Sept. 6, 1960 H. U. GARRETT 2,951,536

METHOD AND APPARATUS FOR REMOTE CONTROL OF VALVES OR THE LIKE

Filed Dec. 22, 1955

3 Sheets-Sheet 1

Fig. 3

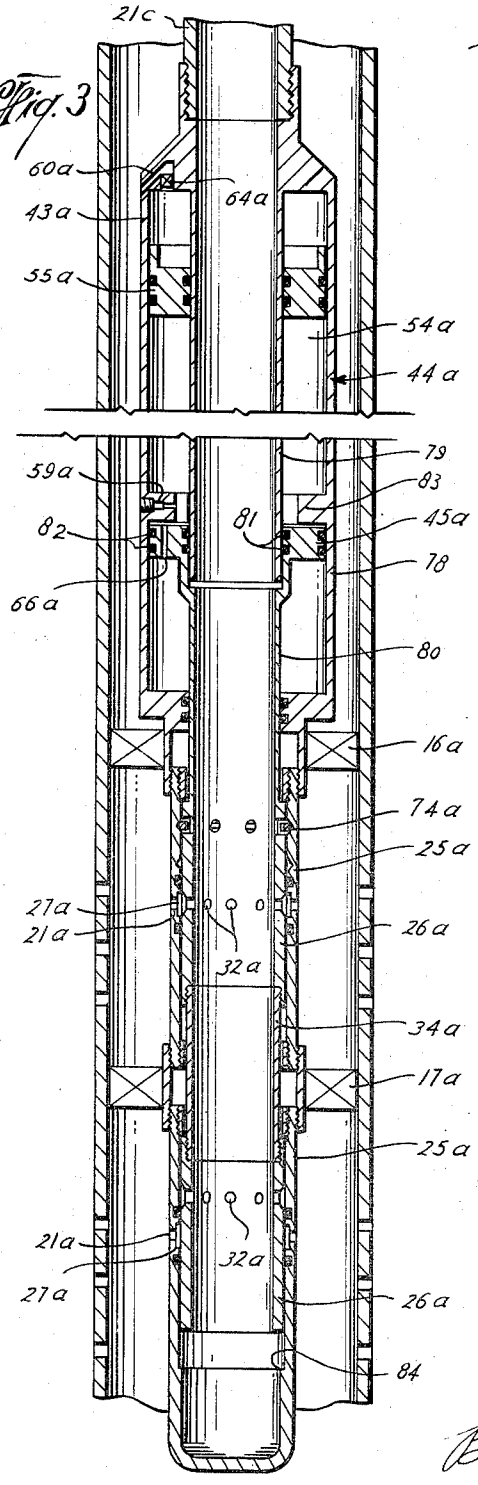
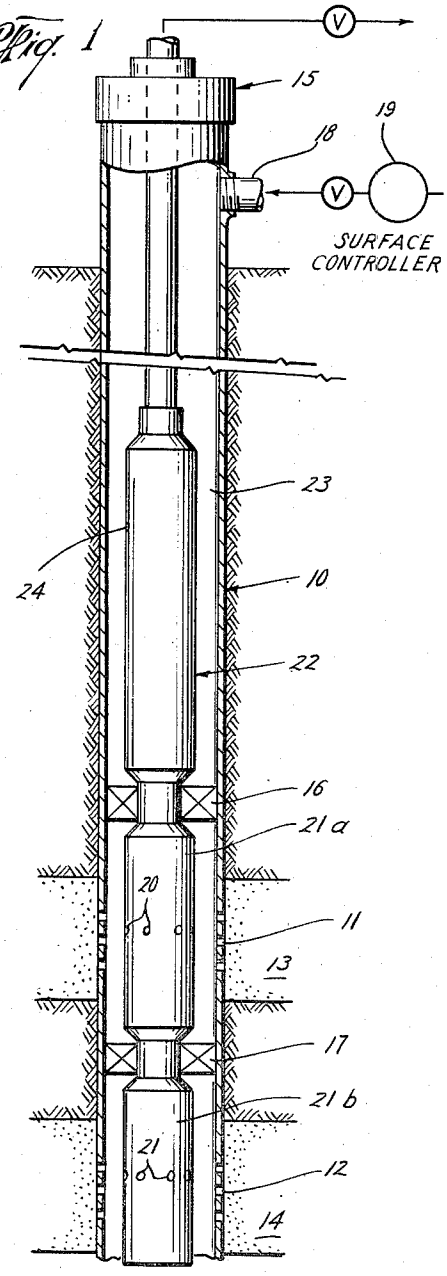


Fig. 1



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3 Sheets-Sheet 2

Fig. 2A

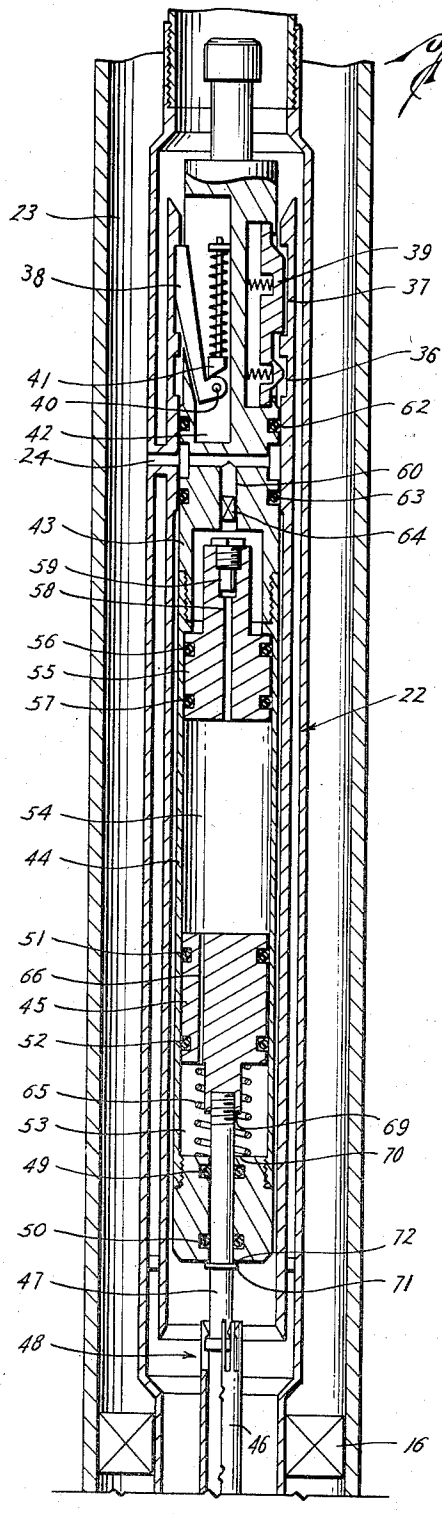
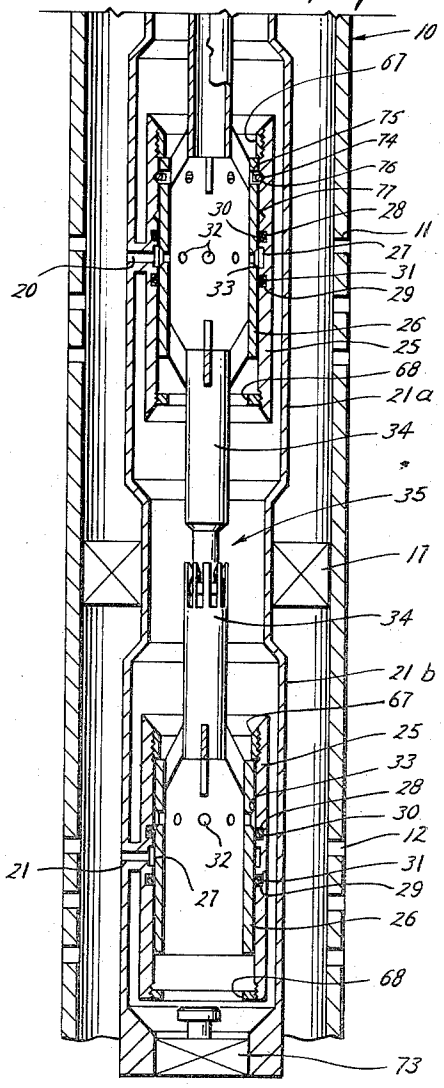


Fig. 2B



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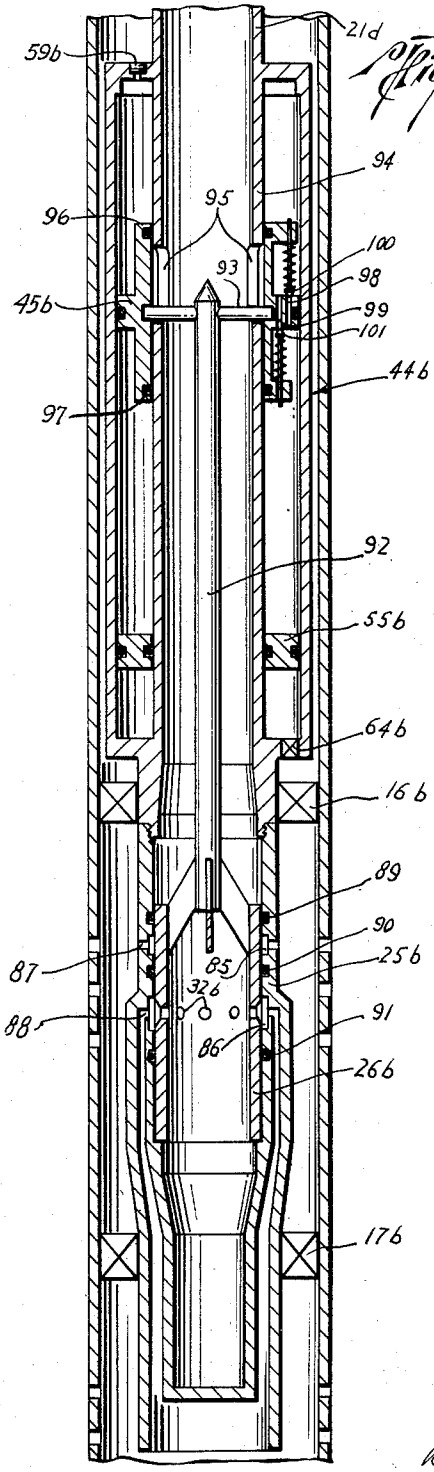
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METHOD AND APPARATUS FOR REMOTE CONTROL OF VALVES OR THE LIKE

Filed Dec. 22, 1955 3 Sheets-Sheet 3

Fig. 4



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2,951,536

METHOD AND APPARATUS FOR REMOTE CONTROL OF VALVES OR THE LIKE

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14 Claims. (Cl. 166—145)

This invention relates to a method and apparatus for pressure shifting a part such as a valve member from a remote location. In one important aspect, it relates to a method and apparatus for the alternative production of one of a plurality of fluid bearing formations.

Many wells extend into more than one petroleum producing formation. Such formations may be relatively close together or spaced apart some distance but in any case will be separated by one or more layers of impermeable material so that they are separate and distinct formations. The laws of many States require that such separate formations be produced in such a manner that the petroleum from each formation is recovered separately at the surface. The conservation laws of many states further require that many formations be produced at less than their full capacity and it is, therefore, possible in many cases to alternatively produce a plurality of formations and obtain all of the petroleum legally permissible. Thus it would be desirable to have an economical, practical way of alternatively producing a plurality of formations.

It has been proposed that such formations be separately produced using valves shiftable between open and closed positions with a wire line actuator to selectively produce one of the formations. See U.S. Letters Patent No. 2,537,066 issued to J. O. Lewis on January 9, 1951.

This system of producing multiple formations is subject to the objection that it requires setting up a wire line apparatus at the wellhead on each occasion that it is desired to shift production from one formation to another.

It has further been proposed to shift a valve member from closed to open position using pressure fluid but such proposal utilized a wire line apparatus to return the valve member to its unshifted position. See U.S. Letters Patent No. 2,307,983 issued January 12, 1943 to C. H. Barnes.

While the gas lift industry has taught the control of a valve member by a pressure fluid controlled from the surface, the pressure applied to shift a valve member must be maintained or the valve member returns to its original position. See, for example, U.S. Letters Patent No. 2,663,265 issued to H. U. Garrett et al. on December 22, 1953.

Desirably, an apparatus and method of fluid shifting a valve member controlling flow from a production formation should be such as to permit the removal of the control fluid pressure while leaving the valve member in its last shifted position so that the intentional or accidental removal of the control pressure will not affect production. As the tubing communicates with the producing formation it is also desirable that the control pressure fluid be introduced through the casing-tubing annulus.

It is, therefore, an object of this invention to provide an apparatus and a method of pressure shifting a part such as a valve member in an inaccessible location such as down in a well between two positions by the control of a single pressure fluid in which the shifting pressure may be removed without corresponding movement of the valve member.

Another object is to provide a method and apparatus for pressure shifting valves of a multiple zone well to permit flow from a selected formation by the application of a pressure fluid controlled at the surface.

Another object is to provide a method and apparatus for shifting with a pressure fluid valves controlling a plurality of petroleum producing formations to produce such formations alternatively in which the controlled pressure fluid may be removed after the valves have been shifted.

Another object is to provide an apparatus for pressure shifting of a valve member or the like down in the hole in which the shifting apparatus may be immersed in a column of liquid or mud and the control pressure exerted through said column of liquid.

Another object is to provide an apparatus for shifting in reciprocal motion a part such as a valve member in which the shifting is accomplished by a confined gas under pressure and shifting of the part by such confined gas is controlled by an extraneous controlled pressure fluid.

Another object is to provide a pressure controlled actuator for shifting a part in a well such as a valve member in two directions in which the actuator may be removed on a wire line.

Another object is to provide an actuator for a part such as a valve member in which the actuator is charged with a gas under pressure which effects movement of the part responsive to an extraneous control fluid pressure, said actuator being removable from the well on a wire line.

Another object is to provide an apparatus for shifting in two directions a part such as a valve member by control of a pressure fluid at the surface of the well in which a pressure differential tending to hold the part in its last shifted position remains after the part has been shifted.

Another object is to provide apparatus for shifting in two directions a part such as a valve member by a confined gas under pressure in response to changes in pressure of an extraneous pressure fluid in which the confined gas always tends to hold the part in its last shifted position after the part has been shifted.

Other objects, features and advantages of this invention will be apparent from a consideration of the drawings, the specification and the appended claims.

In the drawings wherein like figures indicate like reference numerals and there is shown illustrative embodiments of this invention:

Fig. 1 is a vertical sectional view through a well bore illustrating the use of this invention to selectively produce one of two petroleum bearing formations; and

Figs. 2A and 2B are continuation views with Fig. 2B being a continuation of Fig. 2A illustrating in vertical cross-section the use of a form of this invention in alternatively producing a two-zone well in which at least the valve actuator means is removable by wire line.

Figs. 3 and 4 are views in vertical cross-section through wells and two forms of two-zone production apparatus made up as integral parts of the production tubing.

Referring first to Fig. 1, there is shown diagrammatically a petroleum producing well in which the casing indicated generally at **10** has been perforated at vertically spaced points **11** and **12** and completed for production from formations **13** and **14** through perforations **11** and **12**, respectively. The casing-tubing annulus is closed at the surface with the usual wellhead equipment diagrammatically illustrated at **15** and packers **16** and **17** are set between the tubing and casing with packer **16** sealing between the tubing and casing above the uppermost for-

mation 13 and packer 17 sealing between the tubing and casing between the two producing formations 13 and 14. With this arrangement, formations 13 and 14 are isolated from each other and from the tubing-casing annulus above the upper formation 13. The tubing-casing annulus from the surface down to the upper packing 16 forms a sealed chamber, the pressure of which may be controlled by the surface controller indicated at 19. Gas under pressure may be supplied under the regulation of controller 19 to casing-tubing annulus 23 through conduit 18 and may be gas from a gas well in the field or may be supplied by other means such as a compressor. Surface controller 19 increases and decreases the pressure of the control fluid to operate a shifting tool in landing mandrel 22 to shift production between formations 13 and 14 and may be a time cycle controller to automatically shift production. If desired, the controller may be omitted and production shifted by hand control of the pressure.

The tubing is ported at 20 opposite formation 13 and at 21 opposite formation 14. Suitable valve means to be described in detail later are provided within perforated tubing sections 21*a* and 21*b* and are controlled to alternatively open and close ports 20 and 21 by the shifting tool or actuator in landing mandrel 22 which is made up in the tubing string immediately above the uppermost packing 16.

Control fluid pressure from the tubing-casing annulus 23 is introduced into the landing mandrel 22 through port 24 and by manipulation of this pressure as will be more fully explained hereinafter the valve means controlling flow through ports 20 and 21 will be alternatively opened and closed so that when ports 20 are open ports 21 will be closed and vice versa.

Referring now to Figs. 2A and 2B, it will be seen that the valve means used to control flow through the ports 20 and 21 is preferably of the sleeve valve type although these valves may be of any desired form which will control flow through the ports by moving a valve member.

The two sleeve valves are identical in construction except that the valves are arranged so that one will be open while the other is closed and therefore the following description will apply to both valves. Each valve is provided with a sleeve-like body 25 which forms a valve seat in which there is slidably positioned in telescoping relationship a sleeve valve member 26. The valve seat 25 is provided with an annular gathering ring 27 which is in fluid communication with ports 21 in the tubing. The inner wall of seat 25 has formed therein vertically spaced annular grooves 28 and 29 above and below the annular ring of ports 21 and interference type seals such as O-rings 30 and 31 are positioned in the annular grooves and sealingly engage valve member 26 to provide a seal between a seat and valve member. Thus, when a blank portion of the valve member is presented to the ring 27, the O-rings 30 and 31 will contain the pressure fluid in ports 21. The valve member 26 is provided with an annular ring of ports 32 which, with the valve member in open position, are in fluid communication with gathering ring 27 and provide for entry of fluid from the formation through inlet ports 21, distribution ring 27 and ports 32 in the valve member. In order to prolong the life of the O-rings, the outer wall of valve member 26 is provided with V-shaped grooves 33 which do not extend radially through the valve member but open into each of the ports 32. These slots extend away from each of the ports in both of its directions of travel and aid in preventing pinching the O-ring as the sleeve moves therepast. In the assembly shown, the ring of ports 32 in the upper slide valve member 26 are more centrally located in the valve member than those of the lower valve member so that when the upper valve member is positioned to permit flow through ports 20, the lower valve member will be positioned to prevent flow through ports 21 as illustrated.

The two valve means may be held in spaced relationship with each other as by a shifting rod 34 which is preferably formed in two parts and joined together with an articulating joint 35. This articulating joint permits slight misalignment of the two valve members without binding of the valve members.

With the valves so arranged, it will be appreciated that by shifting the valves vertically up and down, selective flow will be had from the two formations 13 and 14.

In order to provide for such selective shifting, there is provided an actuator of the wire line removable type in the landing mandrel 22 positioned immediately above the upper formation 13.

The landing mandrel and latching device for the wire line removable actuator may take any desired form. For instance, in the form shown in the drawing, the mandrel at its upper end is provided with dog receiving slots 36 and 37 for receiving landing dogs 38 and 39 to latch the landing device and actuator in the mandrel. As will be apparent from the drawings, the landing dog 39 prevents further downward movement of the landing device upon outward movement of the dog into annular slot 37. The dog 38 is pivoted about a shear pin 40 and is urged outwardly into the position shown in Fig. 2A by a spring loaded member 41 which engages dog 38 at an eccentric point relative to shear pin 41. With the parts in the position shown in Fig. 2A, the two dogs 38 and 39 hold the actuator means in position in the landing mandrel 22. Upon upward movement of the actuator means with a sufficient force, shear pin 40 will be sheared and the spring loaded means 41 will drive the dog 38 downwardly into slot 42 and withdraw the dog 38 into the interior of the body of the landing device. Thereupon the landing device and actuator means for the valves may be withdrawn from the well in the usual manner with a wire line. As will appear hereinafter, the actuator means may be withdrawn leaving the valves in position in the tubing and the actuator repaired or recharged, etc., or the valves may be withdrawn with the actuator means.

Referring now to the details of the actuator or shifting tool, the body 43 of the tool is provided with a pressure vessel 44 and a pressure responsive member such as piston 45 is provided in the pressure vessel for movement in response to pressure differential thereacross to shift the valves. The piston 45 moves in response to changes in control fluid pressure which changes are effective on the piston through a passageway into the vessel as will appear below. Piston 45 is connected to the uppermost valve member 26 through actuator shafts 46 and 47 which are connected together by an articulating joint 48. The shaft 47 extends through the bottom end of the body 43 and is provided with a sliding seal therewith by O-rings 49 and 50. The actuator piston 45 is adapted to reciprocate within the pressure vessel 44 and is provided with a sliding seal with the wall of the pressure vessel by O-rings 51 and 52 spaced along the piston 45. Thus differential in pressure between the compartment 53 on the one side of the piston and compartment 54 on the other side of the piston will cause movement of the piston 45 in pressure vessel 44.

After the piston has been reciprocated to shift the two valves 26, it is desired that the pressure be equalized across piston 45 so that the control fluid pressure utilized to shift piston 45 may be removed and for this purpose a by-pass is provided between compartments 54 and 53. Such by-pass in the illustrative embodiment is provided by a bleed orifice 66 extending through the piston and interconnecting compartments 53 and 54. The orifice 66 is of a size to permit slow bleed of pressure across the piston at a substantially constant rate, that is, constant except for the slight difference caused by variations in pressure differential across the piston. The bleed rate is less than the rate at which the pressure in the tubing-casing annulus 23 can be increased by conventional equipment. Thus, after the piston 45 has been shifted, the pressure within

compartments 53 and 54 will slowly equalize until the pressure differential across piston 45 has been removed permitting the control fluid pressure to be removed without corresponding movement of piston 45.

It will be appreciated that to reciprocate piston 45 in both directions will require that the pressure vessel be provided with a gas under pressure which can be compressed to permit the compartments 53 and 54 to vary in volume. The actuator will, however, frequently be immersed in liquid, which liquid will form a part of the control fluid for actuating piston 45. For this reason it is preferred to provide a charge of gas under pressure in vessel 44 which is confined by a second pressure responsive member. Provision is made for extraneous pressure fluid to enter the vessel 44 on the side of the second pressure responsive member not exposed to the gas charge to cause movement of the second pressure responsive member which will act on the confined gas to increase or decrease its pressure as the control pressure is varied. This feature of using a confined gas under pressure to shift the piston 45 may be provided by floating piston 55 in compartment 54 which piston is provided with a sliding seal with vessel 44 by spaced O-rings 56 and 57 and which provides a fluid barrier in compartment 54. Piston 55 is, in effect, a free-floating piston, that is, it is free to move under pressure differential thereacross. Gas under pressure may be charged into the sealed portion of vessel 44 which contains actuator piston 45 through passageway 58 extending through floating piston 55 and a charging valve means shown diagrammatically at 59 in the passageway.

The body 43 of the actuator is provided with a passageway 60 extending between compartment 54 on the side of floating piston 55 opposite the actuator piston 45 and the exterior of the actuator body to permit introduction of a control fluid pressure through passageway 60 into compartment 54 to act upon piston 55. Preferably the passageway 60 is positioned with its terminus at the exterior of body 43 in register with port means 24 in landing mandrel 22 to provide for communication between passageway 60 and the casing-tubing annulus 23 so that the pressure within the casing-tubing annulus may be utilized to control movement of the actuator piston 45. O-rings 62 and 63 carried in the body 43 above and below the exterior terminus of passageway 60 to provide a seal between the actuator body 43 and the landing mandrel 22 at points above and below said terminus to prevent the entry of tubing pressure into passageway 60. The tubing-casing annulus 23 will frequently contain liquid having therein suspended solids such as mud and a filter plug 64 may be provided in passageway 60 to prevent these particles of solid material from reaching floating piston 55. The diameter of port means 24, passageway 60 and the flow capacity of plug 64 are greater than the flow rate of bleed 66 to permit the pressure to be increased or decreased more rapidly in compartment 54 than in compartment 53.

Before proceeding with an explanation of the operation of the actuating means, attention is directed to the fact that the effective area on the two sides of actuator piston 45 differs by the diameter of the actuator stem 47, that is, the area on the side of the piston to which the stem is connected is less than the area on the other side of the piston. However, the bottom hole pressure of the well is exerted on the stem 47 and thus this differential in effective area of piston 45 may be compensated by charging the pressure vessel 44 with a pressure substantially equal to the bottom hole pressure of the well. This may vary slightly between the two producing formations and if so, a mean value between these two bottom hole pressures may be selected for charging of the pressure vessel 44. If desired, this differential in area of the two pressure faces of piston 45 may be offset in any desired manner as by a spring such as spring 65 surrounding stem 47 and urging the actuating piston 45 in an upwardly direction as viewed in the drawings to compensate for the differential in area across the actuating piston where the charge pressure is greater than the bottom hole pressure. If bottom hole pressure is greater than casing pressure, then spring 65 may be reversed and urge piston 45 downward.

In the operation of the actuating piston, assuming the piston to be at its uppermost position as indicated in Figs. 2A and 2B, pressure within the tubing-casing annulus 23 is increased at a rate greater than the rate of flow through the control orifice 66 so that pressure within compartment 54 increases more rapidly than in compartment 53 due to the increase in pressure acting upon the exposed side of piston 55. The differential across piston 45 resulting from the rapid increase in pressure in compartment 54 will cause piston 45 to shift to its other position, that is, downwardly as viewed in Fig. 2A and away from the control fluid inlet 60 to shift the two valve members 26 into their down positions providing for flow from the lowermost formation and closing off flow from the uppermost formation. As soon as piston 45 has been shifted, the pressure within the casing-tubing annulus 23 may be removed at a rate less than the bleed rate of passageway 66. If formation changes are to occur at frequent intervals, the pressure fluid may be maintained in the annulus 23 to provide pressure for returning piston 45 to its up position. The fact that the piston 45 has shifted may be noted at the surface by examining the product from the well which will change from formation to formation. This difference between the two formations may be in gravity of the oil, oil-gas ratio, etc., or other ways which will suggest themselves to those skilled in the art. If desired, well conditions being known, the amount of increase in pressure in the tubing-casing annulus 23 above the value of the charge pressure within vessel 44 and the rate of application of this increase in pressure may be calculated and, in this manner, the time of shifting of valve members 26 determined.

Assuming that the piston 45 is in its lowermost position as viewed in Fig. 2A, and it is desired to shift the piston to its uppermost position, the pressure within the tubing-casing annulus 23 is increased, if it has been released, a sufficient amount to provide sufficient gas in compartment 53 at a sufficient pressure to shift piston 45 duced. In this case, the increase in pressure may be either applied slowly or applied rapidly and maintained at a predetermined value above the pressure to which the pressure vessel 44 was originally charged to insure that the pressure within compartment 53 has reached the desired value. The pressure within the tubing-casing annulus 23 is then relieved at a rate greater than the flow rate through control orifice 66 so that the pressure within compartment 54 is rapidly reduced to a value less than the pressure within compartment 53 resulting in a differential across piston 45 which moves it to its uppermost position. As the higher pressure is already in compartment 53, the tubing-casing annulus pressure may be continued to be removed without further shifting of piston 45.

In the explanation of the operation given above, it was assumed that the pressure vessel 44 was charged to a value approximating the bottom hole pressure and that the hydrostatic head of liquid in the tubing-casing annulus exerted a pressure at port 24 which was less than the bottom hole pressure and the pressure within the vessel 44. In cases where the normal pressure within the tubing-casing annulus 23 is greater than bottom hole pressure, it will be appreciated that if the vessel 44 is charged at the surface to any lesser value than the hydrostatic head of pressure within the tubing-casing annulus, this hydrostatic head will cause movement of the compression piston 55 downward to a point where the pressure within compartments 54 and 53 will be equal to the pressure within the tubing-casing annulus. In this case, if the differential between the pressure inside and outside of the tubing is sufficient, it will be desirable to provide some means for compensating for the differential

in pressure area across piston 45 such as spring 65. However, the operation of piston 45 will be carried out in exactly the same manner as explained above. That is, pressure within tubing-casing annulus will be increased and decreased to shift piston 45.

Depending upon whether it is desired to be able to remove just the actuator means or to remove both the actuator and valve means from time to time with a wire line, stop means may be provided at various places in the apparatus to prevent piston 45 from moving the valves 26 more than the desired amount. For instance, where it is desired to remove just the actuator and to leave the valve members down in the hole, stops are associated with the valve members which will prevent movement of the valve members past the proper position upon reciprocation of the actuator piston 45 and which will provide the necessary resistance to permit the actuator stems 46 and 47 to be parted at the articulating joint 48 by an upward pull on the wire line. Such stops may be provided by upper stops 67 threaded or otherwise secured in the top of each valve body 25 to provide an abutment against which the end of the valve members 26 rest when the valve members are in their uppermost position. Such stops will prevent further upward movement of the valve members when the actuator means is raised sufficient to break the articulating joint 48. Stops 68 may be threaded or otherwise secured in the bottom end of the valve bodies 25 to again provide an abutment which the lower end of valve members 26 rest against when the valve members are shifted into their lowermost position.

When it is desired that the valve members be removable from the well with the valve actuator so that workover operations may be conducted through the valve means, the stops are provided in conjunction with the actuator means as by a shoulder 69 formed on an extension of piston 45 and positioned to strike the end 70 of the pressure vessel 44 with the piston in its lowermost position. The other stop may be provided by an outwardly extending annular collar 71 on the actuator stem 47 positioned to abut the end 72 of the body of the actuator upon upward movement of the actuator piston 45 to a position to raise the valve members 26 to their uppermost position. In this form, the articulating joint 48 would be of the type which does not readily disengage so that upon removal of the actuator means the valves would also come out of the hole. In this instance, the stops 67 and 68 would, of course, not be employed.

Where the valve members are removable with the actuator means, the lower end of section 21*b* of tubing 21 may be closed by a wire line removable plug indicated diagrammatically at 73. Thus, with the actuator and both valve members removed, the plug 73 may be removed and workover operations or the like conducted through the tubing.

After the valves have been shifted and pressures equalized across the actuator piston, it is desirable that some means be provided for holding the valve members in their last shifted positions. For instance, a split resilient retainer ring 74 may be carried in a groove 75 in the outer periphery of one of valve members 26 and when the valve members are in fully shifted positions, snap out into one of spaced grooves 76 and 77 to maintain the valve members in shifted position until piston 45 exerts sufficient force to overcome snap ring 74.

Fig. 3 illustrates another form of apparatus for practicing this invention in which both the actuator means and the valve means are made up as integral parts of the tubing string. In this instance, there depends from the tubing string 21*c* an actuator body 43*a* from which is in turn depended valve means as more or less integral portions of the tubing string. The valve means are provided by valve seats 25*a* and valve members 26*a* which are substantially identical with each other and with the valve means of Fig. 2B. A tubular member 34*a* joins the two valve members together and where the formations are sufficiently close together that alignment of the valve members does not present a problem, may be a rigid tubing as shown. If alignment problems are anticipated, an articulating joint may be interposed in member 34*a* as in member 34 of Fig. 2B. Packers 16*a* and 17*a* are again set between the tubing and the casing intermediate the two producing formations and above the producing formation as in the case in Fig. 2 to isolate the formations from each other and from the tubing-casing annulus above the uppermost packer 16*a*. Flow is through ports 21*a* in the valve seat, gathering ring 27*a* and ports 32*a* in the valve member. It will be noted in this instance that the valve seat is, in effect, a part of the tubing and not contained within the tubing as in Fig. 2B. A snap ring 74*a* is again provided in the uppermost valve member to hold the valve in its fully shifted position.

The pressure vessel 44*a* is in this case a ring-like member formed by an annular outer shell 78 and a two-piece inner tube concentric with the shell 78 with the upper member 79 of the two-piece member fixed to the body and the lower piece 80 of the two-piece member slidable in the body and connected at its depending end to the upper valve 26*a*. At the upper end of the tubular member 80 is carried the actuator piston 45*a* which is provided with a sliding seal with the inner wall of annular member 78 and with the outer wall of the tubular member 79 by O-rings 81 and 82 respectively. Again, a control or bleed orifice 66*a* is provided in piston 45*a* to equalize pressure across the piston. A compression piston 55*a* is slidable in compartment 54*a* to confine a gas under pressure on either side of the actuator piston 45*a*. A charging valve means 59*a* is located in the side wall of body 43*a* to permit the pressure vessel to be charged with a gas under pressure. An inwardly projecting shoulder 83 within the pressure vessel provides an upward stop limiting movement of piston 45*a* to position the piston and valves at their uppermost positions and the bottom of the lowermost valve member 26*a* engages a shoulder 84 at the bottom of the lowermost sleeve valve seat member 25*a* to limit movement of the piston and valve members in the other direction. Control fluid entry into the compartment 54*a* is provided through an inlet 60*a* which is again provided with filter 64*a* to prevent solid particles reaching the interior of the pressure vessel.

The operation of this form of the invention is identical with that shown in Figs. 1, 2A and 2B except that the inner diameter of piston 45*a* is equal to the outer diameter of member 80 and therefore the effective pressure areas on the opposite sides of the pressure responsive member 45*a* are equal. Preferably the pressures on the valve members 26 are also balanced. It will be noted that with the valve member 26*a* positioned as shown in Fig. 3, production is from the upper strata and fluid from the upper strata will find its way into the space between the valve seats 25*a* and the connecting tubing 34*a* through ports 32*a* of the lower valve member. This pressure fluid will also find its way into the area between the uppermost valve seat member 25*a* and the tubular member 80 through the ports associated with the holding ring 74*a*. Thus the pressure will always be balanced on the valve members 26*a* and they will be in equilibrium at all times. With the valve members shifted to their other position, flow through lower ports 32*a* reaches the bottom of the lowermost valve 26*a* and the space between the connecting tubing 34*a* and the valve seat members 25*a* through upper ports 32*a*. Again such fluid will reach the space above the uppermost valve member and exterior of tubing 76 through the ports associated with the holding ring 74*a*. While the arrangement is shown to be balanced in this instance, it will be appreciated that an unbalanced design could be used and compensated for in any desired manner as suggested in the description of Figs. 1 and 2.

Fig. 4 illustrates another form of apparatus for practicing this invention. In this form a balanced valve means employing a single valve member controls flow from two formations and a differential may be maintained across the actuator piston to maintain the valve member in its last shifted position.

Referring first to the valve means, packers **16***b* and **17***b* are set between the device and wall of the well to isolate the formations. The valve seat **25***b* is, in effect, a continuation of tubing string **21***d* and is provided with vertically spaced gathering rings **85** and **86** which open into ports **87** and **88** respectively, which separately communicate with the two formations to be produced. O-rings **89**, **90** and **91** are carried by seat **25***b* respectively above, intermediate and below the two gathering rings **85** and **86** to seal between seat **25***b* and slide valve member **26***b* reciprocally mounted in seat **25***b*. Valve member **26***b* has an annular ring of ports **32***b* which with the valve member in one position are positioned opposite gathering ring **85**, and with valve member **26***b* in another position are opposite gathering ring **86**. A blank portion of the valve member is positioned opposite one gathering ring when the ports **32***b* are opposite the other gathering ring.

The valve means is connected to actuator piston **45***b* by a stem **92** connected to the piston by a crosshead **93** carried by piston **45***b*. The inner wall **94** of the pressure vessel **44***b* is provided with slots **95** in which the crosshead **93** reciprocates. The piston **45***b* is provided with O-ring seals **96** and **97** which span slots **95** and which are in sealing engagement with member **94** above and below slots **95** in all positions of piston **45***b* to contain the charge of gas under pressure in vessel **44***b*. Preferably, the crosshead connection between piston **45***b* and stem **92** permits slight misalignment between the piston and stem to prevent binding of the piston and valve member. The vessel may be charged through valve means **59***b* with a gas under pressure and control fluid introduced through filter plug **64***b* to act on floating piston to control movement of piston **45***b*.

While the actuator piston **45***b* functions in the same manner to shift the valve member **26***b*, the bleed orifice across piston **45***b* is controlled to maintain a slight pressure differential across the piston tending to hold the valve member in its last shifted position. This differential is provided by a biased member preventing the differential from dropping below a predetermined value after the pressure in vessel **44***b* has been changed to shift piston **45***b* through the bleed orifice in both directions when a predetermined differential is reached. In the Fig. 4 apparatus the bleed orifice is provided by passageways **98** and **99** which are controlled by spring loaded valve members **100** and **101** respectively. Valve **100** permits upward flow when the upward force of the differential across the piston exceeds the force exerted by its spring. Valve **101** permits downward flow when the downward force of the differential exceeds the force exerted by its spring. Thus with time cycle control or the like, if the pressure change in the control pressure to shift the piston **45***b* is maintained after each shift, the differential across piston **45***b* will maintain the piston in its last shifted position.

It will be appreciated that while the use of a confined gas to shift the actuating piston is preferred, the barrier **55***b* could be eliminated and the gas trapped in the vessel formed of the wall of **44***b* under piston **45***b* would then effectively shift the piston.

In the apparatus shown in Figs. 3 and 4, the pressure vessel is preferably charged to a pressure equal to casing pressure at the depth at which the unit is to be placed as formation pressures will have no effect on the apparatus and any greater pressure will require maintaining a greater pressure than necessary. In this connection, it might be mentioned that the Fig. 1 device might also be charged to casing pressure if desired and the unbalance of the device compensated as by spring **65**, if desired.

It further should be noted that all forms of the apparatus illustrated may be intermittently operated by alternatively increasing and decreasing the pressure of the control fluid at a greater rate than the bleed rate across the actuator piston at spaced time intervals which permit reduction of the pressure differential in the pressure vessel. In this case, the actuator piston will move with each change in pressure. However, the pressure in excess of the normal casing pressure may still be removed at any time if desired by bleeding off the excess pressure at a rate less than the bleed rate.

It is apparent that the apparatus illustrated may be used to control flow from only one formation and that with suitable control equipment at the surface, the apparatus could be made to automatically shut off a formation upon happening of certain conditions such as abnormal pressure changes in the fluid being produced. Thus the apparatus may also be utilized as down in the hole safety equipment. For instance, the identical down in the hole tool may be used with sleeve valve **26***a* having only passage **21***a* and ports **32***a* whose open and closed positions control flow from the single formation between packers **16***a* and **17***a*. A selected casing pressure holds the sleeve valve in open position, and the well produces through it. Packer **16***a* would make the formation and casing pressures common. Any decrease in casing pressure causes the sleeve valve to be shifted to closed position, and the well is shut in at the bottom of the hole.

In the event a valve becomes stuck, a force of any desired magnitude may be imposed on the stuck valve by increasing the spread in pressure above and below the actuator piston to unstick the valve.

From the above it will be appreciated that there has been provided an apparatus and method satisfying the objects of this invention. There has been provided a method and apparatus for alternative production from two separate formations in which flow may be obtained from either formation by selective shifting of valve members by controlling the pressure of a control fluid at the surface. Forms of the invention have been illustrated in which both the valves and actuator means have been made up as parts of the tubing string and also where either the actuator alone or the actuator and the valve members of the valve means may be pulled from the well by a wire line.

There has further been provided a pressure operated actuator for shifting valves or the like down in a hole or other inaccessible position in which the shifting means is provided with a gas under pressure for operating the actuator piston in response to changes in the pressure of an extraneous control fluid, which control fluid pressure may be removed, if desired, without causing movement of the valves.

There has further been provided an apparatus for shifting a valve in response to changes in a control fluid pressure in which a pressure differential tends to hold the valve in shifted position after each shift.

From the foregoing it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and which are inherent to the method and apparatus.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The invention having been described, what is claimed is:

1. A system for controlling fluid communication between the interior and exterior of a tubing down in a well comprising, a string of tubing extending into the well, a port in the tubing providing communication between the interior and exterior of the tubing, valve means for controlling flow through the port, a pressure vessel secured to the tubing, a first pressure responsive member operably connected to the valve means to control opening and closing of the port by movement of the first pressure responsive member, said pressure responsive member dividing the vessel into first and second variable volume compartments, a fluid inlet into the first compartment for introduction of a control fluid under pressure, means for slowly reducing the pressure differential across the first pressure responsive member, a second pressure responsive member in the pressure vessel reciprocal in said first compartment to provide a fluid barrier therein between the inlet and the first pressure responsive member and movable in a path which will maintain one pressure face of the second pressure responsive member exposed to the pressure inlet, a charge of gas under pressure in said vessel on the side of the second pressure responsive member not exposed to the control fluid to provide a compressible pressure fluid for operating the first-mentioned pressure responsive member, and means for changing the pressure in the vessel exerted on said one pressure face of the second pressure responsive member from a first value to a second value and back to the first value with one of said changes carried out at a rate greater than the rate of reduction of differential across the first pressure responsive member to provide for movement of the first pressure responsive member.

2. The system of claim 1 wherein the pressure vessel and pressure responsive members are carried in a wire line retrievable actuator adapted to be landed in the tubing.

3. A system for alternative production of a plurality of fluid bearing formations through a single well comprising, a production string of tubing in the well extending from the surface to said formations, packers between the well bore and tubing isolating said formations from each other, ports in the tubing to provide for flow from the formations into the tubing, valve means for alternatively opening the ports providing for flow from one of said formations while closing the ports providing for flow from the other of said formations, a pressure vessel secured to the tubing, a first pressure responsive member operably connected to the valve means to shift the valve means with movement of the pressure responsive member, said first pressure responsive member dividing the vessel into first and second variable volume compartments, a fluid inlet into the first compartment for introduction of a control fluid under pressure, a second pressure responsive member in said vessel and reciprocal in said first compartment in a path which will maintain one pressure face of the second pressure responsive member exposed to said pressure inlet, said second pressure responsive member providing a fluid barrier between the first pressure responsive member and the inlet into the vessel, a charge of gas under pressure in said vessel on the side of the second pressure responsive member not exposed to the control fluid to provide a compressible pressure fluid for operating the first pressure responsive member, means for slowly transferring said gas between the first and second chambers to reduce the pressure differential across the first pressure responsive member, and means for changing the pressure of the control fluid in the vessel from a first value to a second value and back to the first value with one of said changes carried out at a rate greater than the rate of transfer of said gas to provide for movement of the first pressure responsive member.

4. A well apparatus comprising, a body, a passageway in the body providing for fluid communication between the interior and exterior of the body, valve means for controlling flow through said passageway, a pressure vessel, a first pressure responsive member dividing the vessel into first and second variable volume compartments and operably connected to the valve means to open and close the passageway with movement of the pressure responsive member, a pressure fluid inlet into the first fluid compartment to permit the introduction of control fluid under pressure, a second pressure responsive member in said first compartment providing a fluid barrier between the inlet and first pressure responsive member, a charge of gas under pressure in said vessel on the side of the second pressure responsive member not exposed to the pressure inlet to provide a compressible pressure fluid for operating the first pressure responsive member, and bleed means for slowly transferring said gas between said compartments to permit shifting of the first pressure responsive member in both directions by controlling the pressure applied through said inlet and to permit reduction of a pressure differential across the first pressure responsive member without movement of the first pressure responsive member.

5. A well apparatus comprising, a length of tubing including a hanger mandrel adapted to be made up in a well tubing string, a passageway in the tubing providing fluid communication between the interior and exterior of the tubing, valve means for controlling flow through said passageway, and a wire retrievable shifting tool adapted to be landed in said mandrel for shifting the valve means comprising, a pressure vessel, a pressure responsive member dividing the vessel into two variable volume compartments and releasably connectable to the valve means to open and close the passageway with movement of the pressure responsive member, a pressure fluid inlet into one of the compartments to permit the introduction of control fluid, a floating piston in the compartment responsive to the control fluid to develop a fluid pressure on the dividing member and a bleed passageway for slowly transferring developed fluid pressure between the compartments to permit shifting of the pressure responsive member in both directions by controlling the pressure applied through said inlet onto the floating piston and to permit reduction of the developed pressure differential across the pressure responsive member without movement of the pressure responsive member.

6. A well apparatus comprising, a length of tubing including a hanger mandrel adapted to be made up in a well tubing string, a passageway in the tubing providing fluid communication between the interior and exterior of the tubing, valve means for controlling flow through said passageway, and a wire line retrievable shifting tool adapted to be landed in said mandrel for shifting the valve means comprising, a pressure vessel, a first pressure responsive member dividing the vessel into first and second variable volume compartments and releasably connectable to the valve means to open and close the passageway with movement of the first pressure responsive member, a pressure fluid inlet into the first fluid compartment to permit the introduction of control fluid, a second pressure responsive member in the vessel reciprocal in said first compartment in a path which will maintain one pressure face of the second pressure responsive member exposed to the control fluid inlet, said second pressure responsive member providing a fluid barrier in the first chamber between the first pressure responsive member and the inlet, a charge of gas under pressure in said vessel on the side of the second pressure responsive member not exposed to the pressure inlet to provide a compressible pressure fluid for operating the first pressure responsive member, and means for slowly transferring said gas between the compartments to permit shifting of the pressure responsive mem-

ber in both directions by controlling the pressure applied through said inlet and to permit reduction of a pressure differential across the pressure responsive member without movement of the pressure responsive member.

7. A pressure operated shifting tool adapted to be run into a well and landed in a landing mandrel to shift a part comprising, a body, means carried by the body for releasably latching the tool in a landing mandrel, a pressure vessel in said body, a pressure responsive member dividing the vessel into two variable volume compartments and operably connected to a connector exterior of the shifting tool adapted to engage the part to be shifted and upon movement to shift said part, a pressure fluid inlet into one of the compartments to permit the introduction of control fluid, a floating piston in the compartment responsive to the control fluid to develop a fluid pressure on the dividing member, and a bleed passageway for slowly transferring developed pressure fluid between the compartments to permit shifting of the pressure responsive member in both directions by controlling the pressure applied through said inlet onto the floating piston and to permit reduction of the developed pressure differential across the pressure responsive member without movement of the pressure responsive member.

8. A pressure operated shifting tool adapted to be run into a well and landed in a landing mandrel to shift a part comprising, a body, means carried by the body for releasably latching the tool in a landing mandrel, a pressure vessel in said body, a first pressure responsive member dividing the vessel into two variable volume compartments and operably connected to a connector exposed exteriorly of the shifting tool and adapted to engage the part to be shifted and upon movement of the pressure responsive member to shift such part, a pressure fluid inlet into the first fluid compartment to permit the introduction of control fluid, a second pressure responsive member in the vessel movable in the first compartment in a path which will maintain one pressure face of the pressure responsive member exposed to the pressure inlet, the second pressure responsive member providing a fluid barrier in the first compartment between the inlet and first pressure responsive member, means for charging the vessel on the side of the second pressure responsive member not exposed to the pressure inlet with a gas under pressure to provide a compressible pressure fluid for operating the first pressure responsive member, and means for slowly transferring the gas between compartments to permit shifting of the first pressure responsive member in both directions by controlling the pressure applied through the inlet and to permit reduction of a pressure differential across the pressure responsive member without movement of the pressure responsive member.

9. A well apparatus comprising, a ported tubing adapted to be made up as a part of the production tubing of a well, a sleeve valve controlling flow through the ports of said ported tubing, and a pressure operated actuator for the sleeve valve comprising, a cylinder, a piston reciprocal in the cylinder and dividing the cylinder into two variable volume compartments, a bleed orifice in the piston providing for transfer of fluid through the piston at a slow constant rate, said piston connected to the sleeve valve and shifting the sleeve valve between open and closed positions with reciprocation of the piston, one of said compartments being a sealed chamber in fluid communication with the other compartment through said orifice, the other compartment divided by a free-floating piston and a fluid inlet into the other compartment and on the face of the free-floating piston away from the reciprocal piston for introducing a control fluid pressure for reciprocating the piston.

10. A well apparatus comprising, a ported tubing adapted to be made up as a part of the production tubing of a well, a sleeve valve controlling flow through the ports of said ported tubing, and a pressure operated actuator for the sleeve valve comprising, a cylinder, a piston reciprocal in the cylinder and dividing the cylinder into two variable volume compartments, a bleed orifice in the piston providing for transfer of fluid through the piston at a slow constant rate, said piston connected to the sleeve valve and shifting the sleeve valve between open and closed positions with reciprocation of the piston, one of said compartments being a sealed chamber in fluid comunication with the other compartment through said orifice, a fluid inlet into the other compartment for introducing a control fluid pressure for reciprocating the piston, a second piston in said cylinder and reciprocal in said other compartment and isolating the first-mentioned piston from contact with the control fluid, and means for charging the cylinder on the side of the second piston not exposed to control fluid with a gas under pressure to shift the first-mentioned piston in response to movement of the second piston.

11. A well apparatus comprising, a body, a passageway in the body providing for fluid communication between the interior and exterior of the body, valve means for controlling flow through said passageway, a pressure vessel, a pressure responsive member dividing the vessel into two variable volume compartments and operably connected to the valve means to open and close the passageway with movement of the pressure responsive member, a fluid inlet into one of the compartments to permit the introduction of control fluid under pressure, a floating piston in the first compartment providing a fluid barrier between the inlet and pressure responsive member, bleed means extending between the two compartments to transfer fluid between the two compartments to permit shifting of the pressure responsive member in both directions by controlling the pressure applied through said inlet and to permit reduction of a pressure differential across the pressure responsive member without movement of the pressure responsive member, and means controlling flow through the bleed means and providing a predetermined differential across the pressure responsive member to prevent the differential returning to zero after each change in control pressure to thereby provide a biasing means to maintain the valve means in the position to which it was last shifted by the pressure responsive member.

12. A well apparatus comprising, a body, a passageway in the body providing for fluid communication between the interior and exterior of the body, valve means for controlling flow through said passageway, a pressure vessel, a first pressure responsive member dividing the vessel into first and second variable volume compartments and operably connected to the valve means to open and close the passageway with movement of the pressure responsive member, a pressure fluid inlet into the first fluid compartment to permit the introduction of control fluid under pressure, a second pressure responsive member in said first compartment providing a fluid barrier between the inlet and first pressure responsive member, a charge of gas under pressure in said vessel on the side of the second pressure responsive member not exposed to the pressure inlet to provide a compressible pressure fluid for operating the first pressure responsive member, bleed means for slowly transferring said gas between said compartments to permit shifting of the first pressure responsive member in both directions by controlling the pressure applied through said inlet and to permit reduction of a pressure differential across the first pressure responsive member without movement of the first pressure responsive member, and means controlling flow through the bleed means and providing a predetermined differential across the pressure responsive member to prevent the differential returning to zero after each change in control pressure to thereby provide a biasing means to maintain the valve

means in the position to which it was last shifted by the pressure responsive member.

13. A system for alternative production of a plurality of fluid-bearing formations through a single well comprising, a production string of tubing in the well extending from the surface to said formations, packers between the well bore and tubing isolating said formations from each other, spaced ports in the tubing providing for communication between the formations and the interior of the tubing, valve means for alternatively opening the port providing for communication with one of said formations while closing the port providing for communication with the other of said formations, a pressure compartment carried by the tubing, a pressure responsive member providing a part of the compartment wall and operably connected to the valve means to shift the valve means with movement of the pressure responsive member, means for subjecting the pressure responsive member to a control pressure, means for increasing the control pressure from a first value to a second value and for decreasing it from the second value to a third value to create a pressure differential across the pressure responsive member, and means for decreasing the pressure differential across the

pressure responsive member at a rate less than the rate of one of said changes to move the pressure responsive member and shift the valve means during said one change and then removing said differential at least in part without a corresponding movement of the pressure responsive member and the valve means from the shifted position.

14. The system of claim 13, wherein a controller at surface level regulates the control fluid pressure and intermittently increases and decreases the control pressure, and wherein the rate of both increase and decrease of control pressure is greater than the rate of decreasing said pressure differential so that movement of the pressure responsive member occurs with each change in control pressure.

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