June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 1

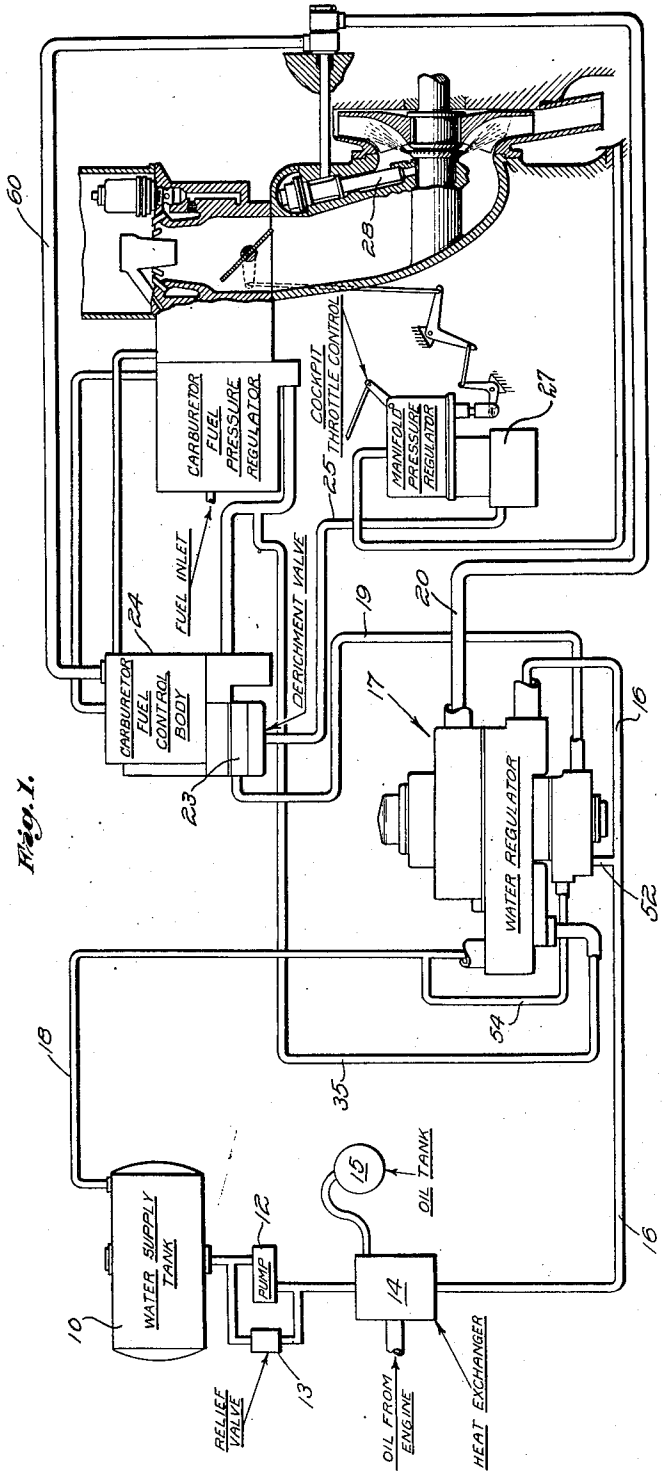


Fig. 1.

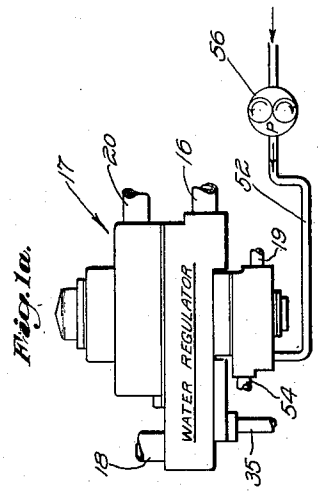


Fig. 1a.

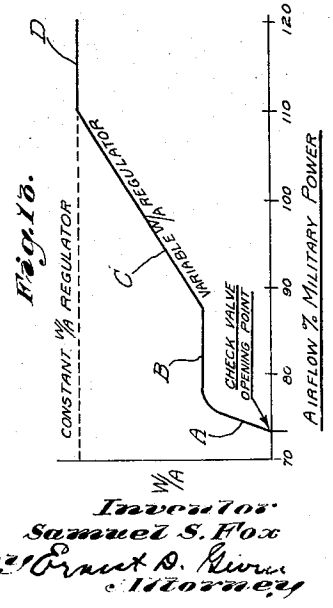


Fig. 1b.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 2

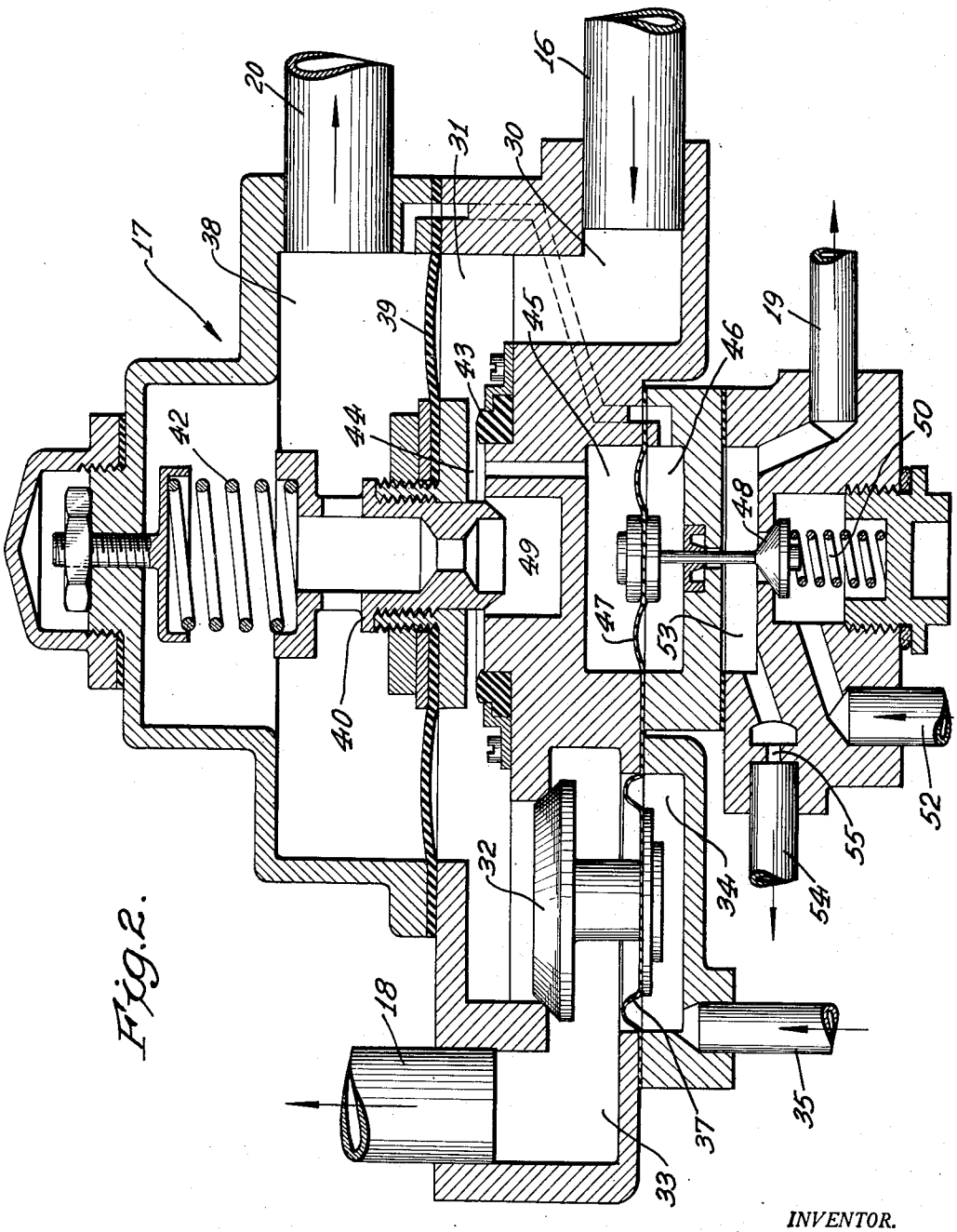


Fig. 2.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 3

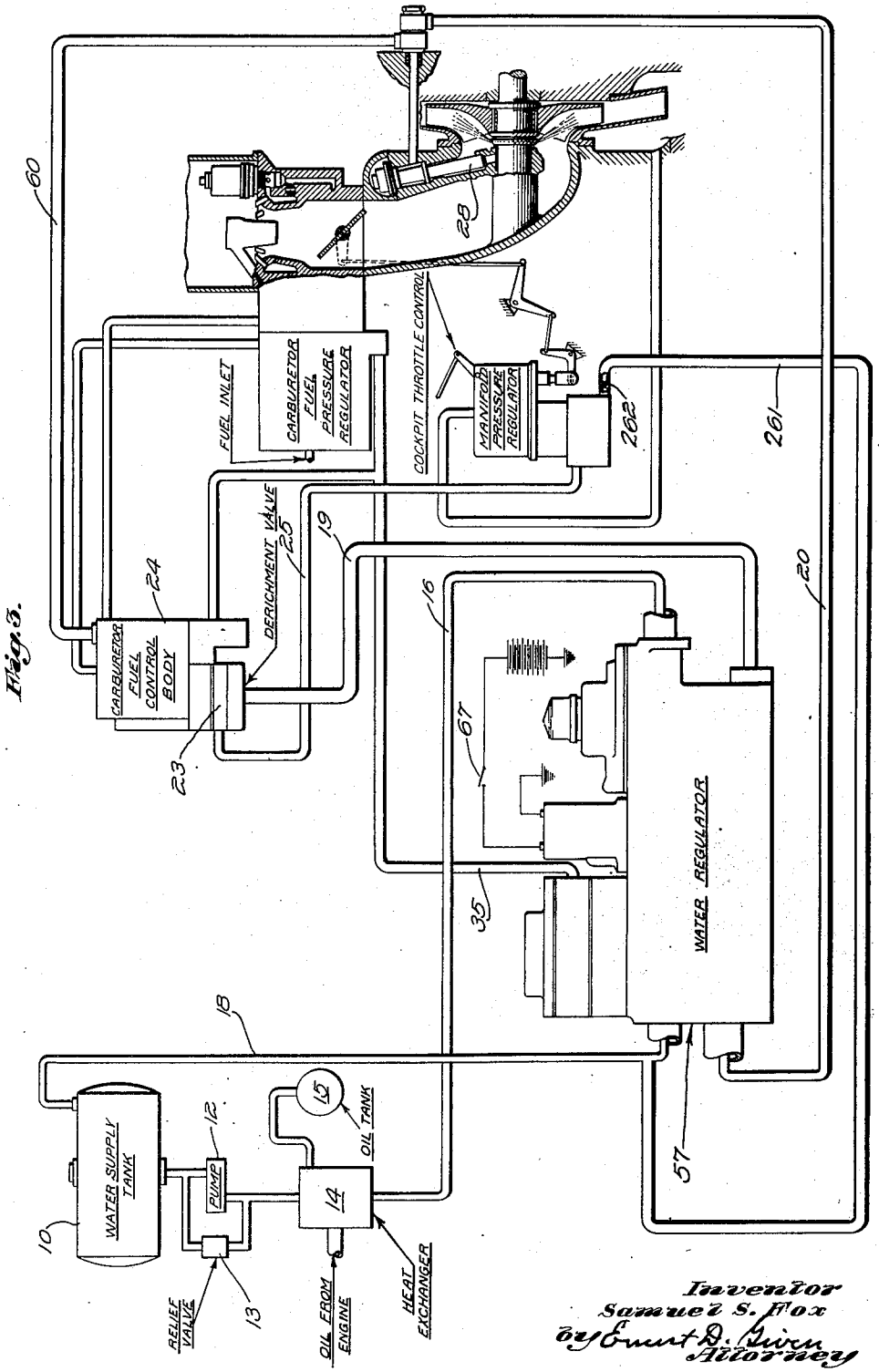


Fig. 3.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 4

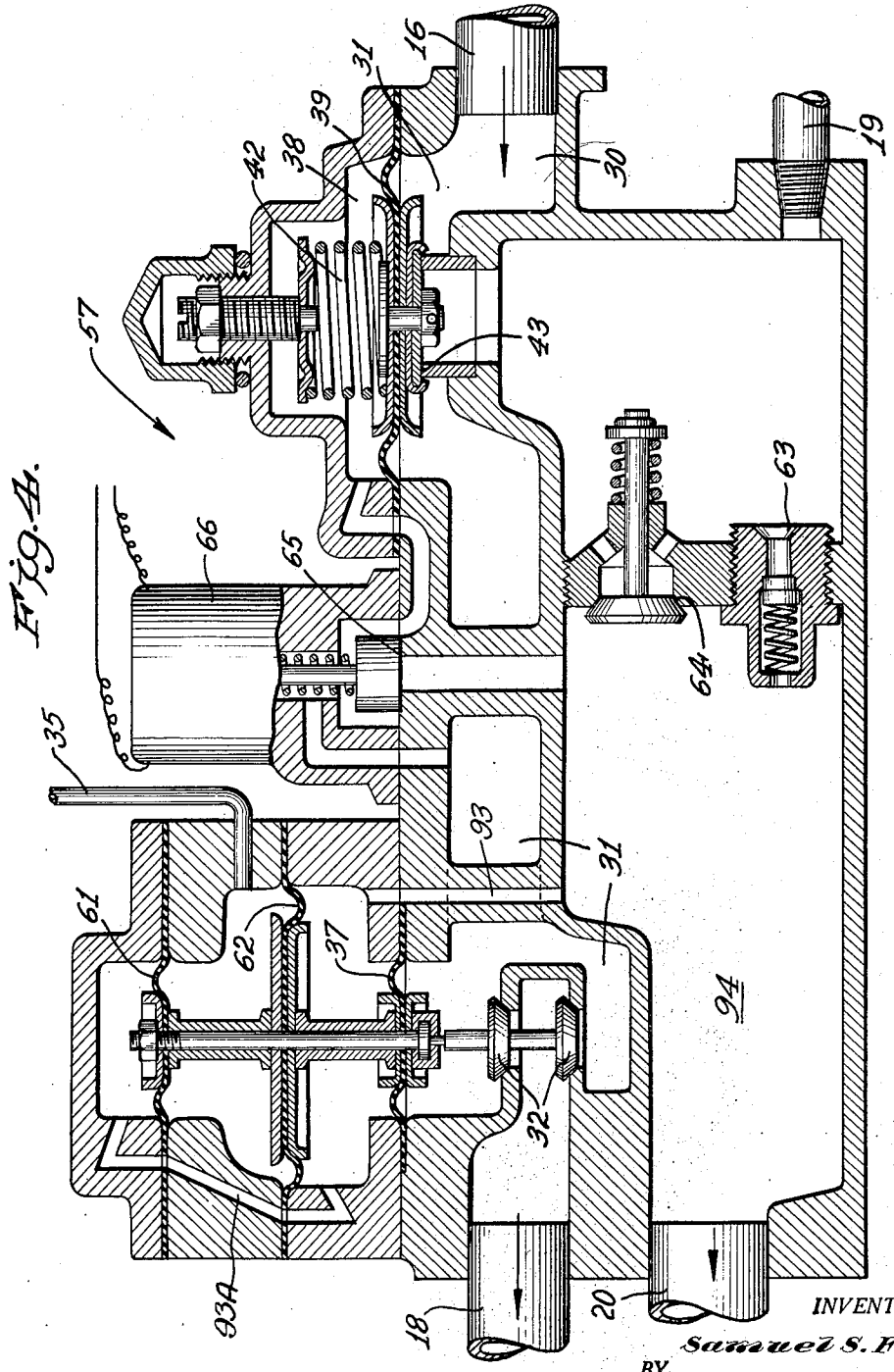


Fig. 4.

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VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 5

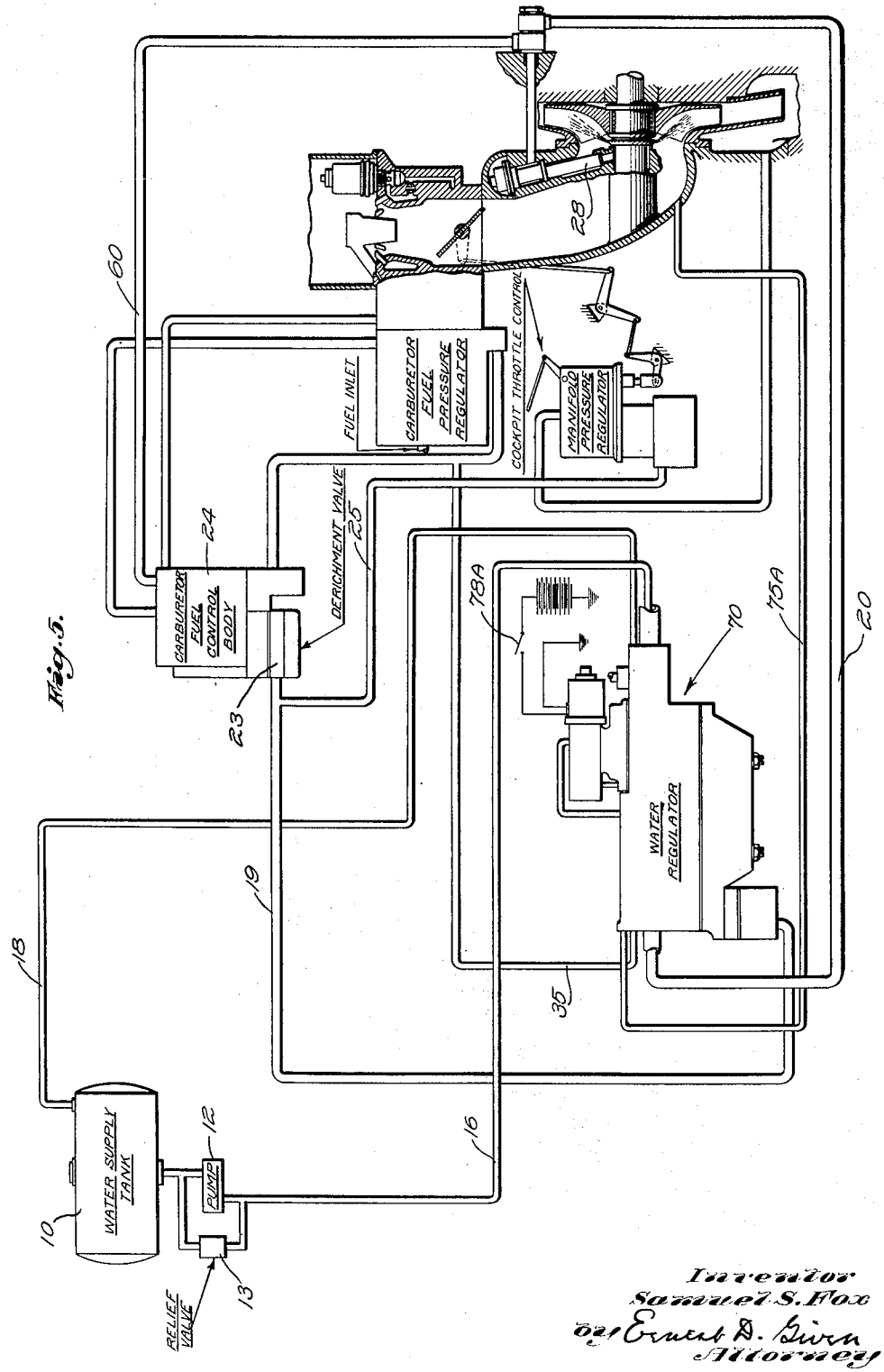


Fig. 5.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 6

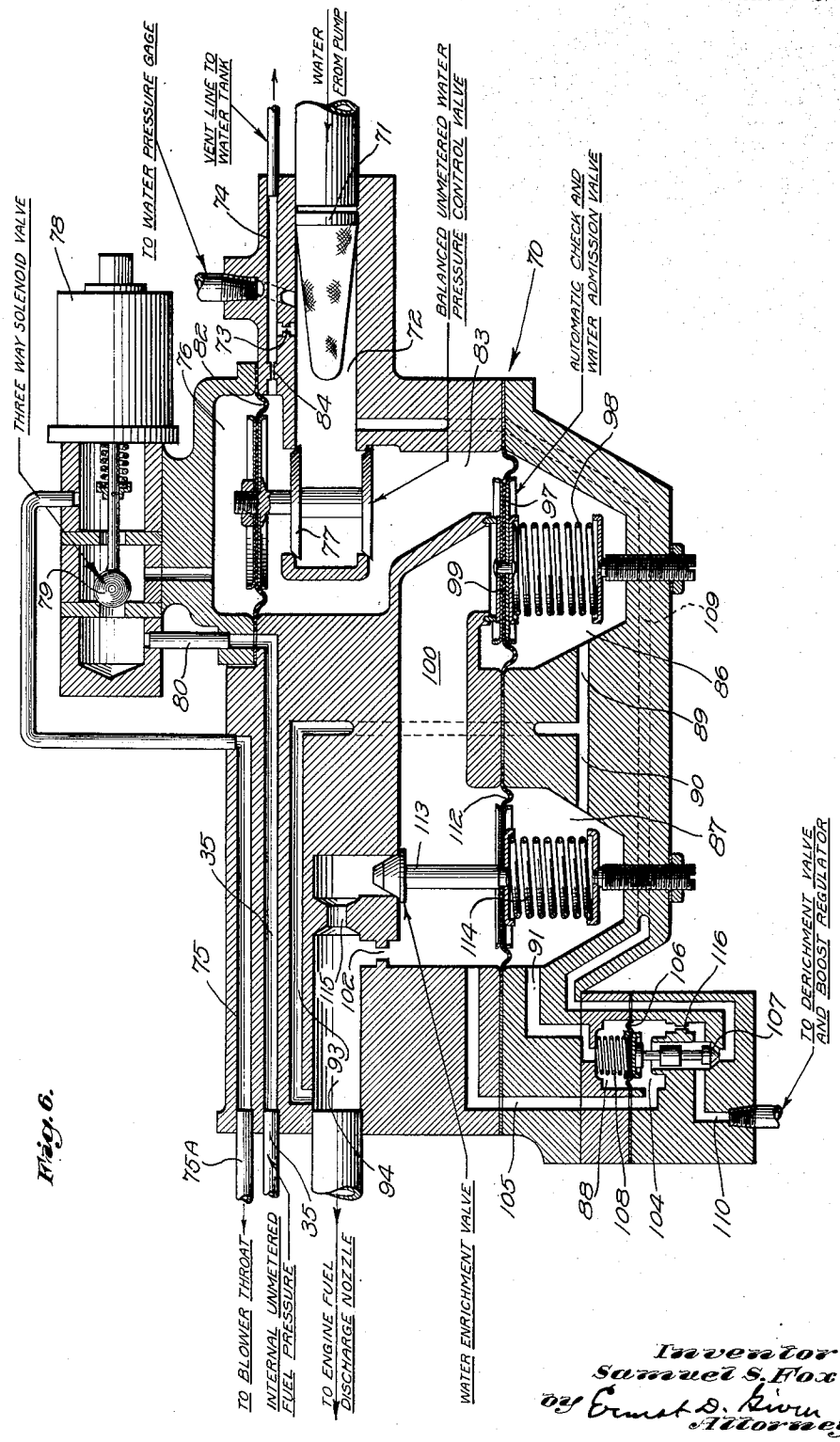


Fig. 6.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 7

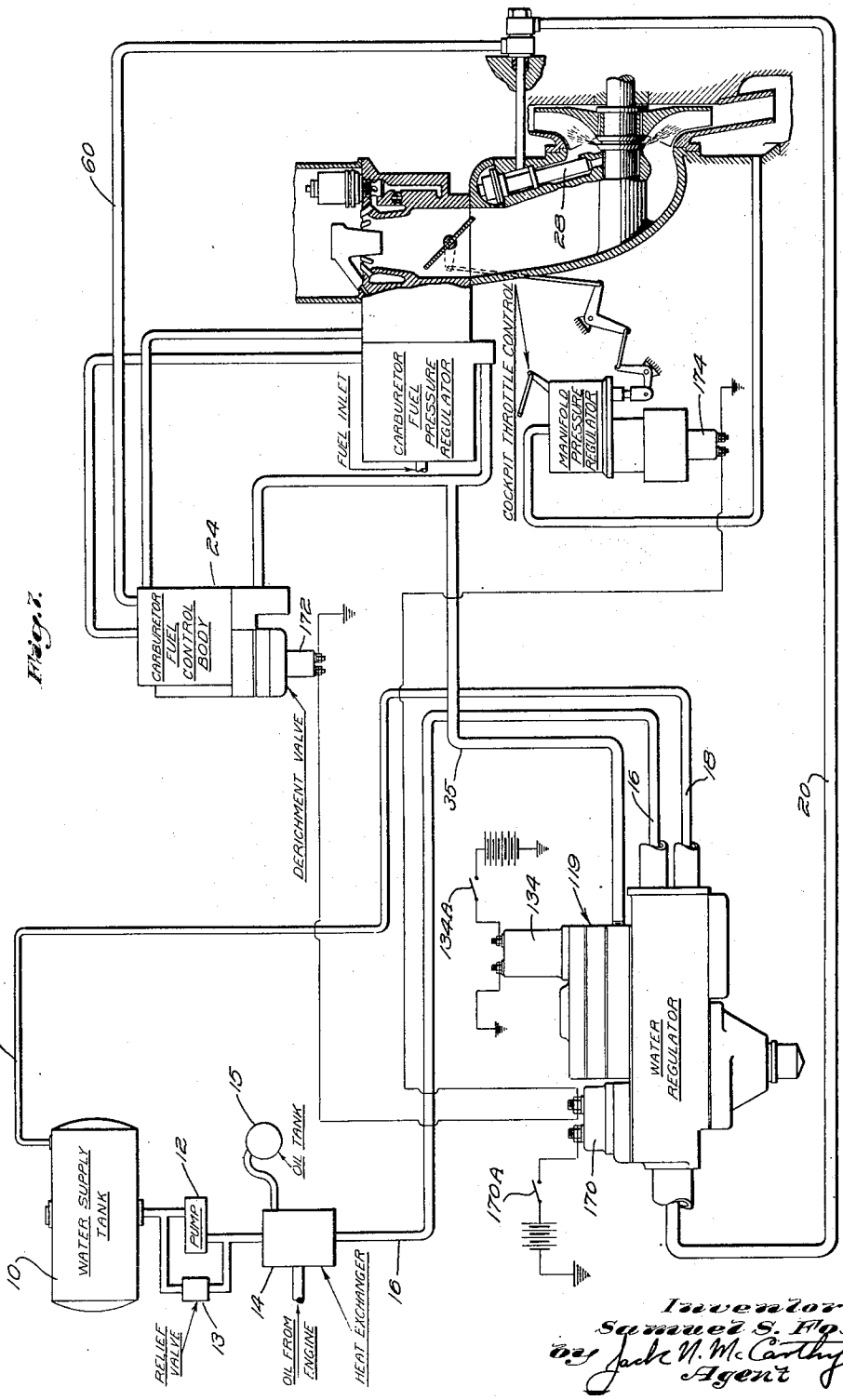


Fig. 7.

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June 15, 1954 S. S. FOX 2,681,048

VARIABLE WATER-AIR REGULATOR

Filed June 21, 1949 8 Sheets-Sheet 8

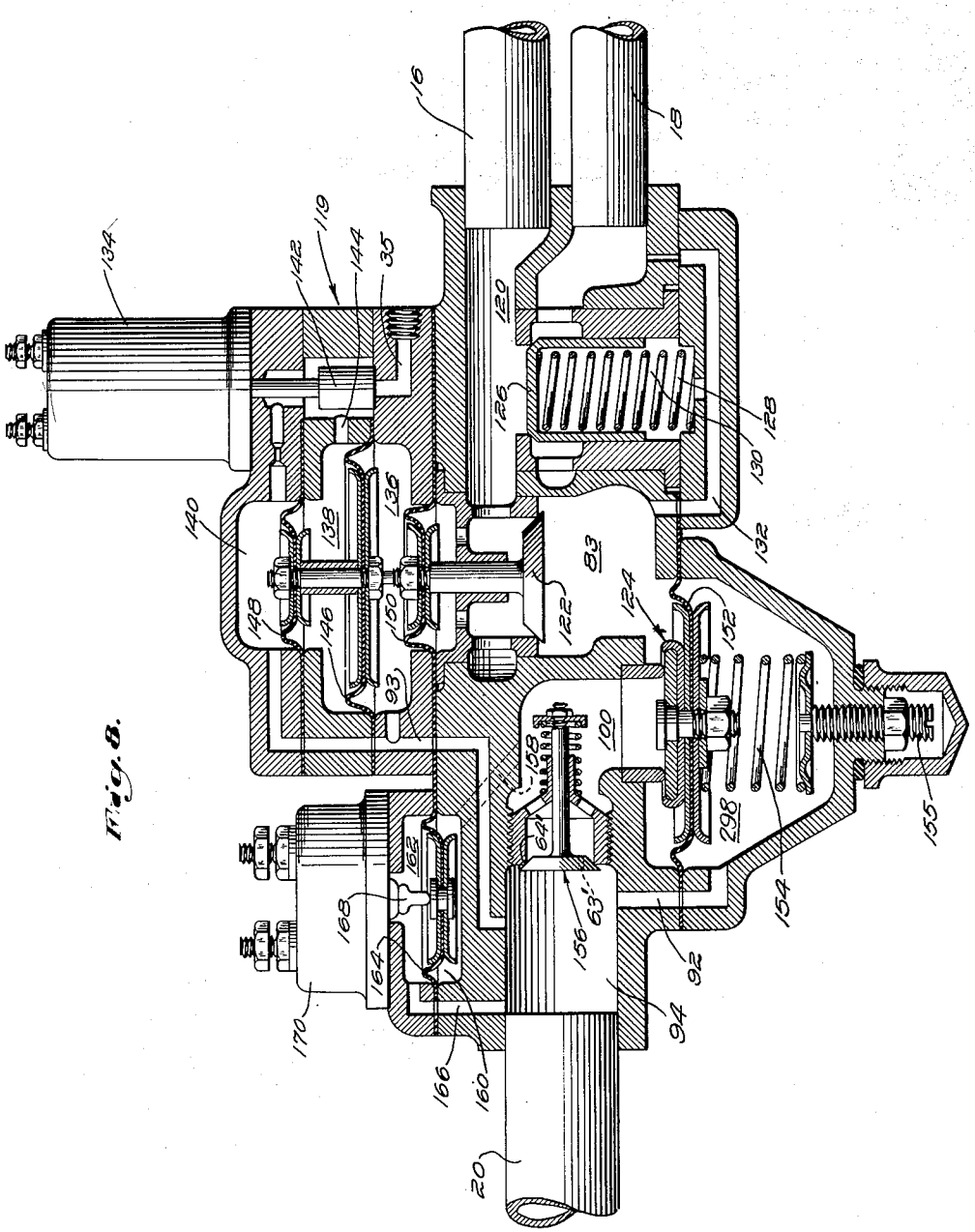


Fig. 8.

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Patented June 15, 1954

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UNITED STATES PATENT OFFICE

2,681,048

VARIABLE WATER-AIR REGULATOR

Samuel S. Fox, West Hartford, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware

Application June 21, 1949, Serial No. 100,355

24 Claims. (Cl. 123—25)

1

This invention relates to fluid injection systems for internal combustion engines, particularly aircraft engines, and has for its object to provide a novel and improved system of this type. This application is a continuation-in-part of my abandoned application Serial No. 673,431, filed May 31, 1946.

Another object of the invention is to provide a novel and efficient liquid metering injection regulator for an engine operating system of the above type.

Various other objects and advantages will be apparent as the nature of the invention is more fully disclosed.

An object and further feature of the invention resides in the provision of means for recirculating with or without heating anti-detonant such as water, water or alcohol or the like, through various parts of the system back to the supply tank of the system.

A further object of the present invention is to provide improved control of water-air ratio, in a variable water-air regulator.

A further object of the present invention resides in the provision of means to provide an instantaneous rather than a gradual fuel derichment in accordance with the metering pressure differential drop across the anti-detonant supply metering orifice.

A further object of the present invention resides in the provision of means for gradually admitting anti-detonant to the system instead of admitting it with a sudden surge as heretofore.

According to the present invention anti-detonant supply to the engine is automatically initiated or suppressed dependent on engine operating conditions (air flow to the engine or engine power) and to provide a lockout mechanism which may be manually controlled for locking the automatic valve in the closed position.

A further feature of the present invention resides in the provision of a manual means which is effective at all times to turn off anti-detonant flow to the engine irrespective of the automatic control.

Although the novel features which are characteristic of this invention are set forth more in detail in the claims appended hereto, the nature and scope of the invention may be better understood by referring to the following description, taken in connection with the accompanying drawings forming a part thereof, in which certain specific embodiments have been set forth for purposes of illustration.

2

In the drawings:

Fig. 1 is a diagrammatic lay-out of a water injection system for an internal combustion engine, embodying the present invention;

Fig. 1*a* is a diagrammatic view showing a modification for adapting the system of Fig. 1 to the use of oil;

Fig. 1*b* is a curve representing the water-air ratios that may be obtained at different intake airflows with any one of the three forms of regulator illustrated in the drawing;

Fig. 2 is a cross-sectional view of a water flow control regulator which is particularly adapted for use with the system of Fig. 1;

Fig. 3 is a diagrammatic view of a modified water injection system;

Fig. 4 is a cross-sectional view of a modified water flow control regulator employed in the system of Fig. 3;

Fig. 5 is a diagram illustrating another system embodying the invention;

Fig. 6 is a sectional view of the variable water-air regulator employed in the system of Fig. 5;

Fig. 7 is a diagram illustrating still another system embodying the invention; and

Fig. 8 is a sectional view of the variable water-air regulator employed in the system of Fig. 7.

In the following description certain specific terms are used for convenience in referring to the various details of the invention. These terms, however, are to be interpreted as broadly as the state of the art will permit.

The water injection system shown in Fig. 1 comprises a water tank 10 with a feed line to a pressure pump 12 which may have a relief valve 13 connected in parallel thereto.

The water is pumped through a heat exchanger 14 where it may be heated to prevent freezing by hot oil coming from the engine or going to the engine, the oil being supplied from the tank 15.

The water from heat exchanger 14 passes through line 16 into the variable water regulator 17, the construction of which is shown in detail in Fig. 2 and will be described later. In Fig. 1 the regulator 17 is shown as having three outlet lines numbered 18, 19 and 20, respectively. Of these, line 18 is the return conduit leading to water tank 10 for the purpose of bypassing back to the tank 10 all water not injected into the engine. Line 19 is connected to the derichment valve 23 on the carburetor 24. From derichment valve 23 liquid is conveyed by conduit 25 to a supercharger or turbo regulator reset mechanism 27. Line 20 is connected to the engine discharge nozzle 28 for injecting metered water into the

engine at a common point with line 60 which conveys metered fuel from carburetor 24 to discharge nozzle 28.

The derichment valve 23 and the supercharger regulator reset mechanism 27 may be of any suitable type and may be actuated either electrically, hydraulically or pneumatically. The derichment valve shown herein for purposes of illustration is a known device which may be similar to that shown in my Patent No. 2,521,002, while the manifold pressure regulator reset mechanism is a known device which may be basically the same in principle as that shown in Fig. 5 of Patent No. 2,553,145. In the instant case the valve 23 and the reset mechanism 27 are assumed to be actuated hydraulically with water.

The construction of the variable water-air regulator 17 is shown in detail in Fig. 2. By referring to Fig. 2 it will be seen that water from the heat exchanger passes through line 16 into the regulator 17, entering through passage 30, passing through chamber 31, and through pressure controlling valve 32 to by-pass chamber 33 which is connected by line 18 to the water tank 10 (Fig. 1). Valve 32 acts as a by-pass or relief valve to maintain the pressure in chamber 31 equal to the pressure in fuel chamber 34, which pressure is equal to the unmetered fuel pressure in the carburetor 24 to which the chamber 34 is connected by conduit 35. Diaphragm 37, which may be of the rubber-cloth type, provides a flexible seal between the fuel chamber 34 and the water by-pass or discharge chamber 33. Chamber 31 is separated from chamber 38 by a diaphragm 39 which may be of the rubber-cloth type or a metal "oil can" spring, the chamber 38 being connected to the line or conduit 20 leading to the engine discharge nozzle.

A combination check valve, variable metering orifice, and maximum flow fixed orifice 40 is mounted on diaphragm 39 and is actuated by said diaphragm. The pressure in chamber 38 is maintained at all times equal to the engine fuel discharge nozzle pressure by means of the direct connection 20 to the discharge nozzle. The pressure differential between chambers 31 and 38 is therefore equal to the carburetor fuel metering differential. The tension of spring 42 holds the check valve 40 on its seat 43 until the differential between chambers 31 and 38 reaches a predetermined value, at which time the force exerted on the valve assembly 40 by diaphragm 39 will cause the valve to lift off the seat 43 thereby admitting water to chamber 44 at a pressure equal to chamber 31.

When valve 40 is sealed on its seat 43 the pressure in chamber 44 is equal to the pressure in chamber 38. The resultant pressure increase in chamber 44 when the valve 40 opens increases the effective area of the diaphragm 39, thereby increasing the resultant force acting against spring 42 and causing the valve 40 to open an additional predetermined amount. Water will then flow through the variable metering orifice formed by the tapered section of valve 40 from chamber 44 to chamber 49 and thence through the fixed metering orifice in valve 40 to chamber 38 and into line 20 to the engine discharge nozzle. The pressure increase in chamber 44 is transmitted to chamber 45 which is sealed from chamber 46 by diaphragm 47. The pressure in chamber 46 at all times remains equal to the pressure in chamber 38. Hence, a pressure differential will be built up between chambers 45 and 46, causing the diaphragm 47 to move

against the stem of valve 48 thereby opening valve 48 against the tension of spring 50 and admitting hydraulic pressure by way of pipe 52 into chamber 53 which is connected by line 19 to the derichment valve 23 and power control reset mechanism 27 of Fig. 1. When valve 48 is closed, the pressure in chamber 53 is vented to the hydraulic tank or drain pressure through pipe 54; and when valve 48 is open, the pressure in chamber 53, because of the restriction 55 in the passage to pipe 54, increases to main hydraulic feed pressure. This pressure change is the actuating pressure change in the derichment valve 23 and the power control reset mechanism 27 of Fig. 1.

In Fig. 2, when the determined differential is reached between the water inlet pressure (i. e., in chamber 31) which is maintained at all times equal to unmetered fuel pressure, and metered water pressure (i. e., in chamber 38) which is maintained at all times equal to metered fuel pressure, water injection will occur automatically. Water injection is thus initiated automatically at a predetermined fuel metering differential and because of the fixed relation of fuel metering differential to airflow through the carburetor, also at a predetermined airflow to the engine. Conversely, the water is also turned off automatically. No manual operation is required for actuation of water injection to the "on" or "off" condition.

The apparatus of Fig. 2 has been generally described as being actuated hydraulically. The connections shown in Fig. 1 illustrate hydraulic actuation by water. The system shown in Fig. 1 may be modified, as illustrated in Fig. 1*a*, to include an oil pump 56 to provide hydraulic actuation by oil. A similar mechanism can also be operated pneumatically.

Fig. 3 illustrates a modified form of water injection system which employs the modified variable water-air regulator 57 of Fig. 4. For the sake of clarity the parts in Figs. 3 and 4 which correspond with similar parts in Figs. 1 and 2 are designated by similar reference numerals.

In Fig. 3 the regulator 57 is shown as having five inlet and outlet lines, 16, 18, 19, 20 and 35, corresponding with the similar lines in Fig. 1. In Fig. 3, furthermore, liquid is conveyed by line 261 containing restrictions 262 to the return conduit 18 leading to the water tank 10 to provide circulation of heated water through line 19, derichment valve 23, line 25, and supercharger or turbo regulator reset mechanism 27 when water injection is in use.

In Fig. 4, two additional diaphragms 61 and 62 cooperate with the diaphragm 37 to actuate the water inlet pressure-controlling valve 32 so that the water inlet pressure and consequent water metering differential will be greater at all times than the fuel metering differential by a constant ratio. Metered water pressure from chamber 94 (which at all times is equal to metered fuel pressure because of the interconnection of lines 20 and 60) is admitted by passages 93 and 93A to the chambers between diaphragms 37 and 62 and above diaphragm 61. Unmetered fuel pressure is admitted through line 35 to the chamber between diaphragms 62 and 61. For a more complete explanation of the mode of operation of valve 32 by diaphragms 37, 61 and 62, reference is made to Fox and Palmer Patent No. 2,399,480, issued April 30, 1946.

In Fig. 4, furthermore, the fixed and variable metering orifices 63 and 64 are separated from the check valve and diaphragm 39. A three-way

solenoid valve 65 actuated by solenoid 66 is provided to change the pressure on the side of check valve diaphragm 39 opposite from the valve seat 43 from water inlet pressure to metered water pressure, and vice versa, thereby providing an alternate electrical control to lock out the check valve. The solenoid is actuated by a manual switch 67 in Fig. 3. It will thus be seen that the system of Figs. 3 and 4 provides a manual (switch 67) "lock out" control superimposed on the automatic water admission (check valve) control. The switch 67 is closed to lift the solenoid valve to its upper seat, against the force of the spring, to unlock the automatic feed of water to the engine by placing chamber 38 in communication with chamber 94. The opening of said switch at any time stops the flow of water to the engine by permitting the spring to move the valve against its lower seat, thereby placing chamber 38 in communication with chamber 31. If the switch 67 is left closed and the airplane descends to a point where water injection is no longer needed, the automatic shutoff previously described will take place. The pilot can always override the automatic control to shut the water off, but not to turn the water on. The pilot can unlock the regulator manually by closing switch 66 and obtaining automatic operation.

Figs. 5 and 6 illustrate a modification of the invention, including a variable water-air regulator incorporating a hydraulic reset for the carburetor derichment valve and using blower throat suction to keep the pressure regulating valve closed when the water regulator is not operating.

In Figs. 5 and 6, water from the pump 12 enters the regulator 70 under pressure through the strainer 71 into chamber 72. Air, water vapor and some water are returned to the supply tank through bleed 73 and vent passage 74 connected to line 18. Blower throat suction is transmitted through internal passages 75A, 75 to chamber 76. The pressure regulating valve 77 attempts to maintain pressure in chamber 83 equal to pressure in chamber 76 and consequently the valve 77 remains closed or nearly closed. When the solenoid 78 is energized by manual switch 78A, passage 75 is closed and passage 80 is opened by valve 79 and unmetered fuel pressure is transmitted through internal passages 35 and 80 to chamber 76. The diaphragm 82 then positions valve 77 to make pressure in chamber 83 equal to unmetered fuel pressure in chamber 76. Any air or water vapor, and some water, are returned from chamber 83 through bleed 84 and passage 74 to line 18 (Fig. 5) and thence to the supply tank 10. The pressures in chambers 86, 87 and 88 are at all times all equal to the metered fuel pressure since they are all interconnected by passages 89, 90 and 91, and vented through passage 93 to chamber 94 which leads directly through line 20 (Fig. 5) to the fuel discharge nozzle 28. The pressure in chamber 83 which is equal to unmetered fuel pressure and the pressure in chamber 86 which is equal to metered fuel pressure create a pressure differential across diaphragm 97 equal to the carburetor fuel metering differential. This pressure differential between chambers 83 and 86 produces a force which at a predetermined value overcomes the force of the spring 98 which is holding the check valve 99 closed. The check valve 99 opens and allows water to flow into chamber 100. The metering orifice 102 restricts the flow from chamber 100 to chamber 94 causing the pressure in chamber 100 to increase to a pressure equal to that in chamber 83. As the pressure in chamber 100 increases to be equal to the pressure in chamber 83, the effective area of diaphragm 97 increases, opening check valve 99 further thus producing a "snap action" of valve 99. Since the water metering differential, which is at all times equal to the carburetor fuel metering differential, is imposed across the metering orifice 102 the water will flow through the orifice in predetermined proportions to fuel flow and thus also to mass airflow from chamber 100 to chamber 94 and then to the engine discharge nozzle 28 through line 20 (Fig. 5).

The pressure in chamber 104 is equal to the pressure in chamber 100 as these chambers are connected by passage 105. Hence the water metering differential is also imposed across diaphragm 106, which opens valve 107 when the predetermined force of spring 108 is overcome. When valve 107 opens, it allows water inlet pressure from chamber 72 and passage 109 to pass through passage 110 and conduit 19 (Fig. 5) to the derichment valve 23 on the carburetor 24 and to the reset mechanism 27 on the manifold pressure regulator, if one is used. This reduces the F/A ratio delivered to the engine to a best power value and resets the manifold pressure to a predetermined value. As the water metering head differential increases, the increasing pressure differential between chambers 100 and 87, acting on diaphragm 112, opens the enrichment valve 113 against the force of spring 114. Water is then also metered by the enrichment valve 113 to chamber 94 and to the discharge nozzle 28 of the engine. Orifice 115 starts to meter the water when the flow through the enrichment valve 113 is sufficient for the orifice 115 to restrict the flow. The contour of the valve 113 and the rate of the spring 114 determined the rate of change of flow with changes in water metering differential between chambers 100 and 94 which also equals the pressure differential between chambers 100 and 87 and which is at all times equal to the carburetor fuel metering differential. When the unmetered fuel pressure in chamber 76 decreases, the unmetered water pressure in chamber 83 decreases, causing the pressure differential across diaphragm 97 to decrease. At a predetermined value of this pressure differential, check valve 99 closes, shutting off the flow of water through the check valve 99 and hence through the metering orifice 102 and the enrichment valve 113. The flow of water can also be stopped by de-energizing solenoid 78 allowing valve 79 to close the unmetered fuel passage 80 to chamber 76 and opening the blower throat suction passage 75 to chamber 76. This creates a pressure differential across diaphragm 82 in the direction to close pressure regulating valve 77, decreasing the pressure in chamber 83 causing check valve 99 to close shutting off flow of water as described above. The decrease in pressure in chamber 100 caused by the closing of check valve 99 allows enrichment valve 113 to close. As the pressure in chamber 100 becomes equal to the pressure in chamber 94 the pressure in chamber 104 becomes equal to the pressure in chamber 88. Hence spring 108 closes valve 107 and the water is allowed to bleed out of passage 110 through bleed 116 relieving the pressure on the derichment valve 23 on carburetor 24 and on the reset mechanism 27 on the manifold pressure regulator, returning them both to normal.

Through the action of the three-way solenoid valve 79, the water flow may be started or stopped manually by energizing or de-energizing the sole-

noid 78 at a point at which the fuel and hence the water metering differential is sufficient to open the check valve 99. If the solenoid 78 is energized at a point below which the check valve 99 opens, water will not start to flow until the metering differential reaches the predetermined value and opens the check valve 99. Likewise the water flow will stop when fuel and hence the water metering differential drops below the predetermined value mentioned above and closes the check valve 99, provided that the solenoid 78 has not been de-energized. If the solenoid 78 is de-energized above the point at which check valve 99 opens, water will cease to flow.

Figs. 7 and 8 illustrate a modification of the invention including a variable water-air regulator incorporating an electric device for operating the carburetor derichment valve and supercharger regulator reset.

In Figs. 7 and 8, water from the pump passes through the heat exchanger 14 and enters the regulator 119 at chamber 120. All water not flowing to the engine through the pressure regulating valve 122 and check valve 124 returns through the pressure controlling valve 126 into the water return duct 18 to the supply tank. The pressure in chamber 120 is maintained at a value equal to the force of the spring 128 divided by the area of valve 126 plus the pressure in chamber 130. The pressure in chamber 130 is at all times equal to the pressure in chamber 83, inasmuch as the two chambers are connected by passage 132. In the "water off" position of the solenoid 134, when the solenoid is not energized, the pressure in chamber 83 is equal to the pressure in chamber 94, because the pressures in chambers 136, 138 and 140 are equal to the pressure in chamber 94, or the discharge nozzle pressure. The chambers 136 and 140 are connected to chamber 94 by the passage 93 and the pressure in chamber 138 is made equal to the pressure in chambers 136 and 140 by the solenoid valve 142 closing off passage 35 which is connected to the unmetered fuel pressure from the carburetor and opening passage 144 to chamber 138.

When the solenoid 134 is energized by manual switch 134A, Fig. 7, passage 144 is closed off from chamber 140 and passage 35 is opened by valve 142 and unmetered fuel pressure is transmitted to chamber 138. The fuel metering pressure differential is then imposed across diaphragm 146 which creates a force on the stem of the pressure regulating valve 122 tending to open the valve. As valve 122 opens, the pressure in chamber 83 is increased, which in turn increases the pressure in chamber 130 tending to close the pressure controlling valve 126 which action increases the pressure in chamber 120 until the pressure controlling and pressure regulating valve system reaches a stabilized condition. This stabilized condition occurs when the pressure in chamber 83 is sufficiently greater than the discharge pressure in chamber 140 to produce a force on the stem of valve 122 which is equal and opposite to the force produced by the carburetor fuel pressure differential between chambers 138 and 136. The areas of diaphragm 148 and 150 are equal to the area of valve 122 and are smaller than the area of diaphragm 146 to the extent that the pressure differential existing between chambers 83 and 140 will be greater than the pressure differential existing between chambers 138 and 136 by a constant predetermined ratio. The pressure built up in this manner in chamber 83 will create a pressure differential across diaphragm 152 since the pressure in chamber 298 on the opposite side of diaphragm 152 is maintained at all times equal to the engine discharge nozzle pressure in chamber 94 by connecting passage 92. This pressure differential between chambers 83 and 298, separated by diaphragm 152, produces a force which will overpower the force of the spring 154, tending to hold the check valve 124 in the closed position, thereby opening the check valve 124 and permitting water to flow into chamber 100.

As the pressure in chamber 100 increases to be equal to the pressure in chamber 83, the effective area of diaphragm 152 increases, opening check valve 124 further, thus producing a "snap action" of valve 124. The force exerted by spring 154 upon check valve 124 can be varied by adjusting screw 155. The combination fixed and variable metering orifice 156 comprising a valve 84' with an opening 63' presents a restriction to the flow of water from chamber 100 to chamber 94, thereby causing the pressure in chamber 100 to increase to a pressure equal to that in chamber 83 when check valve 124 is opened. Hence, the water metering differential which is at all times a constant ratio of the fuel metering differential is imposed across the metering orifice 156 and water will flow through the orifice in predetermined proportions from chamber 100 to chamber 94 and thence to the engine discharge nozzle.

The pressure increase in chamber 100, from a pressure equal to that maintained in chamber 94 by the engine discharge nozzle to a pressure equal to the unmetered water pressure established in chamber 83, is transmitted through passage 158 to chamber 160. Chamber 160 is separated from chamber 162 by a diaphragm 164. The pressure in chamber 162 is maintained equal at all times to the pressure in chamber 94 since it is connected thereto by passage 165. Hence, the water metering differential will be imposed across diaphragm 164 which will move the diaphragm against the electrical switch actuating pin 168, thereby closing the contacts in the electrical switch 170. This closing of the electrical switch contacts will permit electrical current to activate solenoids 172 and 174 thereby operating, respectively, the derichment valve on the carburetor and the supercharger or turbo regulator reset mechanism. This leans out the F/A ratio delivered by the carburetor to the engine and resets the manifold pressure from a normal power value to an emergency power value. A manual switch 170A is provided to open the circuit whenever necessary.

When the solenoid 134 is de-energized and solenoid valve 142 moves to close off passage 35, the reverse sequency of pressure changes within the various chambers will occur causing the pressure in chamber 83 to decrease until it is again equal to the pressure in chamber 140 which will close the check valve 124 shutting off the flow of water through metering orifice 156 and causing the pressure in chamber 100 to decrease to a value equal to that in chamber 94. This decrease in pressure in chamber 100 will consequently equalize the pressure in chambers 160 and 162 permitting the contact points in the electrical switch 170 to open. The opening of the contacts in the electrical switch 170 will therefore open the electrical connection to the derichment valve and supercharger or turbo regulator reset mechanism solenoids returning the fuel mixture strength and the manifold pressure to normal power values.

The same variable water-air regulator system shown in Fig. 8 could be operated without the solenoid valve 142 by blanking off passage 144 which would then produce a regulator automatically providing a flow of water to the engine when the carburetor metering differential reached a predetermined value. Hydraulic operation of the derichment valve and the supercharger regulator could be obtained by removal of the electrical switch 170 and the diaphragm 164, and by plugging passage 166. In this case, passage 158 would be connected directly by pressure transfer lines to the derichment valve and supercharger regulator reset mechanism.

As a variation, chambers 136 and 138 in Fig. 8 could be subjected to the compensated air pressure metering differential as obtained from the carburetor air Venturi system instead of being subjected to the fuel head metering differential as described above.

Referring to Fig. 1b, which is illustrative of a preferred metering schedule, the W/A ratio increases rapidly along section A of the curve during the initial opening of the check valve (43 in Fig. 2 and Fig. 4, 99 in Fig. 6 and 124 in Fig. 8). Because of the "snap-action" operation of the check valve, as previously described, the slope of section A of the curve is relatively steep. The W/A ratio then remains relatively constant as shown in section B of the curve at a value determined by the area of the fixed metering orifices (63 in Fig. 4 and Fig. 8, 102 in Fig. 6, and the annular area between the cylindrical exterior wall of valve 40 and the cylindrical interior wall of chamber 49 in Fig. 2). Then at a predetermined water metering differential the W/A ratio begins to increase as shown in section C of the curve (this action is effected in Fig. 4 and Fig. 8 by variable orifice 64, in Fig. 6 by variable orifice 113, and in Fig. 2 by further opening of valve 40 so that the tapered metering portion of the valve is gradually moved past the edge of the cylindrical wall of chamber 49). At maximum airflow the W/A ratio again becomes relatively constant as shown in section D of the curve at a value determined by the limiting orifice (115 in Fig. 6, the maximum opening of orifice 64 in Fig. 4 and Fig. 8, and the orifice in valve 40 in Fig. 2).

Although certain specific embodiments have been shown and described herein for purposes of illustration, it will be evident to those skilled in the art that the invention is capable of various modifications and adaptations within the scope of the appended claims.

I claim:

1. A liquid injection system for supplying metered liquid to an internal combustion engine, comprising a source of liquid, a liquid flow control regulator connected to said source having a metering valve controlling the flow of liquid to said engine, a diaphragm-actuated valve in said regulator controlling the flow of liquid to said metering valve, a pressure control valve located between said diaphragm-actuated valve and said source of liquid maintaining the water pressure acting on said diaphragm-actuated valve at a value dependent on a reference pressure, and means for returning unmetered liquid from said regulator to said source.

2. A liquid injection system for supplying metered liquid to the discharge nozzle of an internal combustion engine, comprising a liquid supply tank, a pressure pump connected thereto, a liquid flow control regulator connected to said pump having a metering valve controlling the flow of liquid to said discharge nozzle, a diaphragm-actuated valve in said regulator controlling the flow of liquid to said metering valve, a pressure control valve located between said diaphragm-actuated valve and said source of liquid maintaining the water pressure acting on said diaphragm-actuated valve at a value dependent on a reference pressure, and means for returning unmetered liquid from said regulator to said supply tank.

3. A liquid injection system for supplying metered liquid to the discharge nozzle of an internal combustion engine, comprising a liquid supply tank, a pressure pump connected thereto, a liquid flow control regulator having a metering valve controlling the flow of liquid to said discharge nozzle, a diaphragm-actuated valve in said regulator controlling the flow of liquid to said metering valve, means in said regulator controlled by the operation of said engine for operating said diaphragm-actuated valve to discharge measured amounts of liquid through said metering valve, a derichment valve and a regulator reset mechanism associated with said engine, means responsive to the pressure differential actuating said diaphragm-actuated valve for operating said derichment valve and said regulator reset mechanism, and means for circulating liquid from said regulator through said derichment valve and said regulator reset mechanism.

4. A liquid injection system for supplying metered liquid to the discharge nozzle of an internal combustion engine, comprising a liquid supply tank, a pressure pump connected thereto, a liquid flow control regulator having a metering valve controlling the flow of liquid to said discharge nozzle, a diaphragm-actuated valve in said regulator controlling the flow of liquid to said metering valve, means in said regulator controlled by the operation of said engine for operating said diaphragm-actuated valve to discharge measured amounts of liquid through said metering valve, a derichment valve and a regulator reset mechanism associated with said engine, means responsive to the pressure differential actuating said diaphragm-actuated valve for operating said derichment valve and said regulator reset mechanism, means for circulating liquid from said regulator through said derichment valve and said regulator reset mechanism, and means for by-passing unmetered liquid from said regulator to said supply tank.

5. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, an outlet chamber for connection to said discharge nozzle, a liquid return chamber for discharging unmetered liquid from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a pressure chamber in said regulator controlled by the operation of said engine, means separating said return chamber and said pressure chamber and actuating said pressure control valve for controlling the flow of unmetered liquid to said return chamber, and a check valve between said inlet and outlet chambers and controlling the flow of liquid therebetween.

6. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, an outlet chamber for connection to said discharge nozzle, a liquid return chamber

for discharging unmetered liquid from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a fuel chamber for connection to the fuel pressure system of said engine, means separating said return chamber and said fuel chamber and actuating said pressure control valve for controlling the flow of unmetered liquid to said return chamber, a check valve between said inlet and outlet chambers and controlling the flow of liquid therebetween, and means controlling the pressure differential in said inlet and outlet chambers for actuating said valve.

7. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, an outlet chamber for connection to said discharge nozzle, a flexible diaphragm separating said inlet and outlet chambers, a liquid return chamber for discharging unmetered liquid from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a pressure chamber in said regulator controlled by the operation of said engine, a flexible diaphragm separating said return chamber and said pressure chamber and actuating said pressure control valve for controlling the flow of unmetered liquid to said return chamber, and a check valve carried by said first-mentioned flexible diaphragm between said inlet and outlet chambers and controlling the flow of liquid from said inlet chamber to said outlet chamber.

8. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, an outlet chamber for connection to said discharge nozzle, a flexible diaphragm separating said inlet and outlet chambers, a water return chamber for discharging unmetered water from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a fuel chamber for connection to the fuel pressure system of said engine, a flexible diaphragm separating said return chamber and said fuel chamber and actuating said pressure control valve for controlling the flow of unmetered water to said return chamber, and a check valve carried by said first-mentioned flexible diaphragm between said inlet and outlet chambers and controlling the flow of water from said inlet chamber to said outlet chamber.

9. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, an outlet chamber for connection to said discharge nozzle, a flexible diaphragm separating said inlet and outlet chambers, a water return chamber for discharging unmetered water from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a fuel chamber for connection to the fuel pressure system of said engine, a flexible diaphragm separating said return chamber and said fuel chamber and actuating said pressure control valve for controlling the flow of unmetered water to said return chamber, a check valve carried by said first-mentioned flexible diaphragm between said inlet and outlet chambers and controlling the flow of water from said inlet chamber to said outlet chamber, and means controlling the pressure differential in said inlet and outlet chambers for actuating said diaphragms.

10. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, an outlet chamber for connection to said discharge nozzle, a flexible diaphragm separating said inlet and outlet chambers, a water return chamber for discharging unmetered water from said regulator, a pressure controlling valve between said inlet chamber and said return chamber, a fuel chamber for connection to the fuel pressure system of said engine, a flexible diaphragm separating said return chamber and said fuel chamber and actuating said pressure control valve for controlling the flow of unmetered water to said return chamber, a check valve carried by said first-mentioned flexible diaphragm between said inlet and outlet chambers and controlling the flow of water from said inlet chamber to said outlet chamber, means including a valve in said regulator for controlling the flow of oil therethrough, and means controlled by the pressure differential in said inlet and outlet chambers for actuating said oil control valve.

11. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, means in said chamber for by-passing unmetered liquid to a return passage, a liquid outlet chamber for connection to said discharge nozzle, a metering chamber and metering means therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber operable by the pressure differential therein, a regulating valve between said pressure chamber and said inlet chamber, and means for actuating said regulating valve to connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said liquid outlet chamber.

12. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, a pressure controlling valve in said chamber for by-passing unmetered liquid to a return passage, a liquid outlet chamber for connection to said discharge nozzle, a metering chamber and a metering valve therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by the pressure differential therebetween, a regulating valve between said pressure chamber and said inlet chamber, and means for actuating said regulating valve to connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said liquid outlet chamber.

13. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, a pressure controlling valve in said chamber for by-passing unmetered liquid to a return passage, a liquid outlet chamber for connection to said discharge nozzle, a metering chamber and a metering valve therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure

chamber and the other side thereof open to said outlet chamber so as to be operable by the pressure differential therebetween, a regulating valve between said pressure chamber and said inlet chamber, a plurality of flexible diaphragms supporting said regulating valve and forming a plurality of chambers connected to said outlet chamber to maintain them at the same pressure as said outlet chamber, and means for controlling the pressure acting on certain of said diaphragm chambers to actuate said regulating valve and thereby connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said liquid outlet chamber.

14. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, a pressure controlling valve in said chamber for by-passing unmetered water to a return passage, a water outlet chamber for connection to said discharge nozzle, a metering chamber and a combination fixed and variable orificed metering valve therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by the pressure differential therebetween, a regulating valve between said pressure chamber and said water inlet chamber, a plurality of flexible diaphragms supporting said regulating valve and forming a plurality of chambers connected to said outlet chamber to maintain them at the same pressure as said outlet chamber, and means for controlling the pressure acting on certain of said diaphragm chambers to actuate said regulating valve and thereby connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said water outlet chamber.

15. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, a pressure controlling valve in said chamber for by-passing unmetered water to a return passage, a water outlet chamber for connection to said discharge nozzle, a metering chamber and combination fixed and variable orificed metering valve therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by the pressure differential therebetween, a regulating valve between said pressure chamber and said water inlet chamber, a plurality of flexible diaphragms supporting said regulating valve and forming a plurality of chambers connected to said outlet chamber to maintain them at the same pressure as said outlet chamber, and means including a solenoid valve for controlling the flow of engine fuel under pressure to certain of said diaphragm chambers to actuate said regulating valve and thereby connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said water outlet chamber.

16. A variable water flow control regulator for injecting water into the discharge nozzle of an internal combustion engine, comprising a water inlet chamber, a pressure controlling valve in said chamber for by-passing unmetered water to a return passage, a water outlet chamber for connection to said discharge nozzle, a metering chamber and a combination fixed and variable orificed metering valve therein for connecting said metering chamber to said outlet chamber, a pressure chamber connected to said return passage, a check valve between said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by the pressure differential therebetween, a regulating valve between said pressure chamber and said water inlet chamber, a plurality of flexible diaphragms supporting said regulating valve and forming a plurality of chambers connected to said outlet chamber to maintain them at the same pressure as said outlet chamber, means including a solenoid valve for controlling the flow of engine fuel under pressure to certain of said diaphragm chambers to actuate said regulating valve and thereby connect said inlet chamber to said pressure chamber and thence through said check valve and said metering chamber to said water outlet chamber, an electrical switch in said regulator, and means including a flexible diaphragm subject to variations in pressure in said metering chamber for operating said electrical switch.

17. An anti-detonant supply regulator for internal combustion engines, including a combination, a pressure metering orifice to meter the flow of anti-detonant to the engine, a fuel derichment control means, and means responsive to the pressure differential across the aforesaid orifice for instantaneously operating said fuel derichment means upon the attainment of a predetermined differential pressure.

18. An anti-detonant supply regulator for an internal combustion engine, comprising in combination, control means for causing derichment of a fuel mixture, means for controlling the supply of anti-detonant to the engine, said last mentioned means including a metering orifice, and means for controlling said derichment control means in accordance with the pressure differential across said metering orifice.

19. An anti-detonant regulator for internal combustion engines, including in combination, means for admitting anti-detonant supply to the engine in accordance with an air flow condition thereto, and further automatic means for progressively varying the supply of anti-detonant relatively to the air supply as said air flow increases, said first named means including a pressure control valve and a diaphragm-actuated valve, said pressure control valve maintaining the anti-detonant pressure acting on said diaphragm-actuated valve at a value dependent on an air flow condition.

20. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, means in said chamber for bleeding air, liquid vapor, or liquid to a return passage, a pressure chamber connected to a return passage, a pressure controlling valve between said inlet chamber and said pressure chamber for

maintaining a desired pressure in the pressure chamber, a liquid outlet chamber for connection to a discharge nozzle, a metering chamber and metering means for connecting said metering chamber to said outlet chamber, a check valve separating said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by a pressure differential therebetween, means operable to predetermine the pressure differential at which said check valve will open, and means including a flexible diaphragm subject to a pressure differential for controlling a derichment valve.

21. A variable liquid flow control regulator for injecting liquid into the discharge nozzle of an internal combustion engine, comprising a liquid inlet chamber, means in said chamber for bleeding air, liquid vapor, or liquid to a return passage, a pressure chamber connected to a return passage, a pressure controlling valve between said inlet chamber and said pressure chamber for maintaining a desired pressure in the pressure chamber, a liquid outlet chamber for connection to a discharge nozzle, a metering chamber and metering means for connecting said metering chamber to said outlet chamber, a check valve separating said pressure chamber and said metering chamber, a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by a pressure differential therebetween, means operable to predetermine the pressure differential at which said check valve will open, and means including a flexible diaphragm subject to a pressure differential for controlling a manifold pressure regulator.

22. A variable liquid flow regulator comprising a liquid inlet chamber, a pressure chamber, a pressure controlling valve between said inlet chamber and said pressure chamber for maintaining a desired pressure in the pressure chamber, a liquid outlet chamber, a metering chamber and metering means for connecting said metering chamber to said outlet chamber, a check valve separating said pressure chamber and said metering chamber, and a flexible diaphragm supporting said check valve and having one side thereof open to said pressure chamber and the other side thereof open to said outlet chamber so as to be operable by a pressure differential therebetween.

23. A variable liquid flow regulator comprising, a liquid inlet chamber, a pressure chamber, means for maintaining a desired pressure in the pressure chamber, a liquid outlet chamber, a metering chamber and metering means for connecting said metering chamber to said outlet chamber, a check valve separating said pressure chamber and said metering chamber, and means supporting said check valve operable by a predetermined pressure differential.

24. A liquid injection system for supplying metered liquid to the discharge nozzle of an internal combustion engine, comprising a liquid supply tank, a pressure pump connected thereto, a liquid flow control regulator connected to said pump having a metering valve controlling the flow of liquid to said discharge nozzle, a diaphragm-actuated valve in said regulator controlling the flow of liquid to said metering valve, a derichment valve associated with said engine, means responsive to the pressure differential actuating said diaphragm-actuated valve for operating said derichment valve.

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