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[54] RETRIEVABLE FLUID CONTROL VALVE
AND METHOD

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166/224, 166/307

[51] Int. Cl. E21b 43/25, E21b 43/27

[58] Field of Search..... 166/305 R, 315, 131, 133,
166/188, 224, 307, 308, 250, 313, 53; 137/509

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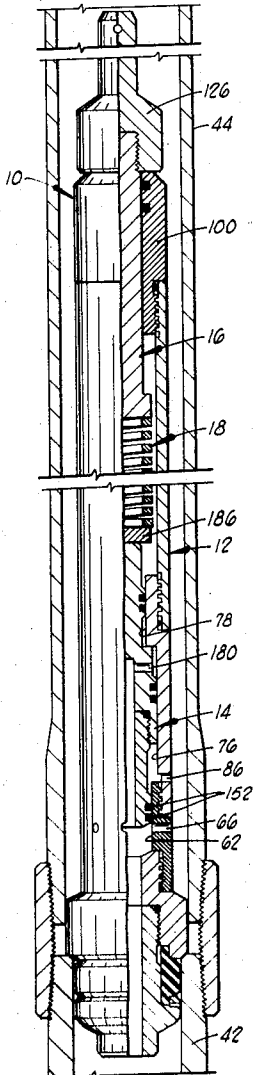
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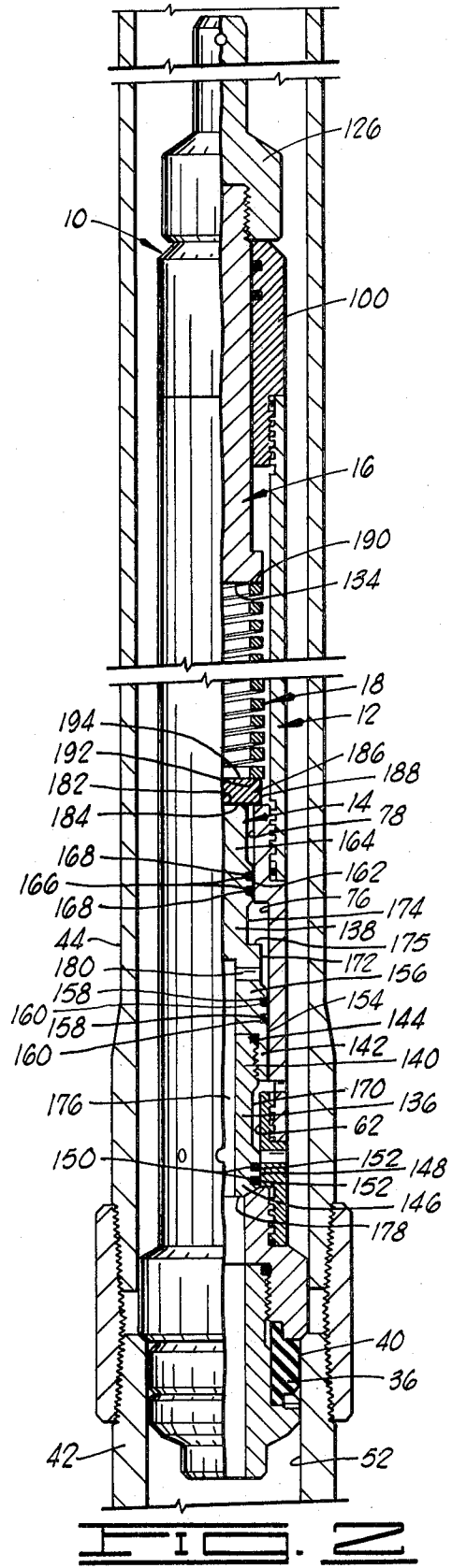
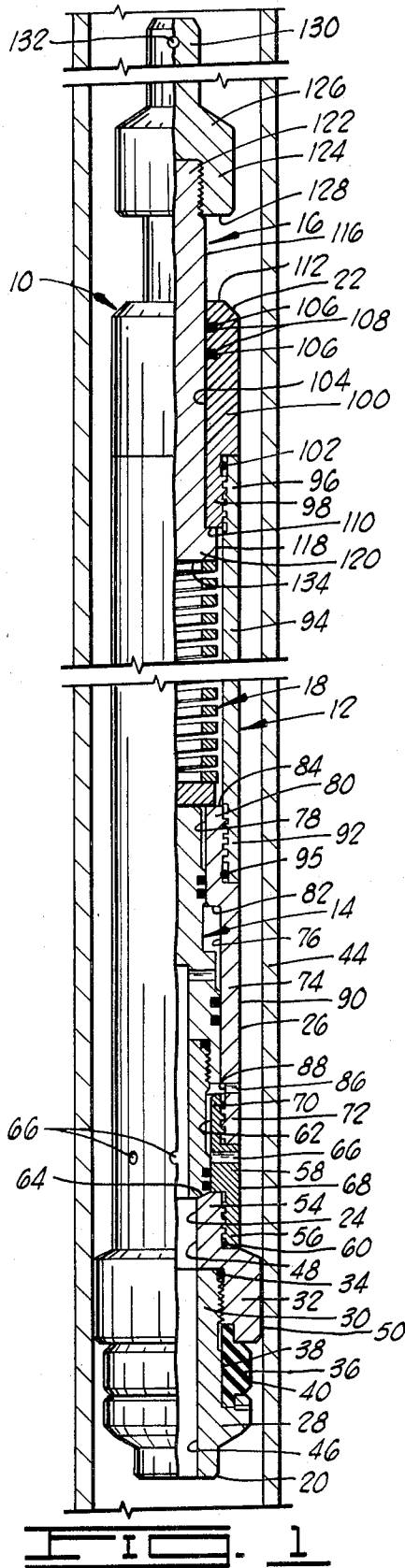
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[57] ABSTRACT

A normally closed retrievable valve assembly for posi-
tioning within a tubing string located in a bore hole.
The valve assembly includes a piston, responsive to
the pressure of the fluid in the tubing string above the
valve assembly, for compressing a spring carried by
the valve body a predetermined amount. A valve
member is positioned in the valve body and is respon-
sive to the pressure of fluid in the tubing string above
the valve assembly to move the valve member from
the normally closed position to an open position
against the bias of the spring when a predetermined
valve-opening pressure is met or exceeded by the fluid
in the tubing string. The valve assembly includes
means for unseating and retrieving the valve assembly
from its operating position within a tubing string. A
method of employing the valve assembly in treating an
oil well or the like is disclosed.

12 Claims, 10 Drawing Figures





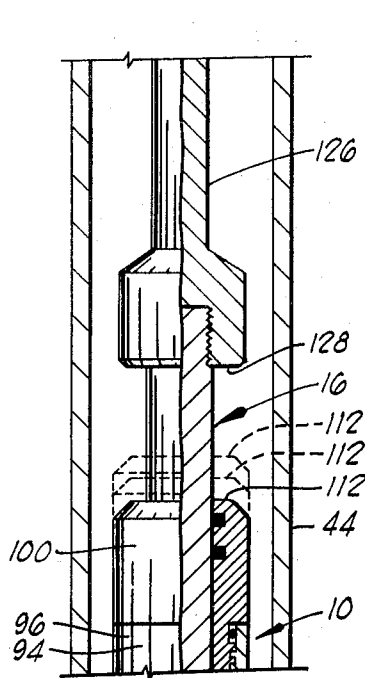


FIG. 5

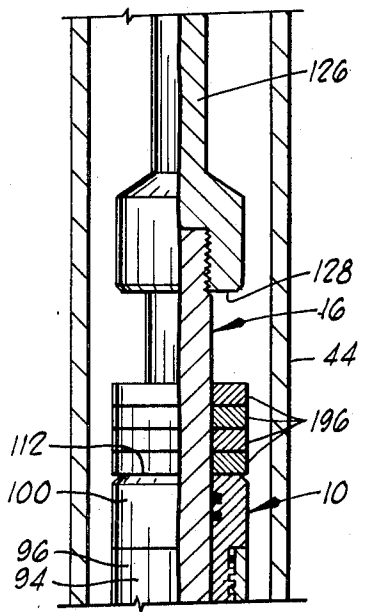


FIG. 6

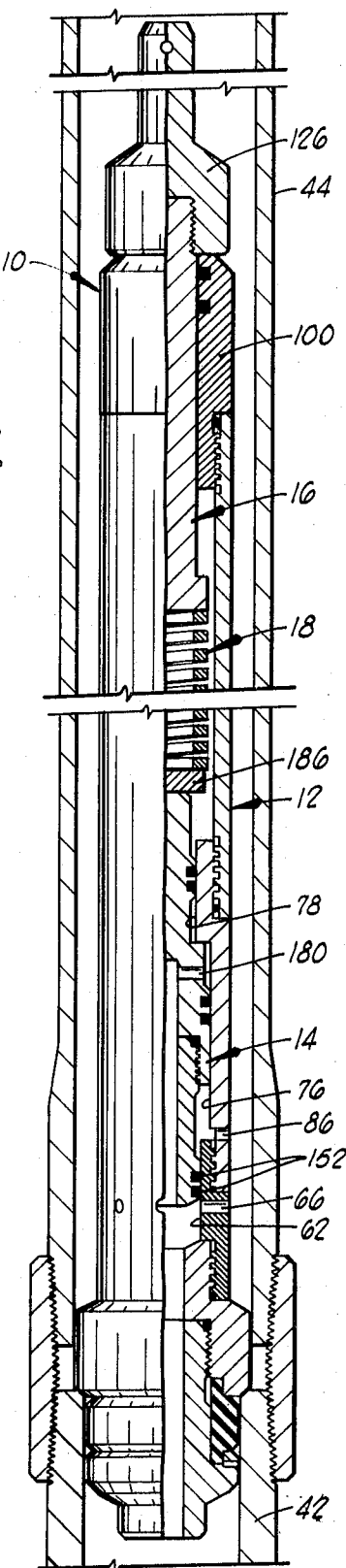


FIG. 3

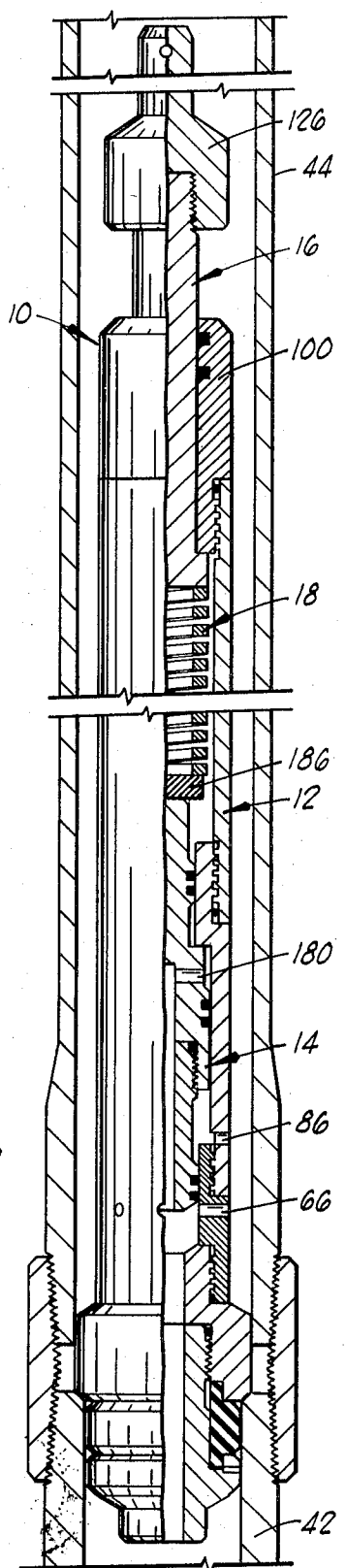
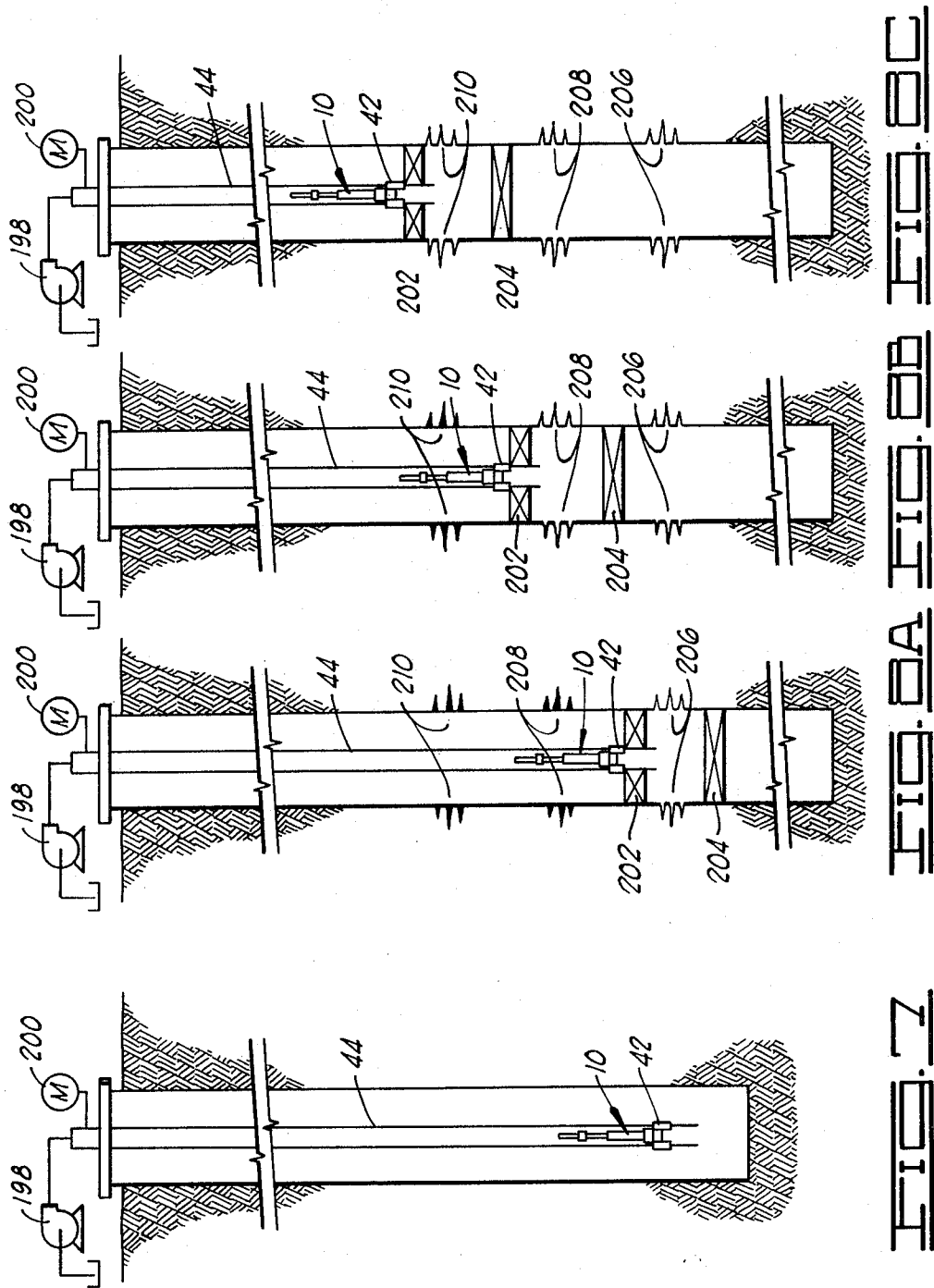


FIG. 4



RETRIEVABLE FLUID CONTROL VALVE AND METHOD

BACKGROUND OF THE INVENTION

The prior art contains a number of teachings of valves for use in conjunction with a tubing string in a bore hole beneath the surface of the ground. These valves, however, are generally limited in that they must be secured to the tubing string as an integral part thereof. Such structure therefore requires that the tubing string must be pulled in order for the valve installed therein to be inserted, removed, replaced or adjusted.

U.S. Pat. No. 3,713,490 issued to Watson teaches a pre-loaded regulated type check valve assembly which provides means for spotting fluid from a tubing string downhole in a bore hole. The Watson apparatus has the disadvantage that it must be integrally connected to the lower end of the tubing string before the tubing string is run into the bore hole. This limitation prevents the Watson valve from being retrieved from the tubing string without the complete removal of the tubing string from the bore hole.

The Watson apparatus is further limited by the employment of a by-pass means which, when actuated, permits flow to and from the tubing string into the bore hole in by-pass relationship to the check valve assembly. When the by-pass means of Watson is activated, however, the check valve portion of the apparatus is rendered inoperative. The tubing string must then be completely withdrawn from the bore hole and the Watson apparatus completely rebuilt before the apparatus can again be used as a check valve.

SUMMARY OF THE INVENTION

The present invention contemplates a retrievable pressure actuated valve assembly for controlling the flow of fluid through a conduit in response to fluid pressure within the conduit. The valve assembly comprises a valve body positionable within the conduit, and having an outer periphery, a first end portion and a second end portion, and having a longitudinal passageway extending therethrough and intersecting the first and second end portions. A conduit seal is carried by the valve body for sealingly engaging the periphery of the conduit. A piston is slidably disposed in the passageway through the valve body adjacent to the second end portion thereof for longitudinal movement within the valve body. A retaining collar is formed on the second end portion of the valve body for retaining the piston within the valve body. A rod member is connected to the piston and has an outer end thereof extending through the retaining collar for communicating with the fluid in the conduit. A limiting member is secured to the outer end of the rod member for limiting the longitudinal movement of the piston within the valve body toward the first end portion thereof. The rod member includes means carried thereon securable to an external source of power for moving the piston longitudinally within the valve body toward the second end portion thereof.

The valve assembly further includes a valve member slidably disposed within the passageway through the valve body intermediate the first end portion thereof and the piston. The valve member has an outer periphery, a first end portion positioned proximate to the first

end portion of the valve body, a second end portion positioned proximate to the piston, and a medial portion intermediate the first and second end portions. The valve member includes a cavity formed therein and intersecting the first end portion thereof, with a port formed in the valve member communicating between the cavity and the outer periphery of the valve member intermediate the medial portion and the second end portion thereof.

A first cylindrically shaped inner surface is formed in the passageway of the valve body adjacent to the first end portion of the valve member. A second cylindrically shaped inner surface is formed in the passageway of the valve body adjacent to the second end portion of the valve member. A medial cylindrically shaped inner surface is formed in the passageway of the valve body intermediate the first and second cylindrically shaped inner surfaces and adjacent to the medial portion of the valve member. The medial cylindrically shaped inner surface has a diameter greater than the diameter of the first cylindrically shaped inner surface and greater than the diameter of the second cylindrically shaped inner surface.

A first seal is carried by the first end portion of the valve member for providing a sliding seal between the first end portion of the valve member and the first cylindrically shaped inner surface of the valve body. A second seal is carried by the second end portion of the valve member for providing a sliding seal between the second end portion of the valve member and the second cylindrically shaped inner surface of the valve body. A medial seal is carried by the medial portion of the valve member for providing a sliding seal between the medial portion of the valve member and the medial cylindrically shaped inner surface of the valve body.

The valve body further includes means for restricting the sliding movement of the valve member within the passageway of the valve body between a closed position proximate to the first end portion of the valve body and an open position distal from the first end portion of the valve body. A biasing spring is disposed within the passageway through the valve body intermediate the second end portion of the valve member and the piston for urging the valve member longitudinally away from the piston into the closed position.

A fluid flow control port is formed in the valve body and communicates between the outer periphery thereof and the passageway therethrough. The fluid flow control port is positioned in the valve body such that when the valve member is in the closed position the first seal is positioned longitudinally intermediate the first flow control port and the first end portion of the valve body, and when the valve member is in the open position the first seal is positioned longitudinally intermediate the fluid flow control port and the second end portion of the valve body. A valve member actuator port is formed in the valve body and communicates between the outer periphery thereof and the passageway therethrough. The valve member actuator is positioned in the valve body such that it remains longitudinally intermediate the first seal and the medial seal in all longitudinal positions of the valve member relative to the valve body.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial cross-sectional view of the valve assembly of the present invention within a tubing string

and illustrates the relative positions of the elements thereof as the valve assembly is moving downwardly through the tubing string toward its seated position.

FIG. 2 is a partial cross-sectional view of the valve assembly within the tubing string and seated in a seating nipple installed therein, and illustrates the relative positions of the elements thereof when the valve assembly is in the closed position.

FIG. 3 is a partial cross-sectional view of the valve assembly seated in the seating nipple of the tubing string and illustrates the relative positions of the elements thereof when the valve assembly is in the open position and fluid is passing downwardly through the tubing string and through the valve assembly.

FIG. 4 is a partial cross-sectional view illustrating the valve assembly seated in the seating nipple of the tubing string and illustrates the relative positions of the elements thereof with the piston in its uppermost position just prior to the unseating of the valve assembly from the seating nipple.

FIG. 5 is a fragmentary partial cross-sectional view illustrating the various sizes of piston-retaining collars installed on the valve assembly of the present invention.

FIG. 6 is a fragmentary partial cross-sectional view illustrating the installation of spacer rings intermediate the piston-retaining collar and the fishing neck to adjust the valve-opening pressure of the valve assembly.

FIG. 7 is a schematic view of the valve assembly of the present invention installed within a tubing string and in operation in treating a bore hole.

FIGS. 8a, 8b and 8c are schematic views illustrating the installation of the valve assembly of the present invention within a tubing string and in operation treating three zones in a bore hole in successive stages.

DETAILED DESCRIPTION

Referring now to the drawings, and to FIGS. 1-6 in particular, the retrievable pressure actuated valve assembly of the present invention is generally designated by the reference character 10. The valve assembly 10 comprises a valve body 12, a valve member 14 carried by the valve body, a piston 16 carried by the valve body, and a compression spring 18 carried by the valve body and positioned intermediate the valve member 14 and the piston 16.

The valve body 12 is in the form of an elongated, generally tubular member having a lower or first end portion 20 and an upper or second end portion 22. A longitudinal passageway 24 extends through the valve body 12 and intersects the first and second end portions 20 and 22 thereof. The outer periphery 26 of the valve body 12 is substantially cylindrical in shape. The valve body 12 includes a lower guide member 28 which is threadedly secured at the upper end 30 thereof within a no-go shoe or ring 32. An annular seal 34 provides a fluid-tight connection between the guide member 28 and the no-go shoe 32. An annular seal 36 is positioned in a circumferential groove 38 formed in the guide member 28 and is securely retained therein by the guide member 28 and the no-go shoe 32. The outer periphery 40 of the annular seal 36 is suitably sized to provide a fluid-tight seal between the valve assembly 10 and a seating nipple 42 of the tubing string 44 as is clearly shown in FIGS. 2-4. The seal 36 may be suitably

formed of an elastomeric or synthetic resilient material.

The guide member 28 includes a cylindrically shaped inner periphery 46 which communicates with a cylindrically shaped inner periphery 48 of the no-go shoe 32, the inner peripheries 46 and 48 forming a portion of the passageway 24 through the valve body 12. The diameter of the outer periphery 50 of the no-go shoe 32 is suitably sized such that it is less than the inner diameter of the tubing 44 and is greater than the diameter of the inner periphery 52 of the seating nipple 42 thereby providing a positive support for the valve assembly 10 within the tubing string 44.

The upper end portion 54 of the no-go shoe 32 is threadedly secured within the lower end portion 56 of the flow port member 58. An annular seal 60 provides a fluid-tight seal between the no-go shoe 32 and the flow port member 58. The flow port member 58 includes a first cylindrically shaped inner surface 62 coaxially aligned with the longitudinal axis of the valve assembly 10 and the inner peripheries 46 and 48 of the member 28 and the no-go shoe 32. The diameter of the inner surface 62 is greater than the diameter of the inner periphery 48 of the no-go shoe 32. An annular wall 64 is formed on the upper end portion 54 of the no-go shoe 32 and extends between the inner periphery 48 of the no-go shoe and the first cylindrically shaped inner surface 62. A plurality of circumferentially spaced, radially extending flow control ports 66 are formed in the flow port member 58 and communicate between the inner surface 62 thereof and the cylindrically shaped outer periphery 68 thereof.

The upper end portion 70 of the flow port member 58 is threadedly secured within the lower end portion 72 of an actuator port member 74. The actuator port member 74 includes a medial cylindrically shaped inner surface 76 coaxially aligned with the surface 62 and extending upwardly from a point near the threaded interconnection between the actuator port member 74 and the flow port member 58. A second cylindrically shaped inner surface 78, having a diameter less than the diameter of the medial cylindrically shaped inner surface 76 and coaxially aligned therewith extends downwardly from the upper end portion 80 of the actuator port member 74. An annular wall 82 is formed on the actuator port member 74 and interconnects the cylindrically shaped inner surfaces 76 and 78. An upper end face 84 is formed on the upper end portion 80 of the actuator port member 74.

At least one actuator port 86 extends radially through the actuator port member 74 and communicates between an annular chamber 88 having a diameter slightly greater than the diameter of the medial cylindrically shaped inner surface 76 and positioned intermediate the medial cylindrically shaped inner surface 76 and the upper end portion 70 of the flow port member 58. Each actuator port 86 communicates between the annular chamber 88 and the cylindrically shaped outer periphery 90 of the actuator port member 74.

The upper end portion 80 of the actuator port member 74 is threadedly secured within the lower end portion 92 of a cylindrically shaped spring housing 94. An annular seal 95 provides a fluid-tight seal between the actuator port member 74 and the spring housing 94. The upper end portion 96 of the spring housing 94 is threadedly secured about the lower end portion 98 of

a piston-retaining collar 100. An annular seal 102 provides a fluid-tight seal between the spring housing 94 and the piston-retaining collar 100.

The collar 100 includes a cylindrically shaped inner surface 104 extending therethrough in substantial coaxial alignment with the longitudinal axis of the valve assembly 10. A pair of annular grooves 106 are formed in the collar 100 and extend radially outwardly from the inner surface 104. A suitable annular seal member 108, such as an O-ring, is disposed within each groove 106 for purposes which will be described more fully hereinafter.

The piston-retaining collar 100 also includes a lower end face 110 and an upper end face 112. The cylindrically shaped inner surface 104 intersects the upper and lower end faces 112 and 110.

The piston 16, having a cylindrically shaped outer periphery 116 formed thereon, is slidably disposed within the cylindrically shaped inner surface 104 of the piston-retaining collar 100. The piston 16 is adapted for longitudinal movement relative to the collar 100. The seals 108 provides a fluid-tight sliding seal between the piston 16 and the piston-retaining collar 100.

An outwardly extending flange 118 is formed on the lower end portion 120 of the piston 16. Upward movement of the piston 16 relative to the collar 100 is restricted by the abutment of the flange 118 with the lower end face 110 of the collar 100, as shown in FIG. 1. The upper end portion 122 or rod end of the piston 16 extends outwardly through the collar 100 and is threadedly secured within the lower end portion 124 of a fishing neck 126. The fishing neck 126 includes a lower end face 128 which limits the downward movement of the piston 16 relative to the collar 100 by abutting the upper end face 112 of the piston-retaining collar 100, as shown in FIG. 2. The upper end portion 130 of the fishing neck 126 includes a transverse aperture 132 formed therein which may be secured to a wire line or a sand line (not shown) for lowering the valve assembly 10 downwardly through the tubing string 44 and, alternately, retrieving the valve assembly 10 upwardly through the tubing string 44. A lower end face 134 is formed on the lower end portion 120 of the piston 16.

The valve member 14 comprises a lower element 136 and an upper element 138. The upper end portion 140 of the lower element 136 is threadedly secured within the lower end portion 142 of the upper element 138. An annular seal 144 provides a fluid-tight seal between the lower element 136 and the upper element 138.

The lower or first end portion 146 of the valve member 14 includes a cylindrically shaped outer periphery 148 sized to provide a sliding fit within the first cylindrically shaped inner surface 62 of the valve body 12. A pair of annular grooves 150 are formed in the cylindrically shaped outer periphery 148 and extend radially inwardly therefrom. A pair of annular seal members 152, such as O-rings, are disposed respectively in the grooves 150 and provide a sliding, fluid-tight seal between the lower end portion 146 of the valve member 14 and the first cylindrically shaped inner surface 62 of the valve body 12.

A cylindrically shaped outer periphery 154 is formed on the medial portion 156 of the valve member 14. The cylindrically shaped outer periphery 154 is sized and shaped to be slidably received within the medial cylindrically shaped inner surface 76 of the valve body 12.

A pair of annular grooves 158 are formed in the cylindrically shaped outer periphery 154 and extend radially inwardly therefrom. A pair of annular seal members 160, such as O-rings, are disposed respectively in the annular grooves 158 and provide a sliding, fluid-tight seal between the medial portion 156 of the valve member 14 and the medial cylindrically shaped inner surface 76 of the valve body 12.

A cylindrically shaped outer periphery 162 is formed on the upper or second end portion 164 of the valve member 14. The cylindrically shaped outer periphery 162 is sized and shaped to provide a close, sliding fit within the second cylindrically shaped inner surface 78 of the valve body 12. A pair of annular grooves 166 are formed in the cylindrically shaped outer periphery 162 and extend radially inwardly therefrom. A pair of annular seal members 168, such as O-rings, are disposed respectively within the annular grooves 166 and provide a sliding, fluid-tight seal between the upper or second end portion 164 of the valve member 14 and the second cylindrically shaped inner surface 78 of the valve body 12.

An annular recess 170 is formed in the outer periphery of the valve member 14 intermediate the cylindrically shaped outer periphery 148 and the cylindrically shaped outer periphery 154. Annular recesses 172 and 174 are formed on the outer periphery of the valve member 14 intermediate the cylindrically shaped outer periphery 154 and the cylindrically shaped outer periphery 162. The annular recesses 172 and 174 are connected by a radial wall 175.

A cylindrically shaped, blind cavity 176 is formed in the valve member 14 and intersects the lower end face 178 of the valve member 14. A pressure equalization port 180 is formed in the valve member 14 and communicates between the cavity 176 and the annular recess 172.

The upper end face 182 of the valve member 14 abuts the lower end face 184 of a spring stop 186. The spring stop 186 has a cylindrically shaped outer periphery 188 having a diameter greater than the diameter of the second cylindrically shaped inner surface 78 of the valve body 12.

The compression coil spring 18 is disposed within the spring housing 94 and intermediate the piston 16 and the spring stop 186. The upper end 190 of the spring 18 abuts the lower end face 134 of the piston 16, while the lower end 192 of the spring 18 abuts the upper end face 194 of the spring stop 186.

DESCRIPTION OF THE EMBODIMENT OF FIG. 6

FIG. 6 illustrates alternate structure for predetermining the valve-opening pressure of the valve assembly 10. The adjustment of the valve-opening pressure in the apparatus of FIG. 6 is accomplished by the positioning of one or more spacer rings 196 around the piston 16 intermediate the upper end face 112 of the piston-retaining collar 100 and the lower end face 128 of the fishing neck 126. As each spacer ring 196 is added to the valve assembly 10, the valve-opening pressure is proportionately decreased. It will be readily apparent that the valve-opening pressure may be accurately predetermined by selecting the proper number and thickness of spacer rings 196 for installation on the valve assembly 10.

OPERATION OF THE PREFERRED EMBODIMENT

The operation of the valve assembly 10 is clearly illustrated in FIGS. 1-4. FIG. 1 illustrates the relationship of the various elements of the valve assembly 10 as the valve assembly 10 is being dropped through the tubing string 44 to its ultimate seating position below. The valve assembly 10 may be allowed to freely fall through the tubing string 44, as shown in FIG. 1, or it may be lowered by means of a wire line or sand line (not shown) secured through the aperture 132 in the fishing neck 126. In either case, the relationship of the elements of the valve assembly 10 will be as illustrated in FIG. 1.

It will be seen in FIG. 1 that, as the valve assembly is moving downwardly through the tubing string 44, the valve member 14 is at its lowest position within the valve body 12. In this case the lower end face 178 of the valve member 14 abuts the annular end wall 64 of the valve body 12. The annular seal members 152 sealingly engage the first cylindrically shaped inner surface 62 of the valve body 12 below the flow control ports 66. When the valve member 14 is in this position relative to the valve body 12, the valve assembly 10 is in the closed position.

FIG. 2 illustrates the valve assembly 10 in its seated position with the no-go shoe 32 engaging the seating nipple 42, and with the annular seal 36 providing a fluid-tight seal between the valve assembly 10 and the inner periphery 52 of the seating nipple 42. It will also be understood that the tubing string 44, as illustrated in FIG. 2, has been loaded with suitable treating liquid which is confined within the tubing string 44 by means

of the closed valve assembly 10. As the pressure of the fluid within the tubing string 44 is increased by a suitable pump (not shown) at the ground surface, the piston 16 is forced downwardly in response to the hydraulic pressure acting across the area defined by the diameter of the outer periphery 116 of the piston 16. The movement of the piston 16 in the downwardly direction is resisted only by the compression spring 18 and the air at atmospheric pressure trapped within the longitudinal passageway 24 of the valve body 12 between the annular seal members 108 and 168.

When the piston 16 is moved downwardly by the increased fluid pressure within the tubing string 44, the compression spring 18 is compressed to its predetermined valve-opening value. The valve-opening value is determined by the spring rate of the compression spring 18 and the length of stroke of the piston 16. For a compression spring 18 of a given spring rate, various valve-opening values may be predetermined by selecting a piston-retaining collar 100 having a specific longitudinal length from the lower end face 110 to the upper end face 112. It will be seen that the greater the longitudinal distance between the lower end face 110 and the upper end face 112, the less the spring 18 can be compressed by the piston 16 and, therefore, the lower the predetermined valve-opening pressure. It will also be apparent that by selecting a shorter piston-retaining collar 100, a higher valve-opening pressure will be obtained. FIG. 5 illustrates three sizes of the collar 100 with the collar configured for the highest valve-opening pressure shown by solid lines while the configuration of

collars designed for lower valve-opening pressures are partially illustrated by dashed lines.

As the hydraulic pressure within the tubing string 44 is increased by the pumping action, the fluid communicating with the cross-sectional area of the valve member 14 defined by the diameters of the medial cylindrically shaped inner surface 76 and the first cylindrically shaped inner surface 62 through the actuator port 86 overcomes the downward bias of the spring 18 on the valve member 14 and forces the valve member 14 upwardly into the open position. When the valve member 14 is moved upwardly into the open position, the radial wall 175 of the valve member 14 abuts the annular wall 82 of the valve body 12 thus limiting the upward movement of the valve member 14 relative to the valve body 12, as shown in FIG. 3. It will be seen also that the annular seal members 152 are now positioned above the flow control ports 66, thereby allowing fluid to flow through the flow control ports 66 into the passageway 24 through the valve body 12 and downwardly out of the valve assembly 10 into the portion of the tubing string 44 below the valve assembly 10 and into the area to be treated. Because the differential area defined by the diameters of the medial and first cylindrically shaped inner surfaces 76 and 62 is specifically designed to be slightly less than the area defined by the diameter of the outer periphery 116 and the piston 16, the upward movement of the valve member 14 can only compress the compression spring 18, and the piston 16 will remain in its lowermost position.

It should also be noted that when the valve assembly 10 is in the open position, fluid pressure acting through the cavity 176 and the pressure equalization port 180 is applied to a differential cross-sectional area defined by the diameters of the medial and second cylindrically shaped inner surfaces 76 and 78, which differential area is equal to the cross-sectional area defined by the diameter of the first cylindrically shaped inner surface 62. This differential area relationship prevents the pressure below the valve assembly 10 from having any effect on the operation of the valve assembly 10.

When pumping ceases, and the pressure on the fluid in the tubing string 44 is allowed to fall below the predetermined opening pressure of the valve assembly 10, the spring 18 forces the valve member 14 downwardly thereby closing the flow control ports 66, thus placing the valve assembly 10 back in the condition illustrated in FIG. 2.

When treatment has been completed and pumping has been discontinued, a conventional overshot (not shown) may be lowered through the tubing string 44 to engage the upper end portion 130 of the fishing neck 126 and may be pulled upwardly to move the piston 16 upwardly thereby de-energizing the spring 18. This action may also be accomplished by moving the fishing neck 126 upwardly by pulling a wire line or sand line (not shown) engaged through the aperture 132 upwardly through the tubing string 44. This action allows the hydraulic pressure within the tubing string 44 to operate through the actuator port 86 on the differential area defined by the diameters of the first cylindrically shaped inner surface 62 and the medial cylindrically shaped inner surface 76 to move the valve member 14 up into the open position. This movement of the valve member 14 allows the tubing pressure to equalize through the valve assembly 10 through the flow control ports 66 through the cavity 176 into the tubing string

44 below the valve assembly 10 to form a by-passing action so that the valve assembly 10 can be retrieved off its seat on the seating nipple 42. FIG. 4 therefore shows the relationship of the elements of the valve assembly 10 when it is desired to retrieve the valve assembly 10 and when the tubing pressure is higher above the valve assembly 10 than below.

One application of the valve assembly 10 has been demonstrated in the chemical treatment of an oil well to remove calcium sulfate scale from an open hole section. The valve assembly 10 was used in this particular low fluid level well to control chemical placement. The valve assembly 10 was dropped through the tubing string 44 and seated in a seating or landing nipple 42 at 4,198 feet, as schematically illustrated in FIG. 7. The tubing string 44 was then loaded with 800 gallons of oil. The oil was displaced with 220 gallons of chemical, followed with water. The chemical was spotted in the well bore at a rate of $2\frac{1}{4}$ barrels per minute in two stages of 110 gallons each.

The spotting of the chemical was accomplished by raising the fluid pressure within the tubing string 44 with a suitable pump 198 to a pressure above the predetermined opening pressure of the valve assembly 10 and then measuring the flow through the tube string with a suitable flowmeter 200 to determine when 110 gallons had been pumped. Upon determination of the pumping of 110 gallons, pumping was discontinued and the pressure in the tubing string 44 was allowed to drop below the valve-opening pressure of the valve assembly 10. After the second 110 gallons of chemical was pumped through the valve assembly 10, pumping was discontinued and the tubing string 44 was swabbed dry in a conventional manner to remove the displacing fluid remaining in the tubing string. The valve assembly 10 was then retrieved from the tubing string 44 on a sand line and the well was put back on production.

FIGS. 8a, 8b, and 8c schematically illustrate another application for the valve assembly 10. This particular application involved the acidizing of three sets of perforations in an oil well. In this well, paper had been used to seal off the three sets of perforations while the hole was deepened. The valve assembly 10 was used successfully to selectively acidize the perforations and aid in the removal of the paper therefrom. A conventional retrievable packer 202 and a conventional retrievable bridge plug 204 were run in conjunction with the tubing string 44.

The lower zone 206, comprising the first set of perforations, was straddled and sealed off with the packer 202 and the bridge plug 204, as shown in FIG. 8a. The valve assembly 10 was run in through the tubing string 44 on a sand line and seated at 3,415 feet in a landing or seating nipple 42. The tubing string 44 was loaded with 1,500 gallons of acid above the closed valve assembly 10. A total of 500 gallons of acid was pumped by pump 198 into each set of perforations located respectively in the lower, middle, and upper zones, 206, 208 and 210, successively, at a rate of two barrels per minute, as shown in FIGS. 8a, 8b and 8c. The volume of the fluid displaced into zone was measured by a conventional flowmeter 200. Displacement fluid for the lower and middle zones 206 and 208 was the acid for the treatment of the next set of perforations. Volume of flow into each zone was measured by flowmeter 200.

As the packer 202 and bridge plug 204 were moved to straddle the zone next above, the closed valve assembly 10 held the acid in place in the tubing. Water was used as the displacing fluid for the treatment of the upper zone 210.

The tubing string 44 was swabbed dry in a conventional manner after the upper zone 210 was acidized to keep the displacing fluid from entering the zone. The valve assembly 10 was then retrieved on a sand line upwardly through the tubing string 44 and the packer 202 and bridge plug 204 were removed and the well was successfully completed.

Using this procedure employing the valve assembly 10, each set of perforations in the respective lower, middle and upper zones 206, 208 and 210, received the prescribed 500 gallons of acid. The use of the valve assembly 10 further allowed the use of acid as the displacing fluid for the next successive treatment stage thereby eliminating the need to swab the displacing fluids out of the tubing string between stages, and preventing overflushing the spent acid into the next zone to be treated.

SUMMARY OF THE ADVANTAGES

From the foregoing detailed description of the retrievable fluid control valve assembly 10, and its operation, it will be seen that the valve assembly 10 provides a number of distinct advantages to the user. The valve assembly can be run into a well and can be removed and replaced therefrom without the necessity of pulling the string of tubing. The valve assembly 10 may be run into a tubing string and retrieved therefrom on a wire line or sand line, or it may be dropped through the tubing string into operating position. The valve assembly 10 provides reliable means for retaining expensive chemicals in place within the tubing string in low fluid level wells. The employment of the valve assembly 10 permits the removal of the final displacement fluid after a treating job from the tubing string without subjecting the formation under treatment to the displacement fluid. The capability of the valve assembly 10 for permitting the predetermined valve-opening pressure to be readily adjusted permits its use in bore holes of various depths and with various fluid weights.

Changes may be made in the construction and arrangement of parts or elements of various embodiments described herein without departing from the spirit and scope of the present invention as defined herein.

What is claimed is:

1. A retrievable fluid control valve for seating in a seating nipple within a tubing string to control the flow of fluid downwardly through the tubing string in response to fluid pressure applied thereto, comprising:
 - a valve body having opposite end portions and a longitudinal passageway extending therethrough and having a fluid flow control port and a valve member actuator port formed therein, each port communicating between the passageway and the outer periphery of said valve body;
 - a valve member slidably disposed within the passageway of said valve body for longitudinal movement therein between a closed position blocking fluid flow between the outer periphery of said valve body and the passageway therethrough and an open position allowing fluid flow between the outer periphery of said valve body and the passageway

through the fluid flow control port responsive to fluid pressure acting thereon through the valve member actuator port in said valve body;
 means formed on said valve body intermediate one end portion thereof and the fluid flow control port for seating the valve body in the seating nipple;
 means formed on said valve body for providing a fluid-tight seal between the outer periphery of said valve body and the tubing string intermediate the fluid flow control port and the one end portion thereof;
 piston means slidably disposed in the passageway adjacent to the opposite end portion of said valve body and longitudinally movable therein in response to the fluid pressure within the tubing string acting thereon; and
 biasing means disposed intermediate said valve member and said piston means for urging said valve member into the closed position in response to the movement of said piston means responsive to the application of fluid pressure to said piston means.

2. The retrievable fluid control valve as defined in claim 1 characterized further to include:
 means carried by said valve body and engageable with said piston means for limiting the movement of said piston means in response to fluid pressure acting therein whereby said biasing means urges said valve member into the closed position with a force corresponding to a predetermined valve-opening fluid pressure.

3. The retrievable fluid control valve as defined in claim 2 characterized further to include:
 means securable to said piston means and responsive to an external force applied thereto for moving said piston means in a direction opposite to the direction of movement thereof responsive to fluid pressure within the tubing string.

4. The retrievable fluid control valve as defined in claim 2 characterized further to include:
 means securable to said piston means and responsive to an external force for moving said piston means in a direction opposite to the direction of movement thereof responsive to fluid pressure within the tubing string, and unseating said valve body from said seating nipple and retrieving said valve from said tubing string.

5. A retrievable pressure actuated valve assembly for controlling the flow of fluid through a conduit in response to fluid pressure within the conduit, comprising:
 a valve body positionable within the conduit, said valve body having an outer periphery, a first end portion and a second end portion, and having a longitudinal passageway extending therethrough and intersecting the first and second end portions;
 conduit seal means carried by said valve body for sealingly engaging the inner periphery of the conduit;
 piston means slidably disposed in the passageway through said valve body adjacent to the second end portion thereof for longitudinal movement within said valve body;
 retaining means formed on the second end portion of said valve body for retaining said piston means within said valve body;

rod means connected to said piston means and having the outer end thereof extending through said retaining means for communicating with the fluid in the conduit;
 limit means secured to the outer end of said rod means for limiting the longitudinal movement of said piston means within said valve body toward the first end portion thereof;
 means carried by said rod means securable to an external source of power for moving said piston means longitudinally within said valve body toward the second end portion thereof;
 a valve member slidably disposed within the passageway through said valve body intermediate the first end portion thereof and said piston means, said valve member having an outer periphery, a first end portion positioned proximate to the first end portion of said valve body, a second end portion positioned proximate to said piston means, and a medial portion intermediate said first and second end portions, said valve member having a cavity formed therein and intersecting the first end portion thereof and having a port formed therein communicating between the cavity and the outer periphery of said valve member intermediate the medial portion and the second end portion thereof;
 a first cylindrically shaped inner surface formed in the passageway of said valve body adjacent to the first end portion of said valve member;
 a second cylindrically shaped inner surface formed in the passageway of said valve body adjacent to the second end portion of said valve member;
 a medial cylindrically shaped inner surface formed in the passageway of said valve body intermediate the first and second cylindrically shaped inner surfaces and adjacent to the medial portion of said valve member, said medial cylindrically shaped inner surface having a diameter greater than the diameter of the first cylindrically shaped inner surface and greater than the diameter of the second cylindrically shaped inner surface;
 first seal means carried by the first end portion of said valve member for providing a sliding seal between the first end portion of said valve member and the first cylindrically shaped inner surface of said valve body;
 second seal means carried by the second end portion of said valve member for providing a sliding seal between the second end portion of said valve member and the second cylindrically shaped inner surface of said valve body;
 medial seal means carried by the medial portion of said valve member for providing a sliding seal between the medial portion of said valve member and the medial cylindrically shaped inner surface of said valve body;
 means carried by said valve body for restricting the sliding movement of said valve member within the passageway of said valve body between a closed position proximate to the first end portion of said valve body and an open position distal from the first end portion of said valve body;
 biasing means disposed within the passageway through said valve body intermediate the second end portion of said valve member and said piston means for urging said valve member longitudinally

away from said piston means into the closed position;

a fluid flow control port formed in said valve body and communicating between the outer periphery thereof and the passageway therethrough, said fluid flow control port being positioned in said valve body such that when said valve member is in the closed position said first seal means is positioned longitudinally intermediate said fluid flow control port and the first end portion of said valve body, and when said valve member is in the open position said first seal means is positioned longitudinally intermediate said fluid flow control port and the second end portion of said valve body; and

a valve member actuating port formed in said valve body and communicating between the outer periphery thereof and the passageway therethrough, said valve member actuating port being positioned in said valve body such that it remains longitudinally intermediate said first seal means and said medial seal means in all longitudinal positions of said valve member relative to said valve body.

6. A method of treating a formation in a bore hole having a tubing string disposed therein, said tubing string including a seating nipple therein, comprising the steps of:

introducing a closed, de-energized, pressure-controlled fluid control valve, having a predetermined opening pressure, through the tubing string into sealing relationship with the seating nipple;

loading the tubing string above the closed fluid control valve with a predetermined amount of treating fluid to thereby energize the valve;

pumping a displacement fluid into the tubing string to raise the pressure within the tubing string action on the valve at least to the predetermined opening pressure of the valve;

automatically opening the valve at the predetermined opening pressure in response to the application of fluid pressure in the tubing string acting on the valve;

pumping the predetermined amount of treating fluid through the open valve into the formation;

ceasing pumping when the predetermined amount of treating fluid has passed through the open valve into the formation and lowering the pressure in the tubing string acting on the valve below the predetermined opening pressure; and

automatically closing the pressure-controlled fluid control valve in response to the application of fluid pressure in the tubing string on the valve at a pressure below the predetermined opening pressure of the valve.

7. The method as defined in claim 6 and characterized further to include the additional steps of:

removing the displacement fluid from the tubing string; and

retrieving the valve up through the tubing string.

8. A method of treating a plurality of zones in a bore hole comprising the steps of:

running a tubing string, with a seating nipple therein, into the bore hole with a retrievable packer and a retrievable bridge plug;

straddling a first zone with the packer and the bridge plug;

setting the packer in sealing relation between the tubing string and the bore hole;

setting the bridge plug in sealing relation with the bore hole to close the bore hole below the tubing string;

introducing a closed, de-energized, pressure-controlled fluid control valve, having a predetermined opening pressure, through the tubing string into sealing relation with the seating nipple;

loading the tubing string with a predetermined amount of treating fluid to thereby energize the valve;

pumping a displacement fluid into the tubing string to raise pressure within the tubing string acting on the valve at least to the predetermined opening pressure of the valve;

automatically opening the valve at the predetermined opening pressure in response to the application of fluid pressure in the tubing string acting on the valve;

pumping a predetermined portion of the treating fluid through the open valve and out of the tubing string into the first zone between the packer and the bridge plug;

ceasing pumping when the predetermined portion of the treating fluid has passed through the open valve, and lowering the pressure in the tubing string acting on the valve below the predetermined opening pressure of the valve;

automatically closing the valve in response to the fluid pressure in the tubing string acting on the valve at a pressure below the predetermined opening pressure of the valve;

treating the first zone with the treating fluid;

releasing the packer from sealing relation between the tubing string and the bore hole;

releasing the bridge plug from sealing relation with the bore holes;

straddling a second zone with the packer and the bridge plug;

setting the packer in sealing relation between the tubing string and the bore hole;

setting the bridge plug in sealing relation with the bore hole to close the bore hole below the tubing string;

pumping a displacement fluid into the tubing string to raise the pressure within the tubing string acting on the valve at least to the predetermined opening pressure of the valve;

automatically opening the valve at the predetermined opening pressure in response to the application of fluid pressure in the tubing string acting on the valve;

pumping a predetermined portion of the treating fluid through the open valve and out of the tubing string into the second zone between the packer and the bridge plug;

ceasing pumping when the predetermined portion of the treating fluid has passed through the open valve and lowering the pressure in the tubing string acting on the valve below the predetermined opening pressure of the valve;

automatically closing the valve in response to the application of fluid pressure in the tubing string acting on the valve at a pressure below the predetermined opening pressure of the valve; and

treating the second zone with the treating fluid.

9. The method as defined in claim 8 wherein the predetermined amount of treating fluid loaded into the tubing string comprises the predetermined portions of the treating fluid pumped into the first and second zones.

10. The method as defined in claim 9 characterized further to include the additional steps of:

removing the displacement fluid from the tubing string; and

retrieving the valve up through the tubing string. 10

11. The method as defined in claim 10 characterized further to include the additional steps of:

releasing the packer from sealing relation between the tubing string and the bore hole;

releasing the bridge plug from sealing relation with the bore hole; and 15

retrieving the packer and bridge plug from the bore hole.

12. A method of controlling the application of a treating liquid to a formation penetrated by a bore hole 20 having a tubing string disposed therein, comprising the

steps of:

adjusting a closed, de-energized, hydraulic pressure-energized liquid control valve to open at a predetermined hydraulic pressure;

5 introducing said liquid control valve into said tubing string;

energizing said liquid control valve by introducing said treating liquid into said tubing string;

increasing the hydraulic pressure of said treating liquid in said tubing string at said valve to a value at least equal to said predetermined hydraulic pressure to thereby open said valve;

maintaining at least said predetermined hydraulic pressure at said valve to permit the passage of said treating liquid through said open valve and into contact with said formation; and

reducing the hydraulic pressure at said valve to a value less than said predetermined hydraulic pressure to close said valve and thereby terminate passage of said treating liquid therethrough.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,847,223 Dated November 12, 1974

Inventor(s) Theron A. Scott and Walter E. Hyde

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 9, line 26, delete the word "tube" and insert therefor the word --tubing--.

In Column 9, line 63, between the words "into" and "zone" insert the word --each--.

In Claim 2, at Column 11, line 29, delete the word "therein" and insert the word --thereon--.

In Claim 6, at Column 13, line 37, delete the word "action" and insert the word --acting-- therefor.

In Claim 12, at Column 16, line 18, delete the word "valve" and insert the word --value-- therefor.

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents