

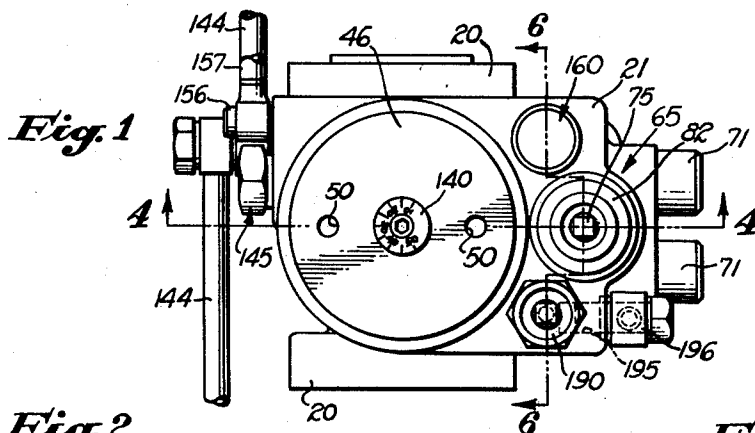
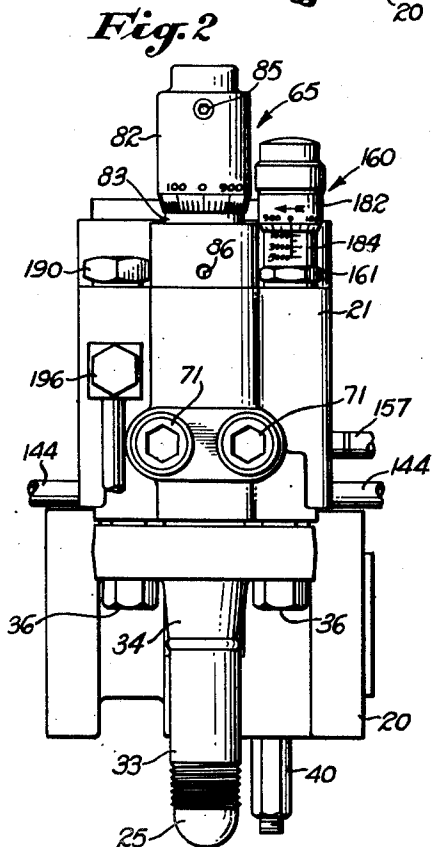
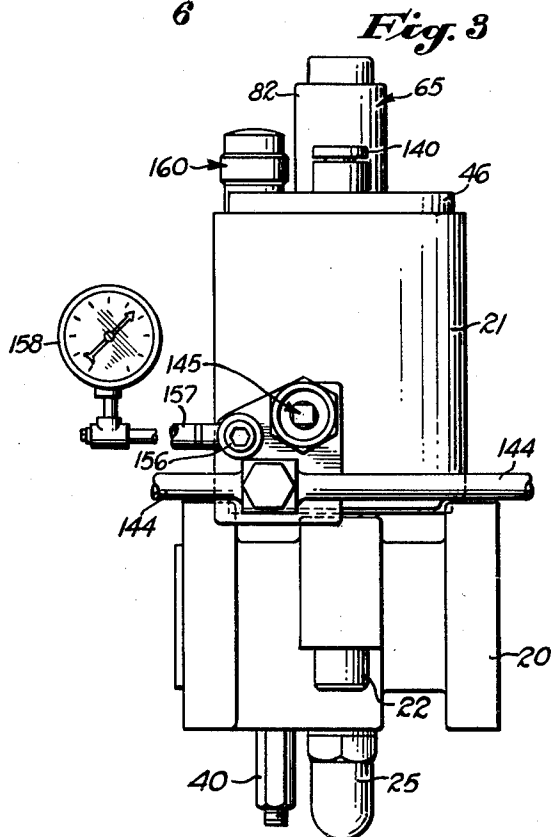
Nov. 10, 1953

C. J. COBERLY
FLOW METERING DEVICE

2,658,522

Filed May 19, 1947

3 Sheets-Sheet 1



INVENTOR:
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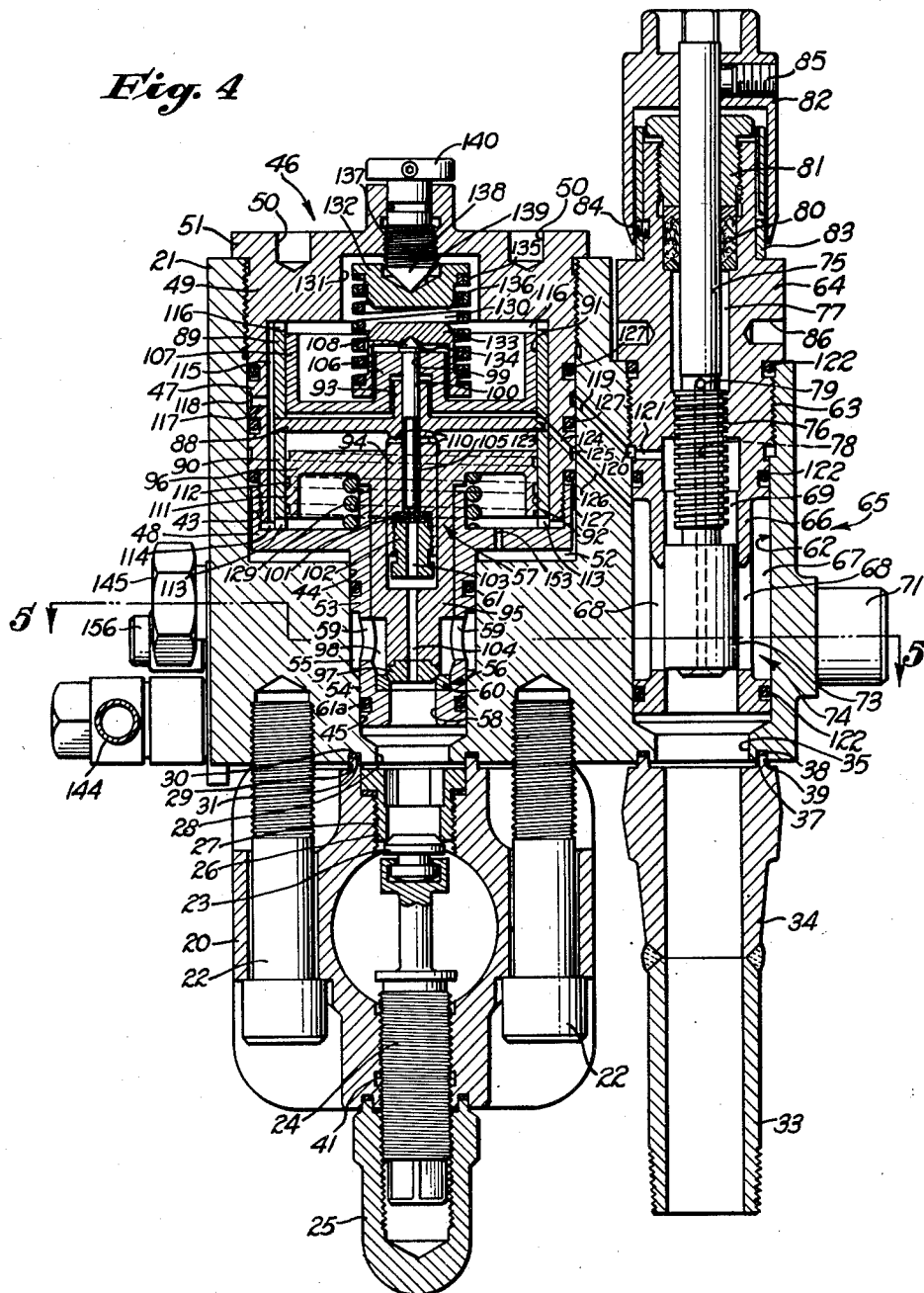
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3 Sheets-Sheet 2.



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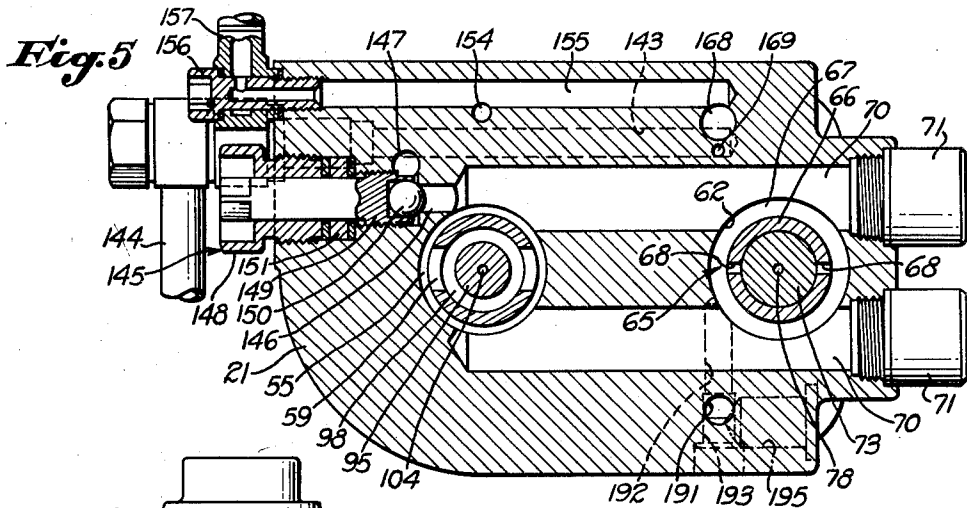
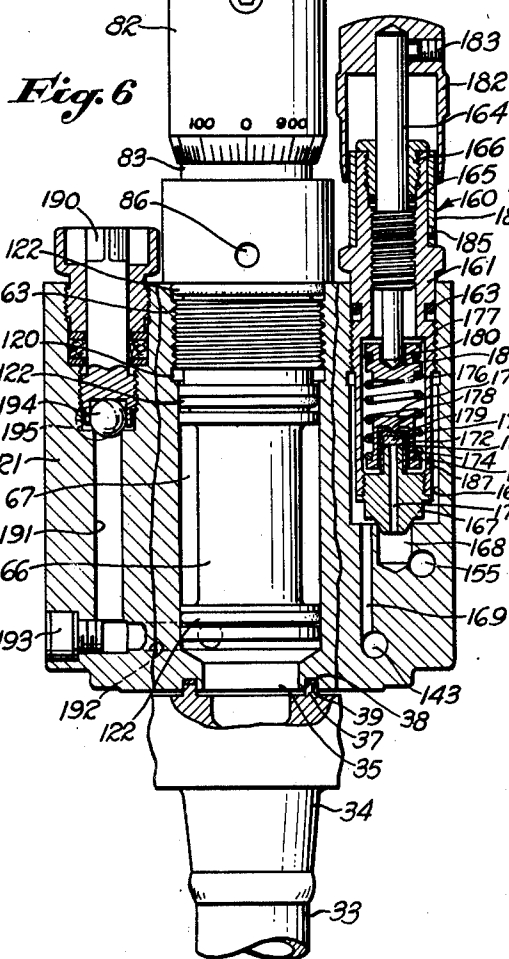
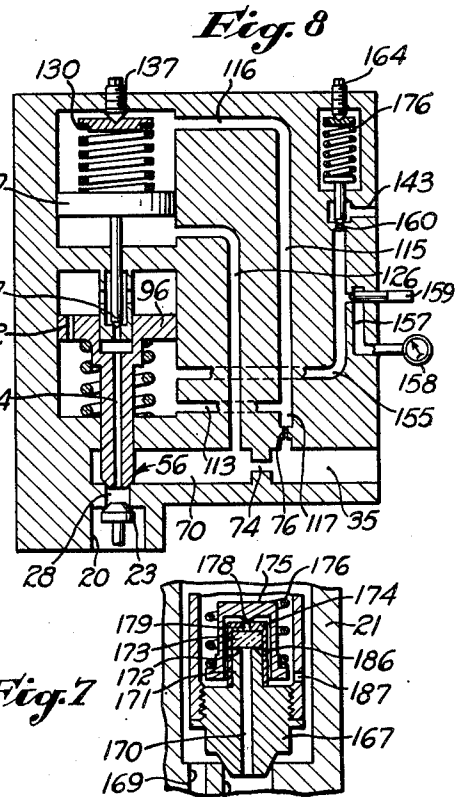
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FLOW METERING DEVICE

Filed May 19, 1947

3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,658,522

FLOW METERING DEVICE

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Application May 19, 1947, Serial No. 748,921

12 Claims. (Cl. 137-468)

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This invention relates to flow metering or governing devices, and more particularly to a device for controlling the flow of a high pressure operating fluid to a fluid operated pump.

The invention is of particular utility in the oil industry and, consequently, is described in connection with such use, although it is to be understood that I do not intend to be limited thereby since the invention is susceptible of other diverse uses.

Fluid operated pumps for use in deep wells ordinarily include a fluid motor, with a pump unit operatively connected thereto, adapted to pump oil or other well fluid from the well up through a production conduit leading to the top of the well. The fluid motor and the pump unit are customarily at, or near, the well bottom and, consequently, far removed from observation, with the operating fluid pumped to them under pressure from a surface pumping unit through a supply conduit, and it becomes important to have automatic controlling devices with which to regulate the flow of the operating fluid to the fluid motor in accordance with conditions existent at the well bottom. In order to facilitate control and observation of operation, it is desirable to have the control devices for a large number of wells closely grouped and such a group of controls may conveniently receive operating fluid from a single high pressure surface-pumping unit through a manifold common to all members of the group. It is furthermore desirable that the operating fluid, passing through the individual controls, should flow to the individual wells at pressures and rates of flow which are peculiar to the operating conditions of each well and which are governable individually in response to those conditions. The fluctuations of pressure and flow occurring at each of the fluid operated pumps may then be recorded by suitable attachments to the control device to provide a history of the operation of each individual well, available at one central inspection point.

Operating conditions for all of a group of wells connected to the same operating fluid manifold are not likely to be the same and the operating fluid passing to each pump must be regulated to suit specific circumstances. The specific operating conditions may include, as major variables, the rate of production which may be required of a given well from time to time, and fluctuations in the load on the fluid operated pump as represented by the pressure of operating fluid required to operate the fluid motor at a predetermined speed and as caused by such factors as changes in the density of the liquid entering the pump, emulsification of the liquid to various degrees, and gas entering the pump along with the liquid. As a constant, the maximum pressure to which it is desirable to load the supply conduit

or the fluid motor should be considered. Variable factors which may be termed minor but which are none the less important in maintaining a calculated rate of production include the specific gravity and the temperature of the operating fluid.

It is, therefore, a primary object of my invention to provide a control device for a fluid operated pump which may be installed in the supply line of an individual pump leading from a manifold supplying operating fluid to a group of pumps and which will convert the hydraulic conditions of the manifold to hydraulic conditions suitable to the individual pump.

Another object of my invention is to provide a control device for governing the flow of operating fluid from a source of supply to a fluid operated pump which will regulate the speed of the pump by regulating the volume of flow of the fluid through the control device.

A further object of my invention is to provide a control device for governing the flow of operating fluid to a fluid operated pump which will regulate the speed of the pump by regulating the pressure at which the fluid is released from the control device.

Yet another object of my invention is to provide a control device for governing the flow of operating fluid to a fluid operated pump which will regulate the intake of fluid from the source of supply thereof so as to prevent the pump from exceeding a desired maximum speed whenever the pressure at which the fluid is released from the control device is less than a selected maximum and which will, whenever the pressure at which the fluid is released from the control device has attained the selected maximum, thereafter regulate the intake of fluid so as to prevent the pressure from exceeding the selected maximum.

A further object of my invention is to provide a control device which will prevent racing of a pump by decreasing the rate of flow of operating fluid thereto in response to a decrease in pressure in the fluid passing from the control device to the pump below a selected value.

A still further object of my invention is to provide a control device for governing the flow of operating fluid to a fluid operated pump which will so compensate for changes in the temperature of the fluid at the control device that any rate of flow through the control device will be volumetrically constant when measured at a constant temperature.

Yet another object of my invention is to provide a control device for the purpose indicated which may be adjusted for use with operating fluids of varied specific gravities, so as to maintain with such varied fluids like volumes of flow under like conditions of entrance and discharge pressures.

Another object of my invention is to provide a control device for the purpose indicated having auxiliary outlets for the supply of operating fluid at a regulated pressure to accessory devices in addition to the pump to which it is primarily connected, and so arranged that its operation may be regulated by back pressure imposed on it by an accessory device.

Other objects and advantages will appear in the following specification and in the drawings, in which:

Fig. 1 is a plan view of my invention showing a unit control device adapted to be joined to similar units to form a continuous manifold in which each unit is also a T-outlet;

Fig. 2 is a side elevational view of my invention taken from the right of Fig. 1;

Fig. 3 is a side elevational view of my invention taken from the left of Fig. 1;

Fig. 4 is an enlarged vertical sectional view taken on the line 4—4 of Fig. 1, and showing the arrangement and the intercommunicating channels of the main valve, the pilot valve, and the metering orifice, the valves and the orifice being shown in closed position;

Fig. 5 is a horizontal sectional view taken on the line 5—5 of Fig. 4, and showing the flow channels through which the operating fluid passes;

Fig. 6 is an enlarged vertical sectional view taken on the line 6—6 of Fig. 1, and showing the pressure control mechanism and auxiliary outlets;

Fig. 7 is a vertical sectional view on a further enlarged scale, of a detail of the pressure control valve shown in Fig. 6; and

Fig. 8 is a diagrammatic illustration of the principal flow channels of my invention, each channel formed by a group of passages being indicated by the reference number of one member of the group.

Referring to the details of the drawings, I show a manifold section 20 to which a housing 21 is secured by bolts 22, and it is to be understood that a plurality of manifold sections 20 may be suitably secured to each other in end to end relation so as to form a continuous manifold, each section of which bears its own housing. The manifold section 20 is provided with a shut-off valve 23, which is mounted on a valve stem 24, protected and secured by a locking cap 25, and which seats upon a valve seat 26 threadedly secured in a port 27 aligned with an inlet port 28 in the housing 21. To seal the joint between the manifold section 20 and the housing 21, the former is provided with an annular ridge 29 which fits within an annular groove 30 in the housing 21 and is there held against a gasket 31. A discharge pipe 33 is secured to a flange member 34 which is secured to the housing 21 in alignment with a discharge port 35 by studs 36, the joint between the flange and the housing being sealed similarly to that between the manifold section and the housing by an annular ridge 37 held against a gasket 38 in an annular groove 39. A flow circuit is thus formed from a source of supply (not shown) of high pressure operating fluid through one or more of the manifold sections 20, the valve 23, inlet port 28, and the housing 21 with its hereinafter described mechanism to the discharge port 35 and discharge pipe 33 which leads to a fluid operated pump (not shown) situated in a well and governed in its individual operation by the mechanism secured to the specific manifold

section 20. A grease inlet 40 of the Alemite type, may be provided through which heavy grease may be forced into a groove 41 surrounding the valve stem 24 to prevent leakage of high pressure operating fluid when the locking cap 25 is removed.

The housing 21 is provided with a cylindrical chamber 43 in axial alignment with the inlet port 28 and connected thereto by smaller axial bores 44 and 45. A valve casing 46, comprising an upper casing member 47 and a lower casing member 48, threadedly joined, is threadedly secured in the chamber 43, the upper casing member 47 having a head 49 threaded externally for joining to the housing 21 and provided with spanner sockets 50 by which, by use of a suitable tool, the valve casing 46 may be inserted and removed as a unit, together with its contents. A flange 51 on the upper casing member 47 limits the depth to which the valve casing 46 may be inserted in the chamber 43 so as to leave a space 52 below the lower casing member 48. The lower casing member 48 has a tubular extension 53 fitting closely within the bore 44 and extending partly therethrough, and a further extension 54 of reduced diameter, fitting closely within the bore 45. The reduced diameter of the extension 54 leaves an annular space 55 around that part of the extension 54 contained in the bore 44. A main valve 56 and a pilot valve 57, to be described more fully hereinafter, are housed within the valve casing 46, with the main valve in communication with the inlet port 28 by means of a passage 58 in the lower end of the extension 54, and in communication with the annular space 55 by means of radial ports 59 in the extension 54. A valve seat 60 is provided for the main valve 56 at the end of the passage 58 adjacent the radial ports 59. Sealing rings 61 on the extension 53, and 61a on the extension 54 seal the lower casing member 48 relative to the housing 21 above and below the radial ports 59.

A chamber 62 is formed in the housing 21 in alignment with the discharge port 35 and has threads 63 to receive and secure a valve body 64 of a control valve 65. The valve body 64 has a lower portion 66 which is of reduced diameter so as to leave an annular space 67 between it and the wall of the chamber 62 and which has radial ports 68 communicating between the annular space 67 and a valve chamber 69 within the valve 64. The valve chamber 69 being open at its lower end communicates with the discharge port 35. As best shown in Fig. 5, main flow passages 70 extend into the housing 21 at opposite sides of the chamber 62, being closed at their outer ends by plugs 71 and intersecting at one end the annular space 67 surrounding the control valve 65, and at the other end the annular space 55 adjacent the main valve 56, thus providing flow channels from the inlet port 28 to the discharge port 35 when the main valve and the control valve are open.

The control valve 65 is of plunger type having a plunger head 73 which fits slidably within the reduced portion 66 of the valve body 64 so as to cut off the valve chamber 69 from the annular space 67, and the radial ports 68 form a metering orifice means 74 the effective area of which may be varied by axial movement of the plunger head. The plunger head 73 is mounted on a valve stem 75 which bears threads 76, preferably of acme type, engageable with mating threads in the valve body 64 above the valve chamber 69. The

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valve stem 75 is reduced in diameter above the threads 76 so as to leave an annular space 77 between the valve stem and the valve body 64 and this annular space is in communication with the lower face of the plunger head 73 by means of a longitudinal passage 78 in the plunger head and valve stem and a radial passage 79 in the latter. Above the annular space 77, the valve stem 75 is packed by packing 80 and a gland 81 and the upper end of the valve stem, extending above the valve body 64 is provided with a micrometer thimble 82 registerable with a skirt 83 on the valve body 64 graduated to show the rate of flow which may be expected through the metering orifice 74 throughout its range of setting, or in other convenient units such as the barrels per day pumped by the fluid operated pump at such rate of flow. The skirt 83 is held to the valve body 64 by a set-screw 84, and the thimble 82 is adjustably secured to the valve stem 75 by a set-screw 85. Spanner sockets 86 are provided in the valve body 64 by which the valve body and contents may be installed and removed as a unit by use of a suitable tool.

The interior of the valve casing 46 is divided by a transverse partition 88 held in position by an upper lining sleeve 89 and a lower lining sleeve 90 which bear against the upper and lower casing members 47 and 48, so as to form upper and lower cylinders 91 and 92. The partition 88 has an upper central boss 93 extending upwardly into the upper cylinder 91, and a lower central boss 94 extending downwardly, the exterior of the latter providing a sliding fit guide for a tubular valve stem 95 of the main valve 56 and for a main valve piston 96 integral with the valve stem 95 and reciprocable within the lower cylinder 92. The lower end of the valve stem 95 is fitted with a valve head 97 adapted to seat upon the valve seat 60, and is reduced in diameter to provide an annular space 98 within the extension 54 of the lower casing member 48 of sufficient length that movement of the valve stem 95 to any position within its scope will leave the radial ports 59 fully uncovered. The central bosses 93 and 94 are provided with an axial bore 99 forming a bushing for a needle 100 of the pilot valve 57, and the lower end of the bore 99 is counterbored and threaded to receive valve seat 101 and a plug 102 for retaining it. The valve seat 101 and plug 102 have an axial passage 103 in extension of the axial bore 99 communicating through an axial passage 104 in the main valve stem 95 and valve head 97 with the passage 58 and inlet port 28. The needle 100 fits loosely that part of the axial bore 99 within the lower central boss 94 so as to leave an annular space 105 extending to the valve seat 101, and has a close slide fit in the upper part of the axial bore 99 so as to prevent leakage and extends beyond the upper central boss 93 and through a boss 106 on a pilot valve piston 107 reciprocable in the upper cylinder 91, terminating above the boss 106 in a cone 108. The boss 106 has a pressed fit on the needle 100 so that the needle is actuated reciprocably by movement of the piston 107 and may be considered as functionally integral therewith.

Radial ports 110 in the lower central boss 94 connect the annular space 105 with the lower cylinder 92 above the main valve piston 96 to admit high pressure operating fluid thereto from the inlet port 28 when the pilot valve 57 is open. The main valve piston 96 has a skirt 111 grooved on its exterior surface with a helical groove 112 which provides a restricted communication be-

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tween the upper and lower faces of the piston. The cross-sectional area, hydraulic radius, and length of the groove 112 provide a resistance to the flow of operating fluid therethrough resulting in a pressure drop across the main valve piston 96 of determinable amplitude. The lower lining sleeve 90, against which the skirt 111 bears, has a plurality of notches or openings 113 in its lower rim communicating with an annular space 114 between the lower rim of the upper casing member 47 and the head of the lower casing member 48, and the length of the skirt 111 is such as to leave the notches 113 unobstructed when the main valve 56 is seated and the skirt 111 is consequently in its lowest possible position. A vertical groove 115 on the inner surface of the upper casing member 47 extends from the annular space 114 to the head 49 of the upper casing member 47, forming a passage between the upper casing member 47 and the lower lining sleeve 90, the partition 88, and the upper lining sleeve 89, connecting with one of a plurality of notches or openings 116 in the upper rim of the upper lining sleeve 89, similar to the notches 113, and thus connecting with the upper cylinder 91 above the pilot valve piston 107. A radial passage 117 through the upper casing member 47 connects with an annular groove 118 on the exterior surface of the upper casing member 47, and the annular groove 118 communicates through a radially inclined passage 119 in the housing 21 with an annular groove 120 on the exterior surface of the control valve body 64 and thence through a radial passage 121 in the control valve body 64 to the upper portion of the control valve chamber 69 above the plunger head 73. The acme thread 76 permits fluid communication between the upper portion of the valve chamber 69 and the annular space 77 around the control valve stem 75 whence, as already shown, there is communication through the radial passage 79 and longitudinal passage 78 with the lower face of the plunger head 73 and, therefore, with the discharge port 35. Sealing rings 122 seal the control valve body 64 relative to the walls of the chamber 62 above and below the radial passage 121 and below the annular space 67.

The upper cylinder 91 below the pilot valve piston 107 is in communication with the annular space 67 around the control valve body 64, and, therefore, with the upstream side of the metering orifice 74, by means of a notch 123 in the partition 88, an inclined radial passage 124 in the upper casing member 47, an annular groove 125 on the exterior surface of the upper casing member 47, and an inclined radial passage 126 in the housing 21, all interconnecting. Sealing rings 127 are provided above, below, and between the annular grooves 118 and 125 to prevent loss and interchange of pressure.

The cross-areas of all the passages and grooves forming the fluid communication line between the lower cylinder 92, below the main valve piston 96, and the upper cylinder 91 above the pilot valve piston 107, and between the vertical groove 115 connecting these cylinders and the control valve chamber 69, are sufficiently large to maintain substantially equalized pressures throughout the communication line, in view of the relatively restricted helical groove 112 and the small volume of flow possible therethrough. Consequently, the fluid pressures upon the lower side of the main valve piston 96 and upon the upper side of the pilot valve piston 107 are substantially equal, and are less than the fluid pressure at the

main valve 56—or substantially the pressure upon the upstream side of the metering orifice 74 when the main valve 56 is open—by an amount equal to the pressure drops through the pilot valve 57 and through the helical groove 112, and are greater during normal operation than the fluid pressure upon the downstream side of the metering orifice 74 by an amount equal to the pressure drop through the acme thread 16. The fluid pressure upon the upper side of the main valve piston 96 may equal the pressure at the main valve 56 if the pilot valve 57 is fully open, or may have some lower value due to pressure drop through the pilot valve 57 if that valve is partly closed, or may have a value decreasing to the fluid pressure upon the lower side of the main valve piston 96 if the pilot valve 57 is closed. The fluid pressure upon the lower side of the pilot valve piston 107 is substantially the same as the pressure upon the upstream side of the metering orifice 74, any differences being equalized through the connecting elements 123, 124, 125, and 126.

A spring 129, bearing upon the lower side of the main valve piston 96 and upon the lower casing member 48, acts in supplementation of the fluid pressure upon the lower side of the main valve piston 96 and is of sufficient strength to overcome the pressure drop normally existent through the helical groove 112 and thus to hold the main valve 56 normally open. As will be hereinafter shown, the supplementary action of the spring 129 may be overcome by increasing the pressure drop through the helical groove 112 above normal, either by increasing the pressure above the main valve piston 96 or by decreasing or limiting the pressure therebelow.

In a similar way, a spring 130 acts upon the pilot valve piston 107 but acts to urge the pilot valve to a closed position. The head 49 of the upper casing member 47 has a recess 131 which receives a spring follower 132, and a cup member 133 is loosely fitted over the boss 106 on the pilot valve piston 107 and has a conical recess 134 to receive and bear against the cone 108 on the pilot valve needle 100. The spring 130 is mounted between the spring follower 132 and the yoke 133 so as to exert a downward, or closing, force upon the needle 100. To compensate for changes in temperature in the operating fluid, in a manner hereinafter explained, the spring 130 is of bi-metallic construction, having an outer portion 135 having a relatively high coefficient of expansion, such as steel, and an inner portion 136 having a relatively low coefficient of expansion, such as invar metal, so that the outer portion 135 changes in length more rapidly than the inner portion 136 with changes of temperature and tends to cause the spring to wind up with increasing temperature and to unwind with decreasing temperature, and correspondingly to increase and to decrease the loading of and the force exerted by, the spring. To allow for use of operating fluids of various specific gravities, an adjustment screw 137 is provided in the head 49 of the upper casing member 47, having a conical point 138 which engages a conical recess 139 in the spring follower 132, and having a cap 140 which may be calibrated in terms of specific gravity of the operating fluid. By turning the adjustment screw 137, the spring follower 132 may be moved to impart a greater or lesser initial loading to the spring 130.

To allow for drainage, when it is desired to remove the control device as a unit, or any of its operating parts, as best shown in Figs. 5 and 8,

a drainage bore 143 is provided in the housing 21 having a drain pipe 144 secured to its outer end by any suitable fittings and leading to any convenient pits or receptacles. A valve 145, seated in a bore 146 of stepped diameter in continuation of one of the main flow passages 70, opens and closes communication between that main flow passage and the drainage bore 143 through a connecting passage 147, and comprises a tap body 148 threadedly secured in the outer counterbore of the bore 146, a valve stem 149, threaded in an intermediate counterbore of the bore 146 for movement therein, a ball 150 movable by the valve stem 149 to close the bore 146, and packing 151 compressed by the valve body 148.

The lower cylinder 92 on the low pressure side of the main valve piston 96 is connected to the space 52 between the lower casing member 48 and the housing 21 by an orifice 153 through the lower casing member 48, and the space 52 is in turn connected by a vertical passage 154, shown in Fig. 5, to an auxiliary control passage 155 in the lower portion of the housing 21. The fluid pressure in the control passage 155 is, therefore, normally the same as the pressure on the low pressure sides of the main valve piston 96 and the pilot valve piston 107 which are in fluid communication, as hereinbefore described. The outer end of the control passage 155 is provided with a swivel fitting 156 and pipe connections 157 which may connect the control passage to a pressure gauge 158, and which are also adapted to connect the control passage to a control device 159, shown diagrammatically in Fig. 8, of either manually operated or automatically operated type, by which the operation of the control device may be stopped or intermitted.

A pressure control valve 160 is connected to the inner end of the control passage 155, as best illustrated in Fig. 6, and comprises a valve body 161 threadedly secured in a valve cylinder 162 formed in the housing 21 and sealed therein by a sealing ring 163, an adjusting screw 164 movably threaded in the valve body 161 and sealed therein by a sealing ring 165 and a stuffing nut 166, a nozzle 167 threadedly secured in the lower end of the valve body 161, and spring-loaded pressure-release mechanism mounted between the adjusting screw 164 and the nozzle 167. The valve cylinder 162 communicates with the auxiliary control passage 155 by means of a bore 168 in which the nozzle 167 is seated to form a fluid-tight joint, and with the drainage bore 143 by a passage 169. As best shown in Fig. 7, the nozzle 167 has an axial passage 170 and an axial extension 171 chamfered to terminate in a knife-edge valve seat 172 annularly surrounding the passage 170. An optically flat valve head 173, of hard metal or sapphire, is held by a cap 174 which has a sliding fit on the axial extension 171 and is pressed against the valve seat 172 by a cup 175 which fits loosely over the cap 174 and is backed by a spring 176 reacting against a spring follower 177 positioned by the adjusting screw 164. To cause even wear upon the valve seat 172 and the valve head 173 and to hold the various parts in axial alignment, the cup 175 has a conical point 178 bearing against the rim of an axial orifice 179 in cap 174 and the adjusting screw 164 has a conical point 180 engaged by a more obtuse conical recess 181 in the spring follower 177. A micrometer type thimble 182 is secured to the upper end of the adjusting screw 164 by a set screw 183, to register with a calibrated skirt 184 secured to the valve body 161 by a

set screw 185. The thimble 182 and skirt 184 may be calibrated in pounds per square inch or any other convenient units.

The cap 174 has radial ports 186 at the level of the chamfered portion of the nozzle extension 171 admitting fluid which has passed between the valve seat 172 and the valve head 173 to the interior of the valve body 161. A hole 187 in the valve body 161 communicates between the interior of the valve body and the valve cylinder 162 whence there is open communication to the atmosphere through the passage 169 and the drainage bore 143. By turning the adjusting screw to impart a loading to the spring 176, the pressure in the auxiliary control passage 155 may be limited to a desired amplitude, indicated by the micrometer thimble 182 and skirt 184, with surplus pressure being vented through the drainage bore 143.

An auxiliary utility connection is provided as shown in Figs. 5 and 6 by a valve 190, similar to the drain pipe valve 145, in a vertical bore 191 which connects with a horizontal passage 192 communicating with the valve chamber 69 of the control valve 65 below the metering orifice 74. The horizontal passage 192 is closed at its outer end by a plug 193. A ball 194, movable by the valve 190, controls the flow of fluid from the vertical bore 191 to a discharge port 195, threaded to receive pipe connections 196 leading to apparatus (not shown) which it may be desired to operate in conjunction with the fluid operated pump and at the same pressure as is applicable to the pump.

In the operation of my control device, the control valve 65 is opened to an extent at which it will pass operating fluid at a predetermined rate. The number of barrels per day of operating fluid supplied to the fluid operated pump or the strokes per minute which will result is indicated by suitable graduations on the micrometer thimble 82 and skirt 83.

It will be understood that the volume of flow through the control valve 65, at any given extent of opening of the metering orifice 74, will depend upon the difference in pressures on the upstream and downstream sides of the metering orifice 74; and the calibration of the thimble 82 is made with reference to a certain pressure differential which may be termed the normal operating pressure differential. Changing the setting of the control valve 65 so that the thimble 82 indicates an increased pump output of, say, 50 barrels, affects an increase in the opening of the metering orifice 74 to permit passage of operating fluid sufficient to cause the pump to pump 50 additional barrels per day at the same normal operating pressure differential as previously existed. The operation will be best understood by referring to Fig. 8. The manifold section 20 is connected to an adequate supply of fluid at a pressure in excess of that required to operate the fluid actuated pump to be controlled by the metering valve. The valve 23 in the manifold section 20 is fully opened to the inlet port 28 and as the main valve 56 is normally held open by the main valve spring 129, high pressure operating fluid flows from the manifold section 20 through the main flow passages 70 and the metering orifice 74, impressing a fluid pressure differential across the latter. The high pressure component of this pressure differential is communicated to the lower, or high pressure, side of the pilot valve piston 107 through the group of passages including the inclined passage 126, and the low pressure

component thereof is communicated through the group of passages including the acme thread 76 to the radial passage 117, the vertical groove 115 and the notches 116 and thence to the upper, or low pressure, side of the pilot valve piston 107, and through the notches 113 to the lower, or lower pressure, side of the main valve piston 96, and from the latter to the auxiliary control passage 155 where it may be registered on the gauge 158 or be limited by the remote control apparatus 159 or by the pressure control valve 160.

When the valve 23 is first opened, the pressure on the upper, or low pressure, side of the pilot valve piston 107 is initially and momentarily less than normal because of the resistance imposed by the metering orifice 74 and the acme thread 76. The pilot valve spring 130 is adapted to withstand a pressure differential across the pilot valve piston 107 of slightly less amplitude than the normal operating pressure differential across the metering orifice 74 and for the moment the pressure differential across the pilot valve piston is excessive because of the low fluid pressure on the low pressure side of the piston. Consequently, the pilot valve piston 107 moves upwardly and the pilot valve 57 opens and admits high pressure operating fluid to the upper, or high pressure, side of the main valve piston 96 through the group of passages including the passage 104. A pressure differential is thus impressed across the main valve piston 96 greater than the main valve spring 129 is adapted to withstand and the main valve 56 closes partly, at least.

The main valve 56 now throttles the flow of operating fluid to the metering orifice 74 until the pressure differential thereacross is reduced to the normal operating pressure differential. In doing so, it reduces the pressure of the high pressure component of that pressure differential, which is also the pressure of the high pressure component of the differential across the pilot valve piston 107. At the same time there is a flow of fluid through the helical groove 112 to increase the fluid pressure on the low pressure sides of the main valve piston 96 and the pilot valve piston 107. Both of these actions tend to restore the pressure differential across the pilot valve piston 107 to the equilibrating amplitude at which the pilot valve spring is capable of holding the pilot valve 57 floatingly between open and closed positions. When this is accomplished, the control device is in a state of equilibrium which may be termed the normal operating condition and in which the normal operating pressure differential across the metering orifice 74 impresses an equilibrating differential on the pilot valve piston 107, partly opening the pilot valve 57; and the flow through the pilot valve impresses an equilibrating differential on the main valve piston 96, closing the main valve sufficiently to permit a flow to the metering orifice 74 to impress thereon the normal operating pressure differential.

The equilibrating pressure differential across the pilot valve piston 107 is created and transferred thereto by the normal operating pressure differential across the metering orifice 74 and has the same general magnitude and fluctuates in close relationship therewith, varying from it only by the resistance of the passages connecting the two sides of the piston to the two sides of the orifice. The high pressure components of the two pressure differentials are virtually the same because of direct and substantially unrestricted communication through the radial inclined passage 126, and the low pressure components vary

only by the pressure drop through the acme thread 76. The pressure drop through the acme thread 76 is zero when the pilot valve 57 is closed or as soon after the closing of the pilot valve as the pressures at each end of the helix 112 are equalized; and it is constant whenever the system is in equilibrium, and the pilot valve is not moving. As the normal situations are those in which the pilot valve 57 is either closed or in equilibrium, and as the degree of opening of the pilot valve required to increase pressure above the helix 112 is extremely small and, therefore, the flow through the acme thread is extremely light in volume, the pressure differential across the metering orifice 74 and across the pilot valve piston 107 either are equal or differ by a very small and normally constant amount and the difference may be ignored. Loading the pilot valve spring 130 so as to counterbalance a predetermined amplitude of one of these differentials in effect loads it to counterbalance a predetermined amplitude of the other.

The state of equilibrium, defined as the normal operating condition, will prevail until some circumstance changes the pressure differential across the metering orifice 74, when the pilot valve 57 and main valve 56 will move to establish a new rate of flow which will restore the pressure differential across the metering orifice 74 to its normal operating amplitude and so re-establish equilibrium. The pilot valve 57 will respond to increases in the pressure differential across the metering orifice 74 by increasing the extent of its opening and so decreasing the extent of opening of the main valve 56 and, conversely, will cause an increase in the extent of opening of the main valve 56 in response to decreases in the pressure differential across the metering orifice 74. Both actions are held to a rate of change suitable to a search for equilibrium, the one by the resistance of the acme thread 76 as the rate of flow therethrough increases, and the other by the dashpot action through the helical groove 112 when flow through the pilot valve 57 is reduced or cut off.

As is best illustrated by the diagrammatic view of Fig. 8, the main valve piston 96 is in a flow channel which parallels the whole length of the main flow channel of the metering device from the inlet port 28 to the discharge port 35 and which, therefore, has the same over-all fluid pressure drop. In this respect, the invention differs materially from devices of similar function in which operation of the main valve is effected by control members situated in a flow channel which parallels only the main valve itself, these control members in turn responding to a pressure differential across a metering orifice. Devices of the latter type are well adapted for use under conditions permitting employment of an automatically variable metering orifice which will apportion to itself a quantitatively constant part of the over-all pressure drop across the metering device, thereby assuring creation of a constant force with which to actuate the control members. But with a metering orifice, as in the present invention, designed to be set as to permit a very accurately controlled predetermined rate of pumping independent of the magnitude of the pressure differential across the entire valve and with large possible variations in this over-all pressure drop, the forces required to operate the main valve may be largely due to both friction and unbalanced areas. It is, therefore, desirable under some conditions to have the pres-

sure differential across the main valve piston 96 potentially the over-all pressure drop and to utilize such portion of the over-all pressure drop as is necessary to actuate the main valve.

It will be appreciated that the temperature and, therefore, the specific volume of the operating fluid may vary considerably at the control device but that by the time the operating fluid has reached the pump at the bottom of the well, the temperature and specific volume will have been brought to a prevailing constant. Oil, which is used as operating fluid, changes in volume in direct relation with temperature and, therefore, when the temperature of the operating fluid at the control device is high, in relation to a constant, the control device must permit passage of an increased volume in order to obtain at the pump a volume constant in relation to the constant temperature there prevailing. The bimetallic pilot valve spring 130, as heretofore explained, winds up, so as to increase in strength, with an increase in temperature, which is imparted to it by the operating fluid flowing through the control device, and so holds the pilot valve 57 slightly more closed and, consequently, causes the main valve 56 to open slightly wider for a given pressure differential across the metering orifice 74. This is the equivalent of increasing the normal operating pressure differential across the metering orifice 74 and the related equilibrating pressure differential across the pilot valve piston 107 with an increase in temperature of the operating fluid so as to require a wider opening of the main valve 56 to produce an equilibrating rate of flow. Thus, the bimetallic spring 130 serves as a thermostat means for automatically shifting the level at which the pressure differential across the metering orifice 74 is maintained, the pressure-differential level varying directly with temperature, or inversely with specific volume. It permits a production-volume setting on the micrometer thimble 82 at any temperature to indicate accurately the production volume at all temperatures in an expectable range.

In a similar manner, operation of the adjustment screw 137 permits an accurate indication of the production volume coupled with the use of operating fluids of various specific gravities. If the specific gravity of the operating fluid was above normal, the pressure differential across the metering orifice 74 would also be relatively high and, if this pressure differential were higher than the normal operating pressure differential, it would cause opening of the pilot valve 57 and thereby closing of the main valve 56; and, thereafter, when the pressure differential has been restored to the normal operating amplitude, the operating fluid flowing through the control device would have less volume and less productive capacity than was indicated by the micrometer thimble 82. The adjustment screw 137 would, under these circumstances, be turned inwardly to increase the loading on the pilot valve spring 130 and thereby to increase the level of the normal operating pressure differential at which the pilot valve 57 and main valve 56 are held in equilibrium. With the main valve 56 held open to impress upon the metering orifice 74, the new, and higher, normal operating pressure differential, the same volume of operating fluid will flow through the control device as with a lighter fluid, a lighter spring, and a lower normal operating pressure differential. The adjustment of the screw 137 can, therefore, be calibrated directly in fluid gravity so that the control device may

be set for the kind of fluid that is passing through it.

A maximum limit on the pressure in the control passage 155 may be imposed by the pressure control valve 160, and as this passage communicates with the low pressure sides of the pilot valve piston 107 and the main valve piston 96 and also with the low pressure side of the metering orifice 74 through the acme thread 76, the pressure at all three of these points may also be limited. If it is desired to limit the pressure in the supply line from the control device to the fluid operated pump to a certain maximum, the spring 176 is loaded appropriately by adjustment of the adjusting screw 164, with the micrometer thimble 182 indicating the allowable pressure. When that pressure has been attained, surplus pressure will be vented to the atmosphere through the drainage bore 143, and the low pressure components of the operating pressure differential across the metering orifice 74 and of the equilibrating pressure differentials across the pilot valve piston 107 and across the main valve piston 96, will be held to the desired limit. Any further increase in the high pressure components of the pressure differential across the metering orifice 74 and the pilot valve piston 107, which are of the same magnitude, will extend these differentials beyond their normal and equilibrating amplitudes and so cause the pilot valve 57 to open and to cause closure of the main valve 56. It will be seen that the main valve is made abnormally sensitive to closure by the limit imposed on the fluid pressure against the low pressure side of its piston 96 and that any material flow through the pilot valve 57 will cause closure of the main valve. The pilot valve will be held in an equilibrium permitting only a small amount of flow therethrough and, as only this flow can reach the pressure control valve 160 and part of it will pass through the acme thread 76, there will be very little waste to the atmosphere. The action of the pressure control valve 160 effectively cuts off the supply of operating fluid and stops the fluid operated pump if, for any reason, the pressure at the inlet port 22 continues to rise after the pressure at the discharge port 35 has reached the limit imposed by the valve.

The pump may also be stopped or otherwise regulated by control devices connected to the auxiliary control passage 155 through the pressure gauge pipe connections 157. For example, if it should be desired to operate the pump intermittently to allow the well to fill or a receiving tank to empty, a timing device may be employed to open the pipe connections 157 to low pressure at intervals as required, and such a device may be stationed remotely at a convenient central control point from which a group of wells may be controlled. Opening the pipe connection 157 to low pressure will at once upset the equilibrium on the pilot valve piston 107 and the main valve piston 96, causing the pilot valve 57 to open and the main valve 56 to close, but the loss of operating fluid will be limited to the small amount passed by the pilot valve as further restricted by flow through the helical groove 112.

Various devices may be connected to the pipe connections 156, as shown in Figs. 1 and 2, so as to draw operating fluid from the low pressure side of the control valve 65 and to operate in parallel with the fluid operated pump and such devices may be operated at the same pressure as the pump or at a lower pressure, provided the supply line thereto is furnished with suitable

pressure control mechanism; and their operation will not interfere with the operation of the control device, as their fluid take-off point is no more closely related to the pilot valve system than is the fluid take-off point of the pump itself.

Various modifications in the arrangement of the cooperating parts of my invention will be apparent to one skilled in the art and such modifications do not depart from the spirit of my invention, nor do changes in areas and resistances altering the pressures of equilibrium as may be desirable to adapt my invention to various usages. Consequently, I do not intend to be limited to the specific embodiment shown and described, but desire to be afforded the full scope of the following claims.

I claim as my invention:

1. In a control assembly for a fluid flow governor, the governor including a housing having an inlet, an outlet, passage means connecting said inlet and said outlet, and a metering orifice in the line of said passage means, the combination of: a sub-housing securable in the housing and readily removable therefrom, said sub-housing providing a first chamber and a second chamber; a main valve piston disposed in said first chamber; a pilot valve piston disposed in said second chamber; means carried by said sub-housing and forming a main valve seat which extends into the line of the passage means between the inlet and the metering orifice when said sub-housing is secured in the housing; main valve means connected to said main valve piston and movable into seating engagement with said main valve seat to control the flow of fluid therethrough; pilot valve means connected to said pilot valve piston and disposed in a passage from the inlet to one side of said main valve piston, the other side of said main valve piston being exposed to the fluid pressure in the outlet; and means connecting said second chamber across said metering orifice to apply the fluid pressures on opposite sides of said metering orifice to opposite sides of said pilot valve piston.

2. In a device for regulating the flow of a fluid, the combination of: a main passage for the fluid; a pilot passage communicating with said main passage; means in the line of said main passage for producing a fluid pressure differential; pressure-actuable pilot valve means in the line of said pilot passage and exposed to said fluid pressure differential for regulating flow through said pilot passage; pressure-actuable main valve means in the line of said main passage and exposed to pressure variations resulting from variations in the flow through said pilot passage for regulating flow through said main passage; pressure-limiting means for limiting the low pressure component of said pressure differential to a predetermined maximum value; thermostat means acting on said pilot valve means and exposed to the temperature of the fluid for compensating for variations in said fluid pressure differential due to variations in the specific volume of the fluid; and adjustable means acting on said thermostat means for compensating for variations in said fluid pressure differential due to variations in the specific gravity of the fluid.

3. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; a pilot passage in parallel with said main passage; pressure-actuable main valve means in the line of said main passage and actuable by a main pressure differential for regulating fluid flow through said main passage; means in the line

of said main passage for producing a pilot pressure differential; means in the line of said pilot passage, including pressure-actuable pilot valve means exposed to said pilot pressure differential, for producing said main pressure differential and for applying it to said main valve means; and pressure-limiting means for limiting the low pressure components of both of said pressure differentials to predetermined maximum values.

4. A device according to claim 3 including passage means connecting said main and pilot passages for substantially equalizing said low pressure components.

5. In a device for regulating flow of a fluid, the combination of: a passage for the fluid; means in the line of said passage for producing a pressure differential; pressure actuable valve means including a pilot valve exposed to said pressure differential and including a main valve in the line of said passage for maintaining said pressure differential substantially constant relative to a predetermined pressure-differential level; and thermostat means operatively connected to said pilot valve for shifting said pressure-differential level in inverse relation to variations in the specific volume of the fluid resulting from variations in the temperature thereof so as to maintain substantially constant the ratio of the volumetric rate of flow of the fluid through said passage to the specific volume of the fluid.

6. A device as defined in claim 5 including manually adjustable means acting on the means last defined in claim 5 for shifting said pressure-differential level.

7. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; a pilot passage in parallel with said main passage; means in the line of said main passage for producing a fluid pressure differential; pressure-actuable pilot valve means in the line of said pilot passage and exposed to said fluid pressure differential for regulating flow through said pilot passage; pressure-actuable main valve means in the line of said main passage and exposed to pressure variations resulting from variations in the flow through said pilot passage for regulating flow through said main passage; and thermostat means exposed to the temperature of the fluid and cooperating with said pilot valve means to move said main valve means toward its open and closed positions in response to increases and decreases, respectively, in the temperature of the fluid.

8. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; a pilot passage in parallel with said main passage; means in the line of said main passage for producing a fluid pressure differential; pressure-actuable pilot valve means in the line of said pilot passage and exposed to said fluid pressure differential for regulating flow through said pilot passage; pressure-actuable main valve means in the line of said main passage and exposed to pressure variations resulting from variations in the flow through said pilot passage for regulating flow through said main passage; and thermostat means acting on said pilot valve means and exposed to the temperature of the fluid, said thermostat applying an increasing force to said pilot valve means with an increasing temperature of the fluid.

9. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; an auxiliary passage in parallel with said main passage; means in the line of said main passage for producing a fluid pressure differential; a main valve in the line of said main passage and movable between open and closed positions for regulating flow through said main passage; displaceable fluid separating means connected to said main valve for moving it between its open and closed positions; means providing fluid communication between opposite sides of said fluid separating means and spaced points in said auxiliary passage; and valve means actuable by said pressure differential for regulating flow through said auxiliary passage.

10. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; a parallel pilot passage communicating with said main passage at two spaced points; means in the line of said main passage between said points for producing a fluid pressure differential; pilot valve means in the line of said pilot passage and actuable by said fluid pressure differential for regulating flow through said pilot passage; and main valve means in the line of said main passage between said points and movable between open and closed positions in response to variations in the flow through said pilot passage for regulating flow through said main passage.

11. In a device for regulating flow of a fluid, the combination of: a valve, metering means in series with said valve for producing a pressure differential; means responsive to a proportion of the difference in pressure across said valve and said metering means for actuating said valve; and means actuable by and exposed to said pressure differential for regulating the proportion of said difference in pressure applied to said valve-actuating means.

12. In a device for regulating flow of a fluid, the combination of: a main passage for the fluid; a pilot passage communicating with said main passage at two spaced points; means in the line of said main passage between said points for producing a fluid pressure differential; pressure-actuable pilot valve means in the line of said pilot passage and actuable by said fluid pressure differential for regulating flow through said pilot passage; passage means for applying said fluid pressure differential to said pilot valve means; and main valve means in the line of said main passage between said points and movable between open and closed positions in response to variations in the flow through said pilot passage for regulating flow through said main passage.

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