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FLUID FLOW CONTROL SYSTEM FOR WELLS

Filed Sept. 20, 1965

2 Sheets-Sheet 1

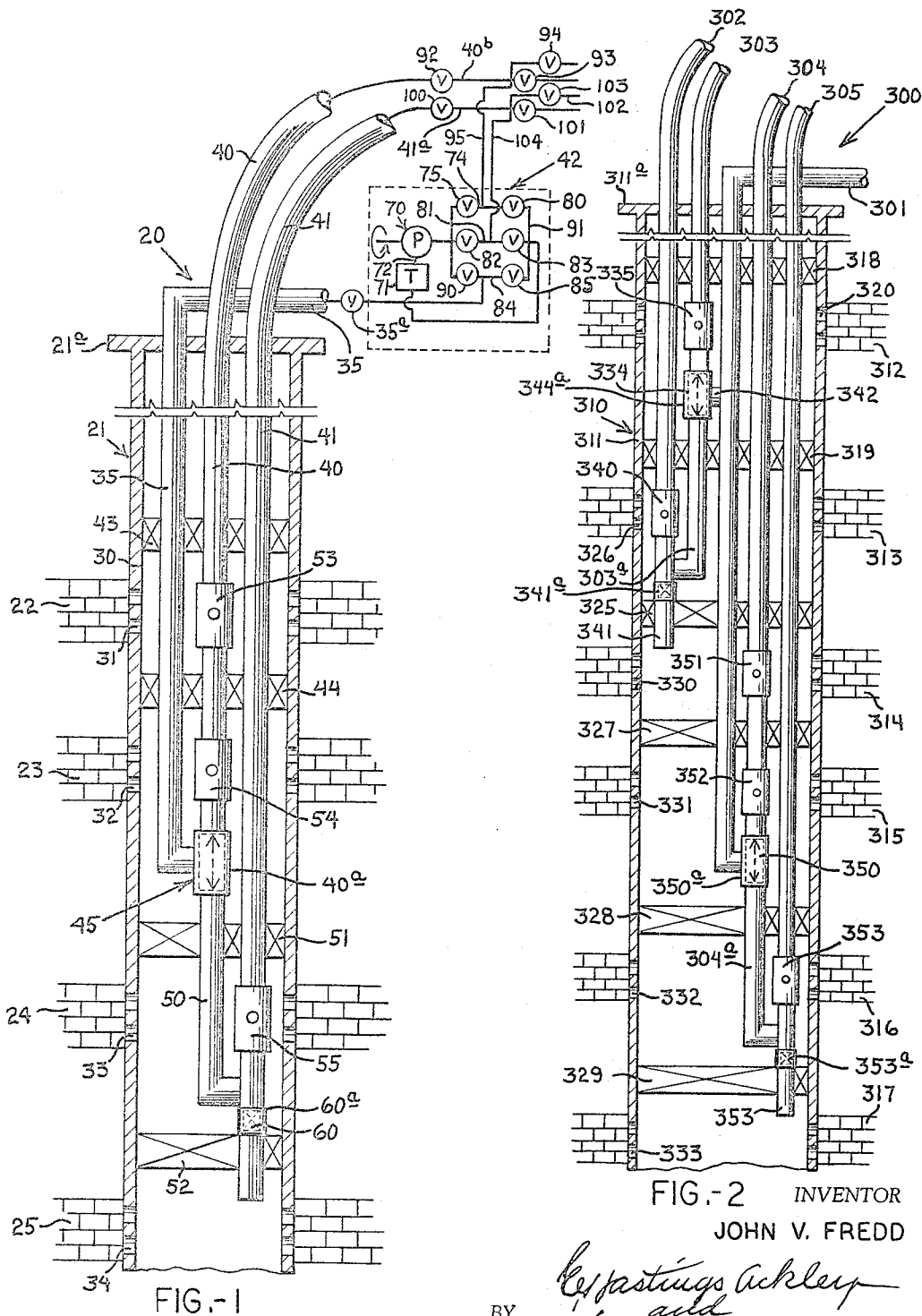


FIG. -2 INVENTOR
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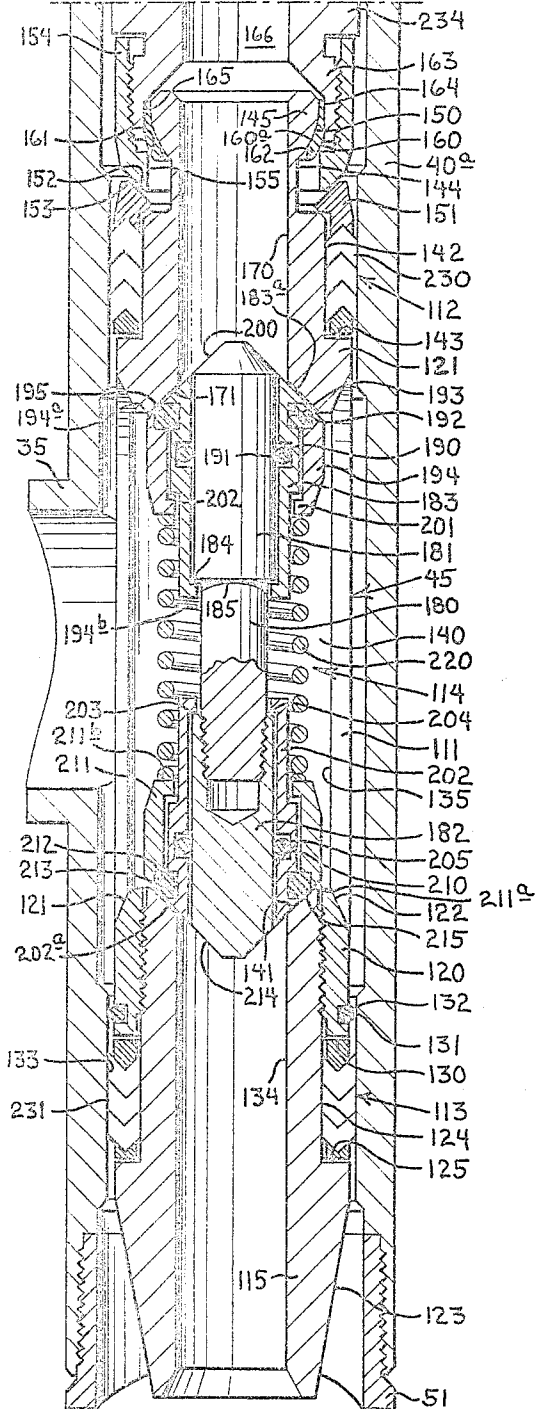


FIG. 3B

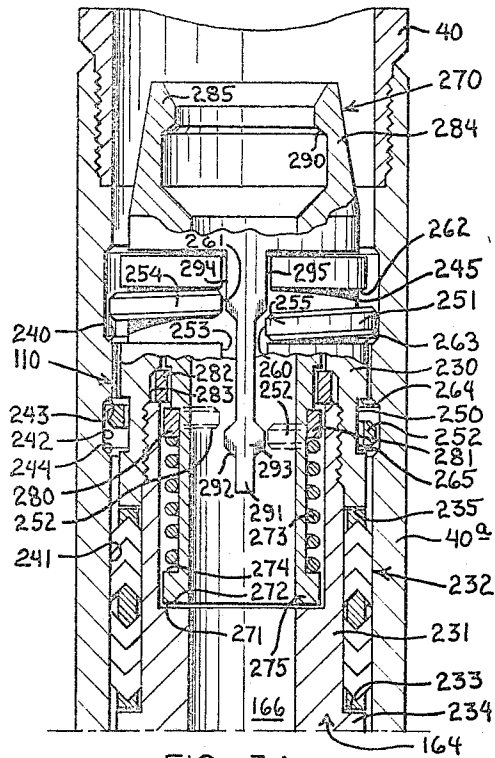


FIG. 3A

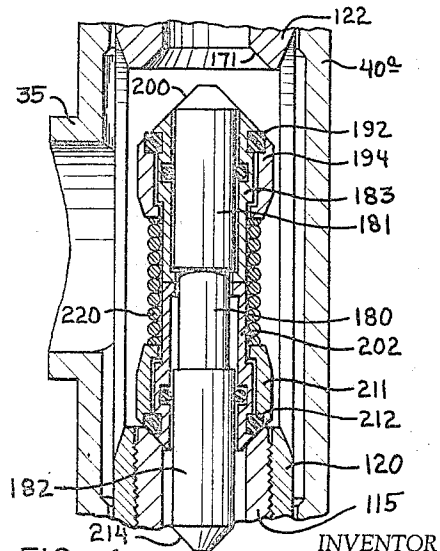


FIG. 4

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FLUID FLOW CONTROL SYSTEM FOR WELLS
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19 Claims. (Cl. 166—147)

ABSTRACT OF THE DISCLOSURE

A fluid flow control system particularly adapted for multiple production zone wells, having production flow conduits communicating with each of the separate zones, and a control fluid conduit communicating with each of the other conduits through a flow control device including valve means for preventing flow between each of the flow conduits to the production zones and operable to selectively control flow through each of said conduits and said control conduit. A valve for such system removably insertable into the flow conduits at the point of communication of the control fluid conduit with said production flow conduit.

This invention relates to fluid flow control systems and more particularly relates to a fluid flow control and tool transportation system for a well bore.

It is a particularly important object of this invention to provide a system for controlling fluid flow through a well bore.

It is another important object of this invention to provide a system for transporting well tools between a desired location within a well bore and a remotely located surface position.

It is another object of the invention to provide a fluid flow system permitting production of well fluids from a plurality of zones at selected spaced apart depths within a well bore.

It is another object of the invention to provide a well flow system which permits fluid communication between selected depth zones within a well bore and a surface location.

It is another object of the invention to provide a well flow system permitting closed circuit fluid flow between a surface location and selected depth zones within a well bore.

It is another object of the invention to provide a fluid flow control system for wells including a plurality of interconnected production tubing strings provided with flow control means for preventing fluid communication between the production strings at all times.

It is another object of the invention to provide a fluid flow control system for wells including a plurality of production strings and a control tubing string wherein a fluid circulating pattern may be established through the control tubing string and one of the production tubing strings while isolating the other production tubing strings from the circulation pattern.

It is an additional object of the invention to provide a fluid flow control system for wells including a fluid flow control device for selectively controlling fluid flow between one control tubing string and any one of a plurality of production tubing strings.

It is another object of the invention to provide a fluid flow control device having a central valve chamber between a control tubing string and a plurality of check valves leading to a plurality of tubing strings.

It is another object of the invention to provide a fluid flow control device between a control tubing string and several production tubing strings wherein fluid flow between the control tubing string and a selected production tubing string is initiated by raising the fluid pres-

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sure within the production tubing string above the fluid pressure within the other production tubing strings connected to the control device subsequent to which the fluid flow may be effected in either direction between the control tubing string and the production tubing string and maintained through the control device so long as the fluid pressure within the central chamber of the control device exceeds the fluid pressure within the remaining production tubing strings connected with and isolated by the flow control device.

It is another object of the invention to provide a fluid flow control system for a well including a plurality of circulation loops having a flow control device positioned substantially at the mid-point of each of the circulation loops whereby the fluid pressure within the central chamber of the control device may be maintained at a higher level than the fluid pressure in any one of the interconnected production tubing strings regardless of the direction of fluid flow due to the resistance to flow in the return fluid flow path.

It is another object of the invention to provide a fluid flow control system for wells which includes a flow control device interconnected between a control tubing string and each pair of production tubing strings included in the system.

It is another object of the invention to provide a fluid control system for wells including apparatus for selectively establishing a plurality of closed fluid circulation loops through which well tools may be pumped to desired locations within the tubing strings in the well bore.

It is another object of the invention to provide a fluid flow control system for wells which is adaptable to wells completed at the floor of a body of water, such as an ocean or lake, to permit remote communication between a water surface or land located control station and a subsurface wellhead.

It is a further object of the invention to provide a well system for transporting well tools by fluid circulation between selected depths within a well bore and a remote surface station.

The invention thus may be said to be directed to a system, particularly adapted for use in wells, for controlling flow of fluids from a plurality of pressure area or zones through separate flow conduits communicating with said zones and with a remote or surface area, and a control fluid conduit communicating with each of said flow conduits to control flow from the pressure zones or areas to the remote or surface area, while maintaining each of the pressure zones separate from each of the other zones.

Additional objects and advantages of the invention will be readily apparent from the reading of the following description of a device constructed in accordance with the invention, and reference to the accompanying drawings thereof, wherein:

FIGURE 1 is a longitudinal diagrammatic sectional view of one well system in accordance with the invention;

FIGURE 2 is a longitudinal diagrammatic sectional view of another well system in accordance with the invention;

FIGURES 3A and 3B taken together constitute a longitudinal view, partially in section and partially in elevation, illustrating a flow control device and a connected locking assembly which may be employed in the well systems of FIGURES 1 and 2; and

FIGURE 4 is a fragmentary longitudinal view in section and elevation of the flow control device of FIGURE 3B with the valve assembly of the device moved to one open position permitting fluid flow between the control tubing string and a production tubing string.

Referring to FIGURE 1, a well flow control and tool transport system 20 according to the invention is installed in a well 21 having a wellhead 21a penetrating a plurality of fluid producing formations 22, 23, 24 and 25. The well is lined with a casing string 30 which has perforations 31, 32, 33 and 34 allowing fluid communication from the zones 22, 23, 24 and 25, respectively, into the well bore. A control tubing string 35, referred to hereinafter as a control string, and two production tubing strings 40 and 41, hereinafter referred to as production strings, are supported within the well bore and interconnected at the surface through a manifold system 42 which permits selective production from either or both of the production strings and the establishment of fluid flow circulation patterns in either direction between the control string and either of the production strings.

The control and production strings extend through two triple packers 43 and 44 positioned within the casing above and below the casing perforations 31. The packers 43 and 44 may each be any suitable form of triple packer such as illustrated at page 3653 of the Composite Catalog of Oil Field Equipment and Services, 1964-65 Edition, published by World Oil, Houston, Tex. The control string is connected at its lower end below the packer 44 into a tubular landing nipple 40a in the production string 40. A flow control device 45, hereinafter referred to as a shuttle valve, the preferred form of which is illustrated in detail in FIGURES 3A and 3B is supported in the landing nipple. A tubing section 50 extends from the landing nipple through a packer 51 between the zones 23 and 24 into the production string 41. The packer 51 is any suitable form of dual packer which will seal within the well casing around the production tubing string 41 and the tubing section 51, such as illustrated at page 3656 of the Composite Catalog of Oil Field Equipment and Services, supra. The shuttle valve permits the control tubing string to be placed in fluid communication with either the production string 40 or the production string 41 through the tubing section 50 while preventing fluid communication between the two production strings. The production string 41 extends through and terminates below a suitable single packer 52, which may be of the type illustrated at page 3656 of the Composite Catalog of Oil Field Equipment and Services, supra.

Two valves 53 and 54 are positioned in the production string 40 above and below the packer 43 to control fluid flow from the zones 22 and 23, respectively, into the production string. A valve 55 is connected in the production string 41 between the packers 51 and 52 to control the flow of fluid into the production string from the zone 24. The valves 53, 54, and 55 may be of the "sliding side door" type illustrated at page 3669 of the Composite Catalog of Oil Field Equipment and Services, supra. The lower end section of the production string 41 may be equipped with a removable bottom plug assembly 60 in a landing nipple 60a to prevent fluid flow into the production string from below the packer 52. A suitable form of valve may be placed in the lower end of the production tubing string in lieu of the plug assembly 60 to selectively control the flow of fluids into lower end of the tubing string.

It will be clear, therefore, that fluids from either or both of the zones 22 and 23 may flow to the surface through the production string 40 while fluids from either or both the zones 24 and 25 may flow to the surface through the production string 41. Generally, local producing regulations prohibit the comingling of production from two separate zones in the same production string and thus the tubing valves and the bottom plug assembly of the two production tubing strings will be used to permit fluid to flow into each of the tubing strings from only one of the producing zones at a time. For example, only one of the tubing valves 53 and 54 in the production string 40 will generally be open during a particular time. In the production tubing string 41

the plug assembly 60 would normally be installed when the bottom zone 25 is no longer to be produced and the tubing valve 55 is to be opened to produce the zone 24.

The manifold and pumping system 42 is adapted to permit fluid flow circulation patterns to be established including the control string 35 and either of the production strings 40 and 41. A suitable pump 70 is selectively connectable to the control string or either of the production strings to supply fluid under pressure into any one of the tubing strings. The pump draws fluid from the tank 71 through the line 72 with the tank also being selectively connectable to the control string or either of the production strings to receive returning fluid so that a complete fluid flow circulation pattern may be established in either direction through the control string and either of the production strings.

A pump discharge line 73 from the pump 70 is connected to a conduit 74 having valves 75 and 80, a conduit 81 having valves 82 and 83, and a conduit 84 having valves 85 and 90. The conduits 74, 81, and 84 are connected with a return line 91 leading to the tank 71. The production string 40 has connected in it two valves 92 and 93 which are spaced apart a distance sufficient to provide a lubricator section 40b so that a well tool string, not shown, may be inserted into the production string between the valves and subsequently pumped into the well, as described hereinafter. The valve 93 is positioned at the surface end of the production string so that when the valve is opened the well tool string is inserted through the valve directly into the section of the tubing string between the valves 92 and 93. A conduit 94 having a valve 94a is connected into the production string 40 for conducting produced fluids from the well to storage and separation facilities, not shown.

A conduit 95 extends from the production string 40 adjacent to the valve 93 to the conduit 74 between the valves 75 and 80 to supply and return fluid between the production string 40 and the manifold and pump system. The conduit 95 is connected into the production string as near the valve 93 as practicable to insure that fluid pumped into the production string from the conduit 95 will enter behind a well total string between the valves so the pressure will displace the tool string into the well in the production string.

The production string 41 is similarly equipped with a valve 100 and a valve 101 spaced apart to permit isolation of a lubrication section 41b to accommodate a well tool string. A conduit 102 having a valve 103 is connected into the production string 41 between the valves 100 and 101 to conduct produced fluids to storage and separation facilities not shown. A conduit 104 extends between the production string 41 and the conduit 84 between the valves 82 and 83 to supply and return fluid between the production string and the manifold and pump system. The conduit 104 is connected into the section of the production string 41 between the valves 100 and 101 as near as possible to the valve 101 so that fluid pumped into the production string through the conduit 104 will enter the conduit behind the tool string allowing the tool string to be pumped into the well through the production string.

FIGURES 3A and 3B illustrate the shuttle valve 45 and a locking device 110 releasably supporting the shuttle valve in the landing nipple 40a. Other suitable shuttle valves are shown in applicant's copending U.S. patent application No. 445,116.

The shuttle valve, as shown in FIGURE 3B, comprises a generally tubular mandrel 111 supporting upper and lower packing assemblies 112 and 113 and housing a longitudinally movable valve assembly 114. The mandrel includes a lower section 115 threaded into a central cage section 120 formed integral with a head section 121 and having a plurality of longitudinally extending circumferentially spaced slots 122. The lower section 115 has a lower external downwardly and inwardly sloping frusto-conical surface 123 to facilitate movement of the shuttle

valve through curved sections of tubing during installation by providing a surface minimizing lodging or jamming of the valve in such tubing sections. The lower section is reduced in external diameter along a major portion of its length providing an upwardly opening external annular recess 124 to receive the packing assembly 113. The lower end of the recess 124 is defined by an upwardly facing external annular shoulder 125 which holds the packing assembly against downward movement on the lower section. A lower end surface 130 on the central section 120 holds the packing assembly against upward movement on the lower section. An external annular recess 131 is formed in the central section near the lower end 130 to receive an O-ring seal 132 for sealing between the external surface of the central body section and an internal seal surface 133 defining a reduced portion of the bore through the landing nipple. A central longitudinal bore 134 extends through the lower section 115 into an enlarged bore section 135 through the central section 120 defining a central valve chamber 140 into which the longitudinal slots 121 open. A downwardly and inwardly convergent annular valve seat surface 141 on the upper end of the lower section 115 around the bore 134 limits the downward movement of the valve assembly 114 and coacts to control fluid flow between the central valve chamber 140 and the bore 134.

The head section 122 of the shuttle valve mandrel is reduced in external diameter providing an external, annular, upwardly opening recess 142 to receive the packing assembly 112. The upwardly facing external annular shoulder 143 defining the lower end of the recess 142 holds the packing assembly against downward movement on the head section. The head section has a reduced neck portion 144 connected with an enlarged head 145 having an external downwardly and inwardly convergent curved bearing surface 150. The upper end component 151 of the packing assembly 112 is an annular female adapter having an upper end downwardly and inwardly convergent annular surface 152 which matches a lower end downwardly and inwardly convergent surface 153 on an annular cap 154 to allow the cap to rock or pivot at the upper end of the valve while holding the packing assembly 112 against upward movement on the valve body.

The cap 154 has a lower end opening 155 which is larger than the external diameter of the head 145 so that the cap may be telescoped downwardly over the head and to the position illustrated in FIGURE 3B. Also, the diameter of the opening 155 is substantially greater than the diameter of the neck section 144 allowing the cap to be pivoted to a substantial degree out of alignment with the longitudinal axis of the valve mandrel as the cap serves a universal joint function in the pivotal connection between the shuttle valve and the locking device 110. An annular split ring 160 preferably formed in two semi-circular sections, having an internal downwardly and inwardly convergent curved surface 160a mating with the surface 150 on the head 145 is confined around the head by engagement of the downwardly and inwardly convergent surface 161 in the cap 154 around its lower end opening 155 and the flange 163 on the lower end of the locking device 110. The ring 160 prevents the cap 154 from pulling off the head 145 while the mating bearing surfaces 150 and 160a permit the cap to pivot around the head. The lower end opening 162 through the ring 160 is larger than the neck section 144 so the ring may rock about the head. The outer cylindrical surface portion 164 of the ring 160 mates with the internal cylindrical surface 165 defining a lower enlarged portion of the bore 166 through the locking device 110. The cap surface 161 together with the cylindrical surface 165 cooperate to hold the ring segments in fixed relationship relative to the flange and the cap so that during pivotal movement between the locking device 110 and the shuttle valve the flange 163, the cap 154, and the ring 160 move as a unit relative to the head 145. The substantial difference

in diameter between the neck section 144 and the lower end opening 155 of the cap permits a substantial pivotal movement of the cap about the neck section of the shuttle valve limited only by engagement of surface 155 with the neck section.

The cap 154 is first placed over the head 145 and forced downwardly against the packing adapter 151. The segments of the ring 160 are inserted into the cap around the head and brought together as the cap is lifted to confine the ring between the cap and head and hold the cap on the head.

A bore 170 extends through the head section 121 opening into the valve chamber 140. An upwardly and inwardly convergent annular valve seat surface 171 on the lower end of the head section limits the upward movement of the valve assembly 114 and cooperates with the valve assembly for controlling fluid flow between the bore and the central valve chamber.

The valve member assembly 114 includes a stem 180 threaded at opposite ends into identical upper and lower head sections 181 and 182, respectively.

An inner valve sleeve 183 is disposed in longitudinally slidable relationship around the head section 181 and held against upward movement on the valve stem by an internal annular lower end flange 184 which engages an external annular lower end surface 185 on the head section. An O-ring 190 is positioned within an internal annular recess 191 of the inner sleeve to seal between the sleeve and the outside surface of the head section 181. An annular seal ring 192 is received in an external annular recess 193 in the inner sleeve and is held in place around the inner sleeve by an outer sleeve 194. The ring seal 192 is rectangular or square in cross section with an exposed corner edge 195 engaging with the seat surface 171 when the valve assembly is seated against the seat surface. The upper end surfaces 183a and 194a of the inner and outer sleeves 183 and 194 are each fragmentary frusto-conical seat surfaces adapted to seat against the seat surface 171 so that upon complete closure of the valve assembly there is metal to metal fluid tight contact between the upper ends of the sleeves and the seat surface 171. An upper end frusto-conical surface 200 on the head section 181 guides the head section 181 into the bore 170 if it is misaligned within the mandrel during the operation. The outer sleeve 194 fits tightly around the inner sleeve 183 and is held against upward movement relative to the inner sleeve by engagement of the internal annular flange 201 with the external annular downwardly facing shoulder 202 around the inner sleeve. The inner and outer sleeves along with the ring seal 192 and the O-ring seal 190 function as a unit with no relative motion occurring between them during reciprocation of the valve member in moving between its closed and two open positions. The flange 184 fits in sliding relationship around the stem 180 so that the stem moves freely relative to the inner sleeve being limited only by the engagement of the flange 184 with the lower end surface 185 on the head section 181.

The lower section of the valve assembly 114 includes components identical with those just described above forming the upper end section of the valve assembly. An inner sleeve 202 is fitted in sliding relationship around the lower head section 182 and held against downward movement on the head section by engagement of the internal upper end flange 203 with the upper end shoulder surface 204 of the head section. An O-ring seal 205 is disposed in the internal annular recess 210 of the inner sleeve to seal between the bore through the inner sleeve and the outer surface of the lower head section 182. An outer sleeve 211 is secured around the inner sleeve and retains a seal ring 212 disposed in an external annular recess 213 around the inner sleeve. Lower end surfaces 202a and 211a on the inner and outer sleeves 202 and 211a, respectively, are fragmentary frusto-conical seat surfaces matching the seat surface 141 to provide a fluid tight seal when

the valve assembly is seated against the lower seat surface. An upper end frusto-conical surface 214 on the lower head section 182 guides the lower head section into the bore 134 if misalignment of the valve assembly occurs. A corner edge 215 of the ring seal 212 also seals with the seat surface 141. The inner and outer sleeves together with the O-ring 205 and the ring seal 212 function as a unit with longitudinal movement being permitted between them and the lower head section 182 and the valve stem 180.

A spring 220 encircling the valve stem 180 and the upper and lower inner sleeves is confined between the lower end surface 194b of the outer sleeve 194 and the upper end surface 211b of the outer sleeve 211 biasing the outer sleeves and their respective inner sleeves and seals apart to the end positions shown in FIGURE 3B. The valve stem and its head section can move longitudinally only by compressing the spring 220. Downward movement of the valve stem and head section compresses the spring 220 and pulls the inner and outer sleeves 183 and 194 downwardly away from the seat 171. Upward movement of the valve stem similarly raises the inner and outer sleeves 202 and 211 and compresses the spring 220. The valve assembly is movable between the fully closed position of FIGURE 3B to a lower position shown in FIGURE 4 when the bores 170 and the valve chamber 140 are in communication and an upper position, not shown, when the bore 134 and the valve chamber are in communication. The bores 170 and 134 are not simultaneously in communication with the valve chamber under normal operating condition. Once the valve is moved to either of its open positions it will remain in such a position so long as the pressure within the chamber 140 exceeds the pressure within the bore of the valve which is closed off. For example, the valve will remain in the position illustrated in FIGURE 4 so long as the pressure within the central valve chamber 140 exceeds the pressure within the lower bore 115 irrespective of the direction of flow or whether or not flow is occurring through the central valve chamber.

As shown in FIGURE 3B the landing nipple 40a is reduced in internal diameter along an upper section 230 and the lower section 231 to provide annular seat surfaces for the sealing engagement of the upper and lower packing assemblies 112 and 113, respectively, above and below the connection of the control string 35 into the landing nipple.

The locking device 110 which supports the shuttle valve in the landing nipple 40a and holds it against upward and downward movement therein is illustrated in detail in FIGURE 3A. The locking device includes the tubular mandrel 164 having an upper latch ring section 230 and a lower seal carrier section 231, the upper end of the seal carrier section being threaded in the lower end portion of the upper latch ring section. A suitable seal assembly 232, which may be of the Chevron type, is disposed on the seal carrier section and its downward movement thereon is limited by its engagement with the upwardly facing external annular shoulder 233 provided by an external annular flange 234 of the seal carrier section. Upward movement of the seal assembly on the seal carrier section is limited by its engagement with the downwardly facing annular end surface or shoulder 235 of the latch ring section. As previously described, the externally threaded lower end flange 163 on the seal carrier section is threaded into the cap 154 to interconnect the locking device and the shuttle valve.

The internal diameter of the landing nipple 40a is decreased to provide an upwardly facing annular top stop shoulder 240 and a seal surface 241 engageable by the seal assembly 232. The seal surface is located below an internal annular latch recess 242 of the landing nipple whose upper and lower ends are defined by the upper and lower inwardly divergent annular shoulders 243 and 244 of the nipple.

The latch ring section 230 has upper and lower external annular recesses 245 and 250 in which are received the inner portions of the spring latch rings 251 and 252, respectively. An external longitudinal recess 253 of the latch ring section opens to the upper end of the latch ring section and intersects the upper and lower latch ring recesses thereof.

The two latch rings are identical in structure and are preferably of a helical form having their upper and lower free end portions 254 and 255 spaced vertically from each other. The latch rings have facing vertical end or stop surfaces 260 and 261. The upper and lower outer edges of the outer surface of the latch rings are chamfered to provide upper and lower external cam surfaces or shoulders which extend divergently inwardly from the vertical external surface of the rings to their top and bottom surfaces respectively. The free end portions 260 and 261 of each of the latch rings has upper and lower cam surfaces which extend divergently from opposite ends of the stop surfaces to the top and bottom surfaces of the ring.

The top surface of the upper latch ring at its upper free end portion engages the top shoulder 262 of the upper latch ring section defining the top end of the upper latch recess 245 and the bottom surface of the latch ring at its lower free end portion engages the shoulder 263 defining the bottom end of the upper latch recess to hold the latch ring against vertical movement as a unit on the mandrel. Similarly the top and bottom surfaces of the lower latch ring at its upper and lower end portions engage the top and bottom shoulders 264 and 265 of the latch ring section of the mandrel defining the top and bottom ends of the lower latch ring recess 250 for the same purpose.

A tubular lock member 270 extends downwardly into the mandrel and its downward movement therein is limited by the engagement of its downwardly facing annular end surface or shoulder 271 with the upwardly facing internal annular shoulder 272 of the seal carrier section 231. Upward movement of the lock member in the mandrel is yieldably resisted by a spring 273 disposed about the locked member whose lower end portion engages the upwardly facing annular shoulder 274 provided by the lower external annular flange 275 of the lock mandrel and whose upper end portion bears against the annular bottom end shoulder of a split ring 280. The split ring is slidable on the lock member and its upward movement is limited by the engagement of its top end surface with the downwardly facing annular shoulder 281 of the lock member. The outer portions of the split ring extend outwardly of the lock member so that the annular top shoulder of the split ring is engageable with the bottom end surface of a split snap ring 282, the outer portions of which extend into an annular internal recess 283 whose lower end is defined by the annular top end surface of the seal carrier section 231. The engagement of the top and bottom end surfaces of the snap ring with the top and bottom surfaces defining the recess 283 prevents longitudinal movement of the ring in the main mandrel. The snap ring 282 is inherently of greater diameter than the internal bore of the upper and lower mandrel sections above and below the recess 283.

It will be apparent that when a force is exerted on the lock member 270 causing it to move upwardly in the mandrel the split ring 280 engages the snap ring 282 whereupon further upward movement of the lock member relative to the main mandrel can take place only against the resistance offered by the spring 273. The upper enlarged end or head portion 284 of the lock member is provided with an internal annular flange 285 which provides a downwardly facing shoulder 290 engageable by a suitable running and pulling tool by means of which the locking device together with the shuttle valve connected to its lower end is lowered through the production tubing 40 to the landing nipple 40a.

The lock member 270 has an elongate external lock bar 291 which extends downwardly from its upper end portion 284. The inner surface of the lock bar is spaced from the outer surface of the lock member below the lock member's upper end or head section so that while the lower tubular portion of the lock member within the spring 273 fits within the main mandrel, the lock bar slides over the main mandrel into the external longitudinal recess 253 formed along the outer surface of the latch ring section 230. The lock bar near its lower end has a pair of oppositely extending bosses 292 and 293 each of which has upper and lower outwardly convergent shoulders which converge toward a vertical outer edge stop surface along each edge of the lock bar as shown in FIGURE 3 near the split ends of the split ring 252. The upper end portion of the lock bar is enlarged providing oppositely facing side stop surfaces 294 and 295 the lower ends of which join inwardly and downwardly convergent cam surfaces extending along the opposite edges of the lock bar.

When the lock member 270 is in its normal lower locking position on the mandrel, the upper enlarged portion of the lock bar having the side surfaces 294 and 295 extends downwardly into the upper portion of the top latch recess 245 and the bosses 292 and 293 are positioned above the shoulder 265 defining the bottom of the lower latch recess 250.

It will be apparent that the end surfaces 260 and 261 of the upper latch ring 251 are engageable with the side stop surfaces 295 and 294 when the top latch ring is in an upper position in the upper latch recess wherein its top edge engages the shoulder 262. Similarly, the end surfaces of the lower latch ring 252 are engageable with the edge stop surfaces of the bosses 292 and 293 when the lower latch ring is in its lowermost position in the lower latch recess with its bottom edge surface engaging the mandrel shoulder 265. It will be apparent that when the upper latch ring is in its uppermost position in its mandrel recess 245 with its free end portions 254 and 255 in the same horizontal plane it is locked against radial contraction by the lock bar and that it is free to contract to a limited degree when it is in its normal position as illustrated in FIGURE 3A wherein its lower end portion 255 is spaced below the cam shoulder at the lower end of the lock surface 295 on the lock bar.

It will be apparent that when the lower latch ring is in its lowermost position in its mandrel recess 250 with its free end portions in the same horizontal planes it is locked against radial contraction and that it is free to contract to a limited degree when it is in its normal position illustrated in FIGURE 3A wherein its upper free end portion is spaced above the upper shoulder or cam surface of the lock boss 292.

During installation of the shuttle valve and the locking device in the landing nipple 40a, as the locking tool moves downwardly into the landing nipple, the lower edge cam surface of the lower latch ring 252 engages the top shoulder 240 of the landing nipple and the camming action therebetween causes the lower latch ring to contract into the lower mandrel recess 250 to permit passage thereof past the upper internal surface of the landing nipple between the internal shoulders 240 and 243 of the landing nipple. Such contraction of the lock ring is possible since the end surface of the latch ring nearest the boss 292 is disposed above the boss and since the lower free end section near the boss 293 engages the nipple shoulder 240 and its downward movement is arrested as continued downward movement of the mandrel and latch member causes the boss 293 to move therebelow.

When the locking device mandrel moves to its lower position in the nipple wherein the lower latch ring is in alignment with the lower latch recess 242, the lower latch ring moves resiliently outwardly thereto so that its outer portions are disposed in the recess. At this time the bottom outer edge cam surface of the upper latch ring at its lower end portion 255 engages the upper cam shoulder 240 of

the landing nipple and similarly the external bottom outer cam surface of the lower latch ring engages the shoulder 244 of the landing nipple. The seal assembly 232 now engages the seal surface 241 to seal against fluid flow around the mandrel.

When a downward force is imparted to the locking device tending to move it downwardly in the landing nipple, as may be effected when disconnecting a running tool from the locking device, the mandrel of the locking device is moved downwardly relative to the latch rings and since the lower end portion, such as the portion 255 of the upper ring 251, of the latch rings engage the mandrel shoulders 263 and 265, respectively, the ends of the latch rings are moved into alignment with one another by their engagement with the nipple shoulders 240 and 244, respectively. The end surfaces of the upper latch ring move into engagement with the stop surfaces 294 and 295 of the lock bar which prevents contraction of the upper latch ring. The latch ring is pressed into the horizontal position with its upper edge engaging the shoulder 262 around the upper latch ring section of the mandrel and with the lower edge of the upper latch ring engaging the shoulder 240 in the landing nipple to hold the locking device against downward movement within the nipple.

Any upward force imparted to the mandrel of the locking device moves the mandrel upwardly relative to the upper end portion of the lower latch ring adjacent the boss 292 of the lock bar due to the engagement of the top surface of the latch ring with the shoulder 264 of the mandrel section. The free end portions of the lower latch ring are thus forced into alignment with one another and their end stop surfaces adjacent the bosses 292 and 293 are moved downwardly on the mandrel into engagement with the outer edges of the bosses 292 and 293 so that the latch ring 252 cannot contract inwardly and thus is held outwardly in the locking recess 242 of the landing nipple to hold the locking device against upward movement within the nipple.

The locking device is removable from the landing nipple by engagement of the upper end or head portion 284 of the lock member by a suitable pulling tool to lift the locking device upwardly. Upward force applied to the locking device is transmitted through the spring 273 to the ring 280 which engages the ring 282 within the latch ring section of the mandrel lifting the mandrel with the lock member until the mandrel is held against further upward movement by engagement of the upper edge of the lower latch ring 252 with the downwardly facing annular landing nipple shoulder 243. Further force applied to the lock member compresses the spring 273 allowing the lock member to move upwardly lifting the locking bar 291 raising the bosses 292 and 293 from within the open ends of the lower latch ring 252 to allow the latch ring to contract inwardly around the mandrel so that the landing nipple recess 243 may cam the lower latch ring inwardly thereby releasing the locking device from the landing nipple so that it may be lifted upwardly.

A locking device identical to that illustrated in FIGURE 3A and described hereinabove is disclosed and claimed in applicant's United States patent application Ser. No. 477,754 filed Aug. 6, 1965.

The well system 20 in accordance with the invention is installed in the well bore 21 by employing suitable standard procedures for introducing the control string 35 together with the production strings 40 and 41 and the packers 43, 44, 50, and 52 into the well bore where the packers are engaged with the well casing 30 to seal around the control and production string above and below the various producing formations. The landing nipple 40a as well as the tubing valves 53, 54, and 55 are included in the production strings and the control string and the production string 40 and the two production strings are interconnected as the control and production strings are run into the well with the packers.

A suitable landing nipple, not shown, may be included

in the production string 41 below the valve 55 and preferably below the location at which the tubing section 50 connects into the production string to receive the bottom plug assembly 60 which is any suitable form of plugging means which is releasable from the production string to permit fluid to flow into its lower end from the zone 25 and is adapted to hold against pressure from above or below the plug. The plug 60 may be of the type illustrated at page 3737 of the Composite Catalog of Oil Field Equipment and Services, supra, or the locking device 110 may be adapted to serve a bottom plugging function by utilizing the locking device alone with a suitable solid cap, not shown, threaded on the lower end flange 163 of the main mandrel so that fluid flow is prevented through the bore of the locking device from either above or below the cap. Generally, the bottom formation 25 will be produced first and the lug assembly will not be required until it is desired to prevent flow into the lower end of the production string 60. If the plug assembly is required initially, it may be run into the well with the production string or installed by pump in or wireline procedures after the well tubing strings are set.

After installation of the control and the production strings with the packers in the well bore, the various surface components illustrated in FIGURE 1, including the manifold system 42 along with the other valves and conduits shown, are connected at the surface with the control and the production strings.

The shuttle valve 45 and its locking device 110 may be installed in the landing nipple at the surface and run in with the production string 40 or they may be run in and remotely locked in accordance with the following procedure.

The shuttle valve is connected with its locking device 110 by engagement of the annular cap 154 on the shuttle valve with the lower end threaded flange 163 on the mandrel of the locking device. The locking device is connected with a suitable running tool, for example, a type W Otis Running Tool illustrated on page 3745 of the Composite Catalog of Oil Field Equipment and Services, supra. The running tool is introduced on a flexible line into the production string 40 until the locking device 110 is locked within the landing nipple 40a in accordance with the previous description of the procedure of latching the locking device in the landing nipple. With the locking device so engaged in the landing nipple the shuttle valve is supported within the nipple as illustrated in FIGURE 3B with the upper and lower packing assemblies 112 and 113, respectively, being engaged with the packing surfaces 230 and 231 above and below the point of connection of the control string 35 into the landing nipple. The running tool is then disengaged from the locking device 110 and withdrawn to the surface.

If the wellhead is substantially displaced horizontally from the surface connections as in the case of shore-located surface connections and an ocean floor mounted wellhead at some distance removed from the shore line, it may be preferred that the shuttle valve and its locking device be installed by pumping them through the production string. The shuttle valve 45 and its locking device are engaged in a pump-down tool string, not shown, including at least one and preferably two spaced apart pumping elements, generally of the type illustrated at page 3634 of the Composite Catalog of Oil Field Equipment and services, supra, and shown in more detail in a copending United States patent application, Ser. No. 312,175, by Norman F. Brown. The pumping elements are cylindrical seal units adapted to permit controlled fluid bypass through them and displaceable through a conduit by a fluid pressure differential established across them. The two pivotally interconnected pumping elements are secured with the head section 284 of the locking device 110 preferably with suitable releasable means permitting disconnection of the pumping elements from the shuttle valve locking device when the locking device and shuttle valve

have been landed and locked in the landing nipple. Releasable means which may be utilized to interconnect the pumping elements and the locking device 110 is illustrated and described in applicant's copending United States patent application Ser. No. 486,641.

The pump-down tool train including the shuttle valve and locking device are inserted into the production string 40 at the surface. With the valve 92 closed, the valve 93 is opened and the tool string is inserted through the open surface end of the production string and the valve 93 into the production string lubricator section 40b between the valves 92 and 93. The valve 94 is closed so that the pressure may be built up to pump the tool string into the well bore through the production string.

The necessary surface valves in the manifold 42 and the production strings are adjusted as required to establish a fluid circulation pattern through the well from the surface with injection into the production string 40 and return to the surface through the control string 35. The tank 71 connected with the pump 70 is filled with a suitable liquid which may be pumped through the fluid flow system and which will not damage any of the producing formations contacted by it. The liquid in the tank may be a suitable drilling fluid or petroleum oil. The valves 35a in the control string 85 and in the conduit 84 are opened while the valves 80, 83, and 90 are closed so that fluid returning from the control string 35 can flow only into the conduit 84 and then through the conduit 91 into the tank 71. The valve 75 is opened and the valve 82 closed so that liquid withdrawn from the tank through the line 72 by the pump is discharged only through the line 73 and the valve 75 into the line 95 through which the liquid flows into the production string section 40b behind the pump-down tool string. The valve 100 in the production string 41 is maintained closed to limit upward flow from the well to the control string while liquid is being pumped into the production string 40.

The well bore and the production and control string preferably have been kept filled with a fluid having sufficient density to balance bottom hole pressures to prevent formations fluids from tending to flow upwardly through the control and production strings.

Fluid from the tank 71 is pulled through the line 72 by the pump 70 and discharged from the pump into the line 73. The fluid flows through the valve 75 and the line 95 into the production string section 40b behind the tool string previously inserted into the production string. The valve 92 is opened and the pressure of the liquid being pumped into the production string is increased to a sufficient level to displace the tool train through the production string 40 from its position between the valves 92 and 93 to the landing nipple 40a where the shuttle valve and the locking device 110 are releasably locked in the landing nipple in the position illustrated in FIGURES 3A and 3B. As the tool train moves through the production string there is substantially no relative movement between the tool train and the fluid being utilized to transport the tool train. Therefore, measurement of the quantity of fluid pumped into the production string by the pump 70 based upon knowledge of the volume of the production string and other conduits between the pump and the landing nipple will provide the operator with sufficient information to generally indicate the arrival of the shuttle valve and locking device in the landing nipple. The stopping of the movement of the tool train by the seating of the shuttle valve and the locking device will be evident by the change in flow rate through the production string 40 and control string 35. The fluid flow will continue at a reduced rate as the pumping elements permit fluid bypass and when the shuttle valve is seated its valve member 114 is displaced downwardly by the pressure differential built up across it. The pressure in the bore 170 of the valve is raised by the pumping to a level above the pressure in the bore 134 causing the valve rod 180 to be displaced downwardly moving the outer and inner sleeves 194 and

183 off the seat 171, as in FIGURE 4, allowing flow from the bore 170 through the chamber 140 into the control line 35 and through the control line back to the surface into the tank 71.

After the locking device 110 is properly engaged in the landing nipple 40a the tool train is disengaged from the locking device so that the pumping elements and the connecting means may be pumped back to the surface through the production string 40 into the section 40b. In order to return the tools to the surface through the production string, it is necessary that the flow pattern be reversed with fluid injection into the control string and fluid return through the production string 40.

To reverse the flow pattern through the control string 35 and the production string 40 it is necessary that two operating conditions be established, opening the shuttle valve and reversing the flow direction. First, the shuttle valve 45 must be open to permit fluid flow through the valve from the control string into the production string 40. The pressure within the production string 40 is raised to a value sufficiently in excess of the pressure within the tubing section 50 connected to the lower end of the shuttle valve that the valve assembly 114 of the shuttle valve will be moved downwardly to the open position illustrated in FIGURE 4. The fluid flow rate through the production string 40 past the tool string is increased to a value sufficient to raise the pressure within the upper bore 170 of the shuttle valve to a value exceeding the pressure within the lower bore 134 of the shuttle valve and sufficient to overcome the force of the spring 220 so that the valve rod 180 with its upper and lower head members 181 and 182 is displaced downwardly along with the inner and outer valve sleeves 183 and 194 with their seal rings 190 and 192. As soon as the valve assembly moves away from the upper seat 171, the pressure within the upper bore 170 and the central valve chamber 140 will be substantially equalized at a value above the pressure in the bore 134 and the valve will be held in the lower open position shown in FIGURE 4 by the force of the pressure within the valve chamber 140 acting over a cross-sectional area of the valve stem 130. The pressure within the valve chamber acts over a cross-sectional area of the lower head member 182 as defined by the line of sealing engagement between the head member and the O-ring 205 to bias the valve member in the lower open position.

With the shuttle valve open communicating the production string 40 and the control string 35, the direction of fluid flow between the control string and the production string is reversed to pump the tool string back out the production string leaving the shuttle valve and its locking device in place in the landing nipple. The shuttle valve will remain in the lower open position so long as the pressure within the central chamber of the shuttle valve is maintained sufficiently above the pressure within the lower bore 134 to keep the shuttle valve member in the position shown in FIGURE 4. The control string 35 is established as the input string and the production string 40 as the return string while holding the pressure at the shuttle valve sufficiently high to maintain it in the open position. The control string 35 is placed in fluid communication with the discharge side of the pump 70 by closing the valve 85, opening the valve 90, and closing the valves 75 and 82 whereby fluid is pumped from the pump through the line 73 and valve 90 into the line 84 between the valve 90 and the closed valve 85. The fluid then flows into the control string through the valve 35a. The tank 71 is placed in fluid communication with the line 95 connected into the production string 40 between the valves 92 and 93 by opening the valve 80 while closing the valve 83, the valve 85 previously having been indicated as closed. Thus, fluid from the production string 40 may flow from the string into the line 95, through the line 74 and the open valve 80 into the line 91, and through the line 91 to the tank 71.

Fluid is now pumped from the pump 70 through the

lines 73, the valve 90 and the line 84 into the control string 35. Fluid flows through the control string 35 into the landing nipple 40a through longitudinal slots 121 in the shuttle valve body into the central chamber 140 of the shuttle valve, and around the downwardly positioned shuttle valve member 114 into the upper bore 170. The fluid flows in the upper bore 170 upwardly through the bore 166 of the locking device 110 into the production string 40 through which the fluid flows to the surface and through the valve 92 into the line 95. The fluid flows from the line 95 into the line 74 and through the valve 80 into the line 91 through which it returns to the tank. The tool string is pumped upwardly through the production string 40 until the tool string is positioned in the section 40b between the valves 92 and 93 at which time pumping may be stopped and the valve 92 closed. The valve 93 is then opened and the tool string is removed from the production string 40 and the valve 93 again closed.

Generally the lower zone 25 will be produced prior to the zone 24 and therefore the bottom end of the production string 41 is not normally initially plugged, such as by the installation of the bottom plug assembly 60. When the bottom zone has been produced to the extent that it is either depleted or the pressure is reduced to the level where further production from it is not practicable the perforations 34 may be closed by a conventional squeeze cementing technique or the bottom plug assembly 60 may be installed within the production string 41 to prevent fluid communication between the production string and the bottom zone through the packer 52. The plug assembly may be installed either by the wire-line method, if the well system permits such an installation, or by the pump-down method previously described in connection with the installation of the shuttle valve.

If the pump-down procedure is used for the bottom plug assembly installation the production string 41 is established as the input flow line while the return liquid used to pump the tool string and bottom plug assembly downwardly returns to the surface through the tubing section 50, the shuttle valve 45, and the control string 35. The surface valves are adjusted to place the pump 70 in fluid communication with the production string 41 through the line 104. With the valves 100 and 103 closed, the valve 101 is opened and the plug assembly connected with a pump-down tool string is inserted through the open surface end of the production string 41 into the section 41a of the production string between the valves 100 and 101. The valve 101 is closed and the necessary valves are adjusted to place the control string 35 in communication with the tank 71 so that the return liquids will pass into the tank.

Pumping is started with the fluid flowing from the tank 71 through the line 72 into the pump 70 and from the pump through the open valve 82 into the line 81 from which the fluid flows through the line 104 into the production string 41 behind the pump-down tool string. The valves 75, 80, 83, and 90 are closed. The fluid pressure from the pump is transmitted through the production string 41 into the tubing section 50 and the lower bore 134 of the shuttle valve. When the pressure within the bore 134 of the shuttle valve is raised sufficiently above the pressure within the production string 40 above the shuttle valve, the valve member 114 shifts to the upper open position with the valve stem 180 and its head section moving upwardly lifting the lower inner and outer valve sleeves 202 and 211 off the lower seat 141 opening the shuttle valve allowing fluid flow from its lower bore 115 into its central chamber 140. The fluid flows from the central chamber 140 outwardly through the longitudinal slots 121 into the landing nipple and then into the control string 35 through which the fluid returns to the surface into the tank 71 through the line 84, the open valve 85, and the line 91. Since the pressure within the central chamber 140 of the shuttle valve exceeds the pressure within the upper bore 170 the valve

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assembly remains in the upper position prohibiting fluid communication between the central valve chamber and the upper bore of the valve. The tool train is pumped downwardly through the production string 41 until the bottom plug 60 is locked in the landing nipple 60a. The pressure at the valve chamber 140 is maintained sufficiently above the pressure within the upper bore 170 of the shuttle valve to maintain the valve in the open position communicating with the production string 41 and the control string while the direction of fluid flow is reversed with fluid being pumped into the control string and returned to the surface through the production string 41 to pump the tool train back to the surface where it is removed from the production string section 41a after closing the valve 100 and opening the valve 101.

During the previously described procedures of installing the shuttle valve and installing the bottom plug assembly 60 the tubing string valves 53, 54, and 55 are normally maintained in the closed position.

During the previously described procedures of installing the landing nipple 40a according to the above described procedures, the well flow system is employed to produce the several formations penetrated by it and to carry out a wide variety of servicing and formation treating techniques. By establishing a variety of fluid circulation patterns between the control string and either of the production strings well tools may be installed and removed, the tubing valves are manipulated and the formations may be treated such as by acidizing and fracturing. Cementing of the casing perforations may be done by squeezing the cement into the zones between the packers.

The shuttle valve effectively prevents fluid communication between the production strings while permitting fluid communication between the control string and either of the production strings and while such communication is established fluids may flow in either direction through the particular flow pattern established so long as the pressure within the shuttle valve central chamber is maintained sufficiently above the pressure within the particular production string isolated from the flow pattern to hold the shuttle valve in the desired open position. The shuttle valve is opened by increasing the pressure within one of the production strings to a sufficiently higher level than the pressure in the other of the production strings to displace the valve assembly of the valve toward the string being isolated though subsequent to opening of the shuttle valve the flow direction may be altered or stopped as desired so long as the pressure within the central chamber of the shuttle valve is maintained sufficiently in excess of the pressure within the isolated production string. Increasing of the pressure in the control string above the pressure within the production strings will not open the shuttle valve but on the contrary biases both ends of the valve assembly to the closed position.

Generally the shuttle valves are positioned at or near the midpoint of each circulation loop which may be set up in the systems of the invention. By so positioning the shuttle valves the resistance to fluid return in the tubing string conducting the fluid back to the surface aids in keeping sufficient pressure in the shuttle valve chamber to hold the valve open as desired. Obviously, each shuttle valve serving formations at different depths cannot be located exactly at the center of each loop which may be interconnected with the valve. However, in view of the substantial distances involved in the wells and between a wellhead and the control manifold on the surface, in most cases, a variation of the shuttle location the distance necessary for the connections between formations or across packers will not seriously affect keeping the needed pressure at the valve.

Formation fluids are produced through any one or all of the producing zones connectable with each production string. For example, fluids from the zone 25

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may flow into the lower end of the production string 41 while fluids from the next zone 24 may also flow through the valve 55 into the production string. Fluids from the upper zones 22 and 23 may flow into the production string 40 through the valves 53 and 54, respectively. While produced fluids are flowing into either or both of the production strings the fluids within one production string may not mingle with the fluids within the other production string due to the presence of the shuttle valve between the production strings. Generally, local conservation regulations prohibit the production of two zones into the same production string and the fluid flow control system 20 is readily adaptable to such area in that the tubing string valves in either of the production strings may be open or closed as required to produce only one zone into each of the production strings.

During fluid production through the production string 41 the formation pressure is applied to the shuttle valve through the tubing section 50. The pressure in the production string 40 is adjusted substantially below the pressure in the tubing 50 so that the fluid from the tubing 50 may not flow into the production string 40. If production is occurring through the production string 40 the pressure will not flow downwardly past the shuttle valve into the tubing section 50. Both production strings may simultaneously produce with the shuttle valve moving toward the lower pressure to close the valve into the string having the lower pressure. During production the control string is normally sealed under adequate pressure to keep the shuttle valve closed in both directions.

In addition to fulfilling functions such as providing means for introducing well tools into and removing such tools from the production strings as described above, the fluid flow system of the invention permits such well known procedures as formation fracturing, acidizing, and cementing to be carried out in all of the formations communicatable with the production tubing strings. These procedures may be carried out without communication with or affecting in any way the formation other the particular one desired to be treated. For example, if cement is to be pumped into the zone 24 for the purpose such as closing off the perforations 33, the pressure within the production string 41 is raised sufficiently above the pressure within the production string 40 to move the shuttle valve member 114 to the upper position communicating the production string 41 with the control string 35 through the tubing section 50 and the shuttle valve central chamber. The cement is pumped through the production string 41 with displaced fluids ahead of the cement within the production and control strings returning to the surface through the shuttle valve and control string. Sufficient back pressure may be held on the control string by its surface valves to force the cement outwardly through the tubing valve 55 between the packers 51 and 52 to seal off the perforations 33. When sufficient cement has been pumped into the formation pumping may continue to circulate the cement through the production string 41 back to the surface through the control string until the strings have been cleared of the cement and the valve 55 may then be closed if desired with suitable pump-down tools.

The fluid flow system of the invention may also be used for such operations as paraffin removal. For example, if paraffin is to be removed from the production string 40, a flow circulation pattern is set up to allow input into the production string and return through the control string. A paraffin removal tool is inserted into the production string section 40b and pumped downwardly to the shuttle valve. Reverse circulation is then established to pump the removal tool back to the surface into the section 40b followed by the paraffin cuttings.

It will now be apparent that a new and improved sys-

tem for controlling fluid flow in a well bore has been described and illustrated.

It will be seen that the fluid flow system of the invention is useful for transporting well tools between a well bore and a remotely located spaced apart control station.

It will be further seen that the fluid flow system includes operable components permitting production of well fluids from a plurality of zones at selected spaced-apart depths within a well bore.

It will also be seen that the well flow system is operable to establish fluid communication between a surface location and a plurality of selected depth zones within a well bore.

It will also be seen that the fluid flow system permits closed circuit fluid flow between a surface location and selected zones within a well bore.

It will also be seen that the well flow system includes one production tubing string for each of the producing zones to be flowed simultaneously and one control fluid tubing string interconnected with all of the production tubing strings in the system.

It will be further seen that the fluid flow control system includes a plurality of interconnected production tubing strings and a control tubing string with flow control means for preventing fluid communication between the production tubing strings.

It will also be seen that the fluid flow control system includes a plurality of production tubing strings and a control tubing string wherein a fluid circulation pattern may be established through the control tubing string and any one of the production tubing strings while isolating the remaining production tubing strings in the system from the particular circulation pattern established.

It will be apparent that there has been described and illustrated a new and novel fluid flow control device for selectively controlling fluid flow between one conduit and any one of a plurality of additional conduits connected with said device.

It will be seen that the fluid flow control device includes a central valve chamber for communication between a control tubing string and a plurality of check valves leading to a plurality of production tubing strings.

It will be further seen that the fluid flow control device includes a central valve chamber communicating with a lateral opening leading thereto and at opposite ends with flow passages selectively closable by check valves positioned within the chamber and interconnected by a common valve rod extendable into the flow passages whereby the valve is operable to control fluid flow between the lateral opening and either of the end flow passages by adjustment of a pressure differential across the valve rod between the end flow passages.

It will also be seen that the fluid flow system includes a fluid flow control device between a control tubing string and a plurality of production tubing strings wherein fluid flow between the control tubing string and a selected production tubing string is initiated by increasing the fluid pressure within the production tubing string to a value in excess of the fluid pressure within the remaining production tubing strings connected to the flow control device subsequent to which fluid flow may be effected in either direction between the control tubing string and the selected production tubing string or fluid flow may be terminated so long as the fluid pressure within the central chamber of the control device exceeds the fluid pressure within the remaining production tubing strings connected with but isolated from the flow control device.

It will be further seen that the flow control system includes a plurality of circulation loops having a flow control device positioned substantially at the mid-point of each of the circulation loops whereby the fluid pressure within the central chamber of the control device may be maintained at a higher level than the fluid pres-

sure in any one of the interconnected production tubing strings irrespective of the direction of fluid flow due to the resistance to fluid flow of the return fluid flow path.

It will be further seen that the fluid flow control system includes a fluid flow control device interconnected between a control tubing string and at least two production tubing strings.

It will also be seen that the fluid flow control system includes apparatus for selectively establishing a plurality of closed fluid circulation loops through which well tools may be pumped to and from desired depth locations within a well bore from a remotely located surface station.

It will be apparent that the well flow control system is adaptable to wells completed at the bottom of a body of water, such as an ocean or lake, permitting remote communication between a water surface or land located control station and the sub-surface wellhead.

It will also be apparent that the well flow control system permits tools to be pumped to and from selected depth locations within a well bore and further permits fluid treatment of any one of the formations penetrated by the well bore while isolating the other formations not being treated.

FIGURE 2 illustrates another arrangement of a well flow system 300 according to the invention including one control tubing string serving four production strings with a shuttle valve being provided between the control tubing string and each pair of the production tubing strings. The well system includes a control tubing string 301 and four production tubing strings 302, 303, 304 and 305. The control and production strings are supported in a well bore 310 provided with a casing 311 having a wellhead 311a. The well bore extends through a plurality of producing formations 312, 313, 314, 315, 316 and 317. Two packers 318 and 319 are positioned within the casing to seal around the control and production strings above and below the formation 312 with the casing being provided with a plurality of perforations 320 to allow formation fluids to flow into the well bore between the packers. A packer 325 is set within the casing below the formation 313 with communication being provided through the casing by the perforations 326 between the packers 325 and 319. The packers 327, 328 and 329 are also set within the casing around the control and production strings to seal above and below the formations 315, 316, and 317. The various packers illustrated, ranging from the single type packer 329 to the packers 318 and 319 sealing around five tubing strings are any suitable available standard packers. The casing 311 is provided with the perforations 330, 331, 332, and 333 to permit fluid communication into the casing from the formations 314, 315, 316 and 317, respectively, between the packers sealing off the formations.

The control string 301 is connected with the production strings 302 and 303 through a shuttle valve 334 positioned in the landing nipple 34 connected in the production string 303 below a tubing valve 335. The lower end of the nipple is connected into a tubing section 303a extending to the production string 302 below the packer 319. A tubing valve 340 is connected in the production string 302 between the packers 319 and 325 to allow fluids from the formation 313 to flow into the production string. The production tubing 302 terminates below the packer 325 and may be plugged at or near its lower end 341 by a plug assembly 341a if production into the string is not desired from the formation 314. A short cross-over connection 342 extends between the control string and the landing nipple 334 to provide the connection between the control string and the landing nipple.

The control string 301 extends downwardly below the landing nipple 334a through the packers 325 and 327 connecting into a shuttle valve 350 in a landing nipple 350a between the packers 327 and 328. The landing nipple 350a is connected in the production string 304. A tub-

ing section 304a extends downwardly from the landing nipple 350a through the packer 328 below which it connects into the production string 305 between the packers 328 and 329. Two tubing valves 351 and 352 are connected in the production string 304 providing fluid communication into the string from the formations 314 and 315, respectively. The production string 305 may communicate with the formations 316 and 317 through a tubing valve 353 and the lower end 354 of the string below the packer 329. The lower end 353 of the production string 305 may be closed with a bottom plug assembly 353a, if desired.

The shuttle valves, the tubing valves, and the bottom plug assemblies of the flow system 300 may be identical to those described and illustrated in connection with the system 20 of FIGURE 1. The system and its various components are installed in the same manner as described above.

The control string 301 and the production strings 302-305 are connected at the surface with a pump, a tank, and the necessary valves, not shown, to permit closed circuit fluid circulation between the control string and any one of the production strings, as described and illustrated in connection with the embodiment of the invention shown in FIGURE 1. The surface facilities thus permit utilizing the control string for both fluid supply and return and for employing any one of the production strings for either fluid supply or fluid return. Well tools may be pumped between the surface and sub-surface locations within the well bore through any one of the production strings and any of the producing formations communicating with the production strings may be produced.

During normal production the pressure is raised in the control string and the string sealed to hold both shuttle valves in the closed position. All four production strings may be simultaneously used to produce fluid without commingling between the strings.

A circulation pattern including the control strings and any one of the production strings may be established. A fluid flow circulation pattern including the production string 302, for example, is established by raising the pressure within the production string 302 to a level sufficiently in excess of the pressure in the production string 303 to shift the shuttle valve 334 to an upper position allowing fluid communication between the production string 302, the tubing section 303a, the shuttle valve, and the control string. The pressure is held at a level sufficient to keep this shuttle valve 350 closed; otherwise, the pressure from one of the lower zones might open the lower shuttle valve resulting in closing the upper shuttle valve.

If a fluid flow pattern through the production string 303 is desired the pressure within the string 303 is raised sufficiently above the pressure within the tubing section 303a below the shuttle valve 334 as applied from the production string 302 to shift the shuttle valve downwardly to place the production string 303 in communication with the control string.

Through the shuttle valve 350 the control string functions to establish a fluid circulation pattern including either of the production strings 304 or 305. To establish a circulation pattern including the production string 304 the pressure within that string is increased above the pressure within the tubing section 305a below the landing nipple 350 to shift the shuttle valve downwardly to place the control string and the production string 304 in fluid communication. If the circulation pattern is to include the production string 305, the fluid pressure within that string through the tubing 304a is raised above the fluid pressure within the string 304 above the valve 350 so that the shuttle valve is moved to the upper position placing the control string and string 305 in communication.

In flowing fluid through each of the circulation patterns established it will be recognized as with the embodiment of FIGURE 1 that the direction of fluid flow or whether or not fluid flow is occurring does not alter the established

flow pattern so long as the pressure within the shuttle valve central chamber is maintained higher than the pressure in the production strings isolated from the particular circulation pattern established. For example, if the circulation pattern includes the production string 302, the pressure within the production string as applied to the shuttle valve through the tubing section 303a must be increased sufficiently above both the pressure at the shuttle valve from the production string 303 and pressure from the production strings 304 and 305 as applied to the shuttle valve 350. Otherwise, even though the shuttle valve 334 is open allowing flow with the production string 303, a fluid pressure from either of the production strings 304 or 305 through the shuttle valve 350 sufficiently high to open such shuttle valve would be transmitted through the control string 301 to the landing nipple 334 and thus would effect closing of the shuttle valve in the nipple 334. A pressure at the shuttle valve 350 sufficiently high to establish a circulation pattern including either of the production strings 304 or 305 must likewise be at a high enough level to maintain the shuttle valve 334 in a fully closed condition.

The flow system 300 is operable in the same manner and for the same purposes as the flow system 20. The system 300 may thus be used for tool insertion and removal in the four production strings and may be used to carry out a wide variety of formation treating and other well processes. Each formation connected into the system is accessible for treatment by using the single control string and one of the production strings.

It will now be apparent that a new and improved fluid flow system has been described and illustrated wherein a substantially unlimited number of circulation patterns may be established and operated from a single control tubing string.

It will be seen that the flow system includes one shuttle valve connected with the control string for each pair of production tubing strings in the system.

The foregoing description of the invention is explanatory only, and changes in the details of the construction illustrated may be made by those skilled in the art, within the scope of the appended claims, without departing from the spirit of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. A fluid flow control system for a well comprising: means providing a first fluid flow passage extending into said well; means providing a second fluid flow passage extending into said well; a control fluid flow passage extending into said well; and fluid flow control means connected between said control fluid flow passage and each of said first and said second fluid flow passages in said well, said fluid flow control means having valve means responsive to the fluid pressure in said flow passages and biased toward a closed position closing off communication between said first and said second flow passages; said valve means being responsive to fluid pressure differential between the pressure in the control fluid passage and the pressure in a selected one of first and second flow passages to open said valve to communicate said selected one of said flow passages with said control fluid passage.

2. A fluid flow control system for a well comprising: first means providing a first fluid flow passage into said well; second means providing a second fluid flow passage into said well; control fluid flow passage means in said well; flow control means connected between said control fluid flow passage means and each of said first and second means in said well for selectively connecting said control fluid flow passage means and said first and second flow passages with each other, said flow control means having valve means operable in response to fluid pressure in said flow passages to open to interconnect said flow passages responsive to the fluid pressure in one of said flow passages, said flow control valve means being operable to be held in a closed position responsive to the fluid pressure in the other of said flow passages, and said flow control

valve means being operable to be maintained in said open position subsequent to initial opening to permit fluid flow in either direction between said first and second flow passages and moving to closed position when fluid flow is terminated between said flow passages responsive to the fluid pressure within said means applied from either of said flow passages.

3. A fluid flow control system for a well comprising: first means providing a first fluid flow passage into said well; second means providing a second fluid flow passage into said well; third means providing a third fluid flow passage into said well; said first, second, and third means being interconnected with each other in said well; and fluid flow control means supported between said first means and said second and third means for controlling fluid flow between said first means and either of said second and third means, said flow control means having valve means operable responsive to fluid pressure differentials between a selected one of said second and third means and said first means to be opened to interconnect said first flow passage with either of said second and third flow passages responsive to a pressure differential established across said flow control means between said second and third flow passages, said flow control valve means moving to a position responsive to such pressure differential to interconnect said first flow passage and the one of said second and third flow passages having the higher pressure therein while isolating the one of the second and third flow passages having the lower pressure therein.

4. A fluid flow control system for a well comprising: a control tubing string extending into said well; a first production tubing string extending into said well; a second production tubing string extending into said well; fluid conducting means interconnecting said control string and said first and second production tubing strings in said well; and fluid flow control means engaged in said fluid conducting means for selectively controlling fluid flow between said control tubing string and said first and second production tubing strings and for preventing fluid flow between said production tubing strings, said flow control means having valve means exposed to fluid pressures in said control tubing string and in said first and said second production strings and movable to communicate said control tubing string with either of said production tubing strings responsive to a fluid pressure differential effected between said production tubing strings across said flow control valve means, said flow control valve means moving to one open position to provide fluid communication between said control tubing string and the production tubing string having the higher of the pressures in both of said production tubing strings, said flow control valve means moving to a closed position respective to communication between said control tubing string and the one of said production tubing strings having the lower of the pressures in said production tubing strings.

5. A fluid flow control system as defined in claim 4 wherein said fluid flow control means and valve means comprises: a tubular mandrel having a central flow chamber and end flow passages through opposite end sections communicating with said central flow chamber, lateral flow port means being provided through said mandrel communicating with said central flow chamber, annular seat surfaces being provided in said mandrel at opposite ends of said central flow chamber around said end flow passages; a valve rod supported within said central chamber, opposite ends of said rod being exposed to the pressures within said end flow passages, said rod being movable longitudinally partially into one of said flow passages responsive to a higher pressure applied to the other end of said rod in the other of said end flow passages; an inner sleeve positioned in a slidable sealed relationship around each end section of said valve rod; an outer sleeve positioned around each of said inner sleeves at each end of said valve rod; a ring seal supported between said inner and outer sleeves at each end of said valve rod; said

inner and outer sleeves at each end of said valve rod each having an end seat surface engageable with the seat surface in said mandrel around said end flow passage adjacent to said inner and outer sleeves; and spring means biasing said inner and outer sleeves at each end of said valve rod in opposite directions on said valve rod.

6. A fluid flow control device comprising: a tubular mandrel having a central flow chamber and end flow passages through opposite end sections communicating with said central flow chamber, lateral flow port means being provided through said mandrel communicating with said central flow chamber, annular seat surfaces being provided in said mandrel at opposite ends of said central flow chamber around said end flow passages; a valve rod supported within said central chamber, opposite ends of said rod being exposed to the pressures within said end flow passages, said rod being movable longitudinally partially into one of said flow passages responsive to a higher pressure applied to the other end of said rod in the other of said end flow passages; an inner sleeve positioned in a slidable sealed relationship around each end section of said valve rod; an outer sleeve positioned around each of said inner sleeves at each end of said valve rod; a ring seal supported between said inner and outer sleeves at each end of said valve rod; said inner and outer sleeves at each end of said valve rod each having an end seat surface engageable with the seat surface in said mandrel around said end flow passage adjacent to said inner and outer sleeves; and spring means biasing said inner and outer sleeves at each end of said valve rod in opposite directions on said valve rod.

7. A fluid flow control system for a well comprising: a control tubing string extending into said well; first and second production tubing strings extending into said well; interconnecting means secured between said control tubing string and said first and second production tubing strings in said well to permit said control tubing string to be selectively placed in fluid communication with said first and second production tubing strings; fluid flow control means positioned in said interconnecting means having valve means operable responsive to fluid pressure in said production strings in said control tubing string for selectively establishing fluid communication between said control tubing string and either of said first and second production tubing strings while preventing fluid communication between said first and second production tubing strings, said flow control valve means being opened to provide fluid communication between said control tubing string and either of said production tubing strings responsive to a fluid pressure differential between said first and second production tubing strings, and said flow control means being operable in response to fluid pressures to communicate said control tubing string and the production tubing string having the higher of the fluid pressures in said production tubing strings; and means including a pump connected with said control tubing and production tubing strings exterior of said well for selectively pumping fluid through said control tubing string and either of said production tubing strings.

8. A fluid flow control system as defined in claim 7 wherein said flow control means and valve means comprises: a tubular mandrel having a central section provided with a valve chamber and lateral port means, opposite end sections each having an end flow passage communicating with said valve chamber and each having an inwardly facing valve seat surface around said flow passage; packing means supported on each of said end sections of said mandrel for sealing around said mandrel with sealing surfaces within a tubular body surrounding said mandrel; a valve stem supported within said valve chamber for longitudinal movement into each of said end flow passages; an inner sleeve positioned around each end section of said valve stem, said inner sleeve being slidable over said valve stem and having means for holding said sleeve on said valve stem; seal means carried by said

inner sleeve to seal around said valve stem while permitting said valve stem to move relative to said inner sleeve; an outer sleeve secured over each of said inner sleeves; said inner sleeve and said outer sleeves at each end of said valve rod having end seat surfaces engageable with the adjacent valve seat surface of said mandrel; a ring seal confined between each of said inner and outer sleeves near the adjacent end of said valve stem, said ring seal having a portion thereof extending between the supporting inner and outer sleeves projecting beyond the end seat surfaces thereof for engagement with the adjacent valve seat surface of said mandrel; a spring positioned around said valve stem confined between the inner and outer sleeve unit at one end of said valve stem and the inner and outer sleeve unit at the other end of said stem to bias said units apart to end positions on said stem; and each end of said valve stem communicating with one of said end flow passages of said mandrel when said valve is in a fully closed position and each of said ends of said stem being movable into the adjacent one of said end flow passages when the fluid pressure in the other of said end flow passages exceeds the fluid pressure in the said adjacent fluid flow passage.

9. A fluid flow control device comprising: a tubular mandrel having a central section provided with a valve chamber and lateral port means, said tubular mandrel also having opposite end sections each having an end flow passage communicating with said valve chamber and each having an inwardly facing valve seat surface around said flow passage; packing means supported on each of said end sections of said mandrel for sealing around said mandrel with sealing surfaces within a tubular body surrounding said mandrel; a valve stem supported within said valve chamber for longitudinal movement into each of said end flow passages; an inner sleeve positioned around each end section of said valve stem, said inner sleeve being slidable over said valve stem and having means for holding said sleeve on said valve stem; seal means carried by said inner sleeve to seal around said valve stem while permitting said valve stem to move relative to said inner sleeve; an outer sleeve secured over each of said inner sleeves; said inner sleeve and said outer sleeves at each end of said valve rod having end seat surfaces engageable with the adjacent valve seat surface of said mandrel; a ring seal confined between each of said inner and outer sleeves near the adjacent end of said valve stem, said ring seal having a portion thereof extending between the supporting inner and outer sleeves projecting beyond the end seat surfaces thereof for engagement with the adjacent valve seat surface of said mandrel; a spring positioned around said valve stem confined between the inner and outer sleeve unit at one end of said valve stem and the inner and outer sleeve unit at the other end of said stem to bias said units apart to end positions on said stem; and each end of said valve stem communicating with one of said end flow passages of said mandrel when said valve is in a fully closed position and each of said ends of said rod being movable into the adjacent one of said end flow passages when the fluid pressure in the other of said end flow passages exceeds the fluid pressure in the said adjacent fluid flow passage.

10. A fluid flow control system for a well comprising: a control tubing string supported in said well; a plurality of production tubing strings supported in said well; means in said well interconnecting said control tubing string and said production tubing strings for permitting fluid communication between said control tubing string and said production tubing strings; and fluid flow control means positioned in said interconnecting means between said control tubing string and a pair of said production tubing strings, one control means being provided between said control tubing string and each pair of said production tubing strings and including valve means operable to selectively place said control string in fluid communication with either one of said pair of production tubing

strings, each said flow control means being operable responsive to the greater of the fluid pressures in said production tubing strings interconnected with said flow control device to communicate said production tubing string having the greater pressure therein with said control tubing string, said higher pressure exceeding the pressure in the remaining of said production tubing strings in said system.

11. A fluid flow control system for a well comprising: a control tubing string supported in said well; a plurality of production tubing strings supported in said well; interconnecting means between said control tubing string and each pair of production tubing strings in said system; and fluid flow control means positioned in each of said interconnecting means and having valve means exposed to fluid pressures in said control tubing string and said pair of production tubing strings and operable by such pressures to selectively control fluid flow between said control tubing string and said production tubing strings; said valve means communicating said control tubing string into only one of said production tubing strings during a selected period while the remaining of said production tubing strings are isolated from said control tubing string and from each other.

12. A fluid flow control system for a well comprising: a control tubing string supported in said well; a plurality of pairs of production tubing strings supported in said well; interconnecting means between said control tubing string and each pair of said production tubing strings for providing fluid communication between said control tubing string and said pair of production tubing strings; a fluid flow control means positioned within said interconnecting means between said control tubing string and each pair of production tubing strings and having valve means exposed to the fluid pressures in said control tubing string and in each of said pair of production tubing strings and operable responsive to such pressures to selectively connect one of said production tubing strings connected into each of said fluid flow control means with said control tubing string to establish a closed fluid circulation loop through said well between said control tubing string and said selected production tubing string, each of said flow control means having a central valve chamber containing said valve means exposed to the fluid pressure within said control tubing string whereby said fluid control valve means is operated responsive to the pressure differential between the control tubing string and the production tubing strings connected with said control means, a selected production tubing string having a higher pressure operating the valve means with which it communicates to establish communication with said control tubing string, said higher pressure acting through said control tubing string on the flow control valve means connected with the other pairs of production tubing strings having lower pressures therein to hold such flow control valve means closed; and means interconnecting the surface ends of said control tubing string and said production tubing strings for selectively circulating fluid through said control tubing string and said selected one of said production tubing strings.

13. A fluid flow control system for a well according to claim 12 wherein each of said fluid flow control means is positioned within said well bore at or about the midpoint of each circulation loop connectable between said control tubing string and said production tubing strings.

14. A fluid flow control system for a well in accordance with claim 12 wherein a production tubing string extends through said well to each of the producing formations to be produced through said well.

15. A fluid flow control system for a well in accordance with claim 12 wherein each of said flow control valve means is a shuttle valve removably positioned within said interconnecting means and adapted to be opened responsive to the higher of the two pressures in the production tubing strings interconnected with said shuttle valve, and

said valve being adapted to be held in open position independent of flow conditions between said control tubing string and the production tubing string interconnected with said control tubing string through said shuttle valve so long as the pressure within the central chamber of said shuttle valve is higher than the pressure within the production tubing string having the lower pressure and isolated by said shuttle valve.

16. A fluid flow control system adapted to establish a plurality of selected fluid circulation patterns within a well for circulating fluid into and through said well along predetermined flow passage routes comprising: a control tubing string supported in said well; a plurality of production tubing strings supported in said well for producing fluids from a plurality of formations penetrated by said well; said control tubing string and said production tubing strings being interconnected within said well by fluid conducting means permitting fluid communication between said control tubing string and all of said production tubing strings; flow control means engaged in said fluid conducting means between said control tubing string and each pair of said production tubing strings in said system; each said flow control means being adapted to be opened to permit fluid communication between said control tubing string and a selected one of said production tubing strings in the pair of said production tubing strings connected with said flow control means while preventing fluid communication between said control tubing string and the remaining production tubing strings isolated from said selected production tubing string and while preventing fluid communication between said remaining production tubing strings in said system; each said flow control means being adapted to be moved to each open position by applying a pressure differential across said control means between the production tubing strings of the pair connected with said control means, said control means moving to a position to communicate said control tubing string with the production tubing string having the higher pressure of the said pair of production tubing strings connected with said control means while said position of said control means closes off fluid communication between said control means and the other production tubing string of said pair connected with said control means having the lower pressure; said control means having a pressure responsive valve assembly exposed at one end to said lower pressure and exposable at the other end to the pressure in the central chamber of said control means whereby said control means after opening is held in open position by the pressure differential between said central chamber of said control means and said production tubing string having the lower pressure, independent of flow conditions between said control tubing string and the production tubing string in fluid communication with said control tubing string; and means connected between the surface ends of said control tubing string and said production tubing strings for establishing selected fluid circulation loops each including said control tubing string and one of said production tubing strings and for introducing fluid into one of said tubing strings to be conducted to said well through said tubing string while receiving fluid from the other of said tubing strings, said fluid being conducted from said well through said tubing string.

17. A fluid flow control system for a well as defined in claim 16 including lubricator means at the surface ends of said control and production tubing strings for introducing into and removing from each of said tubing strings pumpable components.

18. A fluid flow control system as defined in claim 17, wherein said fluid flow control means is a shuttle valve comprising: a tubular mandrel having a central slotted section providing a central valve chamber, said mandrel having opposite end sections having end flow passages each communicating into said central chamber and each having an annular valve seat around its end flow passage

facing said central chamber; an external annular seal assembly on each end section of said mandrel for sealing around said mandrel within a surface around said mandrel above and below said central slotted section; a valve rod having enlarged end head sections supported within said central chamber for longitudinal movement therein, each end of said head section of said valve stem being extendable into the end flow passage adjacent said end of said valve stem, each end of said valve stem being exposed to the pressure of the end flow passage adjacent to said end of said valve stem when said valve is in a fully closed position, and one end of said valve stem being exposed to the pressure within said central valve chamber while the other end of said valve stem is moved into and exposed to the pressure of the end flow passage adjacent said end of said valve stem when said valve stem is in either of its open positions; an inner sleeve slidably engaged over each head section of said valve stem, each of said inner sleeves being movable over said valve stem toward the center of stem while being limited in movement toward the end of said valve stem adjacent said inner sleeve over said head section at said end; a ring seal positioned between each of said inner sleeves and its valve stem head section to provide a fluid seal between said head section and said inner sleeve; an outer sleeve engaged around each of said inner sleeves; the ends of each coengaged inner and outer sleeves having annular concentric seat surfaces whereby a portion of said ends of said sleeves is engageable with the mandrel valve seat adjacent said inner and outer sleeve ends for effecting a fluid tight seal to prevent fluid flow between said central valve chamber and said end flow passage through said valve seat surfaces; a ring seal positioned between each of said inner and outer sleeves adjacent the ends of said sleeves, each of said ring seals having a portion thereof projecting outwardly beyond the end seat surfaces on said inner and outer sleeves whereby when each of said inner sleeves and its outer sleeve moves toward the adjacent mandrel valve seat surface said edge of said ring seal engages said mandrel seat surface prior to engagement of said mandrel seat surface by said seat surfaces on said inner and outer sleeves; and a spring around said valve stem and confined between inward end surfaces of said outer sleeves for biasing each said inner sleeve and corresponding outer sleeve at opposite ends of said valve stem apart from each other on said valve stem and toward seated engagement with the mandrel seat surface at opposite ends of said central chamber, said valve stem being movable at one end into the adjacent end flow passage of said mandrel while moving at the other end out of the adjacent end flow passage at that end of said mandrel, said end of said valve stem moving into an end flow passage of said mandrel moving through and relative to the inner and outer sleeve on said end of said valve stem while the head section and inner and outer sleeves at the other end of said valve stem effects compression of said spring around said valve stem.

19. A shuttle valve comprising: a tubular mandrel having a central slotted section providing a central valve chamber, said mandrel having opposite end sections having end flow passages each communicating into said central chamber and each having an annular valve seat around its end flow passage facing said central chamber; an external annular seal assembly on each end section of said mandrel for sealing around said mandrel within a surface around said mandrel above and below said central slotted section; a valve stem having enlarged end head sections supported within said central chamber for longitudinal movement therein, each end of said head section of said valve stem being extendable into the end flow passage adjacent said end of said valve stem, each end of said valve stem being exposed to the pressure of the end flow passage adjacent to said end of said valve stem when said valve is in a fully closed position, and one end of said valve stem being exposed to the pressure

within said central valve chamber while the other end of said valve stem is moved into and exposed to the pressure of the end flow passage adjacent said end of said valve stem when said valve stem is in either of its open positions; an inner sleeve slidably engaged over each head section of said valve stem, each of said inner sleeves being movable over said valve stem toward the center of stem while being limited in movement toward the end of said valve stem adjacent said inner sleeve over said head section at said end; a ring seal positioned between each of said inner sleeves and its valve stem head section to provide a fluid seal between said head section and said inner sleeve; an outer sleeve engaged around each of said inner sleeves; the ends of each coengaged inner and outer sleeves having annular concentric seat surfaces whereby a portion of said ends of said sleeves is engageable with the mandrel valve seat adjacent said inner and outer sleeve ends for effecting a fluid tight seal to prevent fluid flow between said central valve chamber and said end flow passage through said valve seat surfaces; a ring seal positioned between each of said inner and outer sleeves adjacent the ends of said sleeves, each of said ring seals having a portion thereof projecting outwardly beyond the end seat surfaces on said inner and outer sleeves whereby when each of said inner sleeves and its outer sleeve moves toward the adjacent mandrel valve seat surface said edge of said ring seal engages said mandrel seat surface prior to engagement of said mandrel seat surface by said seat surfaces on said inner and outer sleeves; and a spring

around said valve stem and confined between inward end surfaces of said outer sleeves for biasing each said inner sleeve and corresponding outer sleeve at opposite ends of said valve stem apart from each other on said valve stem and toward seated engagement with the mandrel seat surface at opposite ends of said central chamber, said valve stem being movable at one end into the adjacent end flow passage of said mandrel while moving at the other end out of the adjacent end flow passage at that end of said mandrel, said end of said valve stem moving into an end flow passage of said mandrel moving through and relative to the inner and outer sleeve on said end of said valve stem while the head section and inner and outer sleeves at the other end of said valve stem effects compression of said spring around said valve stem.

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Disclaimer and Dedication

3,381,753.—*John V. Fredd*, Dallas, Tex. FLUID FLOW CONTROL SYSTEM FOR WELLS. Patent dated May 7, 1968. Disclaimer and Dedication filed Jan. 6, 1983, by the assignee, *Otis Engineering Corp.*

Hereby disclaims and dedicates to the Public the remaining term of said patent.

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