention a comparison was made in operation of the present continuous flow multiple injection system applied to a four cylinder Continental A-65 aircraft engine with the same engine equipped with its normal suction-type carburetor incorporating a float bowl, Venturi, and fuel nozzle. Both charge forming systems were placed on the same engine and remained there throughout the tests so that by alternately cutting the fuel flow to each system side by side comparisons of engine performance were made without making any mechanical alterations or stopping the engine. All operating conditions and procedures were identical for the two systems and were as shown in the following table:

Operating conditions of the Continental A-65 aircraft engine

	Part Throttle	Full Throttle
Engine speed, R. P. M.	1,670	2,100
Compression ratio	6.3	6.3
Spark advance, degrees btdc	30	30
Air flow, pounds per hour	constant at 270	constant at 380
Intake manifold vacuum, in Hg	7.9 to 8.7	2.7 to 3.1
Fuel flow, pounds per hour	14 to 18	23 to 30
Intake air temperature, °C	50	50

Although this engine itself has excellent fuel and air distribution characteristics by virtue of its symmetrical X-shaped intake manifold, a consistent advantage for the present charge forming system over the normal carburetor was apparent over the whole power range. This was evidenced by a 2 to 3% increase in power output at constant airflow and a corresponding increase in fuel economy, and a more uniform fuel-air ratio among the cylinders. It was also found that while the present charge forming system produces 2% more peak power than the normal carburetor, it produces 3.5% more power at the minimum specific fuel consumption condition. This may be attributed to the fact that the more uniform fuel-air mixture distribution prevents having relatively lean cylinders which lose power before the other cylinders as the over-all fuel flow is reduced. Exhaust gas fuel-air ratio measurements on each cylinder were made by means of an automatic exhaust gas analyzer using the Orsat principle. On large engines with a more pronounced manifold distribution problem, correspondingly greater improvements in engine performance may be obtained.

It will be apparent that various modifications and/or changes may be made in the above-described embodiments without departing from the spirit of the invention as defined by the appended claims.

This case is a continuation-in-part of my application Serial No. 586,233, filed April 2, 1945 now abandoned.

I claim as my invention:

1. In an apparatus for feeding fuel to a combustion chamber in which air is supplied through an air passage: manual control means for said air passage, a source of fuel at a constant pressure greater than the pressure of the air in said air passage: fuel metering means connected to the discharge of said source of fuel comprising first, second and third parallel fluid passages therethrough; said first fluid passage being provided with a first metering valve adapted to move in response to the rate of air flow in said air passage; said second fluid passage being provided with a valve so connected to said manual control means as to be open only when said control means is set for substantially maximum rate of air flow; said third fluid passage being provided with check valves and with an acceleration pump connected to said manual control means to force additional fuel through the third fluid passage during the opening movement of said control means; and an injection nozzle in said air passage connected to receive fuel from said three fuel passages for discharging fuel into the air passage.

2. The combination according to claim 1 wherein the second fluid passage is provided with a metering valve adapted to move in response to the rate of air flow in said air passage.

3. In apparatus for feeding fuel to internal combustion engines in which air is supplied to an engine cylinder through a throttle-controlled air passage: pump means for delivering fuel at a constant pressure greater than the pressure of the air in said air passage; fuel metering means connected to the discharge of said pump means comprising first, second and third parallel fluid passages therethrough; said first fluid passage being provided with a first metering valve adapted to move in response to the rate of air flow in said throttle-controlled air passage; said second fluid passage being provided with a valve so connected to the throttle of said air passage as to be open only when the throttle is substantially fully open; said third fluid passage being provided with check valves and with an acceleration pump connected to the throttle as to force additional fuel through the third fluid passage during the opening movement of said throttle; and an injection nozzle in said air passage connected to receive fuel from said three fuel passages for discharging fuel into the air passage.

4. The combination according to claim 3 wherein the second fluid passage is provided with a metering valve adapted to move in response to the rate of air flow in said throttle-controlled air passage.

5. In apparatus for feeding fuel to a combustion chamber in which air is supplied through an air passage: manually operable control means; automatic control means responsive to the rate of flow of air through said air passage; a source of fuel at constant pressure greater than the pressure of air in said air passage; fuel metering means supplied from said source of fuel comprising first, second and third parallel fluid passages therethrough; said first fluid passage being provided with a first metering valve operably connected to said automatic control means to permit the flow of fuel substantially at a rate proportional to the rate of flow of air through said air passage; said second fluid passage being provided with a valve so connected to said manually operable control means as to be open only when said control means is set for substantially maximum rate of air flow; said third fluid passage being provided with check valves and with an acceleration pump connected to said manual control means to force additional fuel through the third fluid passage during the opening movement of said manually operable control means; and an injection nozzle in said air passage connected to receive fuel from said three fuel passages for discharging fuel into the air passage.

6. The combination according to claim 5 wherein the second fluid passage is provided with a metering valve operated by said automatic control means to permit the flow of fuel at greater rates as the rate of flow of air through said air passage increases.

7. In apparatus for feeding fuel to multi-cylinder internal combustion engines in which air is supplied to the engine cylinders through a main throttle-controlled air passage connected to separate branch air passages: control means responsive to the rate of flow of air through said main air passage; a source of fuel at constant pressure greater than the pressure of air in said air passage; fuel metering means supplied from said source of fuel comprising first, second and third parallel fluid passages therethrough; said first fluid passage being provided with a first metering valve operably connected to said control means to permit the flow of the fuel substantially at a rate proportional to the rate of flow of air through said main air passage; said second fluid passage being provided with a valve so connected to the throttle of said air passage as to be open only when the throttle is substantially fully open; said third fluid passage being provided with check valves and with an acceleration pump connected to the throttle so as to force additional fuel through the third fluid passage during the opening movement of said throttle; and an injection nozzle in each of said branch air passages connected to receive fuel from said three fuel-passages for discharging fuel into the branch air passages.

8. The combination according to claim 7 wherein the second fluid passage is provided with a metering valve operated by said control means to permit the flow of fuel at greater rates as the rate of flow of air through said main air passage increases.

9. In a charge forming system for a multi-cylinder internal combustion engine, apparatus which comprises in combination: an air intake conduit having a venturi and a throttle vane adaptable to be actuated by a manually operable throttle; a source of fuel and a fuel metering means having separate and parallel first, second and third fluid passages therethrough; said first fluid passage being provided with a first metering valve having a reciprocable valve needle with valve-closing tension means and means adapted to cooperate with said tension means to move said valve needle reciprocably in response to changes in the rate of air flow in said air intake conduit; said second fluid passage being provided with a second metering valve having a valve needle rigidly connected with the valve needle of the first metering valve and provided in series with said second metering valve a slidable valve which is adaptable to be reciprocably actuated by said manually operable throttle; and said third fluid passage being provided with a valve comprising a chamber with check-valved inlet and check-valved outlet passages and a piston therein adaptable to be reciprocably actuated in said manually operable throttle.

10. A fuel metering apparatus adaptable for use in a charge forming system for a multi-cylin-

der internal combustion engine comprising in combination: first, second and third separate and parallel fluid passages; said first fluid passage being provided with a first metering valve having a valve needle with a valve stem adapted to be connected with an expandable fluid chamber and with a valve-closing tension means and thereby cooperating to move said valve needle reciprocably in response to changes in volume of said fluid chamber; said second fluid passage being provided with a second metering valve having a valve needle formed about a part of the valve stem of said first metering valve, and with a slidable valve adaptable to be reciprocably actuated by a manually operable throttle; and said third fluid passage being provided with a chamber having check-valved inlet and check-valved outlet passages and a piston therein adaptable to be reciprocably actuated by said manually operable throttle.

11. In apparatus for feeding fuel to multi-cylinder internal combustion engines in which air is supplied to each engine cylinder through a separate air passage: a source of fuel under pressure; metering means for regulating the fuel flow from said source; a fuel header connected to the discharge of said metering means; individual fuel ducts leading from said fuel header to each of said passages; an injection nozzle in each fuel

duct for discharging fuel into the respective air passage, each nozzle comprising a needle valve having a spring urging the valve to its closed position and arranged to be moved to its open position in response to an increase in the pressure of the fuel in said duct; an air duct connecting a point in the air passage near said injection nozzle with the space in rear of the needle valve, whereby each needle valve is urged to its closed position by the pressure of air in the respective air passage; and an adjustable tuning valve in each of said fuel ducts in advance of the injection nozzle for regulating the flow of fuel to the nozzle associated therewith.

ALBERT L. STANLY.

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