

April 29, 1969

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3,441,084

WELL CROSS-OVER APPARATUS AND TOOLS AND METHOD
OF OPERATING A WELL INSTALLATION

Filed March 10, 1967

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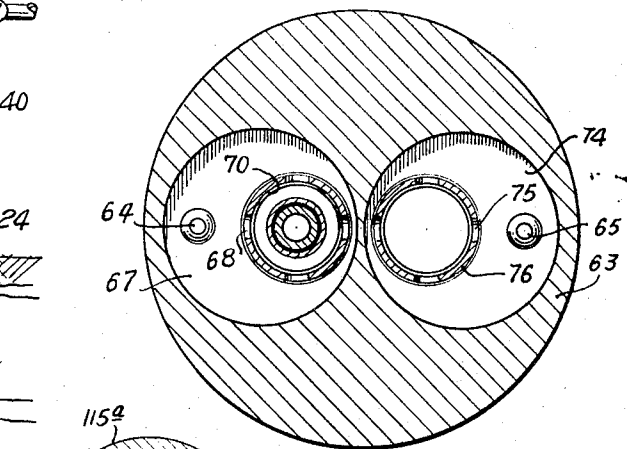
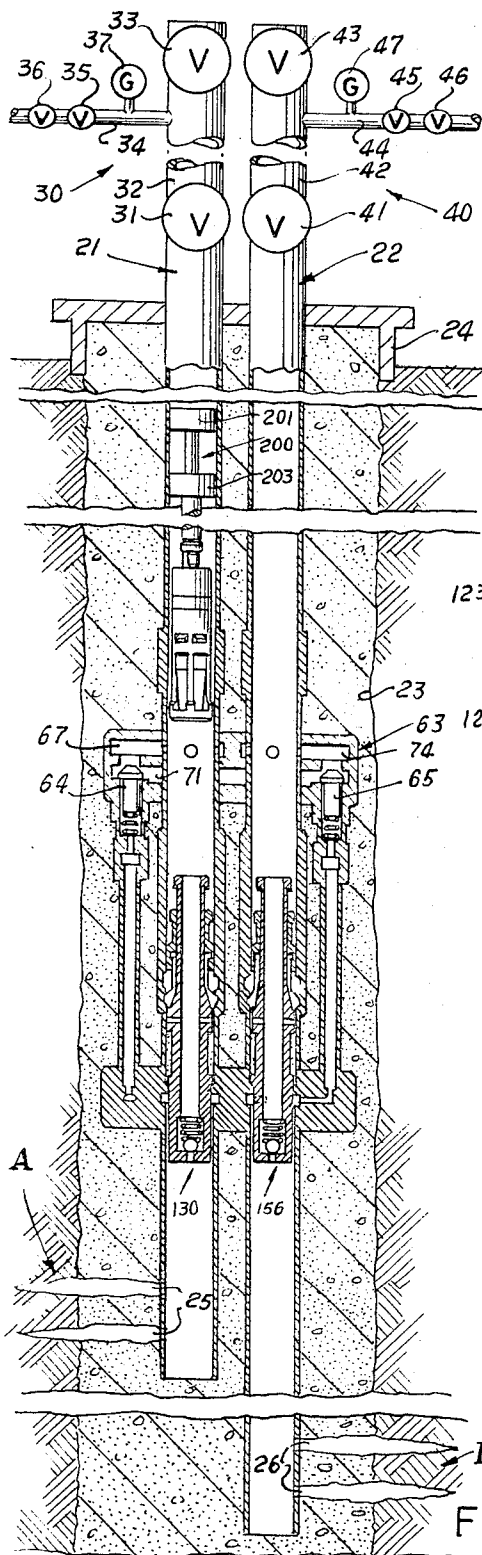


Fig. 3

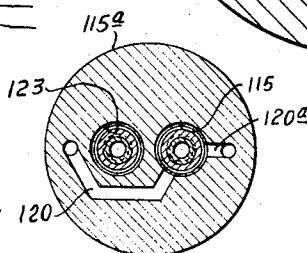


Fig. 6

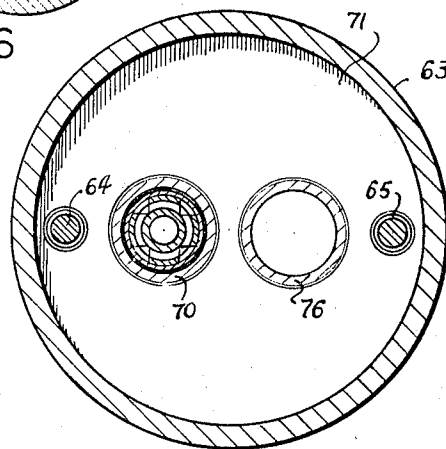


Fig. 4

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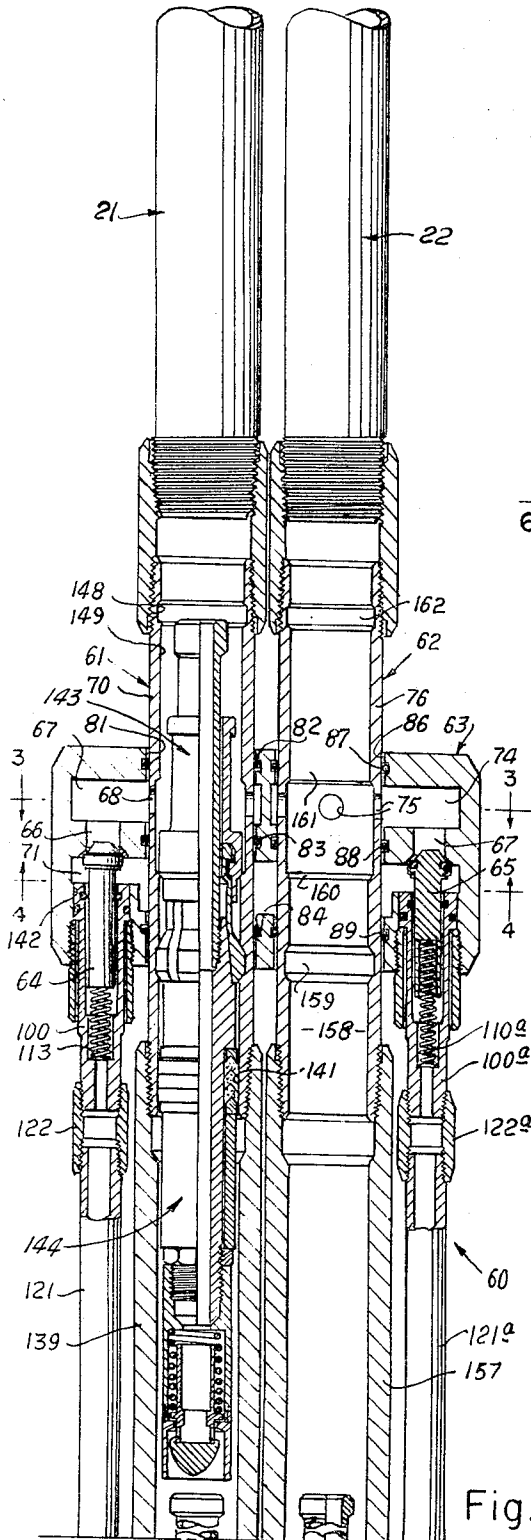


Fig. 2

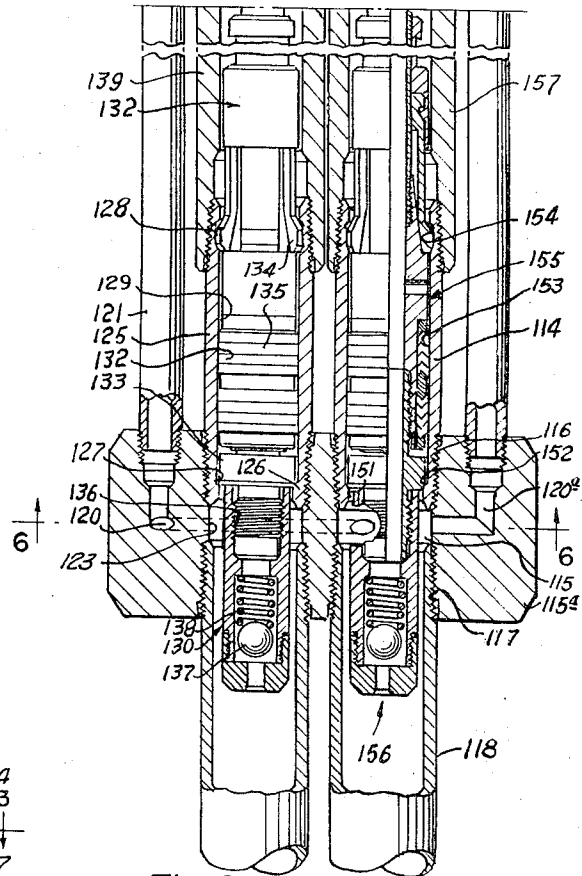


Fig. 2-A

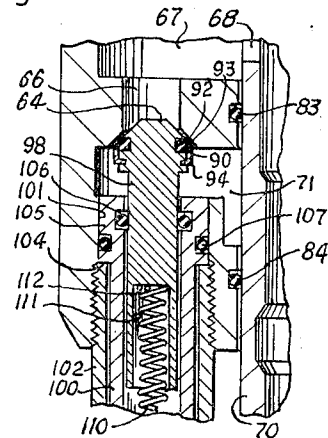


Fig. 5

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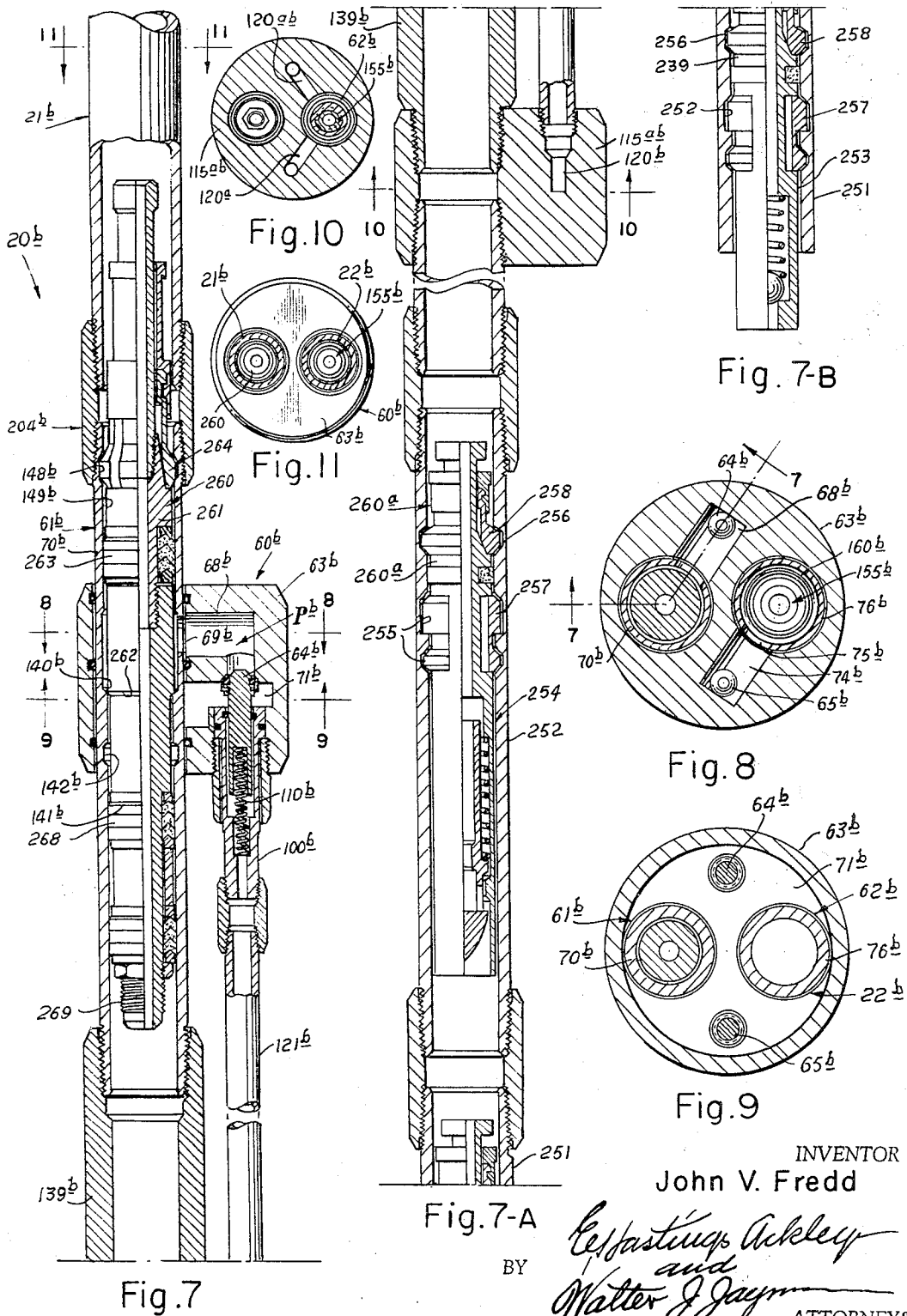
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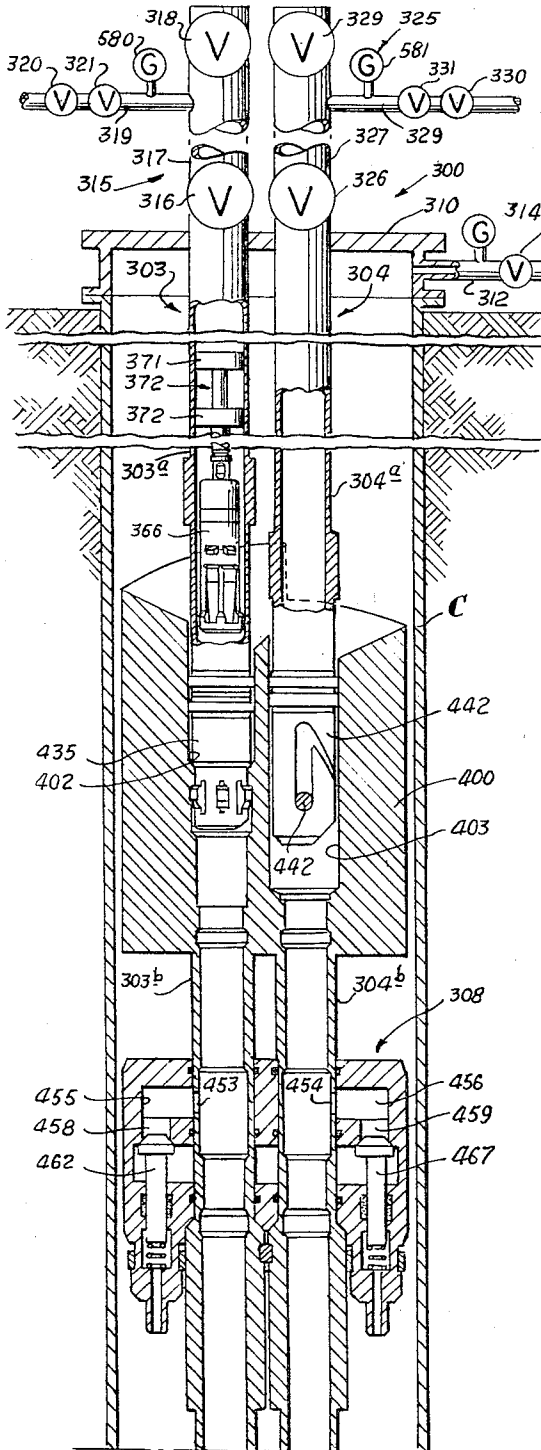


Fig. 12

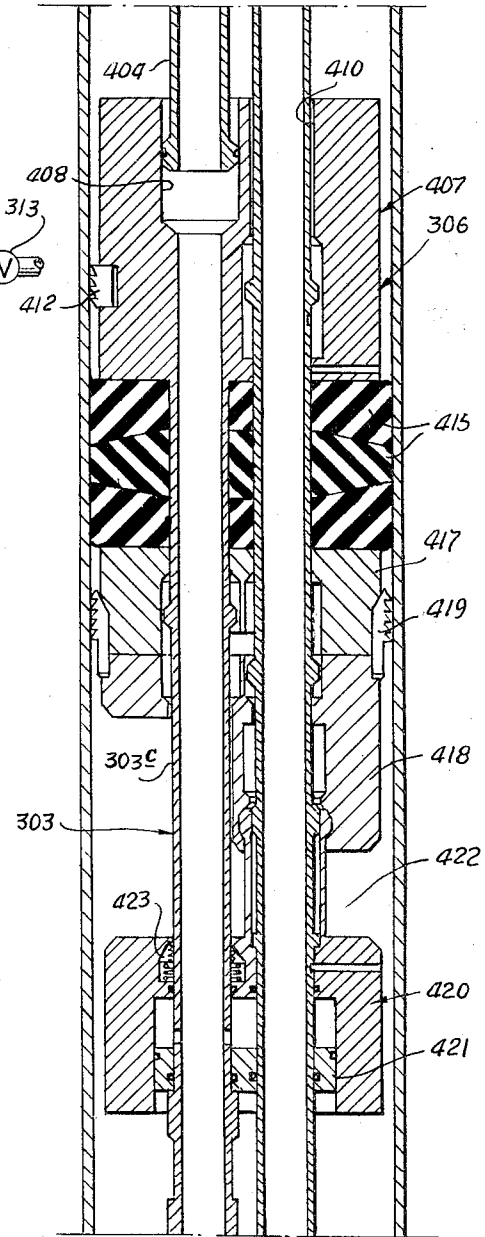


Fig. 12-A

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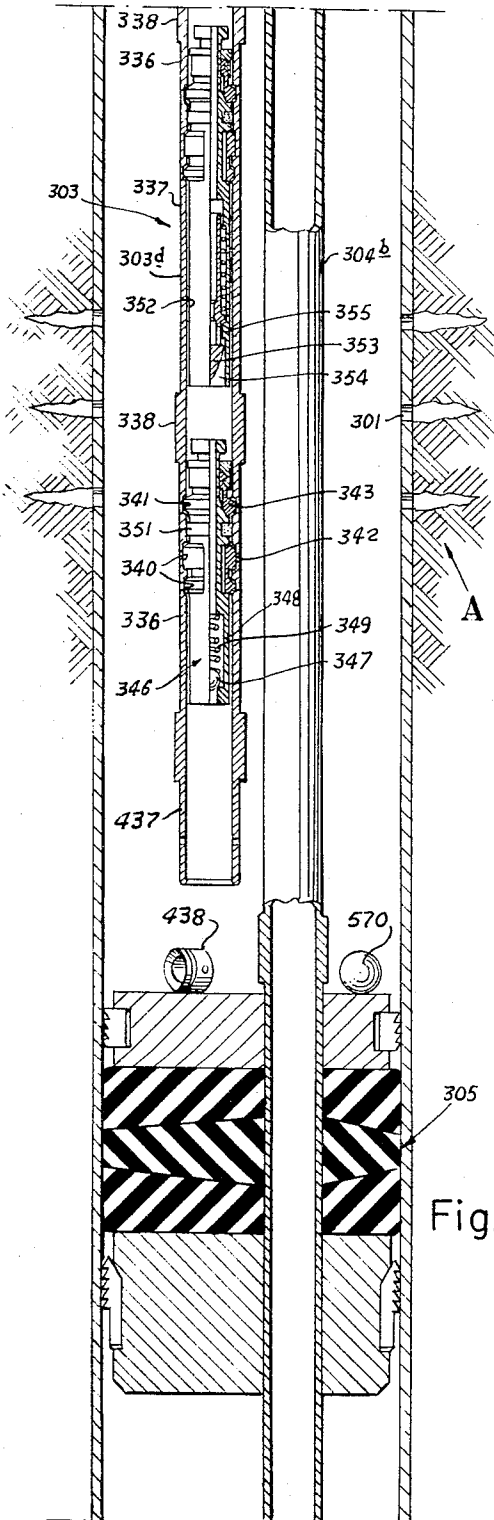


Fig. 12-B

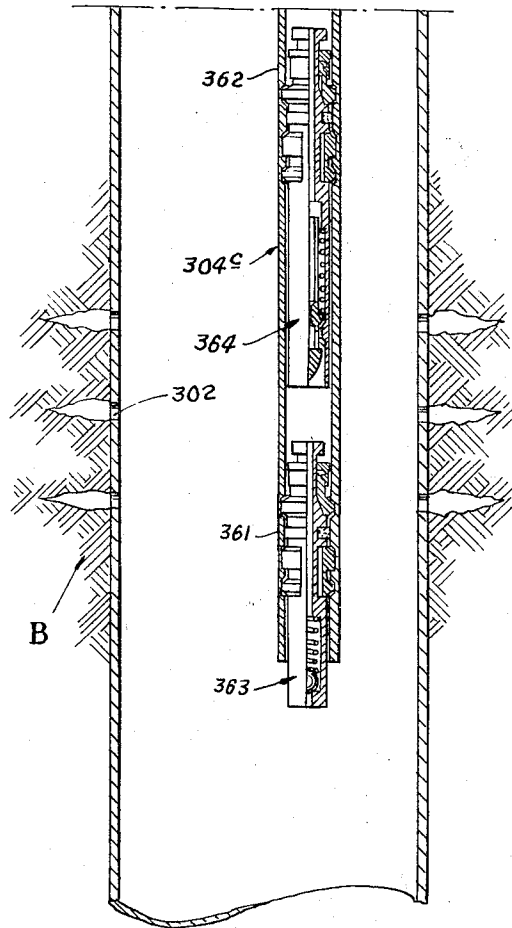


Fig. 12-c

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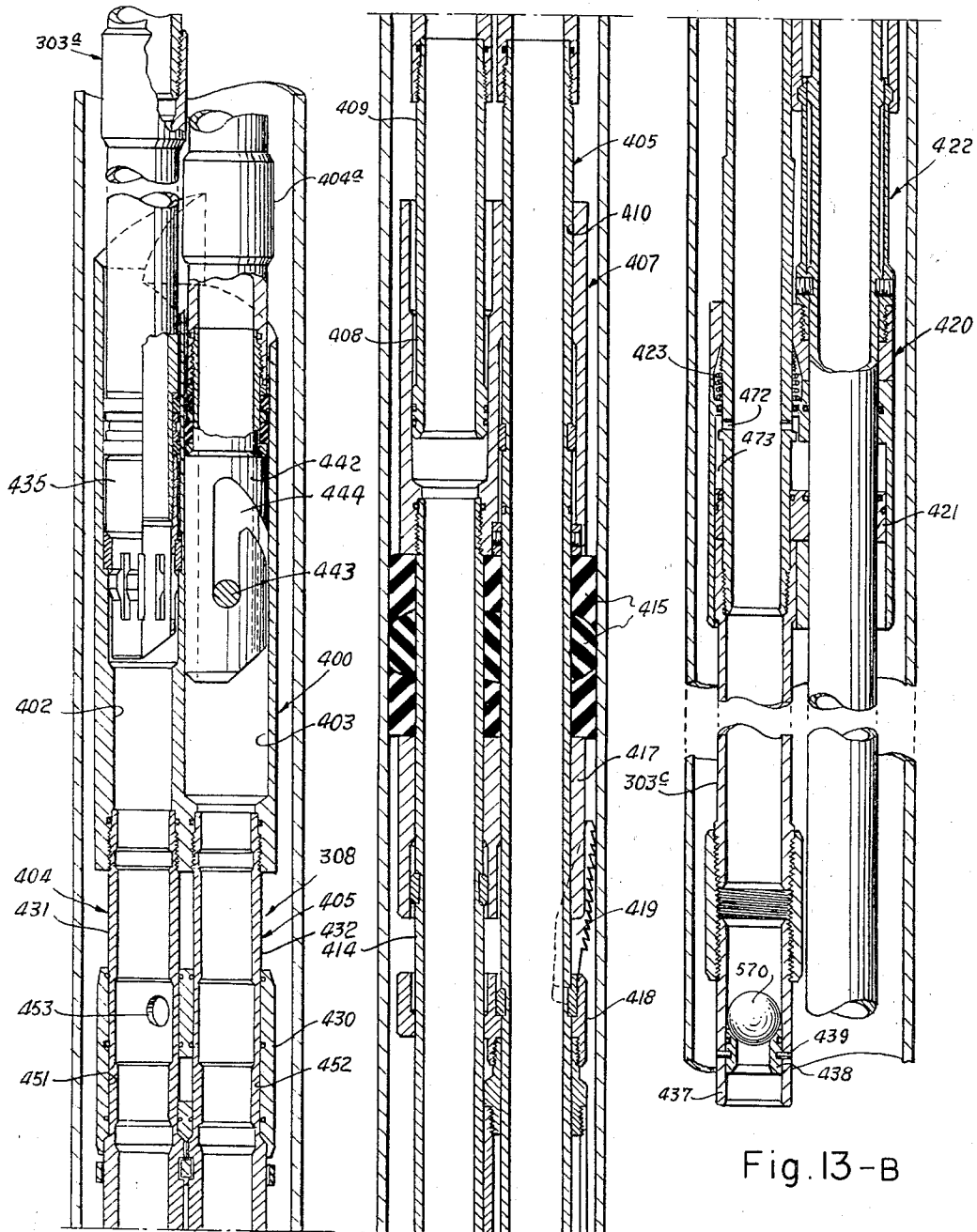


Fig. 13-B

Fig. 13

Fig.13-A

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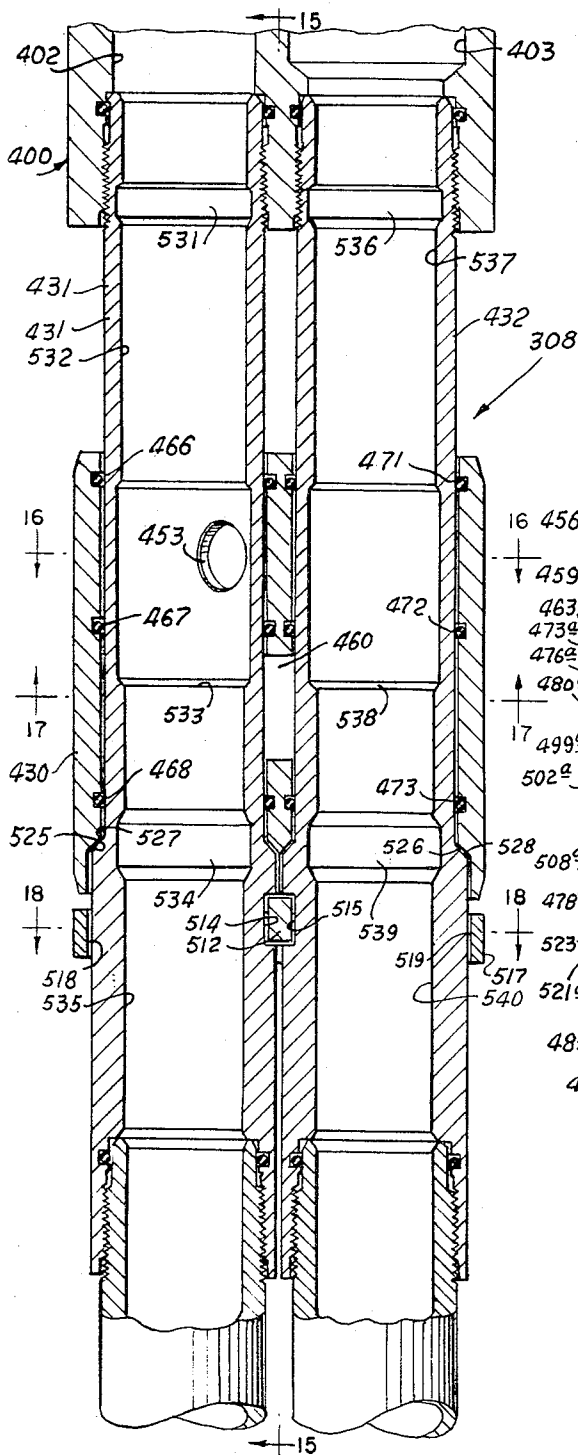


Fig. 14

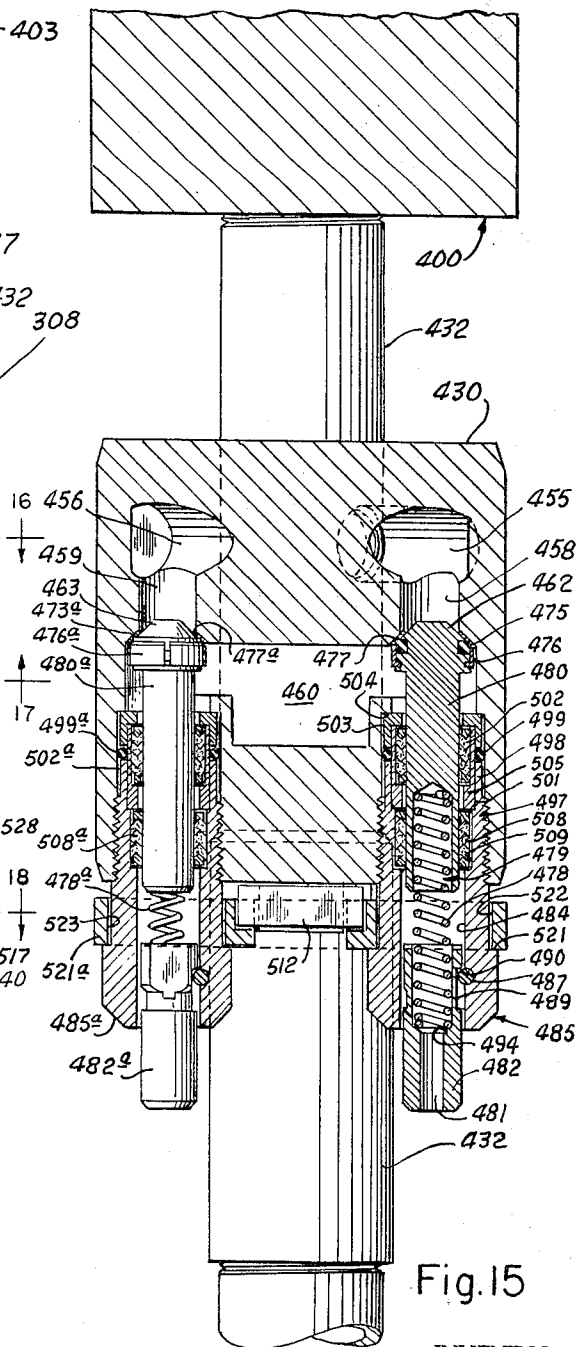


Fig. 15

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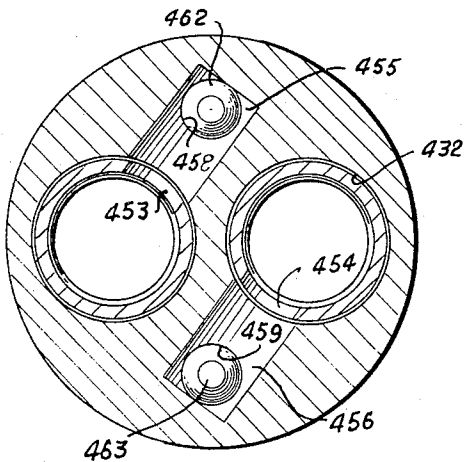


Fig. 16

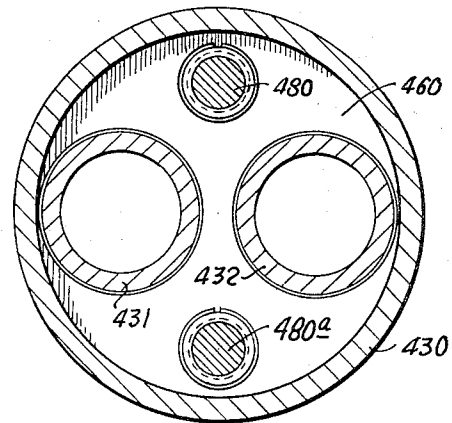


Fig. 17

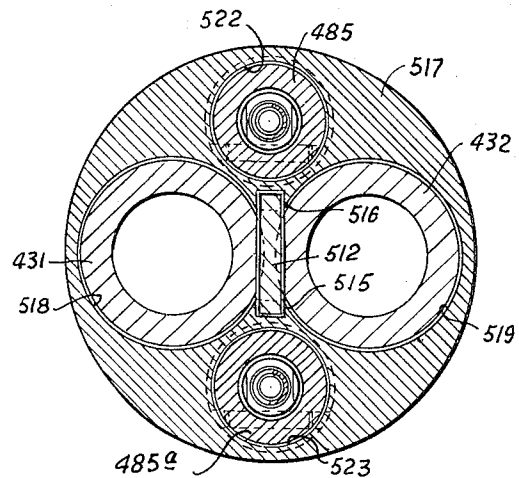


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WELL CROSS-OVER APPARATUS AND TOOLS AND METHOD OF OPERATING A WELL INSTALLATION

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Int. Cl. E21b 23/00

U.S. Cl. 166—250

39 Claims

ABSTRACT OF THE DISCLOSURE

A well apparatus having a pair of flow conductors extending in a well and having means for releasably securing well tools in the flow conductors at predetermined spaced locations therein and a cross-over means for establishing fluid communications between the flow conductors to permit circulation of fluids down one flow conductor and up the other to treat internal surfaces of the flow conductor, to move well tools up and down one or the other of the flow conductors to position and remove well tools from the flow conductors, or to operate well tools connected in the flow conductors below the location of communication of the two flow streams. A cross-over device connectable between a pair of flow conductors for establishing fluid flow communication between the flow conductors and operable when the pressure in both of the flow conductors above the cross-over device is increased above a predetermined value. A method of operating a well installation having a plurality of parallel flow conductors extending into a well by establishing communication between a pair of the flow conductors below the surface to permit circulation of fluids from the surface down one of the flow conductors and then to the surface up the other of the flow conductors to operate, install or remove well tools in such flow conductors and to establish desired circulation between earth formations and the surface.

This invention relates to a well apparatus for controlling fluid flow between the surface and producing earth formations penetrated by the well, to a flow control device of the well apparatus, and to a method for operating a well having a pair of parallel flow conductors extending therein.

An object of this invention is to provide a new and improved apparatus for producing well fluids from earth formations penetrated by a well having a pair of flow conductors extending through the well and having means in the well below the surface of the well for establishing communication between the flow conductors to permit circulation of fluids down one conductor and up the other to provide for treatment of the flow conductors with fluids, to provide for reciprocable movement of well tools in the flow conductors, and to provide for operation of well tools connected in the flow conductors by well tools movable through the flow conductors.

Another object is to provide a well apparatus wherein the operation of the means for establishing communication between the flow conductors or cross-over device is responsive to the fluid pressures in both the flow conductors which are controllable at the surface of the well whereby well operations which require high pressure conditions in one or the other of the flow conductors may be carried on without causing operation of the cross-over device and the establishment of communication between the flow conductors therethrough.

Still another object is to provide a well apparatus wherein the flow conductors below the cross-over device are provided with means in which well tools, such as standing valves, safety valves, plugs and the like, are re-

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movably installable and wherein the well tools may be installed in and removed from the flow conductors by operator tools connectable to a transport train movable reciprocally in the flow conductors by the fluids circulated therein when the cross-over device is open.

A further object is to provide a well apparatus wherein the valve means of the cross-over device is biased to closed position by the pressure in the well exteriorly of the flow conductors and is movable to open position against the force of such exterior pressure by the fluid pressures in the flow conductors when they are raised above a predetermined value.

A further object is to provide a well apparatus wherein the pressure for biasing the valve means toward closed position is that in one of the flow conductors in communication with a producing formation of highest pressure of the well in well installations whose flow conductors are cemented in a casingless well and where such biasing pressure is the pressure above packers of a well installation whose producing formations are separated by packers which close the well bore between producing earth formations.

A still further object is to provide a well apparatus of the type described whose cross-over device may be tested while in the well by control and test means located at the surface and without the necessity of moving tools into the well.

An important object of the invention is to provide a new and improved cross-over device connectable between a pair of flow conductors for establishing communication therebetween.

Another object is to provide a cross-over device having a cross-over passage which communicates with the flow passages of the flow conductors to which the cross-over device is connected and has valve means for closing the cross-over passage.

Still another object is to provide a cross-over device wherein the valve means is biased toward its closed position by pressure from exteriorly of the cross-over device and is movable to its open position by the force of the pressures in both of the flow conductors connected thereto when they are increased to a value sufficiently high that their force overcomes the force biasing the valve means to its closed position.

Still another object is to provide a cross-over device wherein the valve means includes a pair of valves each biased when in their closed position towards open position by pressure from its associated flow conductor and wherein each valve when in its closed position is biased toward closed position by the pressure from the other flow conductor if the other valve is in its open position whereby the cross-over device permits undesired communication between the flow conductors only if both valves are not functioning properly.

Still another object is to provide a cross-over device having tool locating and locking means for positioning a bridge tool therein to prevent flow through the cross-over device if it is determined that the cross-over device is not functioning properly.

A further object is to provide a cross-over device having a body and a pair of nipple means extending through bores in the body, the body having a main passage and a pair of passages, each of the pair of passages communicating with the main passage and the flow passage of one of the nipple means and a pair of valves for preventing communication between each of the pair of passages and the main passage, wherein each of the valves when in its closed position is biased toward its closed position by the fluid pressure in the main passage and is biased toward its open position by the pressure in the flow conductor which is communicated to the passage of the pair of passages which it closes.

A still further object is to provide a cross-over device having means for conducting fluid pressure from one of the pairs of flow conductors in which the nipple means are connectable to constitute sections thereof or by fluid pressure from the exterior of such flow conductors to the valves to bias them toward their closed positions.

Still a further object is to provide a cross-over device wherein the cross-over device has means for installing a flow control device, such as a standing valve, in one of the nipple means above the location at which the pressure from such one of the flow conductors is conducted in order that the pressure in such one flow conductor, which normally has the highest pressure therein, at all times bias both of the valves toward closed positions.

An important object of the invention is to provide a method of operating a well installation having a pair of parallel flow conductors extending in a well by establishing communication between the pair of the flow conductors below the surface by varying at the surface the pressure in the flow conductors to open a cross-over means to permit circulation of fluids from the surface down one of the flow conductors and upward flow of fluids to the surface through the other of the flow conductors.

A still further object is to provide a method of operating a well installation which includes the step of operating well tools connected in such flow conductors by tools movable through the flow conductors by the circulation of fluids down one flow conductor above the tools positioned therein and up another flow conductor.

Another object is to provide a method of operating a well installation which includes the step of installing or removing well tools in such well flow conductors below the location of communication between a pair of the flow conductors by transport tool means, to which the well tools are releasably connectable, by a tool transport means movable reciprocally in the flow conductors.

Still another object of the invention is to provide a method of operating a well installation having a cross-over device for establishing communication between a pair of flow conductors of the well installation and which is operable to establish such communication only when the pressure in both flow conductors is above a predetermined value which includes the step of testing the cross-over device to ascertain whether in its closed condition it effectively prevents communication therethrough between the two flow conductors by increasing the fluid pressure in a first one of the flow conductors while the flow conductors below the cross-over device are closed and observing at the surface whether the pressure increases in the other flow conductor and then increases the fluid pressure in the other flow conductor while the flow conductors are closed below the cross-over device and observing at the surface whether the pressure increases in the first flow conductor.

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 schematic, vertical partly sectional view, with some parts broken away, of a well installation embodying the invention by means of which the method of the invention may be practiced and showing the cross-over means of the well apparatus in open position;

FIGURES 2 and 2-A are vertical sectional views of the cross-over device, FIGURE 2-A being a continuation of FIGURE 2, showing well tools installed in the nipple means of the cross-over device, the well tools being shown schematically;

FIGURES 3 and 4 are sectional views taken on lines 3-3 and 4-4, respectively, of FIGURE 2;

FIGURE 5 is a fragmentary enlarged sectional view of one of the valves of the cross-over device;

FIGURE 6 is a sectional view taken on line 6-6 of FIGURE 2-A;

FIGURES 7, 7-A and 7-B are vertical sectional views taken on line 7-7 of FIGURE 8, of a modified form of the well apparatus embodying the invention, FIGURES 7-A and 7-B being continuations of FIGURES 7 and 7-A, respectively, and showing well tools installed in nipple means of the well apparatus, the well tools being shown schematically;

FIGURES 8 and 9 are sectional views taken on lines 8-8 and 9-9, respectively, of FIGURE 7;

FIGURES 10 and 11 are sectional views taken on lines 10-10 and 11-11, respectively, of FIGURE 7-A;

FIGURES 12, 12-A, 12-B and 12-C are schematic vertical partly sectional views of another modified form of the well apparatus embodying the invention, FIGURES 12-A, 12-B and 12-C being continuations of FIGURES 12, 12-A, and 12-B, respectively;

FIGURES 13, 13-A and 13-B are vertical partly sectional views with some parts broken away, of the upper well packer of the well apparatus illustrated in FIGURES 12, 12-A and 12-B;

FIGURE 14 is an enlarged vertical sectional view taken on line 14-14 of FIGURE 17 of the cross-over device of the well apparatus illustrated in FIGURES 13, 13-A and 13-B;

FIGURE 15 is a vertical partly sectional view taken on line 15-15 of FIGURE 14; and,

FIGURES 16, 17 and 18 are sectional views taken on lines 16-16, 17-17 and 18-18, respectively, of FIGURE 14.

Referring now particularly to FIGURES 1 through 6 of the drawings, the well apparatus 20 includes a pair of flow conductors 21 and 22 which extends into a well bore 23 through a well head 24 and are cemented in the well bore. The lower end of the first flow conductor 21 communicates with an upper producing earth formation A through perforations 25 in the flow conductor and the cement while the second flow conductor 22 is in communication with a lower producing formation B through similar perforations 26 in the second flow conductor and the cement. The first flow conductor 21 has a surface control assembly 30 connected to its upper end by means of which well tools may be moved into the flow conductor or may be removed therefrom and by means of which fluids under pressure may flow from the flow conductor or be introduced into the flow conductor at the surface. The surface control assembly may include a bottom valve 31 of large orifice, an elongate tube or manifold 32, a top valve 33 for closing the upper end of the tube, and a flow conduit 34 having a suitable flow control device connected therein, such as a pressure regulator valve 36 and a shut off valve 35. The flow conduit opens to the manifold below the top valve. The control assembly may also include a pressure gauge 37 connected to the flow conduit between the shut off valve and the manifold 32 and indicates the pressure in the flow conduit, and therefore, in the first conductor 21, when the bottom valve 31 is closed and the top valve 33 is open.

It will be apparent that when the top valve 33 is closed and the bottom valve 31 is open, fluids may flow from the flow conductor through the flow conduit when the shut off valve 35 is opened and that the regulator valve 36 may be set to permit flow of fluids from the flow conductor only as long as the pressure in the first flow conductor at the surface is above a predetermined value. Conversely, fluids under pressure may be introduced into the flow conductor to maintain the pressure therein at a predetermined value by connecting the flow conduit to a suitable source of fluid under pressure, such as a pump, and setting the pressure regulator valve 36 to permit flow into the first flow conductor only when the pressure therein falls below a predetermined value. If it is desired to move a well tool into the first flow conductor while maintaining a predetermined pressure within the first flow conductor, the valves 31 and 35 are closed, the valve 33 is opened and such well tool is inserted into the manifold through the

valve 33. The valve 33 is then closed and the valve 31 is opened to permit downward movement of the well tool into the first flow conductor. If such tool is to be moved downwardly by fluid pressure introduced into the flow conductor, fluid under regulated pressure may then be introduced into the manifold 32 above such tool or assembly through the flow conduit 34. If such tool is to be moved downwardly by a wireline, a suitable stuffing box is secured to the manifold above the valve 33 to seal about the line while the tool is being moved in the flow conductor by means of such line.

The second flow conductor has a similar control assembly 40 connected thereto which includes a bottom valve 41, a manifold 42, a top valve 43 and a flow conduit 44 in which are connected a shut off valve 45 and a pressure regulator valve 46. A pressure gauge 47 is connected to the flow conduit between the manifold and the shut off valve.

The flow conductors 21 and 22 may be the usual strings of tubing whose sections are connectable by the usual collars C. A cross-over assembly 60 for selectively permitting circulation of fluids down one flow conductor to a location above the upper producing formation, over into the other flow conductor, and then upwardly through the other flow conductor is connected to the flow conductors at a location above the uppermost producing earth formation A. The cross-over assembly includes a nipple assembly 61 which is connected in the first flow conductor and constitutes a section thereof, a similar nipple assembly 62 which is connected in the second flow conductor 22 and constitutes a section thereof, and a body or head 63 in which are mounted valves 64 and 65 for closing ports 66 and 67, respectively, of the head. The port 66 opens to a passage 68 of the head which is in communication with the ports 69 of the top nipple 70 of the nipple assembly 61 and to a main passage 71 of the head to which the other port 67 also opens. The port 67 also opens to a passage 74 of the head which is in communication with the ports 75 of the top nipple 76 of the nipple assembly 62. It will be apparent that when the valves 64 and 65 are in their open positions fluid may circulate down one flow conductor, for example, the flow conductor 21 through the nipple ports 69, the head passage 68, the lower main head passage 71, the head port 67, the head passage 74, and the nipple ports 75 into the other flow conductor 22. These passages and ports thus constituting a cross-over passage P between the two flow conductors which is closable by the valves 64 and 65.

The top nipple 70 of the nipple assembly 61 of the first flow conductor extends through a vertical bore or passage 81 of the head which intersects the passages 68 and 71 of the head. A pair of O-rings 82 and 83 disposed in annular recesses which open to the aperture 82 above and below the passage 67 seal between the top nipple 70 and the head and below the passage 68 and the ports 69 of the top landing nipple. The middle O-ring 83 and a bottom O-ring 84 also disposed in an internal annular recess of the head seal between the head and the landing nipple 70 above and below the passage 71.

The top landing nipple 76 of the nipple assembly 62 similarly extends through a vertical aperture 86 of the head which intersects the passages 74 and 71. O-rings 87 and 88 disposed in annular recesses of the head seal between the head and the top nipple 76 above and below the passage 74 of the head and the ports 75 of the top nipple. O-ring 88 and a bottom O-ring 89, also disposed in an internal annular recess of the head, seal between the top nipple and the head above and below the passage 71.

The valve 64 has an annular resilient seal 91 disposed in an annular groove or recess 92 thereof which is engageable with a seat ring 93 secured as by solder and the like to the valve body and which extends about the port 66. The seal is secured to the valve by a split retainer ring 94 whose internal lower flange is received in an annular recess of the valve. The valve has a stem 98 which extends

slidably through a fitting 100 whose upper portion extends into the lower end of a bore 101 which opens to the passage 71. The fitting is held against downward movement in the bore 101 by a retainer sleeve 102 threaded in the lower end of the bore whose annular top end surface engages the downwardly facing annular stop shoulder 104 of the top external annular flange 105 of the fitting 110. An O-ring 106 disposed in an internal annular recess of the fitting seals between the fitting and the valve stem and a similar O-ring 107 disposed in an external annular recess disposed in an external annular recess of the fitting seals between the fitting and the body.

The valve 64 is biased towards its upper closed position by a spring 110 whose upper portion is received in the downwardly opening bore 111 of the valve stem and whose top end bears against the downwardly facing shoulder or surface 112 defining the upper end of the bore. The bottom end of the spring engages the upwardly facing annular shoulder 113 of the fitting. The valve 64 is also biased towards its closed position by fluid pressure in the second flow conductor below the bottom landing nipple 114 of its nipple assembly 61 which is communicated to the lower end of the fitting by means of the vertical passage 115 of a block 115a of the cross-over assembly in whose upper threaded portion 116 is threaded the lower end of the bottom landing nipple 114 and in whose lower threaded portion 117 is threaded the upper end of the section 118 of the second flow conductor, a passage 120 of the block which opens to the passage 115 and to the lower end of a conduit 121 threaded, as at 134, in the vertical portion of the passage 120, the passage of the conduit, and a coupling 122 which connects the upper end of the conduit to the lower end of the fitting.

The valve 65 and the means by which it is mounted for movement between its open and closed positions being similar to the valve 64 and its means, the valve and its associated means have been provided with the same reference numerals, to which the subscript *a* has been added, as the corresponding elements of the valve 64 and its associated means. The conduit 121a whose upper end is connected to the bottom end of the fitting 100a by the coupling 122a has its lower end threaded in the upper vertical portion of the passage 120a of the block 115a which also opens to the passage 115 below the bottom landing nipple 114 so that the valve 65 is also biased upwardly by the pressure in the second flow conductor below its bottom landing nipple as well as by its spring 110a.

The bottom landing nipple 125 of the nipple assembly 61 is threaded in the upper portion of the vertical passage 123 of the block 115a, in whose lower portion is threaded a lower section 124 of the first flow conductor, and has an internal annular flange 126 which provides an upwardly facing annular stop shoulder 127 and an internal annular lock recess 128 adjacent its upper end so that any suitable well tool, such as a standing valve 130, may be releasably secured in the first flow conductor by means of a suitable lock means 132, such as the Otis Type N Lock Mandrel illustrated on page 3816 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 Edition, which has a no-go ring 133 engageable with the stop shoulder 127 to limit its downward movement through the landing nipple and with dogs 134 which are movable into the lock recess 128 to releasably lock the lock mandrel against upward movement in the bottom landing nipple. The lock mandrel also has a seal means 135 which engages the seal surface of the bottom nipple to seal between the mandrel and the nipple so that all flow of fluids through the first flow conductor must take place through the standing valve 130 connected as at 136 to the bottom end of the lock mandrel. The standing valve has a ball 137 biased towards its bottom closed position by a spring 138 wherein it prevents downward flow of fluids through the valve. The operation of the

lock mandrel and the standing valve are well known and will not be described in greater detail.

The top nipple **70** is connected to the bottom nipple by a coupling or spacer **139**. The top nipple has a lower portion of decreased internal diameter which provides an upwardly facing annular stop shoulder **140** and an internal seal surface **141**. An annular internal lock recess **142** is also provided below the stop shoulder so that a lock means **143**, such as the Type E Otis Mandrel illustrated and described on page 3817 of the Composite Catalogue of Oil Field Equipment and Services 1966-67 Edition, may be releasably locked and located in the top nipple **70** to hold another well tool **144**, such as an Otis Type F Tubing Safety Valve illustrated and described on page 3836 of the 1966-67 Edition of the Composite Catalogue of Oil Field Equipment and Services, in the first flow conductor. The safety valve prevents upward flow of fluids therethrough when the pressure differential across the safety valve exceeds a predetermined value, as for example, in the event of failure or damage to the surface well equipment which would otherwise result in unrestricted fluid flow through the first flow conductor. The lock mandrel **143** has a no-go ring **145** which is engageable with the stop shoulder **140** of the top landing nipple to limit downward movement of the lock mandrel through the top nipple, dogs **146** which are receivable in the lock recess **142** for releasably locking the lock mandrel against upward movement in the top nipple and seal means **147** engageable with the seal surface **141** so that all fluid flow takes place through the safety valve and the lock mandrel.

The top nipple also has an upper lock recess **148** near its upper end and a seal surface **149** below its upper lock recess whose function will be described below.

The bottom landing nipple **114** of the nipple assembly **62** may be identical to the bottom landing nipple **125** and have a bottom internal flange **151** which provides an upwardly facing annular stop shoulder **152**, a seal surface **153** and a lock recess **154** so that a lock mandrel **155** and a standing valve **156** carried thereby, which may be identical to the lock mandrel **132** and the standing valve **130** may be releasably locked in the second flow conductor in the position illustrated in FIGURE 2A. The bottom nipple **114** is connected to the top nipple **76** by a flow coupling **157**. The top nipple **76** may be identical in structure to the nipple **70** and having a bottom seal surface **158**, a lower internal annular lock recess **159**, an annular stop shoulder **160**, an upper seal surface **161** and an upper lock recess **162**. It will be apparent that a safety valve identical to the safety valve **144** may be installed in the same manner and by a lock mandrel identical to the lock mandrel **143** to control upward flow of fluids through the second flow conductor.

The well apparatus is installed in the well bore by connecting the cross-over assembly or device **60** to the two flow conductors, as illustrated in FIGURES 1 and 2, with the two nipple assemblies **61** and **62** thereof connected in and constituting sections of the first and second flow conductors **21** and **22**, respectively. The flow conductors are lowered by usual means and methods into the well bore **23** to a desired position therein wherein the cross-over assembly is positioned above the upper producing formation A and each flow conductor extends downwardly past the producing earth formation whose fluids it is to conduct to the surface. The flow conductors and the cross-over device are then cemented in place in the well bore, as illustrated in FIGURE 1, by any conventional method, as by pumping a cement slurry through one or both of the flow conductors into the well bore until the well bore about the flow conductors is filled with cement slurry. The flow conductors **21** and **22** are, of course, cleared of any cement slurry, as by pumping a fluid such as water into the flow conductors at the surface, after a charge of cement slurry of sufficiently great volume to fill the well bore to the surface has been pumped into

the flow conductors to locations below the producing formations A and B, respectively. The cement, of course, closes or plugs the flow conductors below the producing formations.

After the cement has set in the well bore, suitable directional perforating tools are moved through the two flow conductors to the locations of the producing earth formation to form the perforations **25** and **26** through the flow conductors and the cement so that well fluids from the formation A may then flow into the flow conductor **21** and from the producing formation B into the second flow conductor **22**.

The standing valves are then installed in the bottom nipples of the two nipple assemblies and locked therein by means of their lock mandrels. The lock mandrels may be lowered into position and locked in place by a set of suitable wire line operated tools, which may include a suitable running tool to which the lock mandrels are releasably secured, such as the Otis Type H Running Tool illustrated and described on page 3839 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 edition. Such tools are inserted into and removed from the flow conductors by means of suitable surface control assemblies connected to the upper ends of the two flow conductors in the usual well known manner. For example, if a standing valve is to be lowered into the first flow conductor by means of a wire line and a string of wire line tools which includes jars, the string of wire line tools and the lock mandrel **132** and standing valve **130** connected thereto are lowered into the manifold **32** while the lower valve is closed and the upper valve **33** is open. A suitable stuffing box secured to the upper end of the manifold above the upper valve **33** closes the upper end of the manifold about the wire line during the movement of the tools through the first flow conductor. The valve **31** is opened and the well tools are lowered through the first flow conductor until the downward movement of the lock mandrel **132** is arrested due to the engagement of its no-go ring **133** with the stop shoulder **127** of the bottom landing nipple. Downward jars are then imparted by means of the wire line tools and the wire line to the lock mandrel to cause its locking dogs **134** to move into the lock recess **128** and also to release the running tool from the lock mandrel. The string of wire line tools is then removed from the well and lock mandrel left releasably locked in the bottom nipple. Subsequently and in similar manner another well tool, such as the safety valve **144**, may be installed in the top nipple of the nipple assembly **61** by means of a lock mandrel **143**. The standing valve **156** and a safety valve identical to the safety valve **144** may be similarly installed in the nipple assembly **62** through use of wire line tools or a tool string movable through the flow conductor **22** by circulation through the cross-over assembly. The standing valves prevent imposition of excessive pressures on the producing earth formations during subsequent operations of the well apparatus as well as the movement of fluids which may be introduced into the flow conductors at the surface into the producing formations.

The flow conduits **34** and **44** may then be connected to reservoirs or delivery lines to which the fluids produced from the formations A and B, respectively, are to be transported. The pressure regulator valves **36** and **46** are preferably set to maintain predetermined pressures in the two flow conductors and thus control the rate of production of well fluids and the shut off valves **35** and **45** are then opened. If the rate of flow through any flow conductor in which a safety valve is installed exceeds a predetermined value, such safety valve will close.

During normal well fluid producing operations of the well apparatus, the valves **64** and **65** are held in their closed positions by the forces exerted thereon by their biasing springs and by the pressure in the second flow conductor below its standing valve **156**. The flow passages **120** and **120a** of the block **115a** open to the passage **115**

of the block which is in communication with the flow conductor in which the highest pressure is maintained in order that both valves be in their closed positions during normal operation of the well apparatus and that at least one of the valves be biased toward closed position by a force substantially greater than that exerted by its biasing spring. In the illustrated apparatus, it is assumed that the pressure in the second flow conductor is higher than the pressure in the first flow conductor, and therefore, the passages 120 and 120a open to the passage 115 of the block which constitutes a section of the flow passage of the second flow conductor. If the pressure in the first flow conductor was to be maintained at a higher value than in the second flow conductor, the passages 120 and 120a would open to the passage 123 of the block instead of to the passage 115.

The valves are also biased toward their closed positions by any fluid pressure trapped in the main passage 71 of the head since the areas of the valves within the lines of sealing engagement of the seals 90 and 90a with their seat rings are greater than the areas of the valve stems 98 and 98a within the lines of sealing engagement of the O-rings 106 and 106a therewith.

It will be apparent that if the pressure in the first flow conductor at the cross-over assembly of the illustrated apparatus were greater than the fluid pressure in the second flow conductor at the location of the passage 115, as perhaps may sometimes be required during certain operations of the well apparatus, the forces of this fluid pressure exerted on the upwardly facing surfaces of the valve 64 through the top nipple port 69, the passage 68 and the port 66 could exert a force so much greater than the combined force of the spring 110, the force of the liquid pressure from the second flow conductor exerted on the downwardly facing surfaces of the stem 98 and of any fluid pressure trapped in the main passage 71 of the head, that the valve 64 could move to its open position. This would not result in the establishment of communication between the two flow conductors since even if the valve 64 were open and the fluid pressure from the first flow conductor were communicated to the main passage 71, the force exerted on the valve 65, as long as the valve 65 is closed, by the pressure in the main passage would bias it toward its closed position. It is preferable, however, that at least one of the valves have a pressure differential exerted thereacross during normal production operation of the well apparatus which increases the force with which such valve is biased toward closed position, it being apparent that the valve 65 during normal production operation of the well is biased to its closed position mainly by the force of the spring 110a since the pressure within the passage 74 of the cross-over head is substantially equal to the pressure in the passage 115, and the pressure trapped in the main chamber may not be of high value, since some leakage of well fluids could possibly take place past the valve 65 from the passage 71 to the port 67 if the spring 110a exerted a relatively small force on the valve 65 during prolonged periods of such production operation.

It is sometimes desired to circulate fluids down one of the flow conductors through the cross-over passage and upwardly in the other flow conductor, as for example, in order to treat the internal surfaces of the two flow conductors with a corrosion inhibiting liquid or to dissolve and remove deposits or paraffin or other such substances which may have accumulated on the internal surfaces on one or both of the flow conductors. Such deposits normally accumulate at higher locations in the flow conductors above the cross-over assembly where the temperatures are lower than in the lower portions of the well. In this case both flow conduits 34 and 44 are connected to a suitable source of the treating liquid by means of a pump and their shut off and regulator valves are opened. The pressures in the two flow conductors, since they are now both connected to a single source of pressure, now

be raised to equal values at the location of the cross-over assembly. As the pressure in the flow conductors rises as such pump operates, the standing valves of the two flow conductors close and prevent downward flow of fluids from the flow conductors into the producing formations A and B. The valves 64 and 65 are biased upwardly with substantially equal forces since their springs are of equal strength and their stems are exposed to the same formation B pressure. When the pressure in the two flow conductors is increased to a value sufficiently great that its force exerted on the valves 64 and 65 exceeds the upward force exerted on these valves by their springs and by fluid pressure within the second flow conductor 22 below the standing valve 156, the valves 64 and 65 will move simultaneously to their open position. The seals 90 and 90a will not be subjected to great pressure differentials during this opening movement since the pressures in the two flow conductors are equal, it being apparent that if such opening of the valves took place at the time great pressure differentials existed thereacross, the seals could be damaged by the forces exerted thereon.

If it is then desired that the treating fluid circulate down one flow conductor, for example, the flow conductor 21 and up the other flow conductor 22, the pressure regulator valve 46 of the flow conduit 44 is set to maintain a back pressure in the second flow conductor 22 sufficiently great that the valves 64 and 65 will be held in their lower open positions. The conduit 44 is then disconnected from such common source of fluid under pressure and connected to a disposal line to which the treating liquids after their circulation through the flow conductors must be delivered. The treating liquid is then pumped through the conduit 34 into the manifold 32 and thus into the top end of the first flow conductor, flows downwardly through the first flow conductor to the cross-over assembly, then through the cross-over passage of the assembly into the second flow conductor, upwardly through the second flow conductor and to the flow conduit 44. At this time, if the pressure in the flow conduit 34 is raised over the value required to open the valve 64, for example, if the pressure is raised 100 p.s.i. over such valve, the pressure in the flow conduit 44 may be decreased equally since the pressure at the cross-over device will remain substantially equal to that before the pressure was increased in the flow conduit and was decreased in the conduit 44. When the circulation of such treating liquid is completed, the shut off valves 35 and 45 are closed, the flow conduits 34 and 44 are again connected to the storage reservoirs or flow lines to which the well fluids must be delivered, and, when the shut off valves 35 and 45 are again opened after the regulator valves have been set to maintain the pressure in the two flow conductors at desired values, as the pressures in the flow conductors decrease due to the flow of fluids therefrom through their flow conduits, the force of the springs and of the pressure in the second flow conductor below the cross-over assembly causes the valves 64 and 65 again to move to their upper closed positions. As the valves move to their closed positions, any relatively high pressure trapped in the main passage will exert a force on the valves tending to hold them in their closed positions due to the fact that the areas of the valves exposed thereto within the lines of sealing engagement of the seals of the valves are greater than the areas of their stems exposed thereto within the lines of sealing engagement of the O-rings 106 and 106a therewith. Each flow conductor then produces fluids from its respective earth formation.

It will be apparent, that, if desired, the flow conduits 34 and 44 may both be connected to a disposal line for such treating liquids after the circulation thereof is completed for a period of time sufficiently long to cause all treating fluids in the flow conductors and the flow conduits to be flushed out by the well fluids produced by the formations prior to the connection of the flow conduits to the

reservoirs or flow lines to which such well fluids are to be delivered.

Well tools removably installed in one or the other of the flow conductors, such as the safety valve 144 installed in the top nipple 70 of the first flow conductor 21 may be removed therefrom by means of a pump down train of tools 200, which may be similar to the Otis Pump-Down Train of Tools illustrated on page 3780 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 edition, and include locomotives 201 and 202, jars, not shown, and the like, as well as a pulling tool 203 such as the Otis Type R Pulling Tool illustrated and described on page 3839 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 edition. Such tools are preferably connected to one another by suitable couplings which permit a limited pivotal movement of each tool of the train at the location of its connections to the other tools of the train. The locomotives 201 and 202 sealingly engage the internal surfaces of the flow conductor to close its passage and are spaced far enough apart to bridge any internal recesses of the flow conductor, such as coupling collar recesses. The train of tools with the pulling tool at its bottom end is then placed into the manifold 32 after the valves 31 and 35 have been closed and the top locomotive 101 is positioned below the location of communication of the flow conduit 34 with the manifold 32. The valve 33 is then closed and the valves and the flow conduits 34 and 44 are connected to a common suitable source of fluid under pressure and the pressure in the flow conductors is raised to a value sufficiently high to cause the standing valves of the flow conductors to close and the valves 64 and 65 to open. The pressure regulator 46 is then set to permit flow from the first flow conductor when the pressure therein exceeds a predetermined value which, however, is sufficiently high to keep the valves 64 and 65 in their open position. The pressure of the fluid introduced into the first flow conductor is then raised to a sufficiently high pressure to move the train of tools downwardly and cause the fluids in the first flow conductor below the bottom locomotive to flow downwardly therein, through the cross-over passage of the cross-over assembly and then upwardly through the second flow conductor to its flow conduit 44.

The bottom locomotive 102 is spaced from the pulling tool 203 a distance sufficiently great that when the train of tools has moved downwardly to the position wherein the pulling tool has moved into operative engagement with the upper end portion of the lock mandrel 143, the bottom locomotive is positioned above the ports 69 of the top nipple 70. Once the pulling tool has moved into operative and connected engagement with the lock mandrel, the direction of flow of fluids through the flow conductors is reversed, the flow conduit 44 being connected to a source of fluid under pressure and the flow conduit 34 being opened through its valve 55 and pressure regulator valve 56 which is now set to maintain the pressure in the first flow conductor above that necessary to maintain the valves 64 and 65 in their open positions. The fluid then flows down through the second flow conductor and the cross-over passage to the first flow conductor below the bottom locomotive. The train of tools is now moved upwardly in the second flow conductor and since the pulling tool is now secured to the lock mandrel, the lock mandrel and the safety valve now move upwardly with the train and into the manifold 32. The train of tools may then be removed after the valve 31 is closed and the valve 33 is opened.

Another well tool may then be installed in the top nipple 70, such as a new or repaired safety valve 144, by connecting at the bottom end of the pump down train, instead of the pulling tool, a running tool, such as the Type T Otis Running Tool illustrated and described on page 3892 of the 1966-67 Catalogue of Oil Field Equipment and Services, to which the lock mandrel 143 of

the safety valve is secured with its dogs held in retracted position. The train of tools is then inserted into the first flow conductor and pumped down until the lock mandrel moves into the top nipple 70 and is latched therein by its dogs which are then moved to their expanded positions in the lock recess 148. The running tool is released from the lock mandrel by a downward force or jars imparted thereto by the train of tools as the pressure in the first flow conductor is increased at the surface by operation of the surface controls. The direction of circulation of fluids in the flow conductors is then reversed and the train of tools is removed upwardly through and from the first flow conductor.

It will be apparent that the well tools may similarly be installed in and removed from the landing nipples of the second flow conductor by similar running and pulling tools connected to such a pump down train.

It is apparent that it is necessary to remove well tools from each landing nipple before the well tool in the next lower landing nipple may be removed.

It will also be apparent that while each of the nipple assemblies 61 and 62 has been illustrated as having only two nipples in which lock mandrels may be releasably installed that additional such nipples may be connected between the top and bottom nipple in spaced relation to one another and to the top and bottom nipples by suitable couplings, such as the couplings 139 and 157. The lengths of the conduits 121 and 121a would, of course, be increased accordingly.

It will also be seen that, if desired, even the standing valves may be installed in or removed from the bottom nipples by the pump down train of tools, the high pressure in the flow conductors below the lowermost locomotive 102 of the pump down train will, however, be imposed on the producing earth formations as the standing valves are moved from the landing nipples.

While the surface control assemblies 30 and 40 have been shown connected to the two flow conductors at the surface of the well, it will be apparent that in some installations, as for example, in subsea wells, the flow conductors may extend a relatively long distance from the well head to the shore of the body of water and such control assemblies are then connected at such locations remote from the well itself and the flow conductors may have bends or arcuate portions therein. The flexible connection of the various tools of the pump down train, however, permits such pump down train of tools together with the well tool which is being installed or removed from the flow conductor to move through such arcuate portions of the flow conductors. In this case the lock mandrels may be formed of several sections flexibly connected to one another and the well tool carried by such lock mandrel will also preferably be flexibly connected to the lock mandrel.

It will also be apparent that while particular well tools have been illustrated and described for installation in particular nipples in connection with the operation of the well installation 20, other well tools, such as chokes, plugs, and the like, may be moved and operated through the flow conductors of the well installation 20 and may be provided with other lock means adapted to cooperate with nipples other than those illustrated and described in connection with the well installation 20.

It is important in well installations having a plurality of flow conductors which produce fluids from different producing formations that no commingling of the well fluids produced by different formations occur during their production by flow thereof from one such flow conductor to another, as through the cross-over assembly 60 of the well apparatus 20 when its valves are in their closed positions, in order that the rates of production from the different formations can be measured and controlled. It is, therefore, necessary that the well apparatus after its installation and after each opening and closing of the cross-over passage, and at periodic intervals as may be

required by various governmental bodies which regulate the production of well fluids, such as gas and oil, be capable of testing the cross-over assembly to determine if the cross-over passage is effectively closed.

The operative condition of the cross-over assembly 60 may be easily and positively tested without introducing any well tools into the well merely by closing the shut off valves of the flow conductors if the shut in pressure of the formation B in the second flow conductor is considerably greater than the shut in pressure of the formation A in the first flow conductor. When the shut off valves are closed the springs of the standing valves move the balls thereof to their closed positions as the shut in values of the formation pressure are reached in the flow conductors. If the valves 65 and 64 are properly closing the cross-over passage the pressure gauge 37 will not indicate a rise in the pressure in the first flow conductor above the normal shut in pressure of the first flow conductor thus indicating that no fluid flow has taken place between the two flow conductors through the cross-over passage P.

Alternatively, after the shut-off valve 35 is closed, the conduit 44 may be connected to a source of test fluid of higher pressure than the normal shut in value of the formation pressure B in the second flow conductor 22 at the surface. The standing valve 156 will close and the valve 65 will open as the pressure in the second flow conductor is thus increased. If the valve 64 is now not properly closing the cross-over passage, the pressure gauge 37 will indicate a rise in the pressure in the first flow conductor at the surface above the normal shut in value of the formation A. If desired, the cross-over assembly may be further tested by closing the shut-in valve 45, and connecting the flow conduit 34 to a source of pressure higher than the normal shut-in pressure of the producing formations in the flow conductors at the surface of the well. As the pressure in the first flow conductor increases, the standing valve 132 will close and the valve 64 is moved to its open position. If the valve 65 is now not properly closing the cross-over passage, the pressure gauge 47 will indicate a rise in the pressure in the second flow conductor at the surface above that of the shut-in pressure of the producing formation B thus indicating that the valve 65 is not functioning properly.

It will thus be apparent that it is possible to test the cross-over assembly to determine whether it is in proper functioning condition and that it is also possible to test each valve separately.

If the valve 65 is not functioning properly, the higher pressure in the second flow conductor which is then communicated to the main passage 71 of the head will cause a pressure differential to exist across the valve 64 and its stem biasing the valve 64 to its closed position due to the difference in the areas within the seal 90 and the O-ring 106 and since the pressure in the first flow conductor is lower than in the second flow conductor. Any malfunctioning of the valve 65 will not result in any fluid flow between the two flow conductors through the cross-over passage P if the valve 64 is operating properly. If the valve 64, however, is not functioning properly and if the pressure within the second flow conductor is considerably greater than in the flow conductor 21, the valve 65 could be moved to its open position if the pressure in the main passage 71 decreased considerably due to flow from the main passage into the port 66 and the force of the pressure in the second flow conductor exerted on the upwardly facing area of the valve 65 through the port 67 became sufficiently great to move the valve 65 downwardly against the upward force exerted by the spring 110a, by the pressure acting on the stem 98a below the O-ring 106a and by the pressure in the main passage acting on the valve 65. The spring 110a is preferably of such strength that under predictable pressure conditions in the well apparatus it prevents such undesired opening of the valve 65.

If one or the other of the valves is not functioning properly because of pressure of extraneous matter, such as scale, sand and the like, on the valve or its seat ring, the circulation through the cross-over passage may be reversed several times while both valves are held open to cause the fluids flowing therepast to dislodge such matter. After such flushing circulation, the valves will, of course, be tested again.

If it is found that the cross-over assembly is not functioning properly, a suitable bridge tool may be installed in the top nipple of either flow conductor to close the ports 75 or 68 to prevent flow through the ports 75 or 68 as desired as will be explained in connection with a preferred form of the well apparatus 20b embodying the invention illustrated in FIGURES 7 through 11.

Upon the termination of the testing of the cross-over device or upon the termination of circulation of fluids through the two flow conductors by means of the cross-over device, the pressure in one or both of the flow conductors is decreased by operation of the surface controls thereof and the valve or valves which have been open will move upwardly to closed positions while the pressure in one or both of the flow conductors is higher than that normally obtaining therein during normal production of flow of well fluids by the well apparatus. As a result, the fluid pressure trapped in the main passage 71 upon the closing of the valve or valves is higher than the normal fluid pressure in either one of the two flow conductors. This trapped fluid pressure then exerts an additional force biasing the two valves toward their closed positions. The fluids trapped in the main passage are not completely incompressible liquids since the fluids in the flow conductors normally are a mixture of gases and liquids. In any event, any movement of the valves resulting in partial opening of the ports 66 and 67 is very small and does not decrease the volume of the chamber to any appreciable degree so that the ports are opened slightly as either valve is initially moved from its closed toward its open position and any fluids trapped in the main passage which must be displaced from the main passage as the valve moves downwardly therinto may escape from the main passage through such partly opened port.

It will be apparent that since the pressure in both of the flow conductors must be increased above the value predetermined by the forces exerted by the springs of the two valves thereon, by the fluid pressure in one of the flow conductors and by any fluid pressure trapped in the main passage, various operations may be performed by means of the well apparatus 20, during which it is not desired to establish fluid flow communication between the two flow conductors through the cross-over device, which, however, require the raising of the pressure in one or the other of the two flow conductors to a value above that which causes its associated valves 64 and 65 to move to its open position. For example, it may be desired to treat the formation A with treating liquids under relatively high pressure, as for example, to stimulate the production of well fluids from the formation A by the introduction therinto of liquids which increase the permeability of the formation to such well fluids, as by fracturing the formation in the vicinity of the well bore or by removing from the formation connate water or water introduced into the formation during the drilling of the well bore.

In this case, any well tools located in the first flow conductor 21, such as the safety valve 144 and the standing valve 130, are removed therefrom either by wireline tools or by pump down trains of tools as described hereinabove. The flow conduit 34 is then connected to a source of such treating liquids which are then introduced into the upper end of the first flow conductor through the surface control assembly 30 and will flow downwardly through the first flow conductor and through the perforations 25 into the producing formation A. As the pressure in the first flow conductor is thus increased, the valve 64 will open but the valve 65 will remain closed since the

now high pressure in the main passage 71 will actually exert a greater upward force on the valve 65 biasing it toward its closed position.

Similarly, if it is desired to test any of the well tools which are installed in the flow conductors, as for example, the standing valve 156 of the second flow conductor, the flow conduit 44 is connected to a source of fluid of pressure higher than the shut-in pressure of the second flow conductor, and after the pressure in the second flow conductor has been raised to such higher pressure, the shut-off valves 35 and 45 are closed. If the standing valve 156, which is moved to its closed position as the pressure thereabove was increased and the valve 64 are functioning properly, the pressure gauge 47 will show no decrease in pressure in the second flow conductor and the pressure gauge 37 will show no increase in the pressure in the first flow conductor above its shut-in pressure. If the pressure gauge 47 shows a decrease in the pressure in the second flow conductor and the pressure gauge shows no such increase in the pressure in the first flow conductor, it will be apparent that the standing valve 156 is permitting downward flow therethrough and is defective.

It will now be apparent that the cross-over device or assembly 60 provides for a great flexibility of operation of the well apparatus 20 due to the provision of a valve means for closing its cross-over passage P which includes two separate valves, each of which is capable of independently closing the cross-over passage P to flow of fluids between the two flow conductors, for a great reliability of operation, and for a long operational life since both valves and the elements associated with each valve, such as the spring, or the seat rings against which the valves seat must fail, before actual fluid flow can take place between the two flow conductors through the cross-over device.

It will further be seen that the cross-over device includes nipple assemblies which are connectable in the flow conductors to constitute sections thereof and which have means for locating and locking well tools therein to control flow of fluids through the flow conductors.

It will also be seen that the cross-over device has means utilizing the fluid pressure in one of the flow conductors for biasing the valves of the cross-over device toward their closed positions.

The well apparatus 20b embodying the invention illustrated in FIGURE 7, is similar to the well apparatus 20, and, accordingly, its elements have been provided with the same reference characters, to which the subscript *b* has been added, as the corresponding elements of the well apparatus 20. The well apparatus 20b differs from the well apparatus 20 in having the longitudinal axes of the valves 64b and 65b located in a vertical plane perpendicular to the vertical plane in which lie the longitudinal axes of the nipple assemblies 61b and 62b instead of in a single common vertical plane as in the case of the well apparatus 20 in order to minimize the external diametric dimensions of the cross-over device 60b. In addition, the nipple assembly 61b includes only a top landing nipple 70b and a flow coupling or conduit 139b and the first flow conductor below the block 115ab has a plurality of spaced landing nipples 251 and 252 connected therein by means of which well tools such as a standing valve 253 and a safety valve 254 may be releasably secured in the first flow conductor below the cross-over device 60b in such landing nipples.

The landing nipples of the first flow conductor may be of the type described and illustrated in the patent to J. V. Fredd, No. 2,798,559, issued July 9, 1957, each having selector key grooves 255 and a lock groove 256 in which are receivable selector keys 257 and lock means or dogs 258, respectively, of the locator and lock tools or lock mandrels 259 and 260a to which the standing valve and the safety valve are connected. The lock mandrels may be of the type described and illustrated in the patent to J. V. Fredd and also on page 3836 of the Composite

Catalogue of Oil Field Equipment and Services, 1966-67 Edition, wherein is also illustrated and described a safety valve which may be used as the safety valve 254. The selector key grooves of each landing nipple may be of different dimensions or differently spaced than the grooves of the other nipples connected in the flow conductors and the lock mandrels of the different well tools are provided with selector keys of different configurations so that each well tool may be located and locked in a preselected landing nipple of the first flow conductor below the cross-over device assembly by means of a lock mandrel. It will be apparent that the lock mandrel of the standing valve 253 may be located and locked in the bottom landing nipple 251 and the lock mandrel of the safety valve 254 may be located and locked in a landing nipple 252b by means of wireline or pump down tools in the same manner described above in connection with the well apparatus 20.

It will be apparent, of course, that the bottom locomotive of a pump down train of tools connected to the running or pulling tools, by means of which such lock mandrels are installed in or removed from the landing nipples 251 and 252, must be spaced above such running and pulling tools a distance sufficiently great that when such running or pulling tool is in engagement with the upper portion of the lock mandrel when such lock mandrel is locked in its landing nipple, the bottom locomotive of such tool train is above the ports 69b. The nipple assembly 62b is identical to the nipple assembly 62 illustrated in FIGURES 1 and 2 and may have well tools installed therein in the same manner as described above in connection with the well apparatus 20. A standing valve is shown locked in place in the bottom landing nipple of the nipple assembly 62b by a lock mandrel 155b. The valves are biased upwardly by pressure in the nipple assembly 62b below the standing valve, the passages 120a and 120b of the block 115ab opening to the assembly 62b.

It will also be apparent that the cross-over device 60b may be operated in the same manner as the cross-over device 60 to permit circulation of fluids into the formations or down one flow conductor and up the other flow conductor and also be tested in the same manner as the cross-over device 60 and a safety valve may be installed in the top landing nipple 76b of the nipple assembly 62b in the same manner as in the well apparatus 20.

It will also be apparent that since the nipple assembly 61b does not have a bottom nipple, such as the nipple 125 whose internal flange prevents downward movement of well tools therethrough, two or more landing nipples such as the nipples 251 and 252 may be connected in the first flow conductor and well tools may be installed and removed therefrom either by wire line tools and methods or pump down tools.

Referring now particularly to FIGURE 7 of the drawings, if it is found by such testing that the cross-over device has been damaged and may be permitting flow of fluid through its cross-over passage Pb between the two flow conductors, the cross-over passage may be closed by installing a well tool assembly 260 in the top nipple of one of the nipple assemblies 61b or 62b, for example, in the top nipple 70b of the nipple assembly 61b. The tool assembly 260 includes a lock mandrel 261 similar to the lock mandrel 132 having a stop shoulder 262 which engages the stop shoulder 140b of the top landing nipple 70b to limit downward movement of the tool assembly through the top landing nipple and whose seal assembly 263 is spaced above its stop shoulder so that it sealingly engages the seal surface 149b of the top landing nipple 70b. The lock dogs 264 of the lock mandrel 261 are movable into expanded positions in the lock recess 148b and hold the lock mandrel against upward movement in the top nipple. A lower seal assembly 268 on the lock mandrel sealingly engages the lower seal surface 141b of the top nipple. As a result, when the tool assembly 260 is

positioned in the top nipple **70b**, all fluid flow occurring in the first flow conductor past the cross-over device takes place through the lock mandrel and no flow can take place between the two flow conductors through the cross-over passage **Pb** of the cross-over head **63b**.

The tool assembly **260** may be installed in the top landing nipple by means of wire line tools including a running tool such as the Otis Type I Running Tool illustrated and described on page 3892 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 Edition, and if subsequent operation of the well apparatus **20b** requires the circulation of fluids down one flow conductor, through the cross-over device and then up the other flow conductor, the tool assembly **260** may be removed from the top nipple **61** by usual wire line tools which will include a pulling tool such as the pulling tool **203**, prior to the establishment of such circulation.

It will also be apparent that such well tool **260** may also be installed in and removed from the top landing nipple of either the nipple assembly **61** or the nipple assembly **62** of the cross-over assembly **60** of the well apparatus **20** if it is necessary to prevent any possible flow through the cross-over passage **P** of the cross-over device **60**, and that, if desired, a well tool such as a safety valve, could be connected, as at **269**, to the lock mandrel.

It will, of course, be apparent that the well apparatus **20b** may be cemented in place in a well bore and include surface control assemblies connected to its flow conductors **21b** and **22b** of the same type as the corresponding surface control assemblies of the well apparatus **20**.

It will be apparent that the well apparatus **20b** allows for greater flexibility of operation thereof than the well apparatus **20** since it may have two or more landing nipples, such as the landing nipples **251** and **252** connected in the flow conductor in which a lower pressure is maintained during normal operation of the well since its standing valve **253** does not have to be located above the location at which the passages, such as the passages **120b** and **120ab**, communicate with the other flow conductor below its standing valve **156b** such higher pressure being necessary to bias the valves **64b** and **65b** toward their upper closed positions.

Referring now particularly to FIGURES 12 through 18 of the drawings, the well apparatus **300** embodying the invention includes the usual well casing **C** which extends through the well and is provided with sets of perforations **301** and **302** at the locations of the spaced producing earth formations **A** and **B** penetrated by the well bore through which the fluids from the formations **A** and **B** may flow into the casing and be conducted to the surface through the flow conductors **303** and **304**, respectively. The well apparatus includes a lower packer **305** located in the casing between the two sets of perforations which closes the casing and seals between the casing and the second flow conductor **304** which conducts the fluids from the lower producing earth formation **B**. The first flow conductor **303** which conducts the well fluids produced by the earth formation **A** opens to the casing above the lower packer and below a dual packer **306** which closes the well casing above the upper set of perforations and seals between the well casing and both conductors. The lower packer may be of any suitable commercially available type which may be set either mechanically or hydraulically as is well known to those skilled in the art. The upper packer may be of the type described and illustrated in the United States Patent to Carter R. Young, No. 3,288,218, issued Nov. 29, 1966, which is modified by the connection therein of the cross-over device **308** embodying the invention as will be described below. The casing above the upper packer is usually filled at least partially with a liquid such as water or mud so that the pressure in the well casing above the

upper packer is normally higher than the pressures in the two flow conductors.

The well installation includes a casing head **310** secured to the top end of the casing which closes the top end of the casing. The casing head has suitable apertures through which the upper ends of the two flow conductors extend and sealing means which seal between the casing head and the flow conductors so that fluids may flow into and out of the casing at the surface only through a flow conduit **312** in which are connected flow control devices, such as a pressure regulator valve **313** and a shut off valve **314**. The flow conduit may be connected to a source of fluid under pressure, such as a pump or a reservoir, and the like so that the pressure in the casing above the upper packer may be increased, if desired, by introducing gas under pressure into the casing through the conduit until the casing pressure reaches a predetermined value. The pressure within the casing may be decreased to any predetermined value by opening the shut off valve and setting the pressure regulator valve at a desired pressure so that the gas under pressure in the upper end of the portion may flow from the casing until the casing pressure drops to the predetermined value.

The first flow conductor has a surface control assembly **315** connected to its upper end by means of which well tools may be moved into the flow conductor or be removed therefrom and by means of which fluids under pressure may be caused to flow from the flow conductor or be introduced into the flow conductor. The surface control assembly may include a bottom valve **316** of large orifice, an elongate tube or manifold **317** and a top valve **318** for closing the upper end of the tube. A flow conduit **319** having suitable flow control devices connected therein, such as a pressure regulator valve **320** and a shut off valve **321** opens to the tube below the top valve. It will be apparent that when the top valve **318** is closed and the bottom valve **316** is open, fluids may flow from the flow conductor and through the flow conduit if the shut off valve **321** is open, the regulator valve **320** being set to permit flow of fluids from the flow conductor only as long as the pressure in the first flow conductor is above a predetermined value. Conversely, fluids under pressure may be introduced into the flow conductor to maintain the pressure therein at a predetermined value by connecting the conduit to a suitable source of fluid under pressure such as a pump and setting the pressure regulator valve to permit flow into the first flow conductor only when the pressure therein falls below a predetermined value. If it is desired to move a well tool or well tool assembly into the first flow conductor while maintaining a predetermined pressure within the first flow conductor, the valves **316** and **321** are closed, the top valve **318** is opened and such well tool is inserted into the tube through the top valve. The valve **318** is then closed and the valve **316** is opened to permit downward movement of the well tool or assembly downwardly into the first flow conductor. If such tools are to be moved downwardly by fluid pressure introduced into the flow conductor above such well tools, fluid under regulated pressure is then introduced into the tube **317** above such tool through the flow conduit **319**. If such tools are to be moved downwardly by a wireline, a suitable stuffing box is secured above the top valve to seal about the cable and close the top of the manifold while the tool is being moved in the flow conductor and the manifold by means of such line.

The second flow conductor has a similar surface control assembly **325** connected thereto which includes a lower valve **326**, an elongate tube or manifold **327**, a top valve **328**, and a flow conduit **329** in which are connected flow control devices, such as a pressure regulator valve **330** and a shut off valve **331**.

The first flow conductor **303** may be a usual string of tubing having one or more landing nipples, such as the landing nipples **336** and **337** connected therein to consti-

tute sections thereof, the landing nipples being connected to adjacent sections of the string of tubing by the usual coupling collars 338. The landing nipples may be of the type described in the patent to J. V. Fredd, No. 2,798,559, issued July 9, 1957, each having key grooves 340 and a locking groove 341 in which are receivable the selector keys 342 and locking members or dogs 343 of the latch means or lock mandrels which are locatable in selected landing nipples and releasably latched thereby by the latch means. The latch means L is also of the type described in the patent to J. V. Fredd, No. 2,798,559, issued July 9, 1957. The key grooves of each nipple are of different dimensions or are differently spaced than the key grooves of the other nipples connected in the flow conductor and the latch means L of the different well tools are provided with the selector keys of different configurations so that each well tool may be located and locked in a predetermined landing nipple of the first flow conductor by means of the latch means as is fully described in the patent to J. V. Fredd.

The well tools may be of any suitable desired type. In the well installations 300, the well tool 346 located in the bottom landing nipple 336 of the first flow conductor is a standing valve having a valve member or ball 347 biased toward a lower closed position in the body 348 by a spring 349 wherein it prevents downward flow of fluids through the longitudinal passage 350 of the body. The lock mandrel L has seal means 351 which seal between the lock mandrel and the landing nipple. It will be apparent that if the pressure in the casing between the packers is sufficiently higher than the pressure within the flow conductor above the standing valve, the ball is moved upwardly and well fluids may flow upwardly through the standing valve. If the pressure in the first flow conductor above the standing valve is of such value that its force and the force of the spring exerted on the ball are greater than the force exerted on the ball by the pressure in the casing between the packers, the ball will be moved to closed position and thus prevents any downward flow of fluids through the flow conductor into the casing between the packers.

The well tool 352 positioned in the landing nipple of the first flow conductor 337 is a safety valve, such as the Otis Type F Tubing Safety Valve illustrated and described on Page 3836 of the 1966-67 Edition of the Composite Catalogue of Oil Field Equipment and Services, which has a valve member 353 that moves to a closed position to stop upward flow of fluids through the longitudinal passage 354 of the valve body 355 when the pressure differential across the safety valve exceeds a predetermined value, as for example, in the event of failure or damage to the surface well equipment which would otherwise result in unrestricted fluid flow through the first flow conductor.

The second flow conductor similarly has one or more landing nipples, such as the landing nipples 361 and 363 in which are positioned a standing valve 363 and a safety valve 364 which are identical to the standing valve 346 and the safety valve 352, respectively.

The valves are movable through the flow conductors and installable in predetermined landing nipples by a running tool of the type whose structure and mode of operation is described in the patent to J. V. Fredd, No. 2,798,559, and may be released from the nipples and removed from the flow conductors by a suitable pulling tool 366, such as the Otis Type R Pulling Tool illustrated and described on Page 3839 of the Composite Catalogue of Oil Field Equipment and Services, 1966-67 Edition.

The portion of the well apparatus 300 including the single packer, the valves, the flow conductors and the landing nipples connected therein, and the surface equipment of the well are well known to those skilled in the art and, accordingly, will not be described in greater detail herein.

In order to permit for circulation of fluids down one flow conductor to a location above the upper packer and

then upwardly through the other flow conductor, or to permit installation and removal of the flow control devices in the landing nipples by means of a pump down train of tools 370 which may include piston units or locomotives 371 and 373, other suitable tools such as jars, not shown, and the above described running and pulling tools connected at the bottom end of the train, it is necessary to provide a cross-over means for selectively providing a circulation of fluids between the two flow conductors above the top landing nipples of the flow conductors in order that the fluids in a flow conductor below a train of tools moving downwardly therein be permitted to flow to the surface through the other flow conductor and to permit fluid pumped into one flow conductor to flow into the other flow conductor below the locomotives of the train when the train is moved upwardly through such other flow conductor. During normal operation of the well apparatus, such cross-over means must prevent fluid flow between the two flow conductors to prevent commingling of the well fluids produced from the two different earth formations.

The upper packer 306, as is fully illustrated and described in the patent to Carter R. Young, No. 3,288,218, includes a head 400 having a pair of passages 402 and 403 and a dependent tubular extension 404 whose upper end is threaded in the lower end of the first passage 402, a long mandrel 405 whose upper end is threaded in the lower passage 403 of the head and a hold down body 407 have a passage 408 in which the lower end portion 409 of the tubular extension is slidably telescoped, a passage 410 through which the long mandrel extends and plungers 412 which are movable outwardly of the hold down body to engage the well casing and hold the hold down body against upward movement in the well casing. The packer also includes a short mandrel 414 whose upper end is threaded in the passage 408 of the hold down body. The packer also has packer elements 415, an extender 417, a slip carrier 418 with carrier slips 419 which are movable outwardly to expanded positions to engage the well casing when the expander moves downwardly relative thereto, a cylinder 420 and a piston 421 mounted in the cylinder, all of which have apertures through which the short and long mandrels extend. The cylinder and the slip carrier are provided with a latch or holding assembly 422 for releasably holding the slip carrier against downward movement relative to the cylinder and the cylinder has a latch assembly 423 which permits downward movement of the short mandrel relative to the cylinder which prevents its upward movement relative thereto.

The cross-over device 308 includes a cross-over head 430 and a pair of nipples 431 and 432. The nipple 431 constitutes the upper portion of the tubular dependent extension 404 of the packer head, its upper end being threaded in the lower end of the passage 402 of the packer head and its lower end being threaded on the upper end of the lower portion 409 of the extension which telescopes into the passage 408 of the hold down body and is provided with seal means 433 for sealing therebetween. The flow conductor 303 includes a portion 303a which extends downwardly from the surface and is provided at its lower end with a collet mandrel 435 which is telescoped into the top portion of the passage 402 of the packer head of the packer, an intermediate upper portion 303b which includes the passage 402 of the head and its dependent extension 404, a lower intermediate portion 303c which includes the passage 408 of the hold down body and the short mandrel 414 and a bottom portion 303b which is connected to the lower end of the short mandrel and which includes the landing nipples 336 and 337 and a bottom section 437 in which a seat ring 438 is releasably secured by means of shear pins 439.

The other nipple 432 of the cross-over device is connected in and constitutes the top section of the long mandrel 405 of the packer, the upper end of the nipple being threaded in the lower end of the passage 410 of the

packer head and its lower end being threaded in the upper end of the long mandrel of the bottom section 441.

It will now be apparent that the other flow conductor 304 of the well apparatus includes a top portion 304a which extends downwardly from the surface into the well and has a bottom mandrel 442 which is telescopic into the enlarged upper portion of the passage 403 of the packer head and is releasably secured to the head by means of the lugs 443 of the packer head and the J-slots 444 of the mandrel, a middle portion 304b which includes the packer head passage 403 and the long mandrel 414, and a bottom portion 304c which is connected to the bottom end of the long mandrel and includes the landing nipples 361 and 362.

Since the structure and mode of operation of the packer are fully described and illustrated in the patent to Carter R. Young, No. 3,288,218, only such details of the structure and mode of operation of the packer will be described herein as are necessary for the full understanding of the operation of the well apparatus 300 and of the cross-over device 308 which is connected in the well packer.

The nipples 431 and 432 extend through vertical parallel bores 451 and 452, respectively, of the cross-over head 430 and have lateral ports 453 and 454 which open to the upper passages 455 and 456, respectively, of the cross-over head. The cross-over head also has vertical ports 458 and 459 which open at their upper ends to the passages 455 and 456, respectively, and at their lower ends to a main passage 460 of the head. The ports 458 and 459 are closable by valves 462 and 463, respectively. The head 430 has internal annular recesses in its bore 451 in which are disposed O-rings 466, 467 and 468, respectively, the O-rings 466 and 467 sealing between the nipple 431 and the head above and below the nipple port 453 and the upper head passage 455, and the O-rings 467 and 468 sealing between the nipple and the head above and below the main passage 460. The head also has internal annular recesses in its bore 452 in which are disposed O-rings 471, 472 and 473, the O-rings 471 and 472 sealing between the nipple and the head above and below the nipple port 454 and the upper head passage 456 and the O-rings 472 and 473 sealing between the nipple and the head above and below its main passage 460.

The valve 462 has an annular seal 475 held in an external annular recess of the valve by a split retainer ring 476, the seal engaging a seal ring 477 soldered or otherwise suitably secured to the head and about the port 458 to close the port when the valve is in its upper closed position. The valve is biased upwardly toward its closed position by a spring 478 whose upper portion extends into the downwardly opening bore 479 in the lower end of the stem 480 of the valve and whose lower portion is received in the upwardly opening portion of enlarged diameter of the passage 481 of a spring retainer 482 which extends into the longitudinal passage 484 of a tubular seal retainer body 485a. The spring retainer is secured to the seal body by a pin 487 which extends through a suitable aperture in the retainer body and an external recess 489 of the spring retainer which provides a downwardly facing shoulder 490 engaged by the pin to limit downward movement of the spring retainer in the seal body. The upper end of the spring, of course, engages the surface of the valve stem defining the upper end of the bore 479 and the bottom end of the spring engages the upwardly facing stop shoulder 494 of the spring retainer.

The seal retainer body is threaded in the lower enlarged portion of a vertical passage 497 of the head which opens at its upper end to the main passage 460 and has a reduced upper end portion 498 which limits downward movement of a seal or O-ring 499. The O-ring seals between the head and a tubular seal sleeve 501 whose lower portion is telescoped in the upper enlarged portion of the longitudinal passage of the seal retainer body.

Upward movement of the O-ring and of a seal assembly 502 disposed in the seal sleeve is limited by a ring 503 whose lower end portion is telescoped over the seal sleeve and whose top internal annular flange extends over the upper ends of the seal sleeve and the seal assembly. Upward movement of the ring is limited by the downwardly facing annular shoulder 504 of the head. Downward movement of the seal assembly in the seal sleeve is limited by the upwardly facing annular shoulder of a bottom internal annular flange 505 of the seal sleeve. The seal assembly 502 seals between the seal sleeve and the stem of the valve. A lower seal assembly 508 also seals between the stem and the seal retainer body. Downward movement of the lower seal assembly is limited by the upwardly facing annular shoulder 509 of the seal retainer body and its upward movement is limited by the bottom end surface of the seal sleeve.

It will be apparent that the pressure from exteriorly of the head above the upper packer 306 is communicated to the valve stem and exerts an upward force over the area of the stem within the line of sealing engagement of the seal assembly 508 with the stem so that the valve 462 is biased upwardly not only by the force of its spring 478 but also by the well casing pressure about the upper packer as will be explained below.

The valve 463 which closes the port 459 when its seal 473a is in sealing engagement with the seat ring 477a of the head and its mounting means which extend into the bore 510 of the head being identical in structure with the valve 462, the valve 463 and the elements of its mounting means have been provided with the same reference numerals to which the subscript *a* has been added, as the corresponding elements of the valve 462 and its mounting means.

It will be apparent that the valve 463 like the valve 462 is biased upwardly toward its upper closed position by the fluid pressure in the well casing above the sealing elements 415 of the packer.

The cross-over assembly or device 308 is held against upward movement on the mandrels by a flat key 512 which extends through aligned recesses 514 and 515 of the nipples located below the cross-over head. Opposite end portions are disposed in the upwardly opening recesses 516 of a plate 517 through whose apertures 518 and 519 extend the nipples. The plate is held against downward movement relative to the head by the upwardly facing shoulders 521 and 521a of the seal retainer bodies 485 and 485a which are engageable with the bottom surface of the plate about the apertures 522 and 523 of the plate through which extend upwardly the seal retainer bodies. Downward movement of the cross-over device on the nipples is limited by the engagement of the downwardly facing shoulders 525 and 526 of the head at the lower ends of its bores 451 and 452 with the upwardly facing annular shoulders 527 and 528 of the nipples 431 and 432, respectively, that the landing ripples are held against both longitudinal and rotational movement relative to the head in positions wherein their ports 453 and 454 are in proper alignment and communication with the passages 455 and 456 of the head.

The nipple 431 is provided with a top lock recess 431, a top seal surface 532 below the top lock recess and above the port 453, an upwardly facing stop shoulder 533, a bottom lock recess 534 and a bottom seal surface 535 below the port. Similarly, the other nipple has a top lock recess 536, a top seal surface 537, a stop shoulder 538, a bottom lock recess 539 and a bottom seal surface 540.

The well apparatus 300 may be installed in the well casing in the same manner as the well apparatus illustrated in the patent to Carter R. Young, No. 3,288,218, by first setting the bottom packer 305 in the well casing between the two producing formations and then moving the assembly of the well packer with the portions 303b, 303d and 303c of the flow conductor 303 and the full

length of the flow conductor 304 connected by means of the top portion 304a of the flow conductor 304 whose lower end is secured in the passage 403 of the head. This assembly is lowered into the well until the bottom portion 304c of the flow conductor 304 engages the lower packer and extends therethrough to open to the well casing below the lower packer. The upper portions 303a of the flow conductor 303 is then lowered into the well until its lower end telescopes into the passage 402 of the packer head 400 and is releasably secured thereto by means of its collet mandrel. The flow control assemblies 315 and 325 may then be connected to the flow conductors 303 and 304, respectively.

If desired, at least some of the fluids in the well casing, such as drilling mud, above the lower packer 305 may then be circulated out of the casing and replaced by other fluids such as weighted mud having different characteristics, e.g., specific gravity, than the drilling mud, by pumping such fluids into the flow conductor 303 at the surface while permitting flow from the well casing through the flow conduit 312.

The valve 462 of the cross-over device will not open during such operation since the pressure in the passage 456 will be substantially equal to the pressure in the well casing and, therefore, before the stem of the valve 462 and the spring 478a exerts a sufficient force on the valve to maintain it in closed position even through the fluid pressure is exerted over a longer upwardly facing area in the port 459 than over the downwardly facing area of the stem in the body 485a.

When it is desired to set the upper packer 306, a ball 570 is dropped into the flow conductor 303 at the surface by means of the surface control assembly 315 in the usual manner by first closing the valves 316 and 321 and opening the valve 318 to permit the ball to be dropped into the manifold 317 and then closing the valve 318 and opening the valve 316. The ball then drops by gravity through the first flow conductor 303 or may be pumped downwardly therethrough by connecting the flow conduit 319 to a source of fluid under pressure and opening the shut off valve 321. When the ball seats upon the seal ring 438 as illustrated in FIGURE 13-B it closes the bottom end of the flow conductor 303. The pressure in the flow conductor 303 is then increased as by connecting the flow conduit 319 to a source of fluid under pressure and setting the pressure regulator valve 320 to insure that the pressure in the flow conductor will be raised to a value sufficiently high to cause setting of the packer but not so high as to cause the shear pin 439 to shear. Such fluid pressure is then communicated through the ports 572 of the short mandrel to a chamber 573 provided by the cylinder 420 and the force of this pressure exerted on the piston 421 moves the short mandrel and the hold down body 407 downwardly relative to the long mandrel 405, the packer elements 415, the expander 417, the slip carrier 418 and the slips 419 until the teeth of the slips engage the well casing C and arrest further downward movement of the expander. Further downward movement of the hold down body and the short mandrel relative to the now stationary expander 417 causes the resilient packer elements to be compressed and expanded into sealing engagement with the well casing.

As the pressure in the short mandrel is increased the valve 462 may be moved to its lower open position but the cross-over passage P of the cross-over device will remain closed since the valve 463 will remain in its closed position since the pressure in the main passage 460 of the cross-over head exerts a net upward force on the valve, the area of the valve within the line of sealing engagement of its O-ring 475a with the seal ring 477a being greater than the area of the stem 488a within the line of sealing engagement of the packing assembly 502a with the stem.

When the packer elements are in their expanded sealing position, the pressure in the well casing below the

packer elements is communicated by a suitable passage means of the packer to the internal surfaces of the locking plungers 412 of the hold down head and moves them outwardly to cause their upwardly facing teeth to engage the well casing and hold the hold down body against upward movement therein. The fluid pressure in the flow conductor is then increased until the shear pin 439 fails and the seat ring and the ball are forced out of the bottom end of the bottom section 437 of the flow conductor 303 thus opening the lower end of the flow conductor to the well casing between the two packers. The lock assembly 423 now prevents upward movement of the cylinder relative to the short mandrel and the latch assembly 422 prevents downward movement of the slip carrier.

Well tools may now be installed by means of usual wireline tools and a suitable running tool to which the lock mandrels L may be secured and which hold their dogs in their retracted positions until such lock mandrel enters into its preselected landing nipple having selector key recesses 340 of the same configuration and dimensions as its selector keys 342 whereupon the downward movement of such latch mandrel is arrested and the dogs are then moved into their expanded positions in the lock recess 341 of the such nipple by downward jars imparted to running tool which also release the running tool from the lock mandrel. The tools may also be installed in the landing nipples by the use of a pump down train of tools 370 by connecting such running tool to the bottom end of the train of tools, the well tool, of course, being connected by its lock mandrel to such running tool. If the well tool is to be installed in a landing nipple of such train of tools is inserted into the manifold 317 while the valves 321 and 316 are closed and the valve 318 is open. The valve 318 is then closed, the flow conduits 319 and 329 are connected to a suitable source of high pressure and the pressure in both flow conductors is then increased to a value sufficiently great that both valves 462 and 463 of the cross-over device are moved to their open position. The pressure regulator valve 330 of the flow conduit 329 is set to permit flow therethrough only as long as the pressure within the flow conductor 304 exceeds the value necessary to maintain the valve 463 in its open position. The valves of the cross-over device are thus in their open positions as the fluid is now pumped downwardly into the upper end of the flow conductor 303 and the train of tools is moved downwardly, the fluid below its bottom piston unit or locomotive 372 flows into the second flow conductor and then upwardly through the flow conductor 304 to permit the downward movement of the train of tools in the flow conductor 303.

When the lock mandrel of such well tool moves into its appropriate landing nipple in which it is to be locked, the downward force exerted by the pump down train of tools causes its dogs to be moved outwardly into the lock recess of its landing nipple and the running tool to be released from the lock mandrel. The bottom locomotive is spaced a distance sufficiently great above such running tool that when the lock mandrel is positioned in its selected landing nipple, the bottom locomotive is above the port 453 of the nipple 431. The direction of circulation of the fluids is then reversed, the pressure regulator valve 320 is set to permit flow therethrough only as long as the pressure in the first flow conductor 303 exceeds the value thereof necessary to keep the valves of the cross-over device in their open positions and as fluid is introduced into the top end of the flow conductor 304 through its surface control assembly 325, the fluid will flow downwardly in the flow conductor 304 through the cross-over device and upwardly below the bottom locomotive of the train of tools to move the train of tools with the running tool secured thereto upwardly through the flow conductor 303 and to the surface.

The standing valves 346 and 363 are thus installed in the bottom landing nipples of the two flow conductors and will thereafter prevent downward flow through the flow

conductors therepast and into the well casing and subsequently other well tools such as the safety valve may be installed in other higher landing nipples of the flow conductors.

The pressure in the well casing above the upper packer 306 at the location of the cross-over device is in usual practice maintained at a value higher than the shut-in pressure of the producing flow formations in the flow conductors, as by filling the casing above the upper packer with a liquid, such as water or a weighted mud. The conduit 312 of the casing head may, of course, also be connected to a source of fluid under pressure to maintain the pressure in the well casing at a desired value above a predetermined value from falling below the desired value. The cross-over valves 462 and 463 are, therefore, biased upwardly towards their closed positions not only by the force of the springs 478 and 478a but also by the well casing pressure exerted on the downwardly facing areas of their stems 480 and 480a within the lines of sealing engagement of the lower packing seal assemblies 508 and 508a therewith which exerts a much greater upward force thereon than the downward force exerted on the valves by the pressures in the flow conductors to which they are exposed.

If it is thereafter desired to circulate fluids down one flow conductor and up the other flow conductor, the pressures in both of the flow conductors must be increased to such value higher than the casing pressure at the location of the cross-over device, that its force exerted on the upwardly facing areas of the valves 462 and 463, within the lines of sealing engagement of their seals 475 and 475a with their respective seat rings 477 and 477a, exceeds the upward force exerted on the valves by their springs, the well casing pressure and any net upward force exerted on the springs by any fluid pressure which is trapped within the main passage 460 of the cross-over head. Such increase in the fluid pressure may be accomplished by connecting the flow conduits simultaneously to a common source of fluid under pressure, then setting the pressure regulator of one of the flow conduits, for example, the pressure regulator 330 to permit fluid flow therethrough only when the pressure in the flow conductor 304 is above such value necessary to hold the two valves in their open positions, then disconnecting the conduit 329 from such common source and connecting it to a disposal line for the fluid to be circulated from the flow conductor 304 and connecting the conduit 319 to the source of the desired fluid which is to be circulated at such high pressure downwardly into the flow conductor 303. Such circulation of fluids may, of course, be employed to move well tools into, or remove well tools from, one or the other of the flow conductors, or to treat the internal surfaces of the flow conductors with desired fluids or to dissolve and remove deposits therefrom. Each of the valves may be tested separately by introducing a test fluid pressure into the flow conductor to which such valve is exposed when in its closed position. For example, the valve 462 may be tested by closing the shut off valve 321 of the flow conduit 319 and connecting the flow conduit 329 to the source of the test fluid pressure. As the pressure in the flow conductor 304 is increased, the standing valve 363 closes and subsequently the valve 463 moves downwardly and permits fluid communication between the second flow conductor and the main passage 460. If the valve 462 is not functioning properly, the pressure gauge 580 connected to the flow conduit 319 between its shut off valve 321 and the manifold 317 will indicate a rise in the pressure in the flow conduit above the normal shut in pressure of the formation A in the flow conductor 303.

The other valve 463 may be tested by reversing this procedure, that is, by closing the shut off valve 331 of the flow conduit 329 and connecting the flow conduit 319 to the source of test fluid pressure. If the valve 463 is now not functioning properly, the pressure gauge 581 connected to the flow conduit 329 between the shut off valve

and the manifold 327 will indicate a rise in pressure in the first flow conductor above the normal shut in pressure thereof.

It will also be apparent that the well tools installed in the landing nipples of the two flow conductors may also be tested. For example, if it is desired to test the standing valve 363, the test fluid pressure is introduced through the flow conduit 329 to establish a pressure in the second flow conductor greater than the shut in pressure in either of the two flow conductors. As the pressure in the flow conductor 304 thus increases, the standing valve 363 will close and the valve 463 will move to its open position. The shut off valve 329 is closed and if the pressure gauge 581 shows a drop in the test pressure while the gauge 580 has no increase in pressure, it will be apparent that the standing valve 363 is defective.

It will further be seen that a new and improved method of operating a well penetrating a plurality of spaced fluid producing earth formations has been illustrated and described which includes positioning in the well a pair of flow conductors and a cross-over means connected to the flow conductors operable in response to pressure changes in the flow conductors; isolating the producing earth formations in the well by closing the well between the formations, as by packers or by cement; increasing the pressure in both of the flow conductors to operate the cross-over means and establish communication between the flow conductors; and then circulating fluids from the surface down one of the flow conductors through the cross-over means and upwardly through the other of the flow conductors.

The method may also include the step of treating of the flow conductors with treating fluids such as corrosion inhibiting or deposit dissolving and removing liquids by such circulation or the step of moving a tool transport means, such as a pump down train of tools, through one or the other of the flow conductors to install or remove other well devices, such as safety and standing valves, in landing means of one or the other of the flow conductors and then reversing the circulation of the fluids to move the transport means and any tools carried thereby upwardly in the flow conductor for removal therefrom at the surface.

The method may also include the step of closing the flow conductors between the cross-over means and the locations of their communication with the producing earth formations during such circulation of fluids through the flow conductors to prevent flow of such fluids into the producing formations or the imposition of excessive pressures on the producing formations.

The method of operating the well may also include the additional step of testing the cross-over device by closing one of the flow conductors at the surface and then increasing the pressure at the surface in the other flow conductor to open one of the two valves of the flow conductor of the cross-over device and then determining at the surface if the pressure in the first flow conductor increases which can occur only if the other closed valve is not functioning properly, and then testing the first valve by closing the second flow conductor and increasing the pressure in the first flow conductor and determining at the surface if the pressure in the second flow conductor rises.

It will be seen that the method may also include the step of cleaning the valves and the seat rings by repeatedly reversing the circulation of flow to the cross-over device in order to dislodge any dirt or scale particles which may be adhering to either the valves or the seat rings if the testing of the valves indicates that one or the other is not functioning properly.

It will further be seen that the well apparatus provides for great flexibility of operation since the circulation of fluids or the movement of a tool train may be started, stopped, or reversed, as desired, once the bypass passage of the cross-over device has been opened, such operations merely requiring the maintenance of a minimum predetermined pressure at the valve.

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 well apparatus including: a pair of flow conductors extending through a well and having longitudinal passages; control means below the surface of the well providing a cross-over passage between the passages of said flow conductors; and valve means carried by said control means for closing said passage, said valve means being responsive to fluid pressures in said passages of said conductors and being movable to open position to establish fluid communication between the longitudinal passages of said pair of flow conductors when the pressures in the longitudinal passages of both of said flow conductors are increased above a predetermined value.

2. The well apparatus of claim 1, and means operatively associated with said valve means for biasing said valve means to closed position.

3. The well apparatus of claim 2, wherein said biasing means includes means exposed to the pressure from exteriorly of said control means whereby the pressure exteriorly of the control means exerts a force tending to hold said valve means in closed position.

4. The well apparatus of claim 3, wherein said biasing means is exposed to the pressure in the well exteriorly of said control means.

5. The well apparatus of claim 4, and means operable at the surface of the well for varying the fluid pressures in said flow conductors.

6. The well apparatus of claim 5, wherein said well penetrates a plurality of spaced producing earth formations and said apparatus includes barrier means closing the well between adjacent producing formations, said flow conductors having means for establishing communication between their longitudinal passages and the producing formations.

7. The well apparatus of claim 6, wherein said biasing means is exposed to pressure in the well above the uppermost of said barrier means.

8. The well apparatus of claim 5, wherein said well apparatus includes a flow control device in one of said flow conductors below said cross-over passage of said control means for preventing downward flow through said one of said flow conductors and permitting upward flow from the well therethrough.

9. The well apparatus of claim 8, wherein said control means has means providing fluid communication between said valve means and said one of said flow conductors below said flow control device for causing the pressure in said one flow conductor below said flow control device to bias said valve means toward closed position.

10. The well apparatus of claim 9, wherein at least one of said flow conductors is provided with means for releasably securing well tools in said one of said flow conductors below said passage of said control means whereby well tools may be installed in and removed from said one of said flow conductors by transport means movable by fluid circulated in the flow conductors when said valve means is in open position.

11. The well apparatus of claim 10, wherein said flow conductors and said control means are cemented in the well bore of the well.

12. The well apparatus of claim 1, wherein said control means comprises a body having a pair of bores, said flow conductors extending through said bores and having ports, said body having a pair of passages communicating with the ports of said flow conductors, a main passage and ports for providing communication between said passages and said main passage, said flow conductor ports, and said pair of passages, said ports and said main passage of said body comprising said cross-over passage, said valve means

comprising a pair of valves in said body for closing said ports whereby fluid flow from one conductor to the other through said cross-over passage can take place only when when both of said valves are in open positions.

13. The well apparatus of claim 12, wherein said each of said valves has means exposed to the pressure in said main passage when said valve is in closed position for causing the pressure in said main passage to bias toward closed position each of said valves when it is in its closed position.

14. The well apparatus of claim 13, wherein each of said valves when in its closed position is biased towards open position by the fluid pressure communicated from one of the flow conductors to the port of said body which it closes.

15. The well apparatus of claim 14, and means biasing each of said valves toward closed position.

16. The well apparatus of claim 15, wherein said flow conductors are adapted to produce well fluids from different spaced producing earth formations penetrated by the well and wherein said well apparatus includes barrier means below said control means for closing the well between producing earth formations.

17. The well apparatus of claim 16, wherein each of said valves has means exposed and responsive to fluid pressure exteriorly of said body and said flow conductors for biasing said valves toward closed position.

18. The well apparatus of claim 14, wherein said valves have means exposed to pressure exteriorly of said body for causing pressure exteriorly of said body to bias said valves toward closed position.

19. The well apparatus of claim 18, wherein said well apparatus includes locating means for locating and locking a flow control device in one of said flow conductors below said cross-over passage for preventing downward flow through said one of said flow conductors and permitting upward flow therethrough.

20. The well apparatus of claim 19, wherein said control means includes means providing fluid communication between said body and said one of said flow conductors below said locating means for causing the pressure in said one flow conductor below said locating means to be communicated to said valves to bias said valves toward closed positions.

21. The well apparatus of claim 20, and means operable at the surface of the well for varying the fluid pressures in said flow conductors to control operation of said valves of said control means.

22. A cross-over device including: a body having a pair of bores; a pair of flow conductors extending through said bores and each having a lateral port; cooperable means connecting said body to said flow conductors, said body having a cross-over passage for providing communication between said ports of said flow conductors; valve means in said body movable between open position wherein said cross-over passage provides communication between the flow conductors and closed position wherein said valve means closes said cross-over passage, said valve means exposed and responsive to pressure in both of said flow conductors when said valve means is in closed position, said valve means opening to provide communication between said flow conductors only when the pressure in both of said flow conductors at said ports thereof is increased above a predetermined value.

23. The cross-over device of claim 22, and means biasing said valve means toward closed position.

24. The cross-over device of claim 22, wherein said valve means has means exposed and responsive to fluid pressure exteriorly of said body for causing said valve means to be biased toward closed position by fluid pressure from exteriorly of said body.

25. The cross-over device of claim 24, and means for communicating fluid pressure from exteriorly of said body to said means responsive to fluid pressure.

26. The cross-over device of claim 25, wherein said means for communicating fluid pressure includes means providing fluid communication between said body and one of said flow conductors at a location spaced from said body for causing said valve means to be biased towards closed position by fluid pressure in said one of said flow conductors at said location.

27. The cross-over device of claim 26, wherein said valve means comprises a pair of valves when in closed position exposed to the fluid pressure at said lateral ports of said flow conductor, each of said valves independently closing said cross-over passage when in closed position, said valves being exposed when in closed position to fluid pressures from different ones of said flow conductors through said lateral ports thereof.

28. The cross-over device of claim 27, wherein each of said valves when its closed position is biased towards closed position by fluid pressure admitted to said cross-over passage by the other valve when the other valve is in its open position.

29. The cross-over device of claim 22, wherein said body has a pair of passages opening to said lateral ports of said flow conductors, a main passage and a pair of ports each opening to said main passage and one of said pair of passages, said flow conductor ports and said passages, ports and main passage of said body comprising said cross-over passage; said valve means comprising a pair of independently operable valves for closing said ports of said body.

30. The cross-over device of claim 29, and means biasing each of said valves toward closed position.

31. The cross-over device of claim 30, wherein each of said valves has means exposed and responsive to the pressure in said main passage for causing each of said valves when in its closed position to be biased toward closed position by fluid pressure in said main passage.

32. The cross-over device of claim 31, wherein each of said valves has means exposed and responsive to fluid pressure exteriorly of said body for causing said valves to be biased toward closed position by fluid pressure from exteriorly of said body.

33. The cross-over device of claim 32, and means for conducting fluid pressure from one of said flow conductors at a location spaced from said body to said fluid responsive means of said valves.

34. The cross-over device of claim 33, wherein at least one of said flow conductors is provided with tool locating and lock means and with seal surfaces above and below its lateral port whereby a well tool may be positioned in said one of said flow conductors by said locating and locking means to close said lateral port by seal means of the well tool engageable with said seal surfaces.

35. A method of operating a well penetrating two spaced fluid producing earth formations, said method including: moving two flow conductors in the well to position wherein each may be placed in communication with one of the two producing formations and a cross-over means connected to the flow conductors to position above the top producing formations in the well from one another; increasing the pressures in both of the flow conductors to above a predetermined value to open said

cross-over means and establish communication between said flow conductors in the well above the location of communication of the flow conductors with the producing earth formations; and circulating fluids down one of said flow conductors through said cross-over means and upwardly through the other of said flow conductors while maintaining said increased pressures in said flow conductors.

36. The method of claim 35, and moving tool transport means downwardly through one of said flow conductors to a desired position therein by the said circulation of fluids and then reversing said circulation of fluids to move said tool transport means upwardly in said one of said pair of flow conductors for removal therefrom at the surface.

37. The method of claim 36, wherein said method includes the step of closing said flow conductors between said cross-over means and the locations of the communication of the flow conductors with producing flow formations during said circulation of fluids.

38. The method of claim 35, and wherein said cross-over means has a pair of independently operable valves one responsive to pressure change in one of the flow conductors and the other responsive to pressure in the other of said flow conductors, and the step of testing the cross-over means by means operable at the surface of the well by increasing the pressure in one of said flow conductors while the other of said flow conductors is closed below the cross-over means to open one of the valves and determining at the surface if fluid flow is taking place from said one of said flow conductors into the other of said flow conductors and then increasing the pressure in the other of said flow conductors while said one of said flow conductors is closed below the cross-over means to open the other of said valves and determining at the surface if fluid flow is taking place from said other of said flow conductors into said one of said flow conductors.

39. The method of claim 38, and the additional steps of opening both valves if one or the other valves either has been found to be effective and repeatedly reversing circulation through said flow conductor to said cross-over means to clean surfaces of said valve and the seat engaged thereby.

References Cited

UNITED STATES PATENTS

1,431,779	10/1922	Conrader	166—189 X
2,806,429	9/1957	Anderson et al.	
3,008,522	11/1961	Fredd et al.	166—115
3,086,592	4/1963	Hoch	166—224
3,302,721	2/1967	Yetman	166—224 X
3,322,192	5/1967	Woelfel et al.	166—224 X
3,333,639	8/1967	Page et al.	166—131 X
3,363,693	1/1968	Bohlmann.	

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