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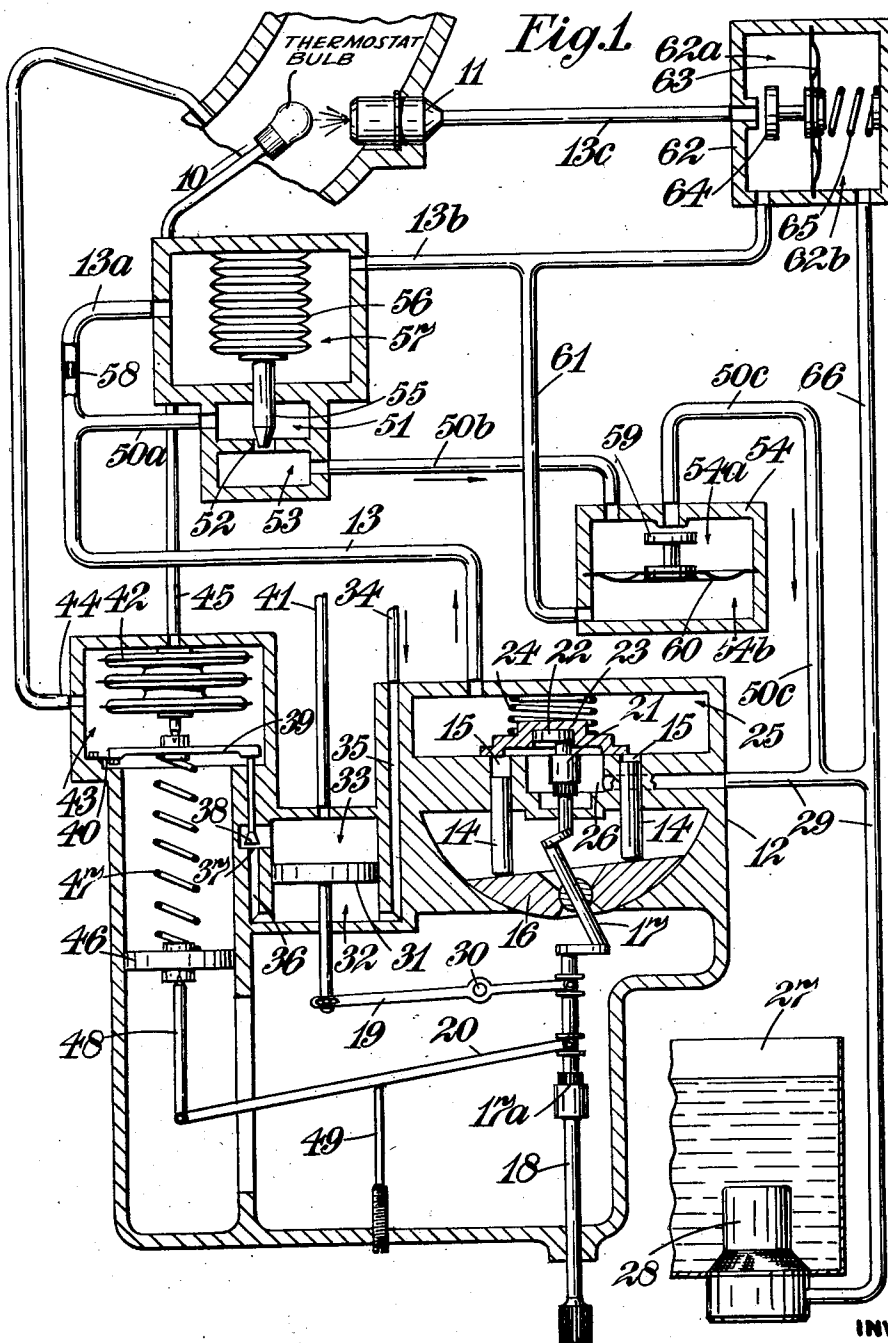
K. A. BASFORD ET AL.

2,806,519

FUEL-SYSTEMS FOR INTERNAL COMBUSTION ENGINES WITH MEANS  
TO COMPENSATE FOR AN OPERATING VARIABLE

Filed June 16, 1950

4 Sheets-Sheet 1



INVENTORS  
K. A. BASFORD &  
P. REDFERN  
by *William S. Maunier*  
ATTY.

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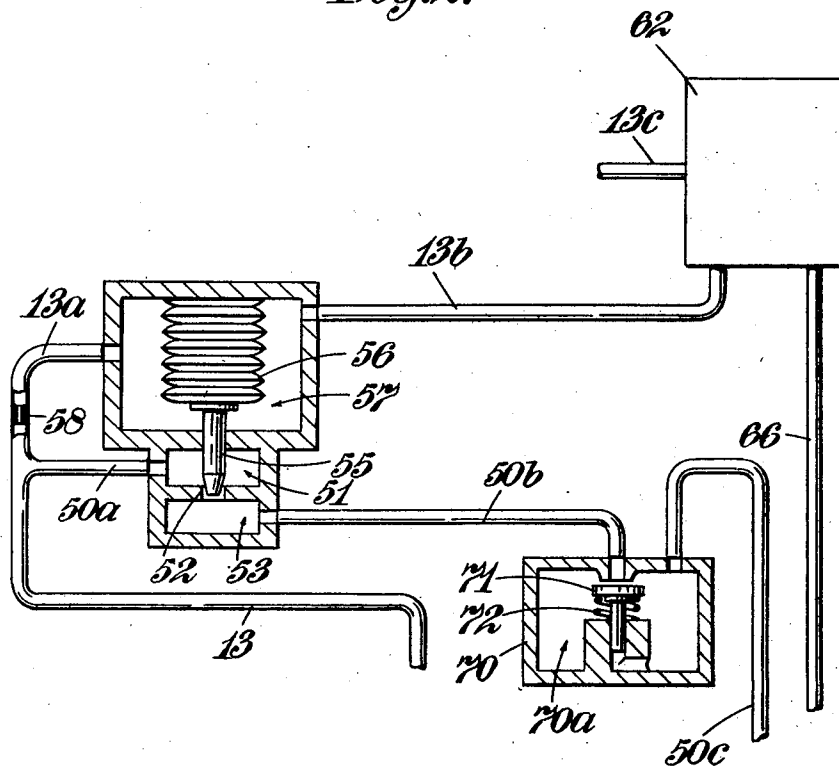
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*Fig.2.*



## INVENTORS

**K. A. BASFORD &  
P. REDFERN**

by Wilkinson & Mauriney  
Attys.

Sept. 17, 1957

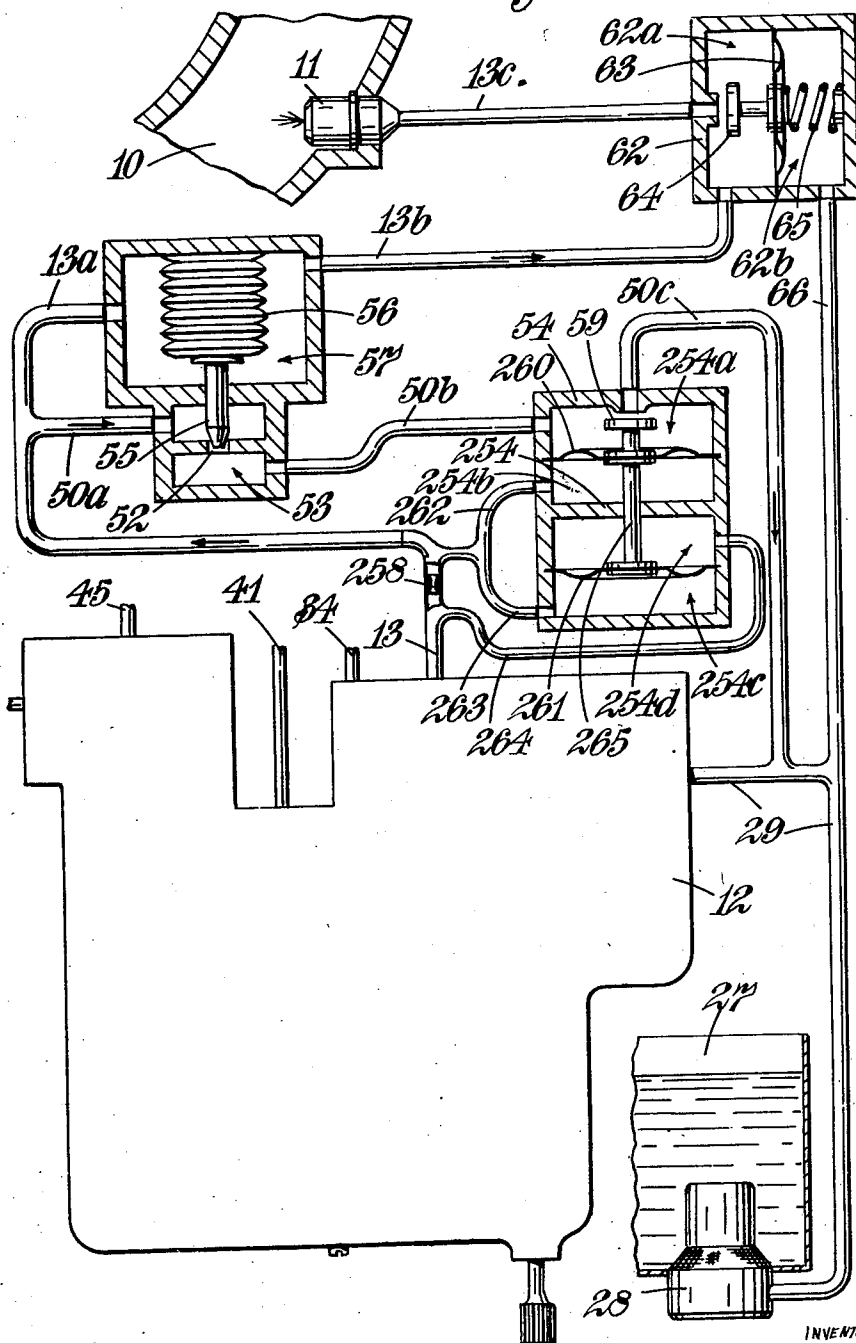
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Fig. 3.



INVENTORS

K. A. BASFORD  
+ P. REDFERN

By *Mantelney & Mantelney*  
ATTORNEYS

Sept. 17, 1957

K. A. BASFORD ET AL

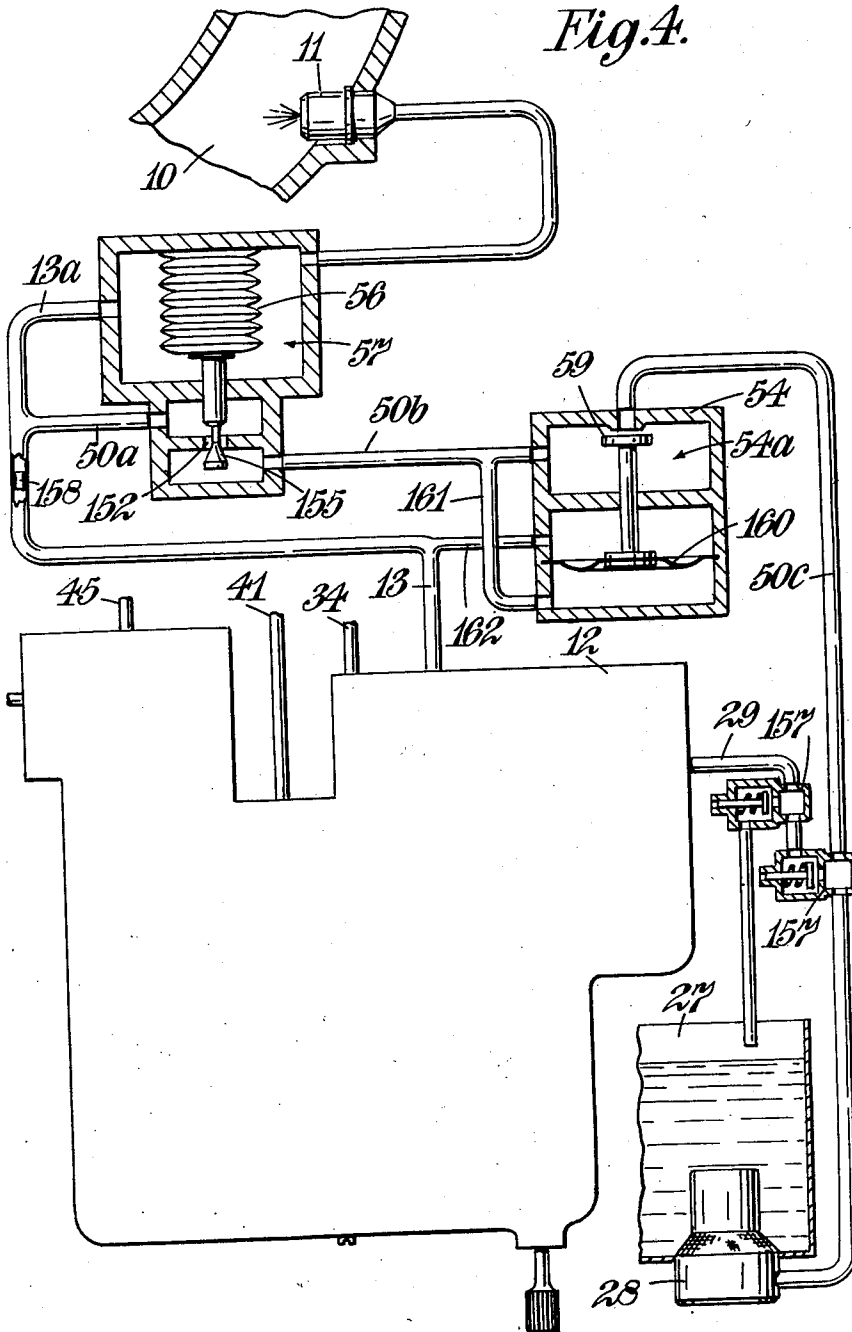
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Fig. 4.



INVENTORS  
K. A. BASFORD  
+ P. REIFERN  
By *Mawhinney & Mawhinney*  
ATTY

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2,806,519

## FUEL-SYSTEMS FOR INTERNAL COMBUSTION ENGINES WITH MEANS TO COMPENSATE FOR AN OPERATING VARIABLE

Kenneth Arnold Basford, Alvaston, Derby, and Peter Redfern, Derby, England, assignors to Rolls-Royce Limited, Derby, England, a British company

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14 Claims. (Cl. 158—36.4)

This invention relates to fuel systems for internal combustion engines.

The invention is concerned with fuel systems of the kind comprising a main fuel conduit and variable-capacity fuel supply means, for example a variable-capacity pump, arranged to deliver into the main conduit a basic volumetrically-metered quantity of fuel.

In one well-known fuel system of this kind for aircraft reciprocating engines, an engine-driven variable-capacity pump is arranged to deliver fuel to the intake manifold of the engine and the capacity of the pump is controlled to meter the fuel volumetrically so that the volume of fuel delivered to the engine is varied as a desired function of the "boost" pressure, that is the pressure in the intake manifold.

In the operation of certain vehicles, especially aircraft such as long range transport or military aircraft, it is important that, under all operating conditions, the fuel consumption should be as low as possible and it has been proposed therefore that the fuel delivery to the engine should be varied not only as a function of the boost pressure but also as a function of air intake temperature or charge temperature, and in one known arrangement for this purpose, the fuel delivery to the engine has been varied by automatically varying the capacity of a volumetric-metering fuel pump as a desired function of both the air intake temperature and the boost pressure.

The present invention has for an object to provide an improved fuel system of the kind specified arranged to give desirable characteristics over the wide range of fuel deliveries.

According to the present invention, a fuel system of the kind referred to comprises the combination with a main fuel delivery conduit and a variable-capacity fuel-supply means connected to deliver a volumetrically-metered basic fuel flow into said main fuel delivery conduit, of an auxiliary-flow conduit connected to said main fuel delivery conduit to carry an auxiliary fuel flow which varies the basic volumetrically-metered flow to give an actual fuel flow in the main conduit downstream of the junction of said main and auxiliary conduits, and fuel-flow-metering means arranged to control the flow in said auxiliary conduit and comprising an orifice device arranged to pass said auxiliary fuel flow, adjusting means arranged to be responsive to an operating variable and by its response to adjust the effective area of said orifice device to vary as a function of said operating variable, and pressure control means arranged to control the difference in pressure in said auxiliary conduit on each side of the orifice device to be a function of a fuel flow in said main fuel conduit.

By adopting the arrangement of the present invention, at any instant the basic and actual fuel flows differ by an amount which is dependent on the instantaneous value of the operating variable in accordance with which the effective area of the orifice device is adjusted and which is also a function of the instantaneous basic or actual fuel flow. Thus, if the pressure control means is arranged to control

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the difference in pressures in said auxiliary conduit on each side of the orifice device to be a function of the actual fuel flow, then the compensating flow through the auxiliary conduit for a given effective area of the orifice device will at any instant be proportional to the instantaneous actual fuel delivery to the engine.

The setting of the variable-capacity fuel supply means may be arranged for automatic control in accordance with one or more operating variables other than that for which the effective area of the orifice is varied, so that the basic fuel delivery into the main conduit is itself varied in accordance with one or more operating variables. For example, a variable-capacity pump forming the fuel supply means, may be arranged to give a basic fuel flow which varies in accordance with the engine boost pressure and the effective area of the orifice device in the auxiliary conduit may be varied in accordance with the charge or air-intake temperature so that the actual fuel flow to the engine is varied in accordance with both the boost pressure and the charge or air-intake temperature.

We have now found that, in addition to compensating the fuel delivery for variations in charge or air-intake temperature and in boost pressure, it is also desirable to provide means for varying the actual fuel flow to the engine as a function of the fuel temperature, since the heat content of a unit volume of fuel of a given specification will vary with changes of the fuel density due to variations in the fuel temperature. Thus if the fuel temperature is high, the fuel density will be low and a smaller amount of heat will be obtained from a given volume of the fuel on combustion than when the fuel temperature is low and the fuel density is high.

In one preferred arrangement of the present invention, therefore, a compensation in the fuel flow is effected for changes in fuel temperature.

Thus, according to one preferred application of this invention the effective area of the orifice device in the auxiliary conduit may be varied as a function of the temperature of the fuel to give a compensation flow through the auxiliary conduit which is a function of fuel temperature. Such a system compensating for fuel temperature is readily applicable to fuel systems of the kind specified in which the capacity of the variable capacity supply means is controlled in accordance with one or more operating variables, such as boost pressure charge or air intake temperature; the system will then provide automatic compensation in respect of boost pressure, charge or air intake temperature, and fuel temperature.

It is preferred that the pressure drop across the orifice device be controlled in accordance with the actual fuel flow to the engine, though the pressure drop may be controlled in accordance with the basic volumetrically-metered flow.

The fuel flow through the auxiliary conduit may be arranged either to reduce or to increase the basic volumetrically-metered fuel flow, that is the auxiliary conduit may act as a bleed pipe from the main fuel conduit or as a supply pipe thereto.

In one preferred embodiment, the basic fuel flow is arranged to be reduced by the flow through the auxiliary conduit to an extent dependent upon the pressure drop across the orifice device and the effective area of the orifice. If the effective area is to be varied in accordance with fuel temperature, then the orifice device will be arranged so that its area decreases with increase of fuel temperature and vice versa, that is so that the amount by which the basic fuel flow is reduced by the flow through the auxiliary conduit decreases with increase of fuel temperature and vice versa.

When the fuel flow through the auxiliary conduit is arranged to increase the basic fuel flow, the effective area of the orifice will, if it is to be varied with fuel tempera-

ture, be decreased with decrease of fuel temperature and vice versa, that is so that the amount by which the basic fuel flow is augmented by flow through the auxiliary conduit increases with increase of fuel temperature.

Four arrangements of control according to this invention will now be described as applied in a fuel system for an internal combustion engine for varying the fuel supply to the engine in accordance with changes in the temperature of the fuel being supplied to the engine.

The description refers to the accompanying diagrammatic drawings in which:

Figure 1 shows one arrangement,

Figure 2 illustrates a modification of this arrangement,

Figure 3 illustrates another arrangement, and

Figure 4 illustrates a fourth arrangement.

Referring to the drawings, there is indicated at 10 a part of the inlet manifold to a reciprocating internal combustion engine into which manifold fuel is injected by a fuel injection device 11.

The injection device 11 is fed with fuel from a known arrangement of variable-capacity pump 12 which delivers into a main fuel delivery pipe 13 leading via sections 13a, 13b and 13c to the injection device 11.

The basic delivery of the pump 12 into the main fuel pipeline 13 is arranged to be varied in known manner in accordance with variations in the pressure in the engine intake manifold (the boost pressure) and in accordance with the charge temperature, that is the temperature of the fuel/air mixture in the inlet manifold 10.

The pump 12 comprises a number of plungers 14 arranged to be reciprocated within cylinder bores 15 formed in the body of the pump 12, under control of a mechanism comprising a swash plate 16 mounted on a cranked portion 17 of an engine-driven multi-section shaft. The section 17 of the multi-section shaft is connected through a splined coupling 17a to a section 18 extending exteriorly of the pump casing to be connected with the engine in any suitable manner. As the shaft sections 17, 18 rotate the swash plate 16 also rotates and causes reciprocation of the plungers 14. The section 17 of the shaft is adjustable axially with respect to the section 18 under control of levers 19 and 20 and rocking of these levers to displace the section 17 axially of its axis of rotation causes a change in the stroke of the plungers 14.

The multi-section shaft also comprises a further section 21 carrying an eccentric 22 engaged within a valve plate 23 which is held by a spring 24 in contact with a surface of the portion of the pump body in which the bores 15 are formed. As the shaft rotates so the valve plate is caused to partake of an oscillatory motion which alternately places the end of the bores 15 into communication with a delivery chamber 25 and a fuel inlet chamber 26. It is arranged that when a plunger 14 is moving in a direction to increase the volume of the bore 15 above it then the bore is in communication with the inlet chamber 26 and that when the plunger is moving in the reverse direction fuel is delivered from the bore into the chamber 25.

Fuel is delivered to the pump 12 from a reservoir 27 by means of a booster pump 28 located in the fuel tank which booster pump 28 delivers by way of a pipeline 29 into the chamber 26 above referred to.

The delivery chamber 25 is connected to the main fuel delivery pipeline 13.

The lever 19 above referred to is pivoted in the pump casing at 30 and is connected to a piston 31 working in a cylinder to divide the cylinder into two chambers 32, 33. The chamber 32 is connected by a pipeline 34 and duct 35 to a suitable source of pressure fluid (not shown) and the chamber 32 is connected by a duct 36 with the chamber 33, the duct 36 comprising within it a valve-controlled orifice 37. The chamber 33 is provided with a drain pipe 41. The orifice 37 is controlled by a poppet valve element 38 on which bears a lever 39 connected

with the casing of pump 12 by means of a leaf spring 40.

It will be seen that when the poppet valve 38 throttles the flow through the duct 36 between the chamber 32 and chamber 33, a difference in pressure is created between the pressures in these chambers and the piston will move to rock lever 19 and displace the shaft section 17.

The lever 39 is arranged to be loaded by an expansible capsule 42 located in a chamber 43 which chamber is connected by a conduit 44 to the manifold 10 so that the pressure within the chamber 43 is the boost pressure. The interior of the expansible capsule 42 is connected by a conduit 45 with a bulb device in the inlet manifold 10 and the bulb device, conduit 45 and capsule 42 are filled with liquid and together form a temperature-sensitive device which is sensitive to the temperature of the charge in the inlet manifold. As the temperature of the charge in the inlet manifold increases so the capsule 42 expands and as the charge temperature decreases so the capsule 42 contracts.

The chamber 43 has a displaceable wall in the form of a piston 46 which is arranged to load the lever 39 through a spring 47 and which is connected by a link 48 to one end of the lever 20 which is provided with an adjustable fulcrum 49 supported in the casing of the pump 12. The link 48 is not pivoted to the piston 46 but merely abuts against it and it will be seen that the fluid pressure load on the piston 31 always acts in such a direction as to tend to maintain the link 48 in contact with the piston 46.

The mechanism just described acts to vary the delivery of the variable-capacity pump 12 in accordance with changes in the charge temperature and boost pressure within the intake manifold of the internal combustion engine with which the fuel system is associated.

Under steady conditions of charge temperature and pressure, the pistons 46 and 31 will take up positions in which the loads acting on them are in equilibrium. Thus the axially-adjustable section 17 of the pump shaft also takes up a defined position and the delivery of the pump as determined by the swash plate 16 is also determined. On increase of charge temperature for example, the capsule 42 expands displacing the poppet valve 38 thereby increasing its throttling effect on the flow of pressure fluid from chamber 32 to chamber 33 and increasing the load on the piston 31 which is thereby displaced and which moves until a new equilibrium position is achieved due to the displacement through the linkage 19, 20 of the piston 46. It will be seen that with this increase of charge temperature the piston 31 moves upwardly, as viewed in the drawings, decreasing the delivery of the pump 12. Conversely, on decrease of the charge temperature an increase of the pump fuel delivery is obtained.

On increase of the boost pressure, that is the pressure within the engine intake 10, the piston 46 is displaced downwardly, as viewed in the drawings, causing an increase in the swash angle of the swash plate 16 and at the same time causing the piston 31 to be displaced downwardly as viewed in the drawings. Such displacement of piston 46 reduces the spring load tending to open poppet valve 38, which therefore reduces the area of the orifice 37. The pressure in chamber 32 therefore increases tending to cause piston 31 to move in an upward direction, and also to cause piston 46 to move upward, through linkage 19, 20; a new equilibrium position corresponding to the new boost pressure is thus established. Conversely, a decrease in the boost pressure causes a decrease in the fuel delivery of the pump 12, equilibrium of the system being established through the linkage arrangement in a similar manner.

The variable-capacity fuel-delivery means above described is well-known in construction and operation, and it is not essential that this arrangement shall be employed, and any other variable-capacity fuel-delivery means may be employed in place thereof.

According to this arrangement of the invention, there is provided means for varying the basic volumetrically-metered fuel flow fed into the main fuel delivery pipe 13 from the pump 12 in accordance with a further operating variable, in this arrangement the temperature of the fuel. It will be appreciated that as the temperature of fuel changes its density changes and therefore that since the quantity of heat which can be derived from a given volume of the fuel also changes, it is desirable to compensate for changes in fuel temperature.

Accordingly, in this arrangement of the invention, there is provided means for bleeding-off fuel from the main fuel delivery pipe 13 and conveying it back to the suction side of the pump 12 and for so controlling the quantity of fuel bled-off that it is proportional not only to fuel temperature, and therefore fuel density, but also to the actual fuel flow delivered to the injector 11.

The means comprises an auxiliary bleed conduit 50 comprising a number of sections 50a, 50b and 50c, whereof the section 50a is connected at one end to the main fuel conduit 13 and at the other end to a chamber 51 having an outlet orifice 52 to a second chamber 53 to which one end of the auxiliary conduit section 50b is connected. The other end of the conduit section 50b is connected to a valve body 54, to which there is also connected one end of the conduit section 50c, the opposite end of which is connected to the pipeline 29.

The orifice 52 has its effective area adjustable by means of a valve member 55, which valve member 55 is arranged for adjustment by a temperature-sensitive capsule 56 accommodated in a chamber 57 having a fuel inlet thereto formed by one end of the main fuel conduit section 13a and a fuel outlet formed by one end of the main fuel conduit section 13b. As the fuel temperature increases the capsule 56 expands and the effective area of the orifice 52 is decreased, and conversely as the fuel temperature decreases the capsule 56 collapses thereby increasing the effective area of the orifice 52.

The pressure difference across the orifice 52 is arranged to be controlled to be a function of the actual fuel flow to the injector 11, that is, fuel flow in the main fuel delivery pipe sections 13a, 13b, 13c downstream of the junction between the main delivery pipeline 13 and the auxiliary conduit section 50a.

This is achieved in the following manner in this arrangement. A flow-restrictor 58 is provided in the main fuel pipeline between the sections 13 and 13a, and a pressure-operated valve is provided in the valve body 54 referred to above.

The pressure-operated valve comprises a mushroom-shaped element 59 carried by a flexible diaphragm 60 which separates the valve body 54 into two chambers 54a and 54b, whereof the chamber 54a has an inlet connection afforded by the auxiliary conduit section 50b and an outlet afforded by the auxiliary conduit section 50c and the valve member 59 is arranged to control the outflow from the chamber 54a. The chamber 54b is connected with the main fuel delivery line by means of a branch pipe 61 leading from the main fuel pipe section 13b to the valve body 54. It will be seen that one side of the diaphragm 60 is subjected to the pressure existing in the auxiliary pipeline section 50b, that is to the pressure existing just downstream of the orifice 52, and that the other side of the diaphragm 60 is subjected to the pressure existing in the main pipeline just downstream of the flow-restrictor 58, so that the valve member 59 will not be lifted off its seat to permit a flow of fuel through the auxiliary pipeline until the pressure in chamber 54a is at least equal to that in chamber 54b.

Thus, the pressure drop across the flow-restrictor 58 and the pressure drop across the orifice 52 will be maintained equal and the flow through the orifice 52 for a given setting of the valve member 55 will be proportional to the flow through the orifice 58, that is to the actual delivery to the injector 11. Moreover, since as stated

above the effective area of the orifice 52 is controlled as a function of the fuel temperature, the flow through the orifice 52 will be dependent not only on the actual flow to the engine but also on the fuel temperature.

The system also preferably includes a back-pressure valve arrangement, such as that illustrated in Figure 1.

The back-pressure valve comprises a valve body 62 divided into two chambers 62a, 62b by a flexible diaphragm 63 which carries a mushroom type valve member 64 and is acted on by a spring 65. The chamber 62a has an inlet thereto formed by the downstream end of the main fuel pipe section 13b and the inflow to the chamber 62a through the pipe section is controlled by the valve member 64. The chamber 62a has an outlet formed by the main fuel pipe section 13c leading to the injector 11. The chamber 62b is connected by a pipeline 66 to the pipeline 29.

It will be seen that, since the opening of the valve 64 is controlled by the difference in the pressures on each side of the diaphragm 63, before fuel injection can be obtained a positive pressure difference must exist between the chambers 62a and 62b in order to overcome the load of the spring 65, and since in operation the pressure in the chamber 62a will be the pressure in the section 13b, and thus in chamber 54b, by providing the back-pressure valve 62 it is ensured that at all times when fuel is injected into the engine manifold there is a positive pressure between the chamber 54a of the valve regulating the flow through the auxiliary pipelines and the inlet 29 of the fuel-metering pump. Thus when the metering pump 12 is inoperative and the booster pump 28 is operative, the valve 64 is closed preventing delivery of fuel to the injector 11 via pipelines 29, 50c, 50b, 13b and 13c.

When a back-pressure valve such as the valve 62 is provided the flow-regulating valve 54 may be replaced by a simple spring-loaded valve arrangement.

Such an arrangement is illustrated in Figure 2 and it will be seen that the valve 54 is replaced by a valve arrangement comprising a valve body 70 having a chamber 70a with an inlet thereto from the auxiliary pipe section 50b and an outlet therefrom to the auxiliary pipe section 50c. The inlet to the chamber 70a is arranged to be controlled by a mushroom type valve member 71 which is spring-loaded by a spring 72 in a manner tending to close off the inlet to the chamber 70a. The spring 72 is matched to the spring 65 of the back-pressure valve 62, so that the effective loadings on the valve members 71 and 64 are equal and in this manner the pressure on the downstream side of the flow restrictor 58 will be substantially equal to the pressure on the downstream side of the orifice 52.

In the arrangements just described, it is arranged that the setting of the metering pump 12 gives a basic fuel flow into the pipe section 13 which is in excess of the actual engine requirements under all operating conditions and for all fuel temperatures likely to be experienced, and the profile of the valve member 55 controlled by the fuel temperature responsive capsule 56 is chosen to permit an appropriate compensating flow through the auxiliary pipe line 50a, 50b, 50c back to the inlet of the metering pump 12, thus reducing the value of the basic volumetrically-metered flow to give an actual metered flow in accordance with the design requirements of the engine, the actual metered flow varying in accordance with change of fuel temperature. Thus for each basic metered fuel flow, an increase in the fuel temperature will cause a reduction in the effective area of the orifice 52 thereby causing a decrease in the flow through the conduit 50 and an increase in actual metered fuel flow to maintain the required heat delivery to the engine; conversely, a reduction in fuel temperature will increase the effective area of the orifice 52, thereby increasing the by-pass flow and decreasing the actual fuel delivery to the engine, in order to maintain the required heat delivery.

Referring now to Figure 3, there is illustrated an ar-

range in which instead of employing a restrictor 58 as in Figure 1 in the main fuel line downstream of the junction with the main fuel line of the branch conduit 50a, the restrictor 258 is placed upstream of this junction.

In order to maintain the pressure drop across the orifice 52 equal to the pressure drop across the restrictor 258 the valve body 54 is employed as compared with Figure 1 as follows. The valve body 54 has an internal wall 254 dividing the valve body into two chambers and each chamber contains a diaphragm dividing the respective chamber into two pressure spaces. Thus, one diaphragm 260 divides one chamber into pressure spaces 254a, 254b whereof the chamber 254a is open to the conduit section 50b and the space 254b is connected by a pipe 262 to the main pipeline 13 downstream of the restrictor 258 so that the diaphragm 260 is loaded in the sense of opening the valve 59 by the pressure drop across the orifice 52. The second diaphragm 261 which is connected to the diaphragm 260 by connecting rod 265 to move therewith, divides the second chamber into a first pressure space 254c and a second pressure space 254d, whereof the pressure space 254c is connected by a pipe 263 to the main pipeline downstream of the restrictor 258 and the pressure space 254d is connected by a pipe 264 to the main pipeline 13 upstream of the restrictor 258; thus the diaphragm 261 is loaded by the pressure drop across the restrictor 258 in the sense to tend to close the valve 59. It will be seen that this arrangement effectively equates the pressure drops across the restrictor 258 and the orifice 52.

It will be appreciated, however, that if desired the pump 12 may give a basic fuel flow which is less than that required by the engine and the fuel flow through the auxiliary pipeline may be arranged to be in the reverse direction so that the actual fuel flow to the engine is in excess of the basic metered flow from the fuel pump 12. In this case as shown in Figure 4 the area of the orifice 152 corresponding to the orifice 52 will be arranged to be increased with increase of fuel temperature and to be decreased on decrease of fuel temperature. For this purpose, a valve element 155 moved by capsule 56 is provided, the valve element 155 having an increasing cross-sectional area towards its tip so that as the capsule expands the effective area of orifice 152 is increased and as the capsule collapses the effective area of orifice 152 is decreased.

In this arrangement, also, relief valve means 157 will be provided in the pipeline 29 to ensure that the pressure upstream of the relief valve means 157 is higher than the pressure in the pipeline 50a which lies downstream of the orifice 152, the auxiliary fuel flow being tapped off from pipeline 29 upstream of the relief valve means 157. Such a relief valve means 157 is not required if the metering unit is not a pump, i. e., if there is a pressure drop from inlet to outlet thereof. The valve arrangement 54 will be such as to maintain the pressure in pipe 50b equal to that in the upstream portion of the main delivery pipe 13, and in this arrangement it is preferred that the flow restrictor 158 (corresponding to the restrictor 58 of Figure 1) is in the delivery pipe upstream of the junction with the auxiliary fuel supply pipe 50a.

The valve arrangement 54 comprises a diaphragm 160 loaded on one side by the pressure in pipe 50b through connection 161 in a manner to tend to close valve 59, and on the other side by the pressure in the main fuel conduit 13 through a connection 162. The valve arrangement 54 thus effectively equalizes the pressure drops across the orifice 152 and the restrictor 158 since their downstream sides are connected to a common point.

It will be appreciated moreover, that the flow through the orifice 52 may be used for the purpose of compensating for operating variables other than fuel temperature, for example, the area of the orifice 52 could be controlled to give a by-pass flow compensating for changes of charge temperature if the delivery of the pump 12 is not in itself compensated for changes of this operating variable.

The fuel system arrangement of this invention has the advantage that the compensation effected not only is dependent upon the operating variable but is also proportional to the actual fuel delivery to the engine so that the necessity for manual adjustment to cater for differing running conditions is avoided.

We claim:

1. A fuel system for an internal combustion engine comprising a variable-capacity fuel-supply means; a main delivery conduit connected to said fuel-supply means and having an upstream portion and a downstream portion; a bleed conduit connected to said main delivery conduit at the junction of the upstream and downstream portions; an orifice in said bleed conduit; a first valve member cooperating with said orifice and adjustable to vary the effective area thereof; temperature-sensitive means subject to the temperature of the fuel in said main delivery conduit and connected to control the adjustment of said first valve member to vary the area of said orifice as a function of fuel temperature, the area increasing with decrease of temperature and vice versa; and means to control the pressure difference in the fuel pressures in said bleed conduit on each side of said orifice to be a function of the flow in the main conduit comprising a flow restrictor in said downstream portion of said main conduit, a valve body, a pressure-sensitive member dividing said valve body into two chambers, one of said chambers being connected in said bleed conduit downstream of said orifice and the other of said chambers being connected to said main conduit downstream of said flow restrictor, an outlet port from said one of said chambers, a second valve member accommodated within said valve body, said second valve member being connected to said pressure-sensitive member to be operated thereby and cooperating with said outlet port to control it, whereby the second valve member cooperates with said port to maintain the pressure drop across said orifice as a function of the pressure drop across said flow restrictor.

2. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit connected to receive fuel from said fuel-supply means; a fixed flow restrictor in said main delivery conduit; a branch conduit connected at one end to said main delivery conduit; a source of fuel supplying said variable capacity fuel supply means and also connected to said branch conduit at its end remote from that connected to said main delivery conduit; an orifice in said branch conduit; a first valve member cooperating with said orifice and movable to vary its effective area; temperature-responsive means responsive to the temperature of the fuel in the main delivery conduit and connected to adjust said first valve member; a valve body connected in said branch conduit on the side of the orifice remote from the junction of said main delivery conduit and said branch conduit; a second valve member controlling flow in said branch conduit through said valve body; pressure-responsive means to load said second valve member; a connection from the main conduit on the side of the flow-restrictor remote from its point of connection with said branch conduit to the pressure-responsive means to load it in one sense; and a second connection from the branch conduit on the side of the orifice remote from the point of connection of the branch conduit and the main conduit to the pressure-responsive means to load it in the opposite sense.

3. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit connected to receive fuel from said fuel supply means; a flow restrictor in said main delivery conduit; a branch conduit connected at one end to said main delivery conduit; a source of fuel connected to said branch conduit at its end remote from that connected to said main delivery conduit; an orifice in said branch conduit; a first valve member cooperating with said orifice to vary its effective area; temperature-responsive

means adapted to be responsive to the temperature of the fuel in the main delivery conduit and connected to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main fuel conduit in the sense to increase the flow in the downstream portion of said main delivery conduit on increase of temperature; a valve body connected in said branch conduit on the side of the orifice remote from the junction of said main delivery conduit and said branch conduit; a second valve member controlling flow in said branch conduit through said valve body; pressure-responsive means connected to operate said second valve member; a connection from the main conduit on the side of the flow restrictor remote from its point of connection with said branch conduit to the pressure-responsive means to load it in one sense; and a second connection from the branch conduit on the side of the orifice remote from the point of connection of the branch conduit and the main conduit to the pressure-responsive means to load it in the opposite sense.

4. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel supply means and a downstream portion connected to said upstream portion; a flow restrictor in said downstream portion of said main delivery conduit; a branch conduit connected at one end to said main delivery conduit at the junction of said upstream and downstream portions and at the other end to a region of low pressure and adapted to bleed fuel from the said main delivery conduit; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary its effective area; means connected to adjust said first valve member; a valve body connected in said branch conduit on the side of the orifice remote from the junction of said main delivery conduit and said branch conduit; a second valve member controlling flow through said valve body; pressure-responsive means connected to load said second valve member; a connection from the downstream portion of the main conduit on the side of the flow restrictor remote from the point of connection of said main and branch conduits to the pressure-responsive means to load it in the sense of closing said second valve member; and a second connection from the branch conduit on the side of the orifice remote from the point of connection of the branch conduit and the main conduit to the pressure-responsive means to load it in the opposite sense.

5. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel supply means and a downstream portion connected to said upstream portion; a flow restrictor in said downstream portion of said main delivery conduit; a branch conduit connected at one end to said main delivery conduit at the junction of said upstream and downstream portions and at the other end to a region of low pressure and adapted to bleed fuel from said main delivery conduit; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary the effective area of said orifice; temperature-responsive means arranged to be responsive to the temperature of the fuel in the main delivery conduit and connected to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main fuel conduit so that the effective area of the orifice is decreased with increasing fuel temperature and vice versa; a first valve body connected in said branch conduit; a second valve member accommodated within said first valve body and adjustable to control flow through said first valve body; pressure-responsive means connected to load said second valve member; a connection from the main conduit on the side of the flow restrictor remote from its point of connection with said branch conduit to the pressure-responsive

means to load it in the sense of closing said second valve member; and a second connection from the branch conduit on the side of the orifice remote from the point of connection of the branch conduit and the main conduit to the pressure-responsive means to load it in the opposite sense.

6. A fuel system as claimed in claim 5, comprising also means connected in said downstream portion of said main delivery conduit to maintain a selected pressure within said downstream portion of the main delivery conduit on the downstream side of the flow restrictor.

7. A fuel system as claimed in claim 6, wherein said means to maintain a selected pressure in said downstream portion of the main delivery conduit downstream of the flow restrictor comprises a second valve body, a flexible diaphragm dividing said second valve body into two chambers, one of said chambers having an inlet and an outlet connected in flow series in said downstream portion of the main delivery conduit; a valve element carried by said flexible diaphragm and co-operating with the outlet from said one chamber, a spring loading said diaphragm to tend to close said valve element on said outlet, and a pressure connection from the second of said chambers to said branch conduit on the side of said first valve body in said branch conduit remote from said orifice.

8. A fuel system for an internal-combustion engine comprising a variable-capacity fuel-supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel supply means and a downstream portion connected to said upstream portion; a flow restrictor in said upstream portion of said main delivery conduit; a branch conduit having an orifice therein and connected at one end to said main delivery conduit at the junction of said upstream and downstream portions; a source of fuel at a pressure higher than the pressure in the branch conduit downstream of said orifice and adapted to feed fuel to said main delivery conduit by being connected to the branch conduit at its end opposite said one end thereof; a first valve member adapted to co-operate with said orifice to vary its effective area; temperature-responsive means adapted to be responsive to the temperature of the fuel in the main delivery conduit and connected to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main conduit in the sense to increase the flow in the downstream portion of the main delivery conduit on increase of said temperature; a valve body connected in said branch conduit on the side of the orifice remote from said one end of said branch conduit; a second valve member to control flow through said valve body; pressure-responsive means to load said second valve member; a connection from the main conduit on the side of the flow restrictor remote from its point of connection with said branch conduit to the pressure-responsive means to load it in the sense of opening said second valve member; and a second connection from the branch conduit on the side of the orifice remote from the point of connection of the branch conduit and the main conduit to the pressure-responsive means to load it in the opposite sense.

9. A fuel system for an internal-combustion engine comprising a variable-capacity fuel-supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel supply means and a downstream portion connected to said upstream portion; a flow restrictor in said upstream portion of said main delivery conduit; a branch conduit having an orifice therein and connected at one end to said main delivery conduit at the junction of said upstream and downstream portions; a source of fuel at a pressure higher than the pressure in the branch conduit downstream of said orifice and connected to the other end of the branch conduit thereby to feed fuel to said main delivery conduit said source of fuel also being connected to supply said variable-capacity fuel supply means; a first valve member adapted to co-operate

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with said orifice to vary its effective area; temperature-responsive means adapted to be responsive to the temperature of the fuel in the said main delivery conduit and to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main fuel conduit in the sense of increasing the effective area of the said orifice with increasing fuel temperature and vice versa; a valve body connected in said branch conduit between said orifice and said source; a second valve member to control flow through said valve member; pressure-responsive means to load said second valve member; a connection from the main conduit on the side of the flow restrictor remote from its point of connection with said branch conduit to the pressure-responsive means to load it in the sense of opening said second valve member; and a second connection from the branch conduit between said orifice and said valve body to the pressure-responsive means to load it in the opposite sense.

10. A fuel system for an internal combustion engine comprising a variable-capacity fuel-supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel-supply means and a downstream portion connected to said upstream portion; a flow restrictor in said downstream portion of said main delivery conduit; a branch conduit connected to said main delivery conduit at the junction of said upstream and downstream portions; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary the effective area of said orifice; temperature-responsive means arranged to be responsive to the temperature of the fuel in the main delivery conduit and connected to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main fuel conduit; a valve body connected in said branch conduit on the side of the orifice remote from the junction of the branch conduit with the main delivery conduit, said valve body having an outlet port; a second valve member co-operating with said outlet port and adjustable to control flow through said valve body; a flexible diaphragm dividing said valve body into two chambers and connected to said second valve member to adjust it, one of said chambers being open to said branch conduit between said orifice and said valve body and including said outlet port and the second of said chambers having a pressure connection to said downstream portion of said main delivery conduit on the downstream side of the flow restrictor, the pressure within said second chamber loading the flexible diaphragm to close said second valve member on said outlet port.

11. A fuel system for an internal combustion engine comprising a variable-capacity fuel-supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel-supply means and a downstream portion connected to said upstream portion; a fixed flow restrictor in one of said portions of said main delivery conduit; a branch conduit connected at one end to said main delivery conduit at the junction of said upstream and downstream portions; a source of fuel connected to said branch conduit at its end remote from that connected to said main delivery conduit, said source also being connected to the variable-capacity fuel supply means to supply fuel thereto; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary the effective area of said orifice; means connected to adjust said first valve member to vary the effective area of said orifice; a valve body connected in said branch conduit on the side of the orifice remote from the junction of the branch conduit with the main delivery conduit; a second valve member co-operating with a port in said valve body and adjustable to control flow in said branch conduit through said valve body; and pressure-responsive means comprising at least one pressure-responsive device to load said second valve member, and pressure connections at least from said branch conduit on the side of the orifice remote from said one end of the

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branch conduit and at least from said main conduit on the side of the restrictor remote from the junction of said main and branch conduits to said pressure-responsive means, said pressure connections effectively applying to said pressure-responsive means the pressure drop across said orifice to tend to close said second valve member and the pressure drop across said flow restrictor to tend to open said second valve member respectively.

12. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit having an upstream portion connected to receive fuel from said fuel supply means and a downstream portion connected to said upstream portion; a flow restrictor in said upstream portion; a branch conduit connected at one end to said main delivery conduit at the junction of said upstream and downstream portions and at the other end to a region of low pressure and adapted to bleed fuel from said main delivery conduit; an orifice in said branch conduit; a first valve member arranged to co-operate with said orifice to vary its effective area; temperature-responsive means arranged to be responsive to the temperature of the fuel in the main delivery conduit and to adjust said first valve member to decrease the effective area of said orifice on increase of the fuel temperature and to increase the effective area of said orifice on decrease of the fuel temperature; a valve body connected in said branch conduit on the side of said orifice remote from the junction of said branch conduit with said main delivery conduit; a second valve member to control flow through said valve body; and pressure-responsive means to control said valve member, said pressure-responsive means being arranged to be loaded in one sense by the pressure drop across said flow restrictor and in the opposite sense by the pressure drop across said orifice whereby said pressure drops are maintained equal.

13. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit connected to receive fuel from said fuel-supply means; a flow restrictor in said main delivery conduit; a branch conduit connected at one of its ends to said main delivery conduit; a source of fuel connected to the opposite end of said branch conduit and also to supply fuel to said variable-capacity fuel supply means; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary the effective area of said orifice; fuel temperature-responsive means connected to adjust said first valve member in accordance with variations of the fuel temperature; a valve body connected in said branch conduit on the side of the orifice remote from said one end of said branch conduit; a second valve member adjustable to control flow in said branch conduit through said valve body; and pressure-responsive means comprising at least one pressure-responsive device connected to load said second valve member, and pressure connections at least from said branch conduit on the side of the orifice remote from said one end of the branch conduit and at least from said main conduit from the side of said flow restrictor remote from the junction of said main and branch conduits to said pressure-responsive means, said connections applying effectively to said pressure-responsive means the pressure drop across said orifice to tend to close said second valve member and the pressure drop across said flow restrictor to tend to open said second valve member respectively.

14. A fuel system for an internal-combustion engine comprising a variable-capacity fuel supply means; a main delivery conduit connected to receive fuel from said fuel-supply means; a flow restrictor in said main delivery conduit; a branch conduit connected at one of its ends to said main delivery conduit; a source of fuel connected to said branch conduit at the other of its ends; an orifice in said branch conduit; a first valve member co-operating with said orifice and adjustable to vary the effective area of said orifice; temperature-responsive means adapted to be responsive to the temperature of the fuel in the main de-

livery conduit and connected to adjust said first valve member to vary the effective area of said orifice on variation of the temperature of the fuel in the main conduit in the sense to increase the flow in the downstream portion of said main delivery conduit on increase of said temperature; a valve body connected in said branch conduit on the side of the orifice remote from said one end of said branch conduit; a second valve member adjustable to control flow in said branch conduit through said valve body; and pressure-responsive means comprising at least one pressure responsive device to load said second valve member, and pressure connections at least from said branch conduit on the side of the orifice remote from said one end of the branch conduit and at least from said main conduit on the side of the restrictor remote from the junction of said main and branch conduits to said pressure-responsive means, said pressure connections effectively applying to said pressure-responsive means the pres-

sure drop across said orifice to tend to close said second valve member and the pressure drop across said flow restrictor to tend to open said second valve member respectively.

## References Cited in the file of this patent

## UNITED STATES PATENTS

|           |                   |               |
|-----------|-------------------|---------------|
| 1,891,238 | Oswald            | Dec. 20, 1932 |
| 2,193,240 | Schmidt           | Mar. 12, 1940 |
| 2,275,689 | Shepperd et al.   | Mar. 10, 1942 |
| 2,352,584 | Ziebolz et al.    | June 27, 1944 |
| 2,422,808 | Stokes            | June 24, 1947 |
| 2,471,541 | Plass             | May 31, 1949  |
| 2,545,698 | Holly et al.      | Mar. 20, 1951 |
| 2,564,107 | Holley            | Aug. 14, 1951 |
| 2,564,124 | Orr               | Aug. 14, 1951 |
| 2,636,553 | Ballantyne et al. | Apr. 28, 1953 |
| 2,658,566 | Wirth et al.      | Nov. 10, 1953 |