Description

The present invention relates generally to annulus pressure responsive downhole tools utilizing a liquid spring chamber.

One operation which is often performed on a well is to flow test the well by lowering a tester value into the well connected to a testing string, with the tester valve in the closed position until it reaches its final location within the well. Then the packer is set and the tester valve is opened by annulus pressure to allow the formation to produce through the test string. Quite often, these tester valves are constructed so that they are operated in response to changes in annulus pressure.

A typical annulus pressure responsive tester valve of the prior art is shown, for example, in U.S. Patent No. 3,856,085, and another somewhat modified example is shown at pages 3310—3311 of "Halliburton Services Sales and Service Catalog—No. 39", and designated as "APR Ball Valve Tester". Both of these tester valves utilize a chamber containing pressurized nitrogen gas as a spring chamber to bias the power piston in a direction opposite the direction in which it is biased by increased annulus pressure.

Also, it has been proposed in connection with a circulation valve to utilize such a compressed nitrogen gas chamber in combination with a floating shoe which transmits the pressure from the compressed nitrogen gas to a non-compressible liquid-filled chamber, which liquid-filled chamber is communicated with a well annulus through both a pressurizing and a depressurizing passage, each of which includes a fluid flow restriction means and a back pressure valve, to trap annulus pressure. This is known in U.S. Patent 4,113,012, which discloses a valve apparatus comprising an elongate housing, a flow passage disposed therein; flow valve means disposed in said housing and movable between a closed position wherein said flow passage is closed, and an open position wherein said flow passage is open; power mandrel means, disposed in said housing, said power mandrel means including a power piston, said power mandrel means being operatively associated with said flow valve means for moving said flow valve means from its closed position to its open position upon movement of said power mandrel means in a first direction longitudinally within said housing from a first position to a second position; power passage means disposed in said housing for transmitting pressure from a well annulus external of said housing to a first side of said power piston; a first chamber disposed in said housing and arranged to be filled with nitrogen gas, a second side of said power piston being in fluid communication with said first chamber so that pressure from said gas is transmitted to said second side of said power piston; a second chamber disposed in said housing; a floating piston means disposed in said second chamber and dividing said second chamber into an oil-filled first zone and a second zone; an equalizing passage means, disposed in said housing for transmitting said pressure from said well annulus external of said housing to said second zone of said second chamber; a pressurizing passage communicating said first chamber with said first zone of said second chamber; a first back pressure check valve means, disposed in said pressurizing passage, for allowing said oil to flow from said first zone of said second chamber through said pressurizing passage into said first chamber when a pressure in said first zone of said second chamber exceeds a pressure of nitrogen gas in said first chamber by a first predetermined value, and for preventing liquid from flowing from said first chamber through said pressurizing passage to said first zone of said second chamber; a depressurizing passage communicating said first chamber with said first zone of said second chamber; and a second back pressure check valve means, disposed in said depressurizing passage, for allowing said oil to flow from said first chamber through said depressurizing passage into said first zone of said second chamber when the gas pressure in said first chamber exceeds the oil pressure in said first zone of said second chamber by a second predetermined value, said second predetermined value being greater than said first predetermined value, and for preventing oil from flowing from said first zone of said second chamber through said depressurizing passage into said first chamber; said first chamber being divided by a floating piston into an upper region containing said gas and a lower region containing said oil.

One significant disadvantage of all these nitrogen gas-filled valves, is that the nitrogen chamber must be filled with pressurized nitrogen gas under extremely high pressures while the valve is still located at the surface, and before it is lowered into the well. This creates safety problems due to the difficulties of containing the high pressure gas.

We have now found that a tool similar to that in U.S. Patent No. 4,113,012 can be modified to operate with a compressible liquid in place of the nitrogen gas. Liquid springs using silicone liquid in downhole tools are discussed in U.S. Patent No. 4,109,724 and U.S. Patent No. 4,109,725.

According to the present invention, there is provided a valve apparatus comprising an elongate housing having an axial flow passage disposed therein; flow valve means disposed in said housing and movable between a closed position wherein said flow passage is closed, and an open position wherein said flow passage is open; power mandrel means, disposed in said housing, said power mandrel means including a power piston, said power mandrel means being operatively associated with said flow valve means for moving said flow valve means from its closed position to its open position upon movement of said power mandrel means in a first direction longitudinally within said housing from a first position to a second position; power passage

means disposed in said housing for transmitting pressure from a well annulus external of said housing to a first side of said power piston; a first chamber disposed in said housing, a second side of said power piston being in fluid communication with said first chamber so that pressure from said first chamber is transmitted to said second side of said power piston; a second chamber disposed in said housing; a floating piston means disposed in said second chamber and dividing said second chamber into a first zone and a second zone; an equalizing passage means, disposed in said housing for transmitting said pressure from said well annulus external of said housing to said second zone of said second chamber; a pressurizing passage communicating said first chamber with said first zone of said second chamber; a first back pressure check valve means, disposed in said pressurizing passage, for allowing fluid to flow from said first zone of said second chamber through said pressurizing passage into said first chamber when a pressure in said first zone of said second chamber exceeds a pressure in said first chamber by a first predetermined value, and for preventing fluid from flowing from said first chamber through said pressurizing passage to said first zone of said second chamber; a depressurizing passage communicating said first chamber with said first zone of said second chamber; and a second back pressure check valve means, disposed in said depressurizing passage, for allowing fluid to flow from said first chamber through said depressurizing passage into said first zone of said second chamber when the pressure in said first chamber exceeds the pressure in said first zone of said second chamber by a second predetermined value, said second predetermined value being greater than said first predetermined value, and for preventing fluid from flowing from said first zone of said second chamber through said depressurizing passage into said first chamber; characterised in that the flow passage extends axially of the housing, the valve means is a ball valve means disposed in the flow passage in the housing; and wherein said first chamber is divided into a first zone and a second zone by a second floating piston; said first zone of said first chamber is filled with a compressible liquid; said second zone of said first chamber is communicated with said pressurizing passage and said depressurizing passage; and both said second zone of said first chamber and said first zone of said second chamber are filled with a substantially noncompressible liquid.

In one preferred embodiment, the invention provides a valve apparatus, as defined above and comprising: an outer housing including: an upper housing adapter; a valve housing section connected to said upper housing adapter; an upper filler nipple connected to said valve housing section; a power housing section connected to said upper filler nipple; a liquid spring chamber connector connected to said power housing section; a liquid spring chamber housing section connected to said liquid spring chamber connector; a lower filler nipple connected to said liquid spring chamber housing section; a lower housing section connected to said lower filler nipple; and a lower housing adapter connected to said lower housing section; valve means, disposed in said valve housing section, and movable between open and closed positions; power mandrel means, disposed in said outer housing, and including a power piston received within a cylindrical inner bore of said power housing section, said power mandrel means being operatively associated with said valve means for movement of said valve means between its open and closed positions upon movement of said power piston within said power housing section, a lower end of said power mandrel means being slidably and sealingly received within a central bore of said liquid spring chamber connector; a power port disposed through a wall of said power housing section and arranged to be in fluid communication with an upper side of said power piston; a liquid spring chamber mandrel means having an upper end connected to said liquid spring chamber connector and a lower end received in a bore of said lower filler nipple, said liquid spring chamber mandrel means being spaced radially inward from said liquid spring chamber housing section so as to define an annular main spring chamber which is in fluid communication with a lower side of said power piston; a lower mandrel having an upper end connected to said lower filler nipple and a lower end sealingly received in a bore of said lower housing adapter, said lower mandrel being spaced radially inward from said lower housing section to define an annular equalizing chamber; a metering cartridge disposed between said lower housing section and said lower mandrel at an upper end of said equalizing chamber; pressurizing passage means, disposed through said lower filler nipple and said metering cartridge, for communicating said main spring chamber with said equalizing chamber; a pressurizing back pressure check valve disposed in said pressurizing passage means within said metering cartridge, for allowing liquid to flow from said equalizing chamber to said main spring chamber; a first time delay liquid flow restriction disposed in said pressurizing passage means within said metering cartridge; a depressurizing passage means, disposed through said lower filler nipple and said metering cartridge for communicating said main spring chamber with said equalizing chamber; a depressurizing back pressure check valve, disposed in said depressurizing passage means within said metering cartridge, for allowing liquid to flow from said main spring chamber to said equalizing chamber; a second time delay liquid flow restriction disposed in said depressurizing passage means within said metering cartridge; an equalizing port disposed through a wall of said lower housing section; said first floating piston means being disposed in said equalizing chamber above said equalizing port.

The invention further provides a method of flow testing a well, said method comprising the steps of: lowering into said well a flow tester valve comprising a valve apparatus of the invention, wherein said compressible liquid is at substantially atmospheric pressure as said lowering is begun; transmitting annulus fluid pressure from an annulus of said well to said compressible liquid as said flow tester valve is lowered into said well; locating said flow tester valve with said well at a final depth; pressurizing said annulus an additional amount, above a hydrostatic pressure therein, sufficient to open said flow tester valve; transmitting at least a portion of said additional amount of annulus pressure to said compressible liquid; depressurizing said annulus to a final annulus pressure; as said annulus is depressurized, trapping a portion of the pressure in said compressible liquid in excess of said final annulus pressure sufficient to close said flow tester valve, so that a trapped amount of liquid pressure energy trapped in said compressible liquid in excess of an amount of liquid pressure energy within said compressible liquid when said liquid spring means was at substantially atmospheric pressure is entirely obtained from transmittal of liquid pressure energy from said well annulus to said compressible liquid; and closing said flow tester valve, upon depressurizing of said annulus, by use of said trapped liquid pressure energy.

In preferred embodiments of the present invention, a tester valve apparatus utilizes a silicone liquid spring chamber. Significant safety advantages are provided as compared to the nitrogen-filled units of the prior art since the safety problems of dealing with high pressure nitrogen are eliminated. Additionally, the structure for, and manner of operating and controlling the pressure within, the silicone liquid spring chamber are improved in numerous respects as compared to the two prior silicone liquid filled tools referred to above.

The valve apparatus of the present invention generally includes an elongate housing with a flow valve means disposed therein for opening and closing an axial flow passage of the housing. A power mandrel means is disposed in the housing and includes a power piston. The power mandrel means is connected to the flow valve means. A power passage transmits well annulus pressure to the top side of the power piston. A first chamber is disposed in the housing and filled at least partially with compressible liquid. The lower side of the power piston is in communication with this first chamber. A second chamber is also disposed in the housing and has a floating piston means disposed therein dividing the second chamber into a first zone and a second zone. An equalizing passage is disposed through the housing for transmitting well annulus pressure to the second zone of the second chamber. Both a pressurizing passage and a depressurizing passage each communicate the first chamber with the first zone of the second chamber. A first back pressure check valve means and a first fluid flow restriction are placed in the pressurizing passage for fluid communication from the first zone of the second chamber to the first chamber. A second back pressure check valve means and a second fluid flow restriction are placed in the depressurizing passage, in reverse order of those just described, for fluid communication from the first chamber to the first zone of the second chamber. This arrangement provides a means for trapping a portion of the well annulus fluid in the first chamber so as to provide liquid pressure energy for returning the power mandrel and the flow-valve to the closed position upon depressurizing of the well annulus.

In an alternative embodiment of the present invention, the power piston includes a main piston and a booster piston. The booster piston aids in initially overcoming the frictional resistance of the ball valve to opening.

In order that the invention may be more fully understood, reference is made to the accompanying drawings, wherein:

Fig. 1 is a schematic elevation view of a representative offshore installation which may be employed for formation testing purposes, and illustrates a formation testing string or tool assembly in position in a submerged well bore and extending upwardly to the floating operating and testing station.

Figs. 2A—2J comprise an elevational section view of a tester valve of the present invention but without a second floating piston in the first chamber;

Fig. 3 is a view similar to Fig. 2G but showing an embodiment in accordance with the present invention wherein a second floating piston is provided in the first chamber.

Fig. 4 is an elevational section view of a locater tool for initially positioning the lower floating piston within the equalizing chamber.

During the course of drilling an oil well, the borehole is filled with a fluid known as drilling fluid or drilling mud. One of the purposes of this drilling fluid is to contain in intersected formations any fluid which may be found there. To contain these formation fluids the drilling mud is weighted with various additives so that the hydrostatic pressure of the mud at the formation depth is sufficiently to maintain the formation fluid within the formation without allowing it to escape into the borehole.

When it is desired to test the production capabilities of the formation, a testing string is lowered into the borehole to the formation depth and the formation fluid is allowed to flow into the string in a controlled testing program. Lower pressure is maintained in the interior of the testing string as it is lowered into the borehole. This is usually done by keeping a valve in the closed position near the lower end of the testing string. When the testing depth is reached, a packer is set to seal the borehole thus closing in the formation from the hydrostatic pressure of the drilling fluid in the well annulus.

The valve at the lower end of the testing string

is then opened and the formation fluid, free from the restraining pressure of the drilling fluid, can flow into the interior of the testing string.

A typical arrangement for conducting a drill string test offshore is shown in Fig. 1. Such an arrangement would include a floating work station 10 stationed over a submerged well site 12. The well comprises a well bore 14 typically lined with a casing string 16 extending from the work site 12 to a submerged formation 18. The casing string 16 includes a plurality of perforations 20 at its lower end which provide communication between the formation 18 and the interior 22 of the well bore 14.

At the submerged well site is located a wellhead installation 23 which includes blowout preventer mechanisms. A marine conductor 24 extends from the wellhead installation to the floating work station 10. The floating work station 10 includes a work deck 27 which supports a derrick 28. The derrick 28 supports a hoisting means 30. A wellhead closure 32 is provided at the upper end of the marine conductor 24. The wellhead closure 32 allows for lowering into the marine conductor and into the well bore 14 of a formation testing string 34 which is raised and lowered in the well by the hoisting means 30.

A supply pump conduit 36 is provided which extends from a hydraulic pump 38 on the work deck 26 of the floating station 10 and extends to the wellhead installation 23 at a point below the blowout preventers to allow the pressurizing of a well annulus 40 surrounding the testing string 34.

The testing string 34 includes an upper conduit string portion 42 extending from the work deck 26 to the wellhead installation 23. A hydraulically operated conduit string test tree 44 is located at the lower end of the upper conduit string 42 and is landed in the wellhead installation 23 to thus support the lower portion of the formation testing string 34.

The lower portion of the formation testing string 34 extends from the test tree 44 to the formation 18. A packer mechanism 46 isolates the formation 18 from fluids in the well annulus 40. A perforated tail piece 48 is provided at the lower end of the formation testing string 34 to allow fluid communication between the formation 18 and the interior of the tubular formation testing string 34.

The lower portion of the formation testing string 34 includes intermediate conduit portion 50 and torque transmitting pressure and volume balance slip joint means 52. An intermediate conduit portion 54 is provided for imparting packer setting weight to the packer mechanism 46 at the lower end of the formation testing string 34.

A circulation valve 56 is located near the lower end of the formation testing string 34. Also near the lower end of the formation testing string 34 below the circulation valve 56 is located a tester valve 58 of the present invention which is described in more detail below.

A pressure recording device 60 is located below the tester valve 58.

The testing string 34 may also include numerous other items of related equipment, as is known to those skilled in the art.

Figs. 2A—2J show a cross-section elevation view of a preferred embodiment of downhole tester valve apparatus 58 of the present invention (except that it has no second floating piston in the first chamber).

The valve apparatus 58 includes an outer housing 62. The outer housing 62 itself includes an upper housing adapter 64, a valve housing section 66, an upper filler nipple 68, a power housing section 70, a liquid spring chamber connector 72, a liquid spring chamber housing section 74, a lower filler nipple 76, a lower housing section 78, and a lower housing adapter 80.

A holder mandrel 82 has an externally threaded upper end 84 threadedly connected to internally threaded surface 86 of a lower end of upper housing adapter 64.

The valve housing section 66 has an upper inner cylindrical surface 88 in which is closely received a lower outer cylindrical surface 90 of upper housing adapter 64. A resilient seal 92 is provided between surfaces 88 and 90, and a resilient seal 94 is provided between upper adapter 64 and holder mandrel 82.

The valve housing section 66 includes a plurality of radially inward extending splines 96 which are meshed with a plurality of radially outward extending splines 98 of holder mandrel 82.

Holder mandrel 82 includes a radially outward extending upward facing ledge 100 which is located below the radially outward extending splines 98 and engages lower ends 102 of the radially inward extending splines 96 so that the valve housing section 66 is held longitudinally and rotationally fixed relative to the upper housing adapter 64 by means of the holder mandrel 82.

An upper seat holder 104 has an upper cylindrical outer surface 106 closely received in a lower bore 108 of holder mandrel 82. A resilient seal 110 is provided between upper seat holder 104 and the bore 108.

Upper seat holder 104 includes a first annular groove 112 in a lower end thereof, within which is received an upper annular resilient seat 114. An upper seat retainer 116 is threadedly attached to upper seat holder 104 to hold the upper seat 114 in the groove 112.

A cylindrical collar 118 has an internally threaded upper end 120 attached to an outer threaded surface 122 of holder mandrel 82. Collar 118 has a radially inward extending lip 124 at a lower end thereof.

A lower seat holder 126 has a radially outward extending downward facing surface 128 engaging an upper side of the lip 124 of collar 118.

A second annular seat receiving groove 130 is disposed in the upper end of lower seat holder 126 and has a lower annular resilient seat 132 received therein. A lower seat retainer 134 is threadedly attached to the lower seat holder 126

to hold the lower seat 132 in the groove 130.

A ball valve 136, which may also be referred to as a full opening ball flow valve means, is spherical in shape and has a central bore 138 therethrough. The flow valve means 136 is shown in Fig. 2B in its closed position wherein its bore 138 is isolated from a longitudinal axial flow passage 140 of the tester valve apparatus 58 by the upper and lower seats 114 and 132. The flow valve means 136 sealingly engages the upper and lower resilient seats 114 and 132.

An operating means 142 includes a pin 144 which extends through a longitudinal opening in the collar 118 into an eccentric hole 146 of the flow valve means 136. Although only two small portions of the collar 118 are shown in Figs. 2A and 2B, the collar 118 is generally an elongated cylinder in shape having a continuous upper end which shows in cross section like the upper end 120 and having a continuous lower end which shows in cross section like the lip 124 with those upper and lower ends being connected by a thin cylinder which has two longitudinal openings therein.

Actually, there are two pins such as 144 which are eccentrically located on opposite sides of the bore 138 in a manner known to those skilled in the art. When the operating means 142 is moved longitudinally downward relative to the housing 62 from the position shown in Fig. 2B, the flow valve means 136 is rotated within the seats 114 and 132 to an open position wherein the bore 138 thereof is aligned with the axial flow passage 140 of the tester valve apparatus 58.

A power mandrel means 148 includes a top power mandrel section 150 and a bottom power mandrel section 152 which are threadedly connected together at 154. Formed on the bottom power mandrel section 152 is a power piston 156 which is received within a cylindrical inner bore 158 of power housing section 70.

Top power mandrel section 150 includes radially outward extending splines 160 which mesh with radially inward extending splines 162 of the lower end of upper filler nipple 68 to prevent relative rotation therebetween.

An intermediate portion of top power mandrel section 150 is closely and sealingly received within a bore 164 of upper filler nipple 68 and a seal therebetween is provided by seals 166.

A power mandrel cap 168 is threadedly attached to the upper end of top power mandrel section 150.

A connector assembly 170 includes an upper connector piece 172 and a lower connector piece 174 threadedly connected together at 176.

The upper connector piece 172 includes a groove 178 within which is received a lip 180 of operating means 142 so that operating means 142 and upper connector piece 172 move together longitudinally within the housing 62.

The power mandrel cap 168 is held between upward and downward facing surfaces 182 and 184 of connector assembly 170 so that upon longitudinal movement of power mandrel means 148, the connector assembly 170 moves longitudinally therewith which also moves the operating means 142 longitudinally therewith so as to operate the closure valve means 136.

A lower end of bottom power mandrel section 152 is closely slidably and sealingly received within a central bore 186 of liquid spring chamber connector 72. The seal therebetween is provided by seals 188 and 190.

A power port 192 is disposed through a wall of power housing section 70 and arranged to be in fluid communication with an upper side 194 of power piston 156.

A seal is provided between piston 156 and bore 158 at seal 196.

A releasable holding means 198 includes a radially resilient collet sleeve 200 held in place within the housing 62 by upper and lower collet retainer pieces 202 and 204 which are threadedly connected together at 206. The assembled upper and lower collet retainer pieces 202 and 204 are held between a downward facing ledge 208 of power housing section 70 and an upper end 210 of liquid spring chamber connector 72.

Releasable holding means 198 also includes a shoulder piece 212 threadedly connected to bottom power mandrel section 152 at threaded connection 214. Shoulder piece 212 includes thereon a plurality of radially outward extending shoulders 216.

Collet sleeve 200 includes upper and lower tapered surfaces 218 and 220, and shoulder 216 includes upper and lower tapered surfaces 222 and 224 arranged so that when shoulder 216 moves past sleeve 200 one of said tapered surfaces of the shoulder 216 engages one of the tapered surfaces of the sleeve 200 and causes the sleeve 200 to expand radially to allow the shoulder 216 to pass therethrough.

A liquid spring chamber mandrel means 226 includes an upper spring chamber mandrel piece 228 and a lower spring chamber mandrel piece 230 connected together at threaded connection 232.

An upper end of upper spring chamber mandrel piece 228 is threadedly connected to liquid spring chamber connector 72 at threaded connection 234.

A lower end 236 of lower spring chamber mandrel piece 230 is closely received within a bore 238 of lower filler nipple 76 and a seal therebetween is provided by seal 240.

Liquid spring chamber mandrel means 226 is spaced radially inward from liquid spring chamber housing section 74 so as to define an annular main spring chamber 242. Main spring chamber 242 communicates with a lower side 244 of power piston 156 through a connecting bore 246 disposed through liquid spring chamber connector 72 and an annular space 248 between power housing section 70 and bottom power mandrel section 152.

A lower mandrel 250 has an upper end connected to lower filler nipple 76 at threaded connection 252 and a lower end sealingly received in

a bore 254 of lower housing adapter 80. A seal is provided between lower mandrel 250 and bore 254 by seal 256.

The lower mandrel 250 is spaced radially inward from lower housing section 78 to define an annular equalizing chamber 258.

A cylindrical metering cartridge 260 is disposed between lower housing section 78 and lower mandrel 250 at an upper end of equalizing chamber 258.

A pressurizing passage means 262 includes an upper portion 264 disposed in lower filler nipple 76 and a lower portion 266 disposed in metering cartridge 260. Pressurizing passage means 266 communicates main spring chamber 242 with equalizing chamber 258.

Pressurizing back pressure check valve 268 is disposed in lower portion 266 of pressurizing passage means 262 for allowing liquid to flow from equalizing chamber 258 to the main spring chamber 242.

A first time delay liquid flow restriction 270 is disposed in lower portion 266 of pressurizing passage means 262. Also, a filter 271 is disposed in lower portion 266 of pressurizing passage means 262.

A depressurizing passage means 272 includes an upper portion 274 disposed in lower filler nipple 76 and a lower portion 276 disposed in metering cartridge 260. Depressurizing passage means 272 also communicates main spring chamber 242 with equalizing chamber 258.

A depressurizing back pressure check valve 278 is disposed in lower portion 276 of depressurizing passage means 272. A second time delay liquid flow restriction 280 is disposed in lower portion 276 of depressurizing passage means 272. Also, a filter 281 is disposed in lower portion 276 of depressurizing passage means 272.

A floating piston means 282 is disposed in equalizing chamber 258 between lower housing section 78 and lower mandrel 250. Seals 284 and 286 are provided between piston 282 and lower housing section 78. Seals 288 and 290 are provided between floating piston 282 and lower mandrel 250.

An equalizing port 292 is disposed through a wall of lower housing section 78 near a lower end thereof.

Upper filler nipple 68 has a fill port 294 disposed therethrough which is closed by a threaded plug 296.

Lower filler nipple 76 includes a fill port 298 closed by a plug 300. Lower filler nipple 76 also includes a second filler port 302 closed by a plug 304.

Lower housing section 78 includes a filler port 306 closed by a plug 308.

Thus, the valve apparatus 58 may generally be said to include the housing 62 having the flow passage 140 disposed therethrough.

Flow valve means 136 is disposed in the housing 62 and is movable between a closed position as shown in Fig. 2B wherein the flow passage 140 is closed, and an open position wherein the bore 138 of flow valve means 136 is aligned with flow passage 140 so that the flow passage 140 is open.

The power mandrel means 148 is disposed in the housing 62 and includes the power piston 156. THe power mandrel means 148 is operatively associated with the flow valve means 136 for moving the flow valve means 136 from its closed position to its open position in one continuous movement simultaneous with movement of the power mandrel means 148 longitudinally downwardly within the housing 62 in one continuous motion from the first position illustration in Figs. 2B—2E to a second position whereupon a lower end 310 of lower connector piece 174 engages an upper end 312 of upper filler nipple 68. The valve means 136 thus snaps open, rather than opening slowly or in incremental steps, and this minimizes fluid erosion problems.

The power port 192 may be described as a power passage means 192 disposed in the housing 62 for transmitting pressure from the well annulus 40 external of the housing 62 to the upper or first side 192 of power piston 156.

A liquid spring chamber, which may also be generally referred to as a first chamber disposed in the housing 62, includes the entire space communicating the bottom or second side 244 of power piston 156 with the fluid flow restrictors 270 and 280 disposed in the metering cartridge 260. This first chamber includes a number of spaces previously defined such as the annular space 248, the bore 246, the main spring chamber 242, and the upper portion 264 of equalizing passage 262 as well as all the other liquid spaces communicated therewith.

In the apparatus shown in Figs. 2A—2E, this entire first chamber is filled with a compressible liquid such as a silicone oil such as that sold under the trademark DOW CORNING 200. The basic properties of that compressible fluid and its changing compressibility characteristics with changes in pressure and temperature are described in detail in U.S. Patent No. 4,109,724 and U.S. Patent No. 4,109,725.

Also disposed in the housing 62 is the equalizing chamber 258 which may also generally be referred to as a second chamber. The equalizing chamber 258 is divided into a first zone 314 and a second zone 316 by the floating piston means 282 seen in Fig. 2I. The equalizing port 292 may generally be described as an equalizing passage means disposed in the housing 62 for transmitting pressure from the well annulus 40 external of the housing 62 to the second zone 316 of the equalizing chamber 258.

The pressurizing passage means 262 and the depressurizing passage means 272 both communicate the main spring chamber portion 242 of the first chamber with the first zone 314 of the second or equalizing chamber 258.

The pressurizing back pressure check valve means 268 allows liquid to flow from the first zone 314 of the equalizing chamber 258 through the pressurizing passage 262 into the main spring chamber portion 242 when a pressure in the first

zone 314 of equalizing chamber 258 exceeds a pressure of the compressible liquid in the main spring chamber 242 by a first predetermined value. The pressurizing back pressure check valve means 268 prevents liquid from flowing from the main spring chamber 242 through the pressurizing passage 262 to the first zone 314 of equalizing chamber 258.

The depressurizing back pressure check valve means 278 allows liquid to flow from the main spring chamber 242 through the depressurizing passage 272 into the first zone 314 of equalizing chamber 258 when the pressure in the main spring chamber 242 exceeds the pressure in the first zone 314 of equalizing chamber 258 by a second predetermined value. This second predetermined value is greater than the first predetermined value. The depressurizing back pressure check valve means 278 prevents liquid from flowing from the first zone 314 of equalizing chamber 258 through the depressurizing passage means 272 into the main spring chamber 242.

As shown in Figs. 2A—2E, the entire first chamber, including all of the main spring chamber 242, is completely filled with the compressible liquid and also the first zone 314 of equalizing chamber 258 is completely filled with compressible liquid so that it is the compressible liquid which flows through the metering cartridge 260. However, in certain installations, wherein the amount of flow back and forth through the flow restricting orifices 270 and 280 is particularly great, there may be a problem of foaming of a compressible liquid such as silicone oil. In that situation, an alternative arrangement, in accordance with the present invention, is preferable wherein a second floating piston 318 is provided in the main spring chamber 242 such as shown in Fig. 3.

This second floating piston divides the main spring chamber 242 into an upper first zone 320 and a lower second zone 322. The first zone 320 is completely filled with the compressible silicone oil liquid. The second zone 322 of the main spring chamber 242 and the first zone 314 of equalizing chamber 258 are both filled with a substantially noncompressible liquid, such as hydraulic oil, which will not present any foaming problem as it passes back and forth through the fluid flow restrictions.

With this one modification, the embodiment of Fig. 3 (which is in accordance with the present invention) is otherwise the same as Figs. 2A—2J.

Continuing with the description of Figs. 2A—2J, it is necessary that an initial volume of the first chamber when the power mandrel means is in its first position, as illustrated in Figs. 2A—2J, be sufficiently large that the amount of compressible silicone oil liquid in the first chamber may be compressed into a final volume of the first chamber as the power mandrel means 148 moves rapidly downward from its first position to its second position wherein the surfaces 310 and 312 engage. This requires that the silicon oil have sufficient compressibility at the pressures and temperatures involved during the operation of the tester valve apparatus 58 that it can be compressed by a volume at least as great as the volume displaced by the power piston 156 when it moves from its first position shown in Figs. 2C—2E to its second position wherein the surfaces 310 and 312 engage as previously described.

A specific detailed example of such a construction is given in U.S. Patent No. 4,109,724, at column 10, line 52-column 11, line 13 thereof, to which reference should be made for further details.

The back pressure check valves 268 and 278 are constructed such that the second predetermined value of the depressurizing back pressure check valve 278 exceeds the first predetermined value of the pressurizing back pressure check valve 268 by an amount sufficient that when a pressure differential of such amount is applied across power piston 156 from the second side 244 toward the first side 194 thereof, when the power mandrel means 148 is in its second position with the surfaces 310 and 312 engaged, a sufficient force is exerted on the power piston 156 to move the power mandrel means 148 back to its first position illustrated in Figs. 2C—2E.

The first flow restrictor 270 which may also be referred to as a flow impedance means 270, is disposed in the pressurizing passage means 262 and impedes the flow of liquid through the pressurizing passage 262 so that upon rapid pressurization of the well annulus 40 an annulus fluid pressure in the annulus 40 will increase faster than the annulus fluid pressure can be transmitted through the pressurizing passage 262 to the main spring chamber 242, thereby creating a pressure differential across the power piston 156 from the upper first side 194 toward the lower second side 244 thereof sufficient to move the power mandrel means 148 from its first position shown in Figs. 2C—2E to its said second position previously described with surfaces 310 and 312 engaged to thereby open the flow valve means 136.

The second liquid flow restrictor 280 which may be generally described as a second flow impedance means 280, disposed in the depressurizing passage 272, impedes flow of liquid through the depressurizing passage 272 so that when the power mandrel means 148 is in its said second position with the surfaces 310 and 312 engaged, and the well annulus 40 is rapidly depressurized, an annulus fluid pressure in annulus 40 will decrease faster than the pressure of the compressible liquid in the main spring chamber 242 will decrease, thereby creating a pressure differential across the power piston 156 from the lower second side 244 thereof toward the upper first side 194 thereof. This pressure differential is greater than an amount by which the second predetermined value of the depressurizing back pressure check valve 278 exceeds the first predetermined value of the pressurizing back pressure check valve 268. In other words,

upon rapid depressurization of the well annulus, there is for a period of time a pressure trapped in the main spring chamber 242 due to the time delay provided by the liquid flow restrictor 280 which exceeds the difference in operating pressure between the check valves 268 and 278.

The releasable holding means 198 is operably associated with the housing 62 and the power mandrel means 148, for holding the power mandrel means in its first position until a pressure differential across the power piston 156 from the upper first side 194 thereof toward the lower second side 244 thereof exceeds a third predetermined value, and for then holding the power mandrel means 148 in its said second position with the surfaces 310 and 312 engaged until a pressure differential across the power piston 156 from its second side 244 toward its first side 194 thereof exceeds a fourth predetermined value, which fourth predetermined value is less than the difference between the first predetermined value of pressurizing back pressure check valve 268 and the second predetermined value of depressurizing back pressure check valve 278. In other words, the pressure differential required across the power piston 156 to force the shoulders 216 attached to the bottom power mandrel section 152 through the collet sleeve 200 is less than the minimum pressure which will be trapped within the main spring chamber 242 due to the different operating pressures of the check valves 268 and 278, thus assuring that even if the well annulus 40 is depressurized very slowly, sufficient pressure will be trapped within the main spring chamber 242 to move the power mandrel means back upward to its first position to close the flow valve means 136.

It will be appreciated that the floating piston means 282 in the equalizing chamber 258 may move in either of two opposite directions relative to the housing 62, i.e., either upward or downward, to either increase or decrease a volume of the first zone 314 of equalizing chamber 258 to allow for either expansion or contraction of the compressible silicone oil liquid due to pressure and temperature changes as the tester valve apparatus 58 is lowered into the well bore 14.

It is important that the floating shoe 282 be initially located at the proper position within equalizing chamber 258 to allow sufficient movement both upward and downward to accommodate all possible volume changes of the compressible liquid encountered during the lowering of the tester valve apparatus 58 into any particular well 14. Accurate positioning of the floating piston 282 is accomplished by means of a positioning tool 324 shown in Fig. 4.

Positioning tool 324 includes an upper threaded portion 326 which threadedly engages an internal lower threaded portion 328 of floating piston 282.

The positioning tool 324 also includes a second threaded portion 330 which threadedly engages the threads 332 of the lower end of lower housing section 78. When the upward facing shoulder 334 of positioning tool 324 engages the lower end 336 of lower housing section 78 the floating piston 282 will be properly located within the equalizing chamber 258. Then the locating tool 324 is unthreaded from the piston 282 and the lower housing section 78 thus leaving the piston 282 in its proper place within the equalizing chamber 258.

The general manner of flow testing a well utilizing the flow tester valve of the present invention with the improved silicone oil liquid spring is as follows. First, a flow pressure valve like the flow tester valve apparatus (in accordance with Fig. 3) is provided.

Prior to placing the valve apparatus 58 in the well 14, the liquid spring means, i.e., the compressible fluid located in the first chamber, is maintained at substantially atmospheric pressure. Thus, the danger encountered with prior art tools wherein the compressible fluid, namely nitrogen gas thereof, must be initially placed under high pressures with its accompanying safety hazards to personnel handling the tool is eliminated.

Then the flow tester valve apparatus is lowered into the well bore 14 with the liquid spring means initially still at substantially atmospheric pressure as the lowering is begun.

As the flow tester valve apparatus 58 is lowered into the well bore 14, annulus fluid pressure from the annulus 40 is transmitted to the liquid spring means through the equalizing chamber 258 and the pressurizing passage 262.

In a preferred embodiment of the present invention, the pressurizing back pressure check valve 268 is set to open at a pressure differential of 551 kPa (80 psi) and the liquid flow restrictor 270 provides a two-minute time delay such that any liquid pressure differential takes two minutes to be completely transmitted therethrough. Thus, as the flow tester valve 58 is lowered into the well bore 14, the pressure in the main spring chamber 242 lags behind the pressure in the equalizing chamber 258 by 551 kPa (80 psi) plus an amount corresponding to a time lag of two minutes.

This time lag is set to be long enough so that the pressure in main spring chamber 242 will not be affected by rapid changes in annulus pressure, and short enough so that with normal rates of lowering a stand of drill pipe into the well the increase in hydrostatic head as the tester valve 58 is lowered into the well will not occur sufficiently fast to prematurely actuate the flow valve means 136.

The flow tester valve is lowered until it is located within the well bore 14 at a final depth wherein the packer 46 is set against the casing 16.

Then the annulus 40 is rapidly pressurized an additional amount above the hydrostatic pressure which is already present therein sufficient to open the flow valve means 136 of the apparatus 58.

When the annulus 40 is rapidly pressurized this increased pressure is communicated to the upper end 194 of power piston 156 through the power port 192, but is not initially transmitted to the main spring chamber 242 because of the two-

minute time delay provided by flow restrictor 270 in the pressurizing passage 262. Thus the pressure on the top of power piston 156 exceeds the pressure communicated with the lower side 244 of power piston 156 and the power piston 156 is moved downward compressing the compressible liquid located within the first chamber and particularly within the main spring chamber 242.

This pressure differential must be sufficient to push the shoulder 216 through the collet sleeve 200 and to compress the compressible silicon liquid located in the first chamber. This opens the flow valve means 136 so that its bore 138 is aligned with the flow passage 140 of the apparatus 58. In a preferred embodiment of the present invention, a pressure differential of 3.1 MPa (450 psi) across the power piston 156 is required to force shoulder 216 through collet sleeve 200, thus the third and fourth predetermined values mentioned above are each equal to 3.1 MPa (450 psi).

The well annulus pressure is maintained at this high level while the flow test is performed. After a period of two minutes, the pressure within the main spring chamber 242 will reach a value 550 kPa (80 psi) less than the well annulus pressure.

Thus, at least a portion of the additional amount of annulus pressure provided to the well annulus 40 when it was rapidly pressurized is transmitted to the liquid spring means in the first chamber.

When it is desired to close the flow valve means 136, the well annulus 40 is rapidly depressurized to a final annulus pressure much less than the prior high annulus pressure.

As the annulus 40 is depressurized rapidly, this pressure change is not immediately seen in the main spring chamber 242 because the liquid flow restrictor 280 in the depressurizing passage means 272 prevents the rapid flow of liquid from the main spring chamber 242 into the first zone 314 of the equalizing chamber 258, thus trapping the pressure in the liquid spring means for a period of time after the annulus 40 is depressurized. Thus, upon initial depressurization, the pressure trapped within the main spring chamber 242 greatly exceeds the pressure in the well annulus 40 and thus a pressure differential is directed upward against the power piston 156 thus moving the power mandrel means 148 upward to its first position and moving the flow valve means 136 to its closed position.

The value of the pressure differential at which the depressurizing back pressure check valve 278 operates is higher than the first predetermined value of the pressurizing back pressure check valve 268, and in a preferred embodiment is 4.13 MPa (600 psi), so that even after more than two minutes have passed since the depressurization of the annulus 40, a minimum portion of the pressure in the main spring chamber 242 which has remained trapped is at least 4.13 MPa minus 0.55 MPa or a total of 3.58 MPa (600 psi minus 80 psi or a total of 520 psi) which will always remain trapped in the main spring chamber 242.

The releasable holding means 198 is constructed to be overcome by a pressure differential of only 3.1 MPa (450 psi) so that this minimum trapped pressure, namely, 3.58 MPa (520 psi), provides sufficient force to move the power piston 156 and the power mandrel means 148 back upward to the first position of the power mandrel means 148.

Also, it is has been determined that in some circumstances it is not necessary to provide a releasable holding means such as 198, but rather the inherent frictional forces opposing movement of the valve means 136 and the attached structure may be relied upon to prevent premature operation of the valve means 136.

This may be described in terms of the liquid pressure energy which is trapped within the first chamber by means of compression of the compressible fluid therein. It may generally be said that a trapped amount of liquid pressure energy trapped in the liquid spring means, in excess of the liquid pressure energy which was present in the liquid spring means when the liquid spring means was at substantially atmospheric pressure, is entirely obtained from transmittal of liquid pressure energy from the well annulus 40 to the liquid spring means while the apparatus 58 is being lowered into the well bore 14. This means that all of the liquid pressure energy present to reclose the flow valve means 136 was provided from the annulus 40 and none of it was initially provided by any initial pressurization of the compressible liquid prior to placing the tool in the well. This is in contrast to prior art wherein much of the fluid pressure energy contained in a nitrogen-filled tool is placed in the nitrogen chamber prior to the time that the tool is placed in the well bore.

This trapped liquid pressure energy is utilized to close the flow valve means 136 upon depressurizing of the well annulus 40 as previously described.

Claims

1. A valve apparatus comprising: an elongate housing (62) having an axial flow passage (140) disposed therein; flow valve means (136) disposed in said housing and movable between a closed position wherein said flow passage is closed, and an open position wherein said flow passage is open; power mandrel means (148), disposed in said housing, said power mandrel means including a power piston (156, 156A), said power mandrel means being operatively associated with said flow valve means for moving said flow valve means from its closed position to its open position upon movement of said power mandrel means in a first direction longitudinally within said housing from a first position to a second position; power passage means (192) disposed in said housing for transmitting pressure from a well annulus external of said housing to a first side of said power piston; a first chamber (242) disposed in said housing, a second side of said power piston being in fluid communi-

minute time delay provided by flow restrictor 270 in the pressurizing passage 262. Thus the pressure on the top of power piston 156 exceeds the pressure communicated with the lower side 244 of power piston 156 and the power piston 156 is moved downward compressing the compressible liquid located within the first chamber and particularly within the main spring chamber 242.

This pressure differential must be sufficient to push the shoulder 216 through the collet sleeve 200 and to compress the compressible silicon liquid located in the first chamber. This opens the flow valve means 136 so that its bore 138 is aligned with the flow passage 140 of the apparatus 58. In a preferred embodiment of the present invention, a pressure differential of 3.1 MPa (450 psi) across the power piston 156 is required to force shoulder 216 through collet sleeve 200, thus the third and fourth predetermined values mentioned above are each equal to 3.1 MPa (450 psi).

The well annulus pressure is maintained at this high level while the flow test is performed. After a period of two minutes, the pressure within the main spring chamber 242 will reach a value 550 kPa (80 psi) less than the well annulus pressure.

Thus, at least a portion of the additional amount of annulus pressure provided to the well annulus 40 when it was rapidly pressurized is transmitted to the liquid spring means in the first chamber.

When it is desired to close the flow valve means 136, the well annulus 40 is rapidly depressurized to a final annulus pressure much less than the prior high annulus pressure.

As the annulus 40 is depressurized rapidly, this pressure change is not immediately seen in the main spring chamber 242 because the liquid flow restrictor 280 in the depressurizing passage means 272 prevents the rapid flow of liquid from the main spring chamber 242 into the first zone 314 of the equalizing chamber 258, thus trapping the pressure in the liquid spring means for a period of time after the annulus 40 is depressurized. Thus, upon initial depressurization, the pressure trapped within the main spring chamber 242 greatly exceeds the pressure in the well annulus 40 and thus a pressure differential is directed upward against the power piston 156 thus moving the power mandrel means 148 upward to its first position and moving the flow valve means 136 to its closed position.

The value of the pressure differential at which the depressurizing back pressure check valve 278 operates is higher than the first predetermined value of the pressurizing back pressure check valve 268, and in a preferred embodiment is 4.13 MPa (600 psi), so that even after more than two minutes have passed since the depressurization of the annulus 40, a minimum portion of the pressure in the main spring chamber 242 which has remained trapped is at least 4.13 MPa minus 0.55 MPa or a total of 3.58 MPa (600 psi minus 80 psi or a total of 520 psi) which will always remain trapped in the main spring chamber 242.

The releasable holding means 198 is constructed to be overcome by a pressure differential of only 3.1 MPa (450 psi) so that this minimum trapped pressure, namely, 3.58 MPa (520 psi), provides sufficient force to move the power piston 156 and the power mandrel means 148 back upward to the first position of the power mandrel means 148.

Also, it is has been determined that in some circumstances it is not necessary to provide a releasable holding means such as 198, but rather the inherent frictional forces opposing movement of the valve means 136 and the attached structure may be relied upon to prevent premature operation of the valve means 136.

This may be described in terms of the liquid pressure energy which is trapped within the first chamber by means of compression of the compressible fluid therein. It may generally be said that a trapped amount of liquid pressure energy trapped in the liquid spring means, in excess of the liquid pressure energy which was present in the liquid spring means when the liquid spring means was at substantially atmospheric pressure, is entirely obtained from transmittal of liquid pressure energy from the well annulus 40 to the liquid spring means while the apparatus 58 is being lowered into the well bore 14. This means that all of the liquid pressure energy present to reclose the flow valve means 136 was provided from the annulus 40 and none of it was initially provided by any initial pressurization of the compressible liquid prior to placing the tool in the well. This is in contrast to prior art wherein much of the fluid pressure energy contained in a nitrogen-filled tool is placed in the nitrogen chamber prior to the time that the tool is placed in the well bore.

This trapped liquid pressure energy is utilized to close the flow valve means 136 upon depressurizing of the well annulus 40 as previously described.

Claims

1. A valve apparatus comprising: an elongate housing (62) having an axial flow passage (140) disposed therein; flow valve means (136) disposed in said housing and movable between a closed position wherein said flow passage is closed, and an open position wherein said flow passage is open; power mandrel means (148), disposed in said housing, said power mandrel means including a power piston (156, 156A), said power mandrel means being operatively associated with said flow valve means for moving said flow valve means from its closed position to its open position upon movement of said power mandrel means in a first direction longitudinally within said housing from a first position to a second position; power passage means (192) disposed in said housing for transmitting pressure from a well annulus external of said housing to a first side of said power piston; a first chamber (242) disposed in said housing, a second side of said power piston being in fluid communi-

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cation with said first chamber so that pressure from said first chamber is transmitted to said second side of said power piston; a second chamber (258) disposed in said housing; a floating piston means (282) disposed in said second chamber and dividing said second chamber into a first zone (314) and a second zone (316); an equalizing passage means (292), disposed in said housing for transmitting said pressure from said well annulus external of said housing to said second zone of said second chamber; a pressurizing passage (262) communicating said first chamber with said first zone of said second chamber; a first back pressure check valve means (268), disposed in said pressurizing passage, for allowing fluid to flow from said first zone of said second chamber through said pressurizing passage into said first chamber when a pressure in said first zone of said second chamber exceeds a pressure in said first chamber by a first predetermined value, and for preventing fluid from flowing from said first chamber through said pressurizing passage to said first zone of said second chamber; a depressurizing passage (272) communicating said first chamber with said first zone of said second chamber; and a second back pressure check valve means (278), disposed in said depressurizing passage, for allowing fluid to flow from said first chamber through said depressurizing passage into said first zone of said second chamber when the pressure in said first chamber exceeds the pressure in said first zone of said second chamber by a second predetermined value, said second predetermined value being greater than said first predetermined value, and for preventing fluid from flowing from said first zone of said second chamber through said depressurizing passage into said first chamber; characterised in that the flow passage extends axially of the housing, the valve means is a ball valve means disposed in the flow passage in the housing, and wherein said first chamber is divided into a first zone (320) and a second zone (322) by a second floating piston (318); said first zone of said first chamber is filled with a compressible liquid; said second zone of said first chamber is communicated with said pressurizing passage and said depressurizing passage; and both said second zone of said first chamber and said first zone of said second chamber are filled with a substantially noncompressible liquid.

2. Apparatus according to claim 1, wherein: said first chamber when said power mandrel means is in its first position is sufficiently large that said compressible liquid in said first zone may be compressed into a final volume as said power mandrel means moves rapidly from its first position to its second position.

3. Apparatus according to claim 1 or 2, wherein: said second predetermined value exceeds said first predetermined value by an amount sufficient that, when a pressure differential of said amount is applied across said power piston from said second side toward said first side thereof, when said power mandrel means is in its said second position, a sufficient force is exerted on said power piston to move said power mandrel means back to its said first position.

4. Apparatus according to any of claims 1 to 3, further comprising: a flow impedance means (270), disposed in said pressurizing passage, for impeding flow of liquid through said pressurizing passage so that upon rapid pressurization of said well annulus an annulus fluid pressure in said annulus will increase faster than said annulus fluid pressure can be transmitted through said pressurizing passage to said first chamber, thereby creating a differential pressure across said power piston from said first side toward said second side thereof sufficient to move said power mandrel means from its said first position to its said second position to thereby open said flow valve means.

5. Apparatus according to any of claims 1 to 4, further comprising: a flow impedance means (280), disposed in said depressurizing passage, for impeding flow of liquid through said depressurizing passage so that when said power mandrel means is in it said second position and said well annulus is rapidly depressurized, an annulus fluid pressure in said annulus will decrease faster than the pressure of the compressible liquid in said first chamber will decrease, thereby creating a pressure differential across said power piston from said second side toward said first side thereof greater than an amount by which said second predetermined value exceeds said first predetermined value.

6. Apparatus according to any of claims 1 to 5, wherein: said floating piston means (282) is arranged within said second chamber so that said floating piston means may move in either of two opposite directions relative to said housing to either increase or decrease a volume of said first zone of said second chamber to allow for both expansion and contraction of said compressible liquid due to pressure and temperature changes as said valve apparatus is lowered into a well.

7. Apparatus according to any of claims 1 to 6, further comprising: releasable holding means (198), operably associated with said housing sand said power mandrel means, for holding said power mandrel means in its said first position until a pressure differential across said power piston from said first side toward said second side thereof exceeds a third predetermined value, and for holding said power mandrel means in its said second position until a pressure differential across said power piston from said second side towards said first side thereof exceeeds a fourth predetermined value, said fourth predetermined value being less than a difference between said first predetermined value and said second predetermined value.

8. Apparatus according to claim 7, wherein: said releasable holding means includes a radially resilient collet sleeve (200) connected to said housing and a shoulder (216) extending radially outward from said power mandrel means, said sleeve and said shoulder each having upper (218)

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and lower (220) tapered surfaces arranged so that when said shoulder moves past said sleeve one of said tapered surfaces of said shoulder engages one of said tapered surfaces of said sleeve and causes said sleeve to expand radially to allow said shoulder to pass therethrough.

9. Apparatus according to any preceding claim, which contains a compressible liquid which is silicone oil.

10. Apparatus according to any preceding claim, wherein said flow passage is a central axial flow passage; and said flow valve means is a full opening ball valve.

11. Apparatus according to any preceding claim, wherein: said power mandrel means and said flow valve means are so arranged and constructed that said flow valve means is moved from its closed position to its open position in one continuous movement simultaneous with movement of said power mandrel means from its first position to its second position in one continuous movement.

12. Apparatus according to any preceding claim, wherein: said power piston (156A) of said power mandrel means includes: a main piston (400) having a first differential area; and a booster piston means (402), operably associated with said main piston, for initially providing an additional differential area to said first differential area of said main piston, and for thereby providing an additional initial force for moving said flow valve means from its closed position to a partially open position.

13. Apparatus according to claim 12, further comprising: limit means (416), operably associated with said booster piston means, for limiting movement of said booster piston means in said first direction when said flow valve has been moved to said partially open position and for allowing said main piston to continue moving in said first direction.

14. Apparatus according to claim 13, further comprising: second limit piston means (418), operably associated with said booster piston means, for limiting movement of said booster piston means in a second direction opposite said first direction, when said booster piston means returns to an initial position thereof.

15. Apparatus according to claim 13 or 14, wherein: said limit means (416) is a stop lug extending radially inward from said housing for engaging said booster piston means and preventing further movement thereof in said first direction.

16. Apparatus according to claim 12, 13, 14 or 15, wherein: said booster piston means is an annular booster piston means disposed concentrically about said main piston; said power piston includes a first annular resilient sliding seal means (408) between said main piston and said booster piston means, and a second annular resilient sliding seal means (410) between said booster piston means and an internal bore of said housing; and said annular booster piston means includes an engagement means (412) for engaging said main piston, and for transferring to said main piston a force resulting from a pressure differential between said well annulus and said first chamber acting across said additional differential area of said annular booster piston means when a pressure of said well annulus exceeds a pressure in said first chamber and when said power mandrel means is in it said first position.

17. A valve apparatus according to claim 1, comprising: an outer housing (62) including: an outer housing adapter (64); a valve housing section (66) connected to said upper housing adapter; an upper filler nipple (68) connected to said valve housing section; a power housing section (70) connected to said upper filler nipple; a liquid spring chamber connector (72) connected to said power housing section; a liquid spring chamber housing section (74) connected to said liquid spring chamber connector; a lower filler nipple (76) connected to said liquid spring chamber housing section; a lower housing section (78) connected to said lower filler nipple; and a lower housing adapter (80) connected to said lower housing section; the valve means (136) being disposed in said valve housing section and movable between open and closed positions; the power mandrel means (148) being disposed in said outer housing, the power piston (156, 156A) being received within a cylindrical inner bore (158) of said power housing section, a lower end of said power mandrel means being slidably and sealingly received within a central bore (186) of said liquid spring chamber connector; a power port (192) disposed through a wall of said power housing section and arranged to be in fluid communication with an upper side of said power piston; a liquid spring chamber mandrel means (226) having an upper end (228) connected to said liquid spring chamber connector and a lower end (236) received in a bore (238) of said lower filler nipple, said liquid spring chamber mandrel means being spaced radially inward from said liquid spring chamber housing section so as to define said first chamber (242) which is in fluid communication with a lower side (244) of said power piston; a lower mandrel (250) having an upper end connected to said lower filler nipple and a lower end sealingly received in a bore (254) of said lower housing adapter, said lower mandrel being spaced radially inward from said lower housing section to define the second chamber (258); a metering cartridge (260) disposed between said lower housing section and said lower mandrel at an upper end of said second chamber; the pressurizing passage (262), being disposed through said lower filler nipple and said metering cartridge, for communicating said first chamber with said second chamber; the first back pressure check valve means (268) being disposed in said pressurizing passage within said metering cartridge, for allowing liquid to flow from said second chamber to said first chamber; a first time delay liquid flow restriction (270) disposed in said pressurizing passage within said metering car-

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tridge; the depressurizing passage (272) being disposed through said lower filler nipple and said metering cartridge for communicating said first chamber with said second chamber; the second depressurizing back pressure check valve (278) being disposed in said depressurizing passage means within said metering cartridge, for allowing liquid to flow from said first chamber to said second chamber; a second time delay liquid flow restriction (280) disposed in said depressurizing passage means within said metering cartridge; an equalizing port (292) disposed through a wall of said lower housing section; said first floating piston means (282) being disposed in said second chamber above said equalizing port.

18. A method of flow testing a well, said method comprising the steps of: lowering into said well a flow tester valve comprising a valve apparatus as claimed in claim 1, wherein said compressible liquid is at substantially atmospheric pressure as said lowering is begun; transmitting annulus fluid pressure from an annulus of said well to said compressible liquid as said flow tester valve is lowered into said well; locating said flow tester valve with said well at a final depth; pressurizing said annulus an additional amount, above a hydrostatic pressure therein, sufficient to open said flow tester valve; transmitting at least a portion of said additional amount of annulus pressure to said compressible liquid; depressurizing said annulus to a final annulus pressure; as said annulus is depressurized, trapping a portion of the pressure in said compressible liquid in excess of said final annulus pressure sufficient to close said flow tester valve, so that a trapped amount of liquid pressure energy trapped in said compressible liquid in excess of an amount of liquid pressure energy within said compressible liquid when said liquid spring means was at substantially atmospheric pressure is entirely obtained from transmittal of liquid pressure energy from said well annulus to said compressible liquid; and closing said flow tester valve, upon depressurizing of said annulus, by use of said trapped liquid pressure energy.

Patentansprüche

1. Ventilgerät enthaltend: ein längliches Gehäuse (62) mit einem darin angeordnetem axialen Strömungskanal (140); in besagtem Gehäuse angeordnete Strömungsventilmittel (136), welche zwischen einer geschlossenen Lage, in welcher besagter Strömungskanal geschlossen ist, und einer offenen Lage, in welcher besagter Strömungskanal geöffnet ist, beweglich sind; Antriebsinnenteilmittel enthaltend einen Antriebskolben (156, 156A), wobei besagte Antriebsinnenteilmittel mit besagten Strömungsventilmitteln in Wirkverbindung stehen, um besagte Strömungsventilmittel aus ihrer geschlossenen Lage in ihre offenen Lage zu bewegen, wenn besagte Antriebsinnenteilmittel in einer ersten Richtung längs innerhalb des besagten Gehäuses aus einer ersten Lage in eine zweite Lage bewegt werden; in dem besagten Gehäuse angeordnete Antriebskanalmittel (192) zur Übertragung von Druck aus einem außerhalb des besagten Gehäuses liegendem Bohrlochringraum zu einer ersten Seite des besagten Antriebskolben; eine in dem besagten Gehäuse angeordnete erste Kammer (242), wobei eine zweite Seite des besagten Abtriebskolbens mit der besagten ersten Kammer in Druckmittelverbindung steht, so daß Druck aus der besagten ersten Kammer zu der besagten zweiten Seite des besagten Antriebskolben übertragen wird; eine in dem besagten Gehäuse angeordnete zweite Kammer (258); in der besagten zweiten Kammer angeordnete schwimmende Kolbenmittel (282), welche die besagte zweite Kammer in eine erste Zone (314) und eine zweite Zone (316) unterteilen; in dem besagten Gehäuse angeordnete Ausgleichskanalmittel (292) zur Übertragung des besagten Drucks aus dem besagten Bohrlochringraum außerhalb des besagten Gehäuses zu der besagten zweiten Zone der besagten zweiten Kammer; ein Druckübertragungskanal (262), welcher eine Verbindung zwischen der besagten ersten Kammer mit der besagten ersten Zone der besagten zweiten Kammer herstellt; erste in dem besagten Druckübertragungskanal angeordnete Rückschlagventilmittel (268), welche ermöglichen, daß die Flüssigkeit aus der besagten ersten Zone der besagten zweiten Kammer durch den besagten Druckübertragungskanal in die besagte erste Kammer fließt, wenn ein Druck in der besagten ersten Zone der besagten zweiten Kammer einen Druck in der besagten ersten Kammer über einen ersten vorbestimmten Wert übersteigt, und welche verhindern, daß Flüssigkeit aus der besagten ersten Kammer durch den besagten Druckübertragungskanal in die besagte erste Zone der besagten zweiten Kammer fließt; einen Druckabbaukanal (272), der eine Verbindung zwischen der besagten ersten Kammer und der besagten ersten Zone der besagten zweiten Kammer herstellt; zweite in dem besagten Druckabbaukanal angeordnete Rückschlagventilmittel (278), welche ermöglichen, daß Flüssigkeit der besagten ersten Kammer durch den besagten Druckabbaukanal in die besagte erste Zone der besagten zweiten kammer fließt, wenn der Druck in der besagten ersten Kammer den Druck in der besagten ersten Zone der besagten zweiten Kammer um einen zweiten vorbestimmten Wert übersteigt, wobei der besagte zweite vorbestimmte Wert größe ist als der besagte erste vorbestimmte Wert, und welche verhindern, daß Flüssigkeit aus der besagten ersten Zone der besagten zweiten Kammer durch den besagten Druckabbaukanal in die besagte erste Kammer fließt; dadurch gekennzeichnet, daß der Strömungskanal sich axial zum Gehäuse erstreckt, die Ventilmittel in dem Strömungskanal in dem Gehäuse angeordnete Kugelventilmittel sind, und bei welchem die besagte erste Kammer in einer erste Zone (320) und eine zweite Zone (322) durch einen zweiten schwimmenden Kolben (318) unterteilt ist; die besagte erste Zone der besagten ersten

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Kammer mit einer kompressiblen Flüssigkeit gefüllt ist; die besagte zweite Zone der besagten ersten Kammer mit dem besagten Druckübertragungskanal und dem besagtem Druckabbaukanal in Verbindung steht; und sowohl die besagte zweite Zone der besagten ersten kammer und die besagte erste Zone der besagten zweiten Kammer mit einer im wesentlichen inkompressiblen Flüssigkeit gefüllt sind.

2. Gerät nach Anspruch 1, bei welchem die besagte erste Kammer, wenn die besagten ersten Antriebsinnenteilmittel sich in ihrer ersten Lage befinden, groß genug ist, daß die besagte kompressible Flüssigkeit in der besagten ersten Zone zu einem endgültigen Volumen komprimiert werden kann, wenn die besagten Antriebsinnenteilmittel sich schnell aus ihrer ersten Lage in ihre zweite Lage bewegen.

3. Gerät nach Anspruch 1 oder 2, bei welchem der besagte zweite vorbestimmte Wert den besagten ersten vorbestimmten Wert um einen Betrag übersteigt, der groß genug ist, daß, wenn eine Druckdifferenz über den besagten Betrag über den besagten Antriebskolben von der besagten ersten Seite zu dessen besagter zweiten Seite gegeben wird, wenn die besagten Antriebsinnenteilmittel sich in ihrer besagten zweiten Lage befinden, eine ausreichende Kraft auf den besagten Abtriebskolben ausgeübt wird, so daß die besagten Abtriebsinnenteilmittel sich zurück in ihre besagte erste Lage bewegen.

4. Gerät nach einem der Ansprüche 1 bis 3, weiterhin enthaltend: in dem besagten Druckübertragungskanal angeordnete Strömungswiderstandsmittel (270) zum Behindern der Flüssigkeitsströmung durch den besagten Druckübertragungskanal, so daß bei schneller Druckübertragung in dem besagten Bohrlochringraum ein Ringraumdruckmitteldruck in dem besagten Ringraum schneller ansteigt als der besagte Ringraumdruckmitteldruck durch den besagten Druckübertragungskanal zu der besagten ersten Kammer übertragen werden kann, wodurch ein Differenzdruck an dem besagten Antriebskolben von der besagten ersten Seite zu der besagten zweiten Seite übertragen wird, der ausreicht, um die besagten Antriebsinnenteilmittel aus ihrer besagten ersten Lage in ihre besagte zweiten Lage zu bewegen, so daß dadurch die Flüssigkeitsventilmittel geöffnet werden.

5. Gerät nach einem der Ansprüche 1 bis 4, weiterhin enthaltend: in dem besagten Druckabbaukanal angeordnete Flüssigkeitswiderstandsmittel (280) zum Behindern von Flüssigkeitsströmung durch den besagten Druckabbaukanal, so daß, wenn die besagten Abtriebsinnenteilmittel sich in ihrer besagten zweiten Lage befinden und der Druck in dem besagten Bohrlochringraum schnell abgebaut wird, ein Ringraumdruckmitteldruck in dem besagten Ringraum schneller abnimmt als der Druck der besagten kompressiblen Flüssigkeit in der besagten ersten Kammer abnimmt, wodurch eine Druckdifferenz an dem besagten Antriebskolben von dessen besagter zweiten Seite zu dessen besagter ersten Seite erzeugt wird, die größer ist als der Betrag, um welchen der besagte zweite vorbestimmte Wert den ersten vorbestimmten Wert übersteigt.

6. Gerät nach einem der Ansprüche 1 bis 5, bei welchem die besagten schwimmenden Kolbenmittel (282) innerhalb der besagten zweiten Kammer angeordnet sind, so daß die besagten schwimmenden Kolbenmittel sich in eine von zwei gegenüberliegenden Richtungen relativ zu dem besagten Gehäuse bewegen können, so daß ein Volumen der besagten ersten Zone der besagten zweiten Kammer entweder steigt oder abnimmt, so daß sowohl Ausdehnung als auch Kontraktion der besagten kompressiblen Flüssigkeit aufgrund der Druck- und Temperaturveränderungen ermöglicht werden, wenn des besagte Ventilgerät in das Bohrloch hinabgelassen wird.

7. Gerät nach einem der Ansprüche 1 bis 6, weiterhin enthaltend: lösbare Haltemittel (198) in Wirkverbindung mit dem besagten Gehäuse un den besagten Antriebsinnenteilmitteln zum Halten der besagten Antriebsinnenteilmittel in ihrer besagten ersten Lage bis eine Druckdifferenz an dem besagten Antriebskolben von dessen besagten ersten Seite zu dessen besagten zweiten Seite einen vorbestimmten dritten Wert übersteigt, und zum Halten der besagten Antriebsinnenteilmittel in ihrer besagten zweiten Lage bis eine Druckdifferenz an dem besagten Antriebskolben von dessen besagter zweiter Seite zu dessen besagten ersten Seite einen vorbestimmten vierten Wert übersteigt, wobei der besagte vierte vorbestimmte Wert geringer ist als eine Differenz zwischen dem besagten ersten vorbestimmte Wert und dem besagten zweiten vorbestimmten Wert.

8. Gerät nach Anspruch 7, bei welchem die besagten lösbaren Haltemittel eine mit dem besagten Gehäuse verbundene, radial elastische Manteilhülse (200) und eine Schulter (216) enthalten, welche sich von den besagten Antriebsinnenteilmitteln radial nach außen erstrecken, wobei die besagte Hülse und die besagte Schulter jeweils eine obere (218) und eine untere (220) kegelförmige Fläche aufweisen, die so angeordnet sind, daß, wenn sich die besagte Schulter hinter die besagte Hülse bewegt, eine der besagten kegelförmigen Flächen der besagten Schulter an einer der besagten kegelförmigen Flächen der besagten Hülse anliegt und bewirkt, daß die besagte Hülse sich radial ausdehnt, so daß ein Durchtritt der besagten Schulter dort hindurch ermöglicht wird.

9. Gerät nach einem der vorstehenden Ansprüche, welches eine komprimierbare Flüssigkeit enthält, die Siliziumöl ist.

10. Gerät nach einem der vorstehenden Ansprüche, bei welchem der besagte Flüssigkeitskanal ein zentraler axialer Flüssigkeitskanal ist; und die besagten Flüssigkeitsventilmittel ein vollständig öffnendes Kugelventil sind.

11. Gerät nach einem der vorstehenden Ansprüche, bei welchem die besagten Antriebsinnenteilmittel und die besagten Flüssigkeitsventilmittel so angeordnet und aufgebaut sind,

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daß die besagten Flüssigkeitsventilmittel in einer durchgehenden Bewegung gleichzeitig mit der Bewegung der besagten Antriebsinnenteilmittel aus ihrer ersten Lage in ihre zweite Lage in einer durchgehenden Bewegung aus ihrer geschlossenen Lage in ihre geöffnete Lage bewegt werden.

12. Gerät nach einem der vorstehenden Ansprüche, bei welchem der besagte Antriebskolben (156A) der besagten Antriebsinnenteilmittel enthält; einen Hauptkolben (400) mit einem ersten Differenzbereich; Hilfskolbenmittel (402) in Wirkverbindung mit dem besagten Hauptkolben, so daß sie zunächst eine zusätzliche Differenzfläche zu der besagten ersten Differenzfläche des besagten Hauptkolbens schaffen und dadurch eine zusätzliche Anfangskraft zur Bewegung der besagten Flüssigkeitsventilmittel aus ihrer geschlossenen Lage in eine teilweise geöffnete Lage hervorrufen.

13. Gerät nach Anspruch 12, weiterhin enthaltend Begrenzungsmittel (416) in Wirkverbindung mit den besagten Hilfskolbenmitteln zur Begrenzung der Bewegung der besagten Hilfskolbenmittel in der besagten ersten Richtung, wenn das besagte Flüssigkeitsventil in die besagte teilweise geöffnete Lage bewegt worden ist, und zur Ermöglichung einer Bewegung des besagten Hauptkolbens weiter in der besagten ersten Richtung.

14. Gerät nach Anspruch 13, weiterhin enthaltend: zweite Betrenzungsmittel (418) in Wirkverbindung mit den besagten Hilfskolbenmitteln zur Begrenzung der Bewegung der besagten Hilfskolbenmittel in eine zweite, der ersten Richtung entgegengesetzte Richtung, wenn die besagten Hilfskolbenmittel in ihre Ausgangsposition zurückkehren.

15. Gerät nach Anspruch 13 oder 14, bei welchem die besagten Begrenzungsmittel (416) eine sich radial von dem besagten Gehäuse nach innen erstreckende Sperrnase ist zur Analge an die besagen Hilfskolbenmittel und zur Verhinderung weiterer Bewegung dieser Kolbenmittel in die besagte erste Richtung.

16. Gerät nach Anspruch 12, 13, 14 oder 15, bei welchem: die besagten Hilfskolbenmittel ringförmige Hilfskolbenmittel sind, die konzentrisch um den besagten Hauptkolben angeordnet sind; der besagte Antriebskolben erste ringförmige elastische Gleitdichtmittel (408) zwischen dem besagten Hauptkolben und den besagten Hilfskolbenmitteln und zweite ringförmige elastische Gleitdichtmittel (410) zwischen den besagten Hilfskolbenmittel un einer Innenbohrung des besagten Gehäuses enthält; und die besagten ringförmigen Hilfskolbenmittel Anlagemittel (412) enthalten zur Anlage an dem besagten Hauptkolben und zum Übertragen einer aus einer Druckdifferenz zwischen dem besagten Bohrlochringaum und der besagten ersten Kammer resultierenden Kraft auf den besagten Hauptkolben, wobei diese Druckdifferenz auf die besagte zursätzliche Differenzfläche der besagten ringförmigen Hilfskolbenmittel wirkt, wenn ein Druck des besagten Bohrlochringraums einen Druck in der besagten Kammer übersteigt und wenn die besagten Antriebsinnenteilmittel sich in ihrer besagten ersten Lage befinden.

17. Ventilgerät nach Anspruch 1, enthaltend: ein Außengehäuse (62) mit: einem äußeren Gehäusezwischenstück (64); einen mit dem besagten oberen Gehäusezwischenstück verbundenen Ventilgehäuseabschnitt (66); ein mit dem besagten Ventilgehäuseabschnitt verbundener oberer Einfüllstutzen (68); einen mit dem besagten oberen Einfüllstutzen verbundenen Antriebsgehäuseabschnitt (70); ein mit dem besagten Antriebsgehäuseabschnitt verbundenes Flüssigkeitsfederkammer-Verbindungsstück (72); einen mit dem besagten Flüssigkeitsfederkammer-Verbindungsstück verbundenen Gehäuseabschnitt mit der Flüssigkeitsfederkammer (74); einen mit dem besagten Gehäuseabschnitt mit der Flüssigkeitsfederkammer verbundenen unteren Einfüllstutzen (76); einen mit dem besagten unteren Einfüllstutzen verbundenen unteren Gehäuseabschnitt (78); und ein mit dem besagten unteren Gehäuseabschnitt verbundenes unteres Gehäusezwischenstück (80); wobei die Ventilmittel (136) in dem besagten Ventilgehäuseabschnitt angeordnet sind und zwischen einer offenen und einer geschlossenen Lage bewegbar sind; die Antriebsinnenteilmittel in dem besagten Außengehäuse angeordnet sind; der Antriebskolben (156, 156A) innerhalb einer zylindrischen Innenbohrung (158) des besagten Antriebsgehäuseabschnitts aufgenommen ist, ein unteres Ende der besagten Antriebsinnenteilmittel gleitbar und abdichtend in einer zentralen Bohrung (186) des besagten Flüssigkeitsfederkammer-Verbindungsstücks aufgenommen ist; einen Antriebsanschluß (192), der in einer Wand des besagten Antriebsgehäuseabschnitts angeordnet ist und mit einer Oberseite des besagten Antriebskolbens in Verbindung stehen kann; Innenteilmittel mit der Flüssigkeitsfederkammer (226) mit einem oberen, mit dem besagten Flüssigkeitsfederkammer-Verbindungsstück verbundenen Ende (228) und einem unterem in einer Bohrung (238) des besagten unteren Einfüllstutzens aufgenommenem Ende (236), wobei die besagten Innenteilmittel mit der Flüssigkeitsfederkammer im Abstand radial einwärts von dem besagten Gehäuseabschnitt mit der Flüssigkeitsfederkammer angeordnet sind, so daß sie die besagte erste Kammer (242) begrenzen, die in Druckmittelverbindung mit einer unteren Seite (244) des besagten Antriebskolbens steht; ein unteres Innenteil (250) mit einem mit dem unteren Einfüllstutzen verbundenen oberen Ende und einem abdichtend in einer Bohrung (254) des besagten unteren Gehäusezwischenstücks aufgenommenem unteren Ende, wobei das besagte untere Innenteil im Abstand radial einwärts von dem besagten unterem Gehäuseabschnitt angeordnet ist, so daß es die zweite Kammer (258) begrenzt; eine Dosierpatrone (260), welche zwischen dem besagten unterem Gehäuseabschnitt und dem besagten unterem Innenteil an einem oberen Ende der besagten zweiten Kammer angeordnet ist; wobei der Druckübertra-

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gungskanal (262) in dem besagten unteren Einfüllstutzen und der besagten Dosierpatrone angeordnet ist, so daß er eine Verbindung zwischen der besagten ersten Kammer und der besagten zweiten Kammer herstellt; die ersten Rückschlagventilmittel (268) in dem besagten Drucksübertragungskanal innerhalb der besagten Dosierpatrone angeordnet sind, so daß er Flüssigkeitsstrom aus der besagten zweiten Kammer zu der besagten ersten Kammer ermöglicht; eine erste Flüssigkeitsströmungsdrossel zur Zeitverzögerung (270), welche in dem besagten Drucksübertragungskanal innerhalb der besagten Dosierpatrone angeordnet ist; wobei der Druckabbaukanal (272) in dem besagten unteren Einfüllstutzen und der besagten Dosierpatrone angeordnet ist, so daß er eine Verbindung zwischen der besagten ersten Kammer und der besagten zweiten Kammer herstellt; das zweite druckabbauende Hinterdruck-Rückschlagventil (278) in den besagten Druckabbaukanalmitteln innerhalb der besagten Dosierpatrone angeordnet ist, so daß er Flüssigkeitsstrom aus der besagten ersten Kammer in die besagte zweite Kammer ermöglicht; eine zweite Flüssigkeitsströmungsdrossel zur Zeitverzögerung (280), welche in den besagten Druckabbaukanalmitteln innerhalb der besagten Dosierpatrone angeordnet ist; ein Ausgleichsanschluß (292), welcher in einer Wand des besagten unteren Gehäuseabschnitts angeordnet ist; wobei die besagten ersten schwimmenden Kolbenmittel (282) in der besagten zweiten Kammer oberhalb des besagten Ausgleichsanschlußes angeordnet sind.

18. Verfahren zur Strömungsprüfung eines Bohrlochs, wobei das besagte Verfahren folgende Schritte aufweist: Hinablassen eines Strömungsprüfungsventils in ein Bohrloch, bei welchem das Strömungsprüfungventil ein Ventilgerät nach Anspruch 1 aufweist, in welchem die besagte kompressible Flüssigkeit auf im wesentlichen Atmosphärendruck ist, als mit dem besagten Hinablassen begonnen wurde; Übertragen des Ringraumflüssigkeitsdrucks aus einem Ringraum des besagten Bohrlochs auf die besagte kompressible Flüssigkeit, wenn das besagte Strömungsprüfungsventil in das besagte Bohrloch hinabgelassen wird; Ablegen des besagten Strömungsprüfungsventils mit dem besagten Bohrloch in einer endgültigen Tiefe; Erzeugen eines zusätzlichen Druckbetrages in dem Ringraum über einen hydrostatischen Druck darin, der ausreicht, um das besagte Strömungsprüfungsventil zu öffnen; Übertragen von zumindest einem Teil des zusätzlichen Betrags an Ringraumdruck auf die kompressible Flüssigkeit; Abbauen von Druck in dem besagten Ringraum bis auf einen endgültigen Ringraumdruck; wenn in dem besagten Ringraum Druck abgebaut worden ist, Einschließen eines Teils des Drucks in der kompressiblen Flüssigkeit über den besagten endgültigen Ringraumdruck hinaus, der ausreicht, um das besagte Strömungsprüfungsventil zu schließen, so daß ein eingeschlossener Betrag an Flüssigkeitsdruckenergie, welcher in der besagten kompressiblen Flüssigkeit eingeschlossen ist über einen Betrag an Flüssigkeitsdruckenergie innerhalb der besagten kompressiblen Flüssigkeit hinaus, wenn die besagten Flüssigkeitsfedermittel im wesentlichen auf Atomosphärendruck waren, ganz aus der Übertragung von Flüssigkeitsdruckenergie aus dem besagten Bohrlochringraum zu der besagten komprimierbaren Flüssigkeit gewonnen wird; und Schließen des besagten Strömungsprüfungsventils bei Druckabbau im besagten Ringraum, unter Verwendung der besagten eingeschlossenen Flüssigkeitsdruckenergie.

Revendications

1. Soupape comprenant: un enveloppe de grande longueur (62) dans laquelle est ménagé un passage axial d'écoulement (140); un obturateur d'écoulement (136) disposé dans cette enveloppe et mobile entre une position fermée, dans laquelle le passage d'écoulement est fermé, et une position ouverte, dans laquelle ce passage d'écoulement est ouvert; un mandrin de commande (148) disposé dans l'enveloppe, ce mandrin de commande comprenant un piston de commande (156, 156A), ce même mandrin de commande étant associé fonctionnellement à l'obturateur d'écoulement en vue de déplacer cet obturateur d'écoulement de sa position fermée à sa position ouverte lors d'un déplacement du mandrin de commande, d'une première position à une seconde position, dans un premier sens suivant la direction longitudinale; un passage de commande (192) ménagé dans l'enveloppe de façon à transmettre une pression provenant d'un annulus de puits, situé à l'extérieure de l'enveloppe, sur une première face du piston de commande; une première chambre (242) ménagée dans l'enveloppe, une seconde face du piston de commande étant en liaison de communication de fluide avec la première chambre de façon qu'une pression provenant de cette première chambre soit transmise sur la seconde face du piston de commande; une seconde chambre (258) ménagée dans l'enveloppe; un piston flottant (282) disposé dans la seconde chambre et divisant cette seconde chambre en une première zone (314) et une seconde zone (316); un passage d'égalisation (292) ménagé dans l'enveloppe de façon à transmettre ladite pression de l'annulus de puits, situé à l'extérieur de l'enveloppe, à la seconde zone de la seconde chambre; un passage de mise sous pression (262) faisant communiquer la première chambre avec la première zone de la seconde chambre, un premier clapet antiretour (268) disposé dans ce passage de mise sous pression et destiné, d'une part, à permettre à du fluide de s'écouler de la première zone de la seconde chambre jusque dans la première chambre en passant par ce passage de mise sous pression lorsque la pression régnant dans cette première zone de la seconde chambre excède, d'une première valeur fixée à l'avance, la pression régnant dans la première chambre, et, d'autre part, à empêcher le fluide de s'écouler de la première

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chambre vers la première zone de la seconde chambre en passant par le passage de mise sous pression; un passage de délestage de pression (272) faisant communiquer la première chambre avec la première zone de la seconde chambre; et un second clapet antiretour (278) disposé dans ce passage de délestage de pression et destiné, d'une part, à permettre à du fluide de s'écouler de la première chambre jusque dans la première zone de la seconde chambre en passant par ce passage de délestage de pression lorsque la pression régnant dans cette première chambre excède, d'une seconde valeur fixée à l'avance, la pression régnant dans la première zone de la seconde chambre, la seconde valeur fixée à l'avance étant supérieure à la première valeur fixée à l'avance, et d'autre part, à empêcher le fluide de s'écouler de la première zone de la seconde chambre jusque dans la première chambre en passant par le passage de délestage de pression, caractérisée en ce que le passage d'écoulement s'étend axialement dans l'enveloppe, en ce que l'obturateur est un obturateur sphérique disposé dans ce passage d'écoulement de l'enveloppe, en ce que la première chambre est divisée en une première zone (320) et une seconde zone (322) par un second piston flottant (318), la première zone de la première chambre étant remplie d'un liquide compressible, la seconde zone de la première chambre communiquant avec le passage de mise sous pression et le passage de délestage de pression, et cette seconde zone de la première chambre et la première zone de celle-ci étant toutes deux remplies d'un liquide sensiblement non compressible.

2. Soupape suivant la revendication 1, dans laquelle, lorsque le mandrin de commande est dans sa première position, la première chambre est suffisamment grande pour que le liquide compressible présent dans la première zone puisse être comprimé, en donnant un certain volume final, lorsque ce mandrin de puissance se déplace rapidement de sa première position à sa seconde position.

3. Soupape suivant l'une des revendications 1 ou 2, dans laquelle la seconde valeur fixée à l'avance excède la première valeur fixée à l'avance d'une valeur suffisante pour que, lorsqu'une différence de pression ayant cette valeur est appliquée entre les deux faces du piston de commande, de la seconde face de celui-ci vers sa première face, lorsque le mandrin de commande est dans sa seconde position, il s'exerce sur ce piston de commande une force suffisante pour ramener le mandrin de commande à sa première position.

4. Soupape suivant l'une quelconque des revendications 1 à 3, comprenant en outre un moyen d'entravement, ou d'étranglement, d'écoulement (270) disposé dans le passage de mise sous pression et servant à entraver, ou étrangler, l'écoulement de liquide à travers ce passage de mise sous pression, de façon telle que, lors d'une mise sous pression rapide de l'annulus du puits, une pression de fluide d'annulus régnant dans cet annulus croisse plus rapidement que cette pression de fluide d'annulus ne peut être transmise à la première chambre en passant par le passage de mise sous pression, ce qui crée ainsi, entre les deux faces du piston de commande, de la première face de celui-ci vers sa seconde face, une différence de pression suffisante pour déplacer le mandrin de puissance de sa première position jusqu'à sa seconde position, ce qui fait ainsi s'ouvrir l'obturateur d'écoulement.

5. Soupape suivant l'une quelconque des revendications 1 à 4, comprenant en outre un second moyen d'entravement, ou d'étranglement, d'écoulement (280) disposé dans le passage de délestage de pression et servant à entraver, ou étrangler, l'écoulement du liquide à travers ce passage de délestage de pression, de façon telle que, lorsque le mandrin de commande est dans sa seconde position et lorsque la pression est rapidement délestée dans l'annulus du puits, une pression de fluide d'annulus régnant dans cet annulus décroisse plus rapidement que ne décroît la pression du liquide compressible dans la première chambre, ce que crée ainsi, entre les deux faces du piston de commande, de la seconde face de celui-ci vers sa première face, une différence de pression supérieure à la valeur dont la seconde valeur fixée à l'avance excède la première valeur fixée à l'avance.

6. Soupape suivant l'une quelconque des revendications 1 à 5, dans laquelle le piston flottant (282) est disposé dans la seconde chambre de façon à pouvoir se déplacer dans l'un ou l'autre des deux sens opposés par rapport à l'enveloppe, de façon soit à augmenter, soit à réduire, le volume de la première zone de la seconde chambre en vue de permettre soit une dilatation, soit une contraction du liquide compressible qui seraient dues à des variations de pression et de température lorsqu'on fait descendre la soupape dans un puits.

7. Soupape suivant l'une quelconque des revendications 1 à 6, comprenant en outre des moyens de support libérable (198) associés fonctionnellement à l'enveloppe et au mandrin de commande et servant à retenir ce mandrin de commande dans sa première position jusqu'à ce qu'une différence de pression entre les deux faces du piston de commande, de sa première face vers sa seconde face, excède une troisième valeur fixée à l'avance, et à retenir ce mandrin de commande dans sa seconde position jusqu'à ce qu'une différence de pression entre les deux faces du piston de commande, de sa seconde face vers sa première face, excède une quatrième valeur fixée à l'avance, laquelle quatrième valeur fixée à l'avance est inférieure à la différence entre la première valeur fixée à l'avance et la seconde valeur fixée à l'avance.

8. Soupape suivant la revendication 7, dans laquelle les moyens de support libérable comprennent un manchondouille (200) radialement élastique, relié à l'enveloppe, et un épaulement

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(216) s'étendant radialement vers l'extérieur à partir du mandrin de commande, ce manchon et cet épaulement comportant chacun des surfaces coniques supérieure (218) et inférieure (220) disposées de façon que, lorsque l'épaulement se déplace en passant devant le manchon, l'une des surfaces coniques de l'épaulement vient au contact de l'une des surfaces coniques du manchon et fait se dilater radialement ce dernier de façon à permettre à l'épaulement de passer à travers lui.

9. Soupape suivant l'une quelconque des revendications précédentes, contenant un liquide compressible qui est une huile de silicones.

10. Soupape suivant l'une quelconque des revendications précédentes, dans laquelle le passage d'écoulement est un passage axial central d'écoulement et l'obturateur d'écoulement est un obturateur sphérique à passage total.

11. Soupape suivant l'une quelconque des revendications précédentes, dans laquelle le mandrin de commande et l'obturateur d'écoulement sont disposés et agencés de façon que l'obturateur d'écoulement soit déplacé de sa position fermée jusqu'à sa position ouverte, suivant un mouvement continu unique qui est simultané au déplacement que le mandrin de commande exécute, d'un mouvement unique continu, de sa première position jusqu'à sa seconde position.

12. Soupape suivant l'une quelconque des revendications précédentes, dans laquelle le piston de commande (156A) du mandrin de commande comporte un piston principal (400), offrant une première section différentielle, et un piston d'amplification (402) associé fonctionnellement au piston principal de façon à fournir initialement une section différentielle qui vient s'éjouter à la première section différentielle du piston principal et à assurer ainsi une force initiale supplémentaire pour déplacer l'obturateur d'écoulement de sa position fermée jusqu'à une position partiellement ouverte.

13. Soupape suivant la revendication 12, comprenant en outre un moyen de limitation (416) associé fonctionnellement au piston d'amplification pour limiter le déplacement de ce dernier dans ledit premier sens lorsque l'obturateur d'écoulement a été déplacé jusqu'à sa position partiellement ouverte, et pour permettre au piston principal de poursuivre son déplacement suivant ce même premier sens.

14. Soupape suivant la revendication 13, comprenant en outre un second moyen de limitation de piston (418) associé fonctionnellement au piston d'amplification pour limiter le déplacement de ce dernier dans un second sens opposé audit premier sens lorsque ce piston d'amplification retourne à sa position initiale.

15. Soupape suivant l'une quelconque des revendications 13 ou 14, dans laquelle le moyen de limitation (416) est une nervure d'arrêt s'étendant radialement vers l'intérieure à partir de l'enveloppe et destinée à offrir un contact au piston d'amplification et à empêcher celui-ci de continuer de se déplacer dans ledit premier sens.

16. Soupape suivant l'une quelconque des revendications 12 à 15, dans laquelle le piston d'amplification est un piston d'amplification annulaire disposé d'une manière concentrique autour du piston principal, le piston de commande comportant un premier joint glissant d'étanchéité (408), annulaire et élastique, entre le piston principal et le piston d'amplification et un second joint glissant d'étanchéité (410), annulaire et élastique, entre le piston d'amplification et un alésage intérieur de l'enveloppe, et le piston d'amplification annulaire comporte un moyen de venue en contact (412) destiné à venir au contact du piston principal et à transférer à ce piston principal une force résultant de la différence de pression existant entre l'annulus du puits et la première chambre et agissant sur la section différentielle supplémentaire du piston d'amplification annulaire lorsque la pression de l'annulus du puits excède la pression régnant dans la première chambre et lorsque le mandrin de commande est dans sa première position.

17. Soupape suivant la revendication 1, comprenant: une enveloppe extérieure (62) comportant: un adaptateur d'enveloppe extérieur (64); une section d'enveloppe de soupape (66) reliée à cet adaptateur supérieur d'enveloppe; un raccord supérieur de remplissage (68) relié à cette section d'enveloppe de soupape; une section d'enveloppe de commande (70) reliée à ce raccord supérieur de remplissage; une connecteur de chambre de ressort hydraulique (72) relié à cette section d'enveloppe de commande; une section d'enveloppe de chambre de ressort hydraulique (74) reliée à ce connecteur de chambre de ressort hydraulique; un raccord inférieur de remplissage (76) relié à cette section d'enveloppe de chambre de ressort; une section inférieure d'enveloppe (78) reliée à ce raccord inférieur de remplissage; et un adaptateur inférieur d'enveloppe (80) relié à cette section inférieure d'enveloppe; l'obturateur (136) étant disposé dans la section d'enveloppe de soupape et mobile entre des positions ouverte et fermée, le mandrin de commande (148) étant disposé dans l'enveloppe extérieure, le piston de commande (156, 156A) étant logé à l'intérieur d'un alésage intérieur cylindrique (158) de la section d'enveloppe de commande, une extrémité inférieure de mandrin de commande étant logée de façon coulissante et de manière étanche dans un alésage central (186) du connecteur de chambre de ressort hydraulique; un orifice de commande (192) ménagé à travers une paroi de la section d'enveloppe de commande et agencé de façon à être en liaison de communication de fluide avec une face supérieure du piston de commande; un mandrin de chambre de ressort hydraulique (226) comportant une extrémité supérieure (228), reliée au connecteur de chambre de ressort hydraulique, et une extrémité inférieure (236) logée dans un alésage (238) du raccord inférieure de remplissage, ce mandrin de chambre de ressort hydraulique étant espacé radialement vers l'intérieur par rapport à la section d'enveloppe de chambre de ressort

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hydraulique de façon à délimiter ladite première chambre (242), qui est en liaison de communication de fluide avec une face inférieure (244) du piston de commande; un mandrin inférieur (250) comportant une extrémité supérieure, reliée au raccord inférieur de remplissage, et une extrémité inférieure logée de manière étanche dans un alésage (254) de l'adaptateur inférieur d'enveloppe, ce mandrin inférieur étant espacé radialement vers l'intérieur par rapport à la section inférieure d'enveloppe de façon à délimiter ladite seconde chambre (258); une cartouche de calibrage (260) disposée entre la section inférieure d'enveloppe et le mandrin inférieur, à une extrémité supérieure de la seconde chambre; le passage de mise sous pression (262) étant ménagé à travers le raccord inférieur de remplissage et la cartouche de calibrage et permettant de faire communiquer la première chambre avec la seconde chambre; le premier clapet antiretour de mise sous pression (268) étant disposé dans ce passage de mise sous pression, à l'intérieur de la cartouche de calibrage, de façon à permettre à du liquide de s'écouler de la seconde chambre vers la première chambre; un premier étranglement d'écoulement de liquide (270), à fonction de retard, étant disposé dans le passage de mise sous pression, à l'intérieur de la cartouche de calibrage; le passage de délestage de pression (272) étant ménagé à travers le raccord inférieur de remplissage et la cartouche de calibrage de façon à faire communiquer la première chambre avec la seconde chambre, le second clapet antiretour de délestage de pression (278) étant disposé dans ce passage de délestage de pression, à l'intérieur de la cartouche de calibrage, de façon à permettre à du liquide de s'écouler de la première chambre vers la seconde chambre; un second étranglement d'écoulement de liquide (280), à fonction de retard, disposé dans le passage de délestage de pression, à l'intérieur de la cartouche de calibrage; un orifice d'égalisation (292) ménagé à travers une paroi de la section inférieure de l'enveloppe, le premier piston flottant (282) étant disposé dans la seconde chambre au-dessus de cet orifice d'égalisation.

18. Procédé permettant de soumettre un puits à un essai de production, ce procédé comprenant les étapes suivantes: faire descendre dans le puits une soupape de tester, ou d'essai de production, comprenant une soupape suivant la revendication 1, dans laquelle le liquide compressible est pratiquement à la pression atmosphérique lorsque la descente commence; transmettre la pression de fluide d'annulus de l'annulus du puits au liquide compressible pendant qu'on fait descendre la soupape de tester dans le puits; positionner la soupape de tester dans ce dernier à une profondeur finale; accroître la pression de l'annulus d'une valeur supplémentaire, au-dessus d'une pression hydraulique qui y règne, suffisante pour faire s'ouvrir la soupape de tester; transmettre au moins une partie de cette valeur supplémentaire de pression d'annulus au liquide compressible; délester la pression de l'annulus jusqu'à une pression finale d'annulus; emprisonner, dans le liquide compressible, pendant qu'on réalise ce délestage de la pression de l'annulus, une partie de la pression qui est en excès par rapport à la pression finale de l'annulus, cette partie étant suffisante pour faire se fermer la soupape de tester, de sortie qu'une valeur emprisonnée d'énergie de pression hydraulique emprisonnée dans le liquide compressible et excédant une valeur d'énergie de pression hydraulique se trouvant dans le liquide compressible lorsque le ressort hydraulique était pratiquement à la pression atmosphérique est entièrement ontenue à partir d'une transmission d'énergie de pression hydraulique de l'annulus du puits vers le liquide compressible; et fermer la soupape de tester, lors d'un délestage de la pression de l'annulus, grâce à l'utilisation de cette énergie de pression hydraulique emprisonnée.

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