United States Patent

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[54] **METHOD AND APPARATUS FOR INSTALLING AND REMOVING GAS LIFT VALVES IN A WELL**
7 Claims, 19 Drawing Figs.

[52] **U.S. Cl.** **137/155, 137/613, 166/46**

[51] **Int. Cl.** **F04f 1/08**
[50] **Field of Search** 137/155, 613; 103/232, 233; 166/224, 3; 251/136

[56] **References Cited**
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Primary Examiner—Alan Cohan
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ABSTRACT: This patent discloses a system for landing tools such as gas lift valves in a well, and particularly by doing so utilizing hydraulic fluids. The patent also discloses equipment to carry out landing of tools hydraulically. These tools include mandrels, gas lift valves, control valves, motors, latching devices, and other structures.

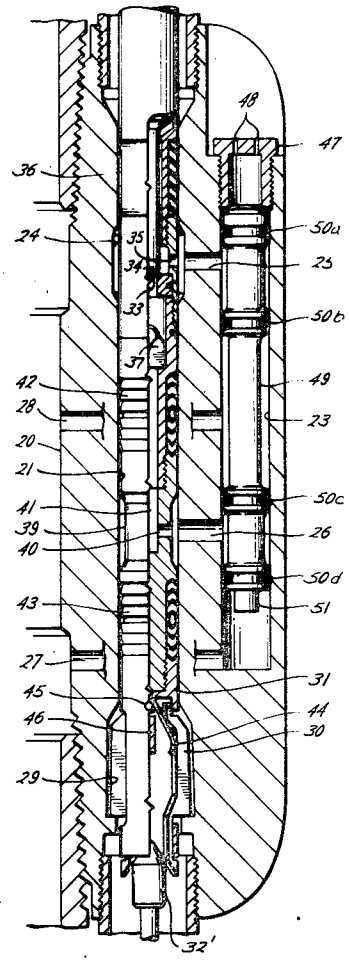


Fig. 1

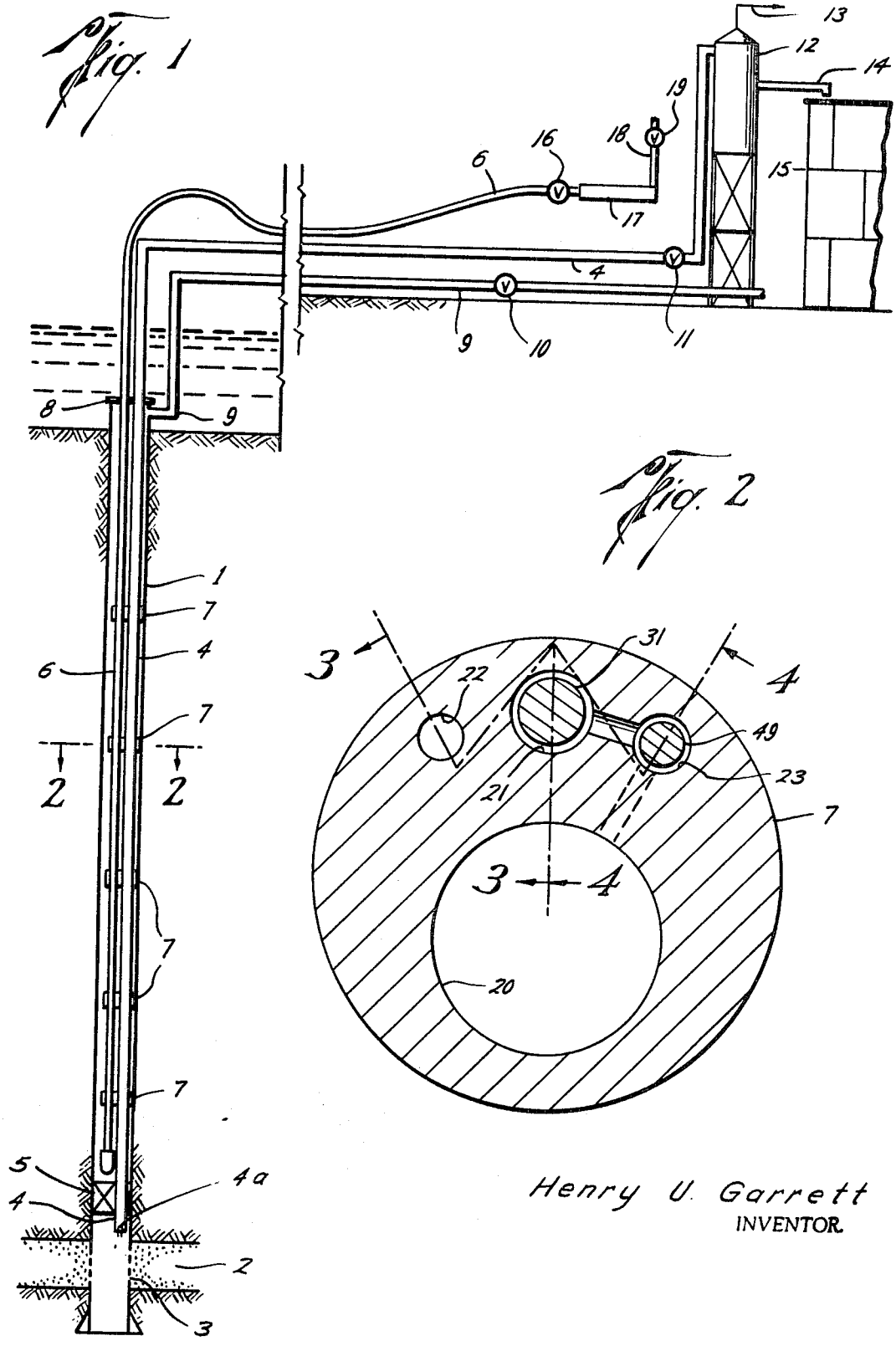


Fig. 2

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Fig. 3

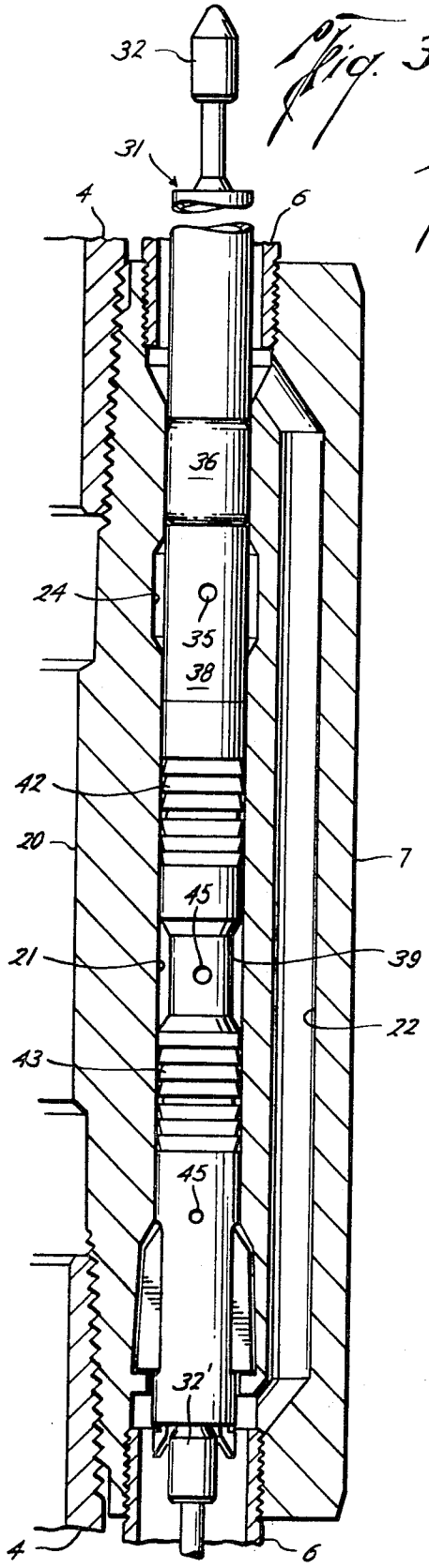
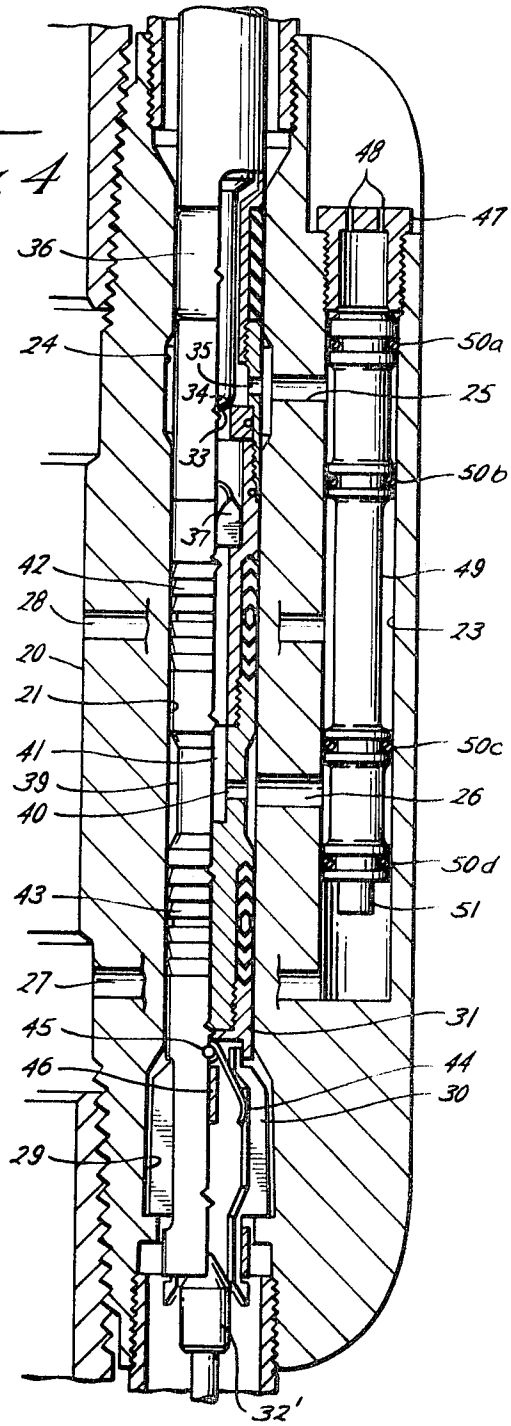


Fig. 4



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Fig. 6

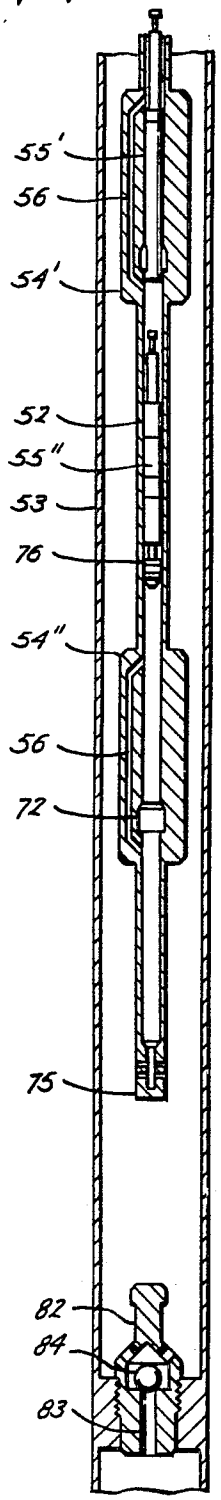


Fig. 7

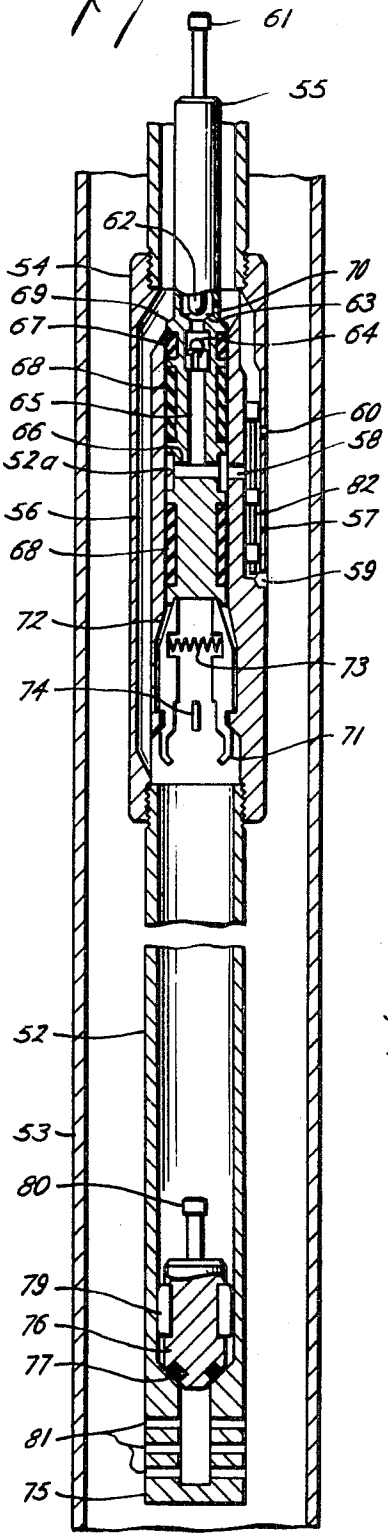
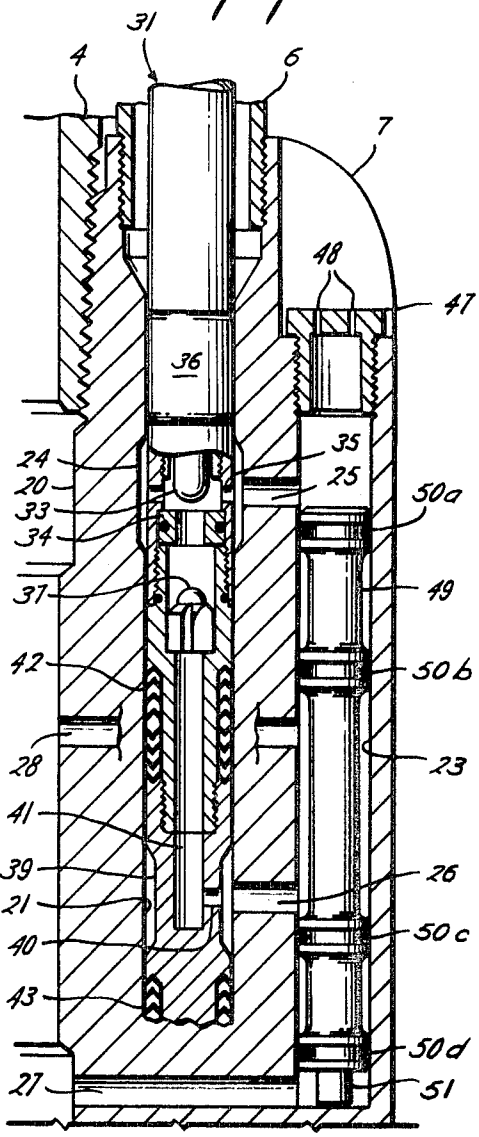


Fig. 5



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Fig. 8A

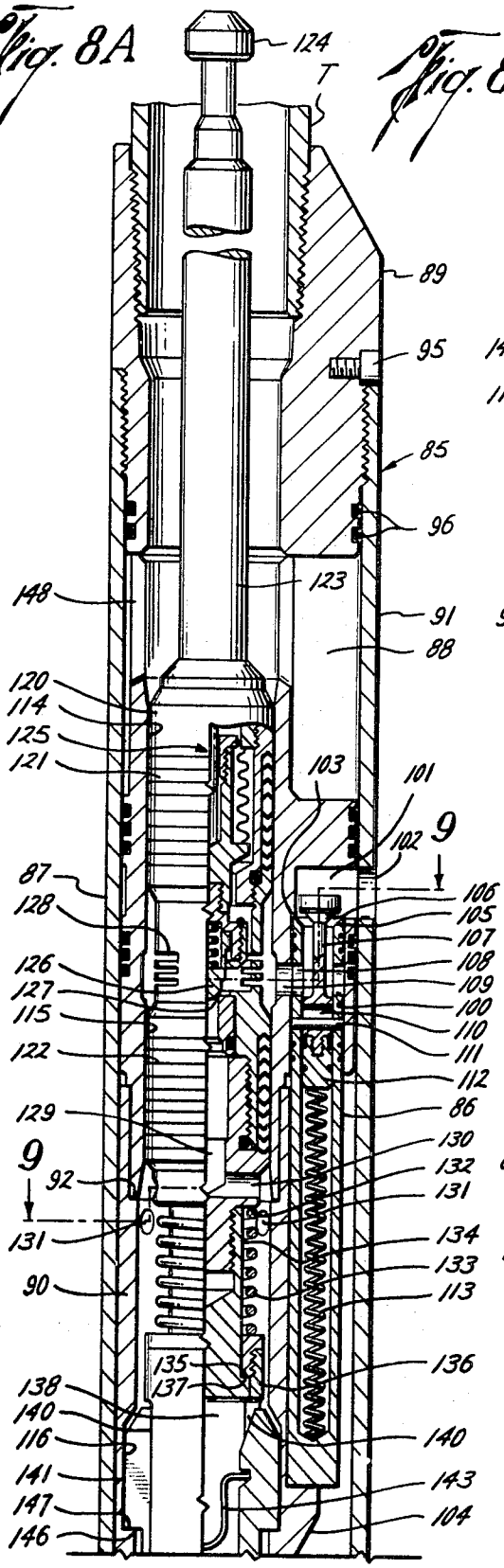


Fig. 8B

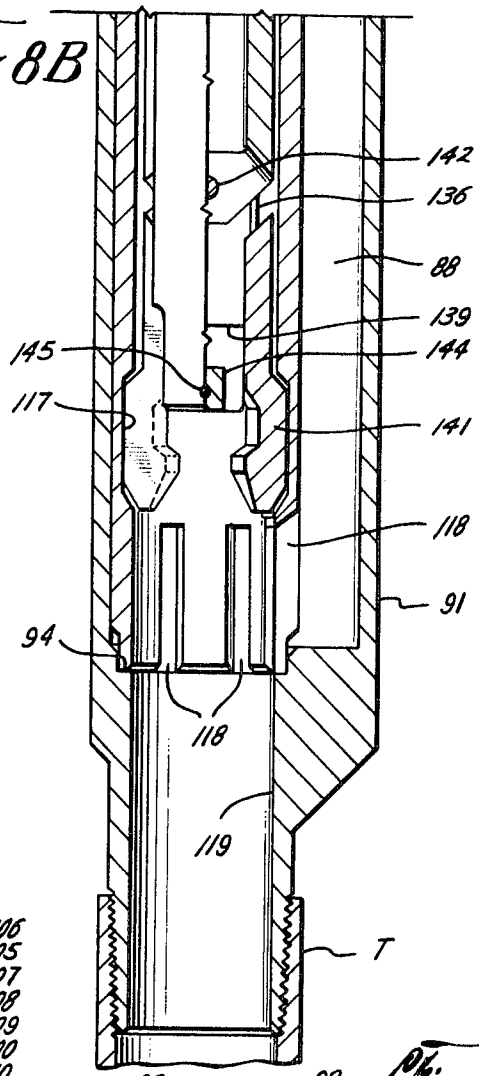
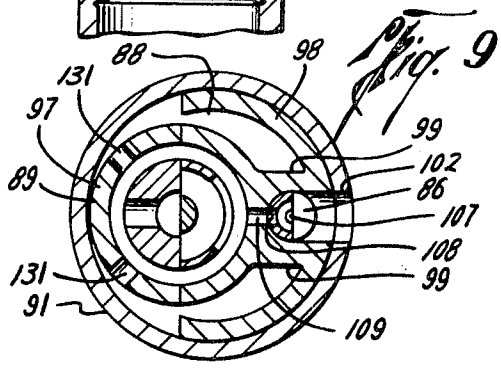


Fig. 9



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Fig. 10A

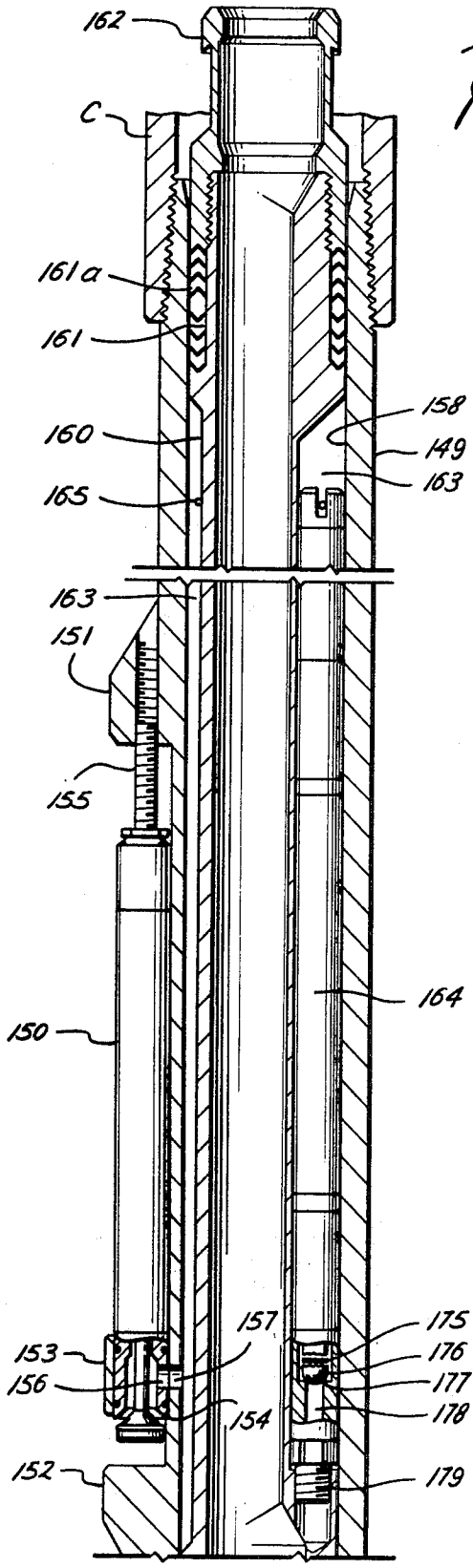
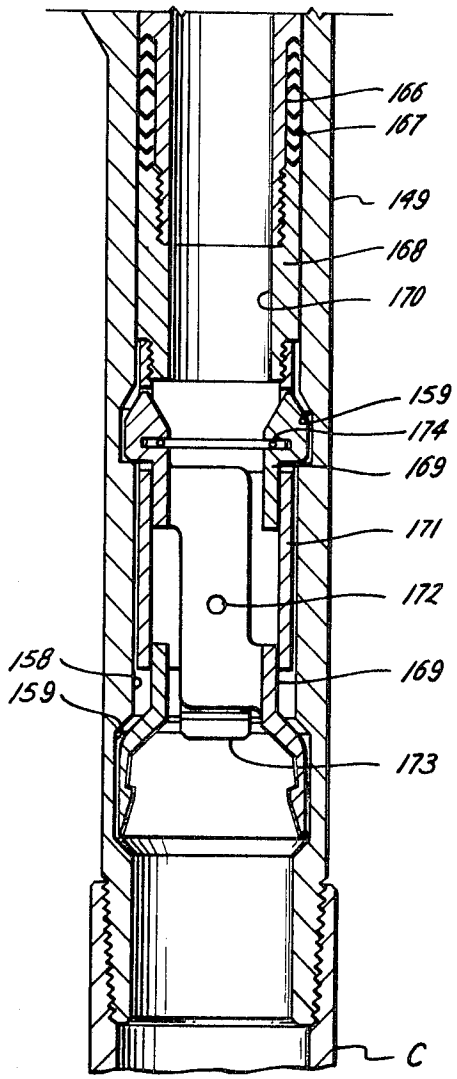


Fig. 10B



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Fig. 11

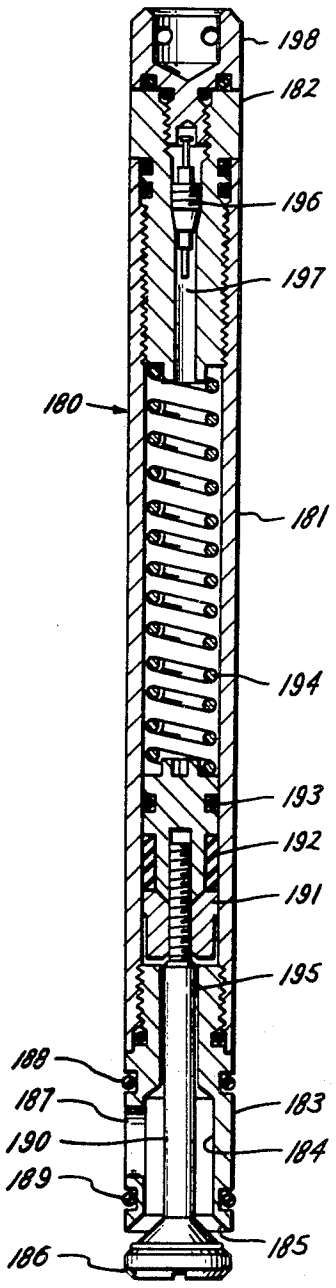


Fig. 12A

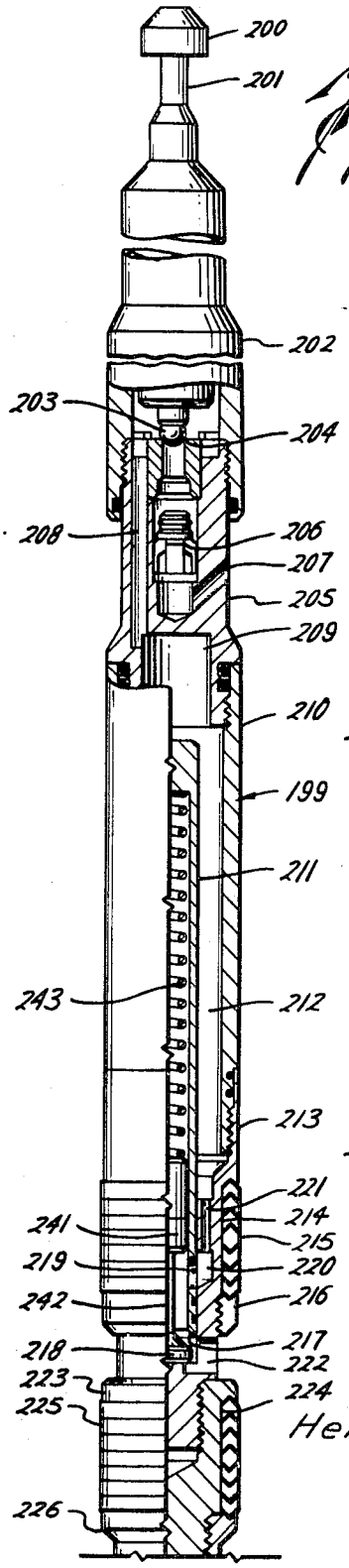
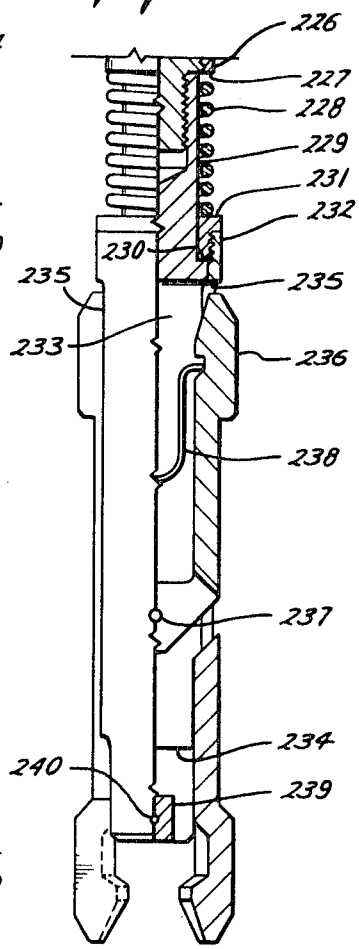


Fig. 12B



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Fig. 13A

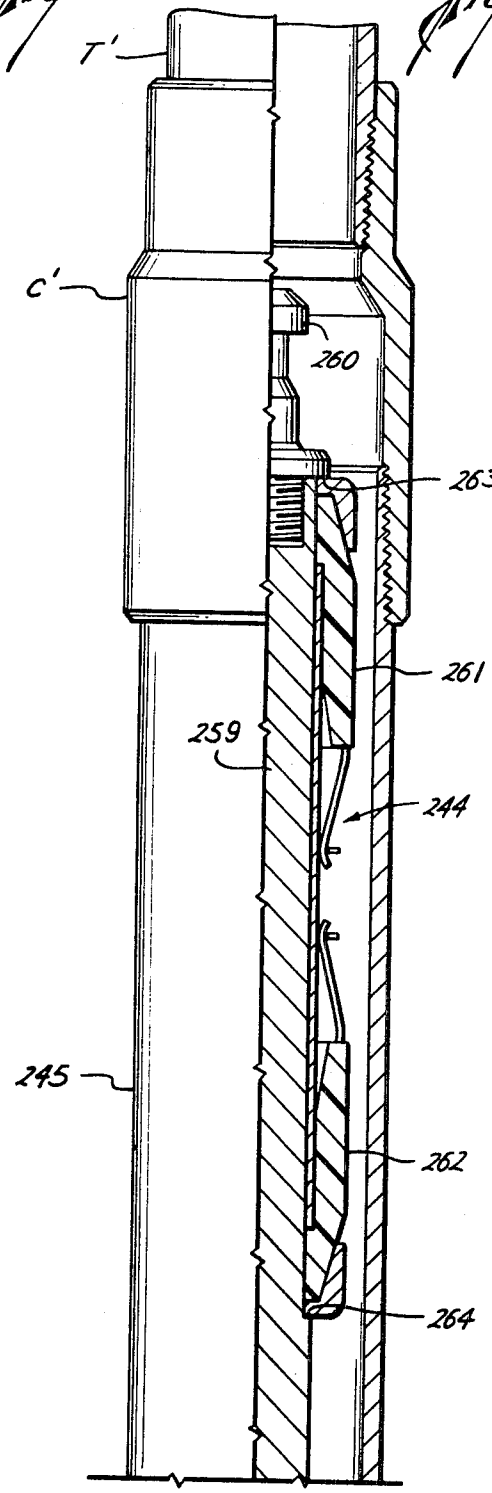
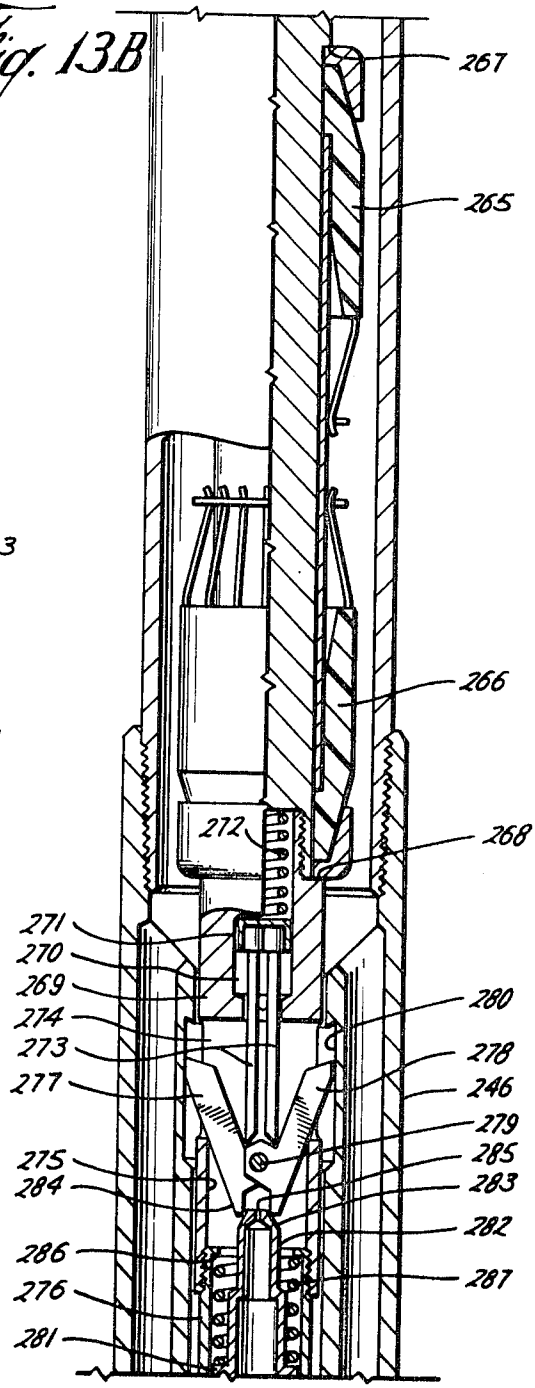


Fig. 13B



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Fig. 13C

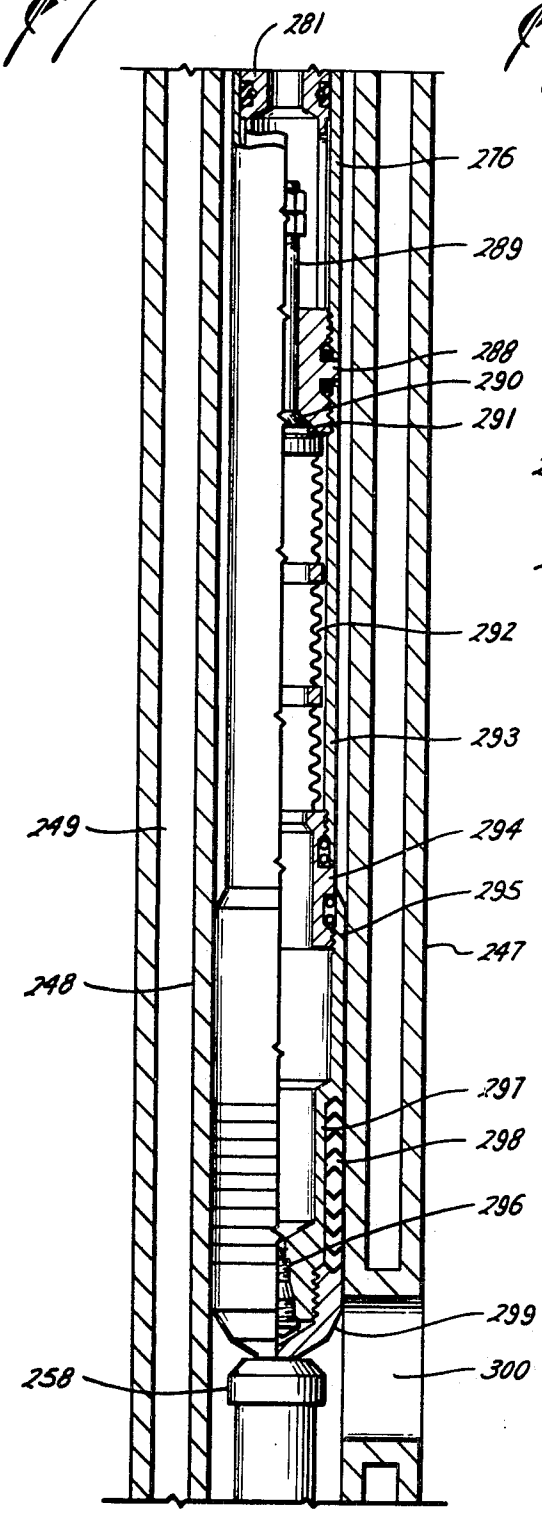
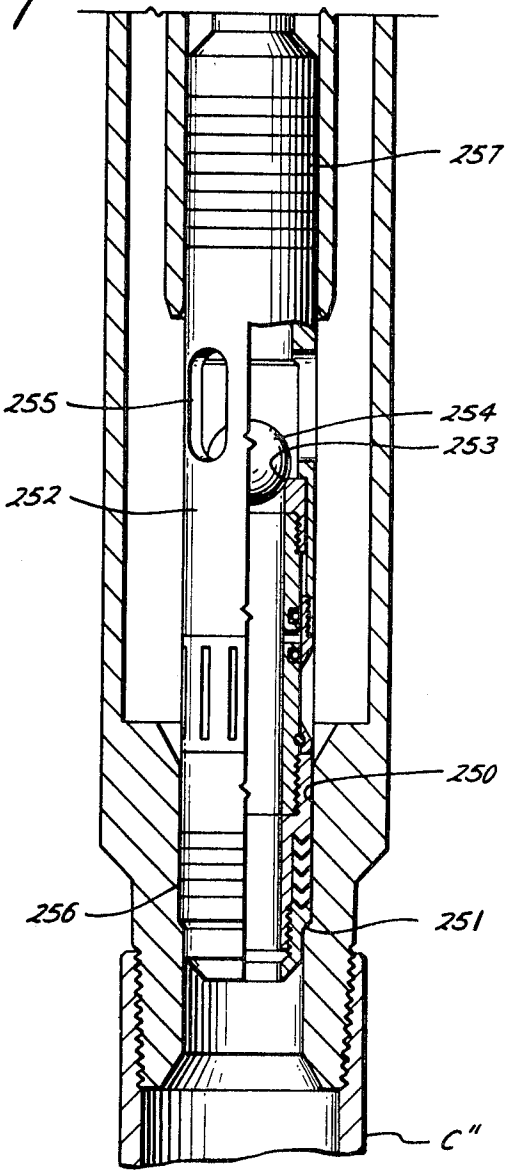


Fig. 13D



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METHOD AND APPARATUS FOR INSTALLING AND REMOVING GAS LIFT VALVES IN A WELL

This application is a division of my copending application Ser. No. 379,064 filed June 1, 1964, now U.S. Pat. No. 3,334,690 issued Aug. 6, 1967, which is a continuation-in-part of my earlier filed application Ser. No. 315,976 filed Oct. 14, 1963, now abandoned.

The present invention relates generally to a system and specific apparatus for the production of petroleum liquids. More particularly, the present invention relates to a system for installation and removal of valves from a producing well, to the tubing mandrels used in such system, to the combination valves and mandrels used in such systems and in another aspect of the invention to the valves and mandrels individually which are suitable for use in such system.

In general a well for the production of petroleum liquids will utilize a tubing string extending down into the production formation. Such tubing strings will often contain valves for gas lifting of the production fluids, chemical injection and other types of valves for controlling various conditions encountered in the completion of the wells and in the production of the petroleum liquids. These valves have been installed in special mandrels in the tubing string at the surface and lowered into position in the producing well with the tubing. Also, such valves have been individually lowered into position by a flexible line operation, commonly called wire line. Malfunction of such valves has required that the whole tubing string be pulled or that each valve be individually picked up by wire line to allow the defective valve or valves to be replaced or repaired. In many installations the pulling of the tubing string or a wire line removal of the valves because of the malfunction of one of the valves is extremely expensive and time consuming. Therefore, a system for ready installation and removal of such valves in the production tubing has long been needed.

The objects of the present invention are therefore as follows:

To provide an inexpensive system of installing and removing valves in a producing well which eliminates the expensive equipment and labor associated with wire line operation and with pulling and running a tubing string.

To provide a system of installing and removing valves in a producing well in which the producing well is an offshore completion having an onshore installation and surface equipment.

To provide a system of installing and removing valves in a slim hole type of producing well.

To provide a system of installing and removing valves in a producing well which requires only a lubricator, a pump and a reservoir of hydraulic fluid.

To provide a system for pumping valves into and from a position within the production tubing of a producing well.

To provide a system for pumping valves through a macaroni string into a producing well in a manner to land in mandrels and provide communication between the casing and tubing for gas lifting of production fluids from the well.

To provide a system for installing and removing valves in a producing well through a macaroni string by pumping and including provisions for closing the upper end of the macaroni string to trap the hydraulic fluid in the macaroni string whereby the valves are held in position and surrounded solely by the hydraulic fluid.

To provide a system for pumping a train of gas lift valves into and from a producing well as a train wherein each valve as it lands disengages from the train during installation and each valve engages and becomes part of the train as it is unseated during removal.

To provide a system for installing and removing gas lift valves in a producing well including means closing a communication from the production tubing to the macaroni string and the casing to prevent loading of the well during installation and removal of the gas lift valves.

To provide a system for installing and removing gas lift valves in a producing well including means closing communication from the interior of the production tubing to the exterior of the production tubing to prevent fluid bypassing portions of the tubing during the removal of the gas lift valves.

To provide a system of pumping gas lift valves into and from a producing well including means to meter the hydraulic fluid to indicate the position of the valves during pumping.

To provide a system for pumping gas lift valves into and from a producing well including a motor member which is powered to pump the valves from the well.

To provide a system of installing gas lift valves in a producing well in which the valves are pumped through a tubing string wherein when the upper valve is landed the pumping fluid is bypassed around the upper valve to permit the pumping of the remainder of the valves to their landed positions in sequence.

To provide a combination gas lift valve and mandrel for a producing well in which the mandrel has a bypass permitting a valve to be pumped to and landed in the mandrel and thereafter bypassing the pumping fluid to pump other valves to lower mandrels.

To provide a gas lift valve having a seal enabling the valve to be pumped through a tubing string into and from a producing well.

To provide gas lift valves having engaging means whereby the gas lift valves will form a train for pumping into and from a producing well.

To provide a mandrel for receiving gas lift valves and having a bypass around the gas lift valve when seated in the mandrel and a communication from the interior of the mandrel to the exterior of the mandrel with means opening and closing the communication.

To provide a combination gas lift valve and mandrel in a producing well in which the gas lift valves are pumped through the production tubing wherein when each valve is landed in a mandrel the production passageway through the mandrel is unobstructed to permit swabbing and fishing operations through such production passageway.

To provide a system for installing and removing gas lift valves in a producing well including a motor member and means retaining such motor member in a seated position during production operations.

To provide a system for installing and removing gas lift valves in a producing well including a motor member which moves said valves into and from tubing in said well responsive to pressures in said tubing.

To provide a pressure responsive valve adapted to be positioned in a mandrel to control the communication between the exterior and the interior of the mandrel.

To provide a combined gas lift valve and shutoff valve including a pressure responsive means for operating said shutoff valve.

To provide a novel latching means for a gas lift valve having an annular configuration with a central passageway therethrough.

To provide a novel latching means for a gas lift valve including a spring-loaded-latching sleeve holding said latching means in latching engagement in the valve seat within a tubing mandrel until said sleeve is moved out of engagement with said latching means.

These and other objects of the present invention will be readily understood from the following explanation and description of the details of the system which are illustrated in the accompanying drawings wherein:

FIG. 1 is a schematic drawing of a typical offshore installation of the present invention in a producing well.

FIG. 2 is a typical cross-sectional view of a producing well taken along lines 2—2 in FIG. 1.

FIG. 3 is a partial cross-sectional view taken along lines 3—3 in FIG. 2.

FIG. 4 is a partial cross-sectional view taken along lines 4—4 in FIG. 2.

FIG. 5 is a partial cross-sectional view similar to FIG. 4 but showing the spool valve in position for gas lift production.

FIG. 6 is a typical cross-sectional view of the installation of a combination mandrel and gas lift valve of the present invention within a tubing string and showing the upper gas lift valve seated within its mandrel and the remainder of the train of gas lift valves proceeding downward.

FIG. 7 is a typical cross-sectional view similar to FIG. 6 showing the gas lift valve in position for production.

FIG. 8A is a partial cross-sectional view of a mandrel with a gas lift valve seated therein and illustrating another form of combined mandrel, gas lift valve and valve closing the communication between the interior and exterior of the mandrel.

FIG. 8B is a continuation of the lower portion of FIG. 8A.

FIG. 9 is a cross-sectional view taken along line 9—9 in FIG. 8A.

FIG. 10A is a cross-sectional view of a mandrel with a gas lift valve positioned within the mandrel having a substantially unobstructed passageway through the center portion of the gas lift valve and an exteriorly mounted valve closing the communication between the interior and exterior of the mandrel.

FIG. 10B is a continuation of the lower portion of FIG. 10A.

FIG. 11 is a detailed sectional view of the valve illustrated in FIGS. 8 and 10 for closing the communication between the interior and exterior of the mandrel.

FIG. 12A is a partial detailed sectional view of a combined gas lift valve and valve means closing the passageway between the interior and exterior of the mandrel in which the valve is to be seated.

FIG. 12B is a continuation of the lower portion of FIG. 12A.

FIG. 13A, B, C, and D are partial sectional views of a motor member which may be used with the present invention and specifically illustrating the means restraining the motor member at the lower portion of the tubing in which the motor member is run.

FIG. 13A illustrates the upper portion of the device.

FIG. 13B is a continuation from the lower portion of FIG. 13A.

FIG. 13C is a continuation from the lower portion of FIG. 13B.

FIG. 13D is a continuation from the lower portion of FIG. 13C.

As shown schematically in FIG. 1, the present invention has application to a producing well wherein the liquid production is produced by a gas lift system. The well casing 1 extends down to the producing formation 2 and is suitably perforated at 3 to allow the well fluids to enter into the well casing 1 from the producing formation 2. Production tubing 4 extends downward within well casing 1 and is suitably sealed against the interior of well casing 1 at a point immediately above-producing formation 2 by packer 5. Check valve 4A is provided in the bottom of tubing 4 to allow flow from producing formation 2 into tubing 4 but preventing flow downwardly out of tubing 4. Macaroni string 6 also extends downward within well casing 1 and terminates at its lower end above packer 5. Macaroni string 6 is supported by a plurality of mandrels 7 mounted on tubing 4 at spaced intervals as shown.

As used herein the term macaroni string is used to designate a tubing string which is suspended in a well and may be larger or the same size as the production tubing in the form of the invention illustrated in FIGS. 1 through 5 but will generally be preferred to be smaller than the production tubing in all forms of the invention. The macaroni string will have to be large enough to receive and allow movement of the gas lift valves therethrough as contemplated by the present invention.

The upper end of well casing 1 is closed by head 8 in the normal manner for submarine well head completions. Line 9 connects into well casing 1 and extends through valve 10 at an onshore installation to suitable pumping equipment (not shown). Tubing 4 extends upward through head 8, through valve 11 into the production separator 12 which is also mounted at the onshore installation. The drawing (FIG. 1) discloses an offshore completion with an onshore installation and all of the lines running from the submarine well head 8 to the onshore installation but it is within the scope of the present invention to have the installation of equipment on a platform or barge above the submarine well head 8 or to include the present invention on production wells which are to be produced by a gas lift system even though they do not involve an offshore well. The use of the present invention is particularly advantageous in an installation having an underwater well head and an onshore installation of production equipment because of the extreme difficulty and expense which would be involved in pulling and rerunning the production tubing or wire line recovery of the gas lift valves for the purpose of replacing or repairing the gas lift valves. The present invention may be used to advantage on any producing well since it will always be easier, less expensive and require less down time to pump the gas lift valves into and from the well in accordance with the present invention than any other known system of installing and removing gas lift valves from a producing well.

Production separator 12 is provided with gas outlet 13 and liquid outlet 14. Gas outlet 13 would normally be connected to a system utilizing the gas at the installation and if sufficient high-pressure gas is produced could be connected to a gas-gathering system. The gas separated from the liquid production in production separator 12 should be recovered and recirculated to the gas lift system. Such gas lift systems involve only the provision of a gas supply at sufficient pressure to provide the necessary gas lift and therefore is not shown in the drawings. The liquids produced are discharged from production separator 12 through liquid outlet 14 into tank 15 for suitable storage.

Macaroni string 6 also extends upward through head 8 and to the onshore installation where it connects through valve 16 into lubricator 17. It should be noted for reasons hereinafter fully explained that macaroni string 6 does not have any sharp bends and that all turns made by macaroni string 6 are long radius bends.

Pipe 18 connects into lubricator 17 as shown in FIG. 1 and is provided with valve 19. Lubricator 17 is a chamber at the onshore termination of macaroni string 6 and is of such design that gas lift valves may be inserted therein for pumping the gas lift valves through macaroni string 6 into their appropriate position within the well and for removal of the gas lift valves from macaroni string 6 which have been pumped from their position within the well. Once the gas lift valves have been inserted into lubricator 17, preferably as a valve train, the lubricator will be closed and valve 19 will be opened. With valves 16 and 19 open, suitable fluid will be pumped through pipe 18 into lubricator 17 and macaroni string 6 which will cause the gas lift valves to be pumped down macaroni string 6 until they are properly seated in their respective mandrels 7. With the gas lift valves all seated, valves 16 and 19 will be closed and valve 10 will be opened. Gas under pressure will then be pumped through line 9 into well casing 1. This gas will surround tubing 4 and macaroni string 6 and will flow through the gas lift valves and the mandrels into the interior of tubing 4 to provide the necessary gas lift for the production from the well.

It should be noted that a suitable liquid or gas may be used to power the pumping of the train of gas lift valves through the macaroni string but it is preferred that a liquid be used because simple measurement of the liquid will provide a quick indication of the location of the valve train. In using a liquid with the form shown in FIGS. 1 through 5, the closing of valve 16 will close macaroni string 6 and prevent accidental dislodging of the gas lift valves from their seats by virtue of the liquid contained within macaroni string 6. Also, this liquid will be pumped from macaroni string 6 as the valves are removed and will provide an indication of the progress of the valves by a measurement of the liquid discharged as hereinafter more fully explained.

If for any reason it is desired that the gas lift valves be removed from the well at any time, it is only necessary to open valves 10, 16 and 19 and to pump hydraulic fluid through line 9, valve 10 and well casing 1. The hydraulic fluid in well casing

will enter macaroni string 6 at its lower end and will pump the gas lift valves up macaroni string 6 into the lubricator 17 where they may be removed, inspected, replaced or repaired and reintroduced into position as hereinbefore explained.

The details of construction of the mandrels 7 whereby they receive and position a gas lift valve and also the operation of the valve mechanism contained in each of the mandrels 7 is shown in FIGS. 2, 3, 4 and 5. Referring to FIG. 2, a typical horizontal cross section of mandrel 7 is shown having a central opening 20 which extends vertically through mandrel 7 and connects at each end to tubing 4 as shown in FIGS. 3 and 4. Mandrel 7 is also provided with passageway 21 which connects at each end of mandrel 7 to macaroni string 6, bypass passageway 22 and cylinder 23. Bypass passageway 22 connects into the upper and lower ends of passageway 21 to provide a bypass around a gas lift valve when positioned within passageway 21 as hereinafter more fully described. Passageway 21 is provided with recess 24 which is connected through port 25 into cylinder 23. Port 26 also connects passageway 21 to cylinder 23 as shown in FIGS. 4 and 5. Ports 27 and 28 connect from the interior of central opening 20 into cylinder 23. The lower portion of passageway 21 is provided with recess 29 which is adapted to receive and seat spring-loaded dogs 30 which are mounted in the lower portion of the gas lift valve 31 which is to be seated in the particular passageway 21. The respective recesses 29 in each of the mandrels 7 are designed to seat only one gas lift valve 31. Each of the recesses 29 are of different length to accommodate the particular set of dogs 30 and the recess 29 in the upper mandrel 7 should have the shortest length and progressively each lower mandrel 7 will have a larger recess 29 than the recess 29 in the mandrel 7 immediately thereabove. With this arrangement of the recesses 29 in the mandrels 7 only the proper gas lift valve 31 will seat in each mandrel and these valves which have larger dogs 30 will continue to move down in macaroni string 6 until they seat in their particular recess 29.

Each of the gas lift valves 31 is provided with an upper fishing head 32 which engages within the dogs 30 of the next higher valve 31 during the time that the valves 31 are being pumped into position through macaroni string 6. When the dogs 30 seat they spring outward into recess 29 and release the fishing head 32 which they had previously engaged allowing the other gas lift valves 31 to continue to be pumped lower in macaroni string 6 until all of the gas lift valves are properly seated in their respective mandrels. Any other means for seating gas lift valves 31 in their proper mandrel 7 which will also engage fishing head 32 of the next valve 31 before seating and release fishing head 32 after the valve has been seated may be used without departing from the spirit of the invention. Such means should also unseat when the fishing head 32 of the next lower valve 31 pushes upward on the valve and at the same time engage such fishing head 32 to keep the gas lift valves being removed from the macaroni string together in a valve train.

The upper portion of each of valves 31 below fishing head 32 contains the actuator (not shown) for the plug 33 which is normally closed on seat 34. Ports 35 connect into the interior of valve 31 at a point above seat 34 and when valve 31 is properly seated within passageway 21 ports 35 are in communication with recess 24 in passageway 21. Seal member 36 surrounds gas lift valve 31 at a position above ports 35 as shown and is of sufficient size to seal against the interior of macaroni string 6 while the gas lift valves 31 are being pumped into position. Check valve 37 is positioned immediately below seat 34 to prevent a reversal of flow through seat 34. The body portion 38 of gas lift valve 31 is recessed at 39 and provided with port 40 which connects into chamber 41 which is in communication with seat 34. Suitable packing 42 and 43 is provided immediately above and below the recess 39 to prevent the flow of fluids within passageway 21 around the body portion 38. Body portion 38 is suitably slotted to allow dogs 30 to extend therefrom when seated in recess 29. Dogs 30 are urged into their seating position by spring 44 which is mounted on pin 45 and member 46 extends across the interior of body portion below spring 44 as shown in FIG. 4. As shown in FIGS. 3 and 4, dogs 30 have just been seated in recess 29 and fishing head 32' of the next lower gas lift valve has just been released and is moving from its engagement with dogs 30.

The configuration of fishing head 32 is such that it will be engaged by dogs 30 when the gas lift valves 31 are being pumped into and from macaroni string 6. The uppermost portion of fishing head 32 will engage member 46 and the lower portion of fishing head 32 will be engaged by dogs 30 whereby a complete train of valves is maintained during pumping operations as hereinafter described.

Cylinder 23 does not extend completely through mandrel 7. The upper end of cylinder 23 is threaded to receive plug 47. Plug 47 is provided with ports 48 connecting from the interior of cylinder 23 to the exterior of mandrel 7 whereby the upper interior of cylinder 23 will at all times be exposed to the pressure within well casing 1. Spool valve 49 is positioned within cylinder 23 as shown and is provided with a plurality of seals 50*a*, 50*b*, 50*c* and 50*d* engaging the interior of cylinder 23, which seals 50*a*, 50*b*, 50*c* and 50*d* are spaced as shown in the drawings in relation to ports 25, 26, 27 and 28. Spool valve 49 is movable within cylinder 23 responsive to pressure within well casing 1 and also responsive to the pressure within tubing 4. The lower end of spool valve 49 is provided with projection 51 which limits the downward travel of spool valve 49 by engagement with the lower end of cylinder 23 as shown in FIG. 5. The operation of spool valve 49 is hereinafter more fully described.

In the form of the invention illustrated in FIGS. 6 and 7 the macaroni string 52 is within tubing string 53. Mandrels 54 are positioned in macaroni string 52 at spaced intervals which intervals are determined by the desired position of the gas lift valves 55.

In FIG. 6 gas lift valve 55' is positioned in mandrel 54' and gas lift valve 55'' is in engagement with motor member 76 (hereinafter more fully described) whereby both valve 55'' and member 76 are traveling between mandrels 54' and 54'' as a train. This is illustrative of the movement of the gas lift valves of the present invention into and from the macaroni string.

Macaroni string 52 is threadedly connected in the upper and lower ends of central opening 52*a* through each of mandrels 54 as shown in FIG. 7. Each mandrel 54 is provided with a central opening 52*a*, a bypass passageway 56 and a cylinder 57. Port 58 connects from cylinder 57 into central opening 52*a* and ports 59 and 60 connect from cylinder 57 to the exterior of mandrel 54. The gas lift valves 55 are similar to gas lift valves 31 and are provided with fishing head 61, plug 62, seat 63, check valve 64, chamber 65 which connects to the exterior of valve 55 through port 66 at a point to connect to port 58 when gas lift valve 55 is properly positioned, seal member 67 and suitable packing 68 to prevent flow of fluids around the exterior of gas lift valve body 69 within central opening 52*a*. Port 70 connects into valve body 69 above seat 63. The lower portion of gas lift valve 55 is provided with dogs 71 to be received in the proper recess 72 within mandrel 54, spring 73 urging dogs 71 outward for engagement within their respective recess 72 and member 74 which extends across the lower portion of valve body 69 as shown.

The lower end of macaroni string 52 is provided with landing fitting 75 which receives motor member 76 as shown in FIG. 7. Fitting 75 is beveled to allow seals 77 on member 76 to properly seal thereon. Motor member 76 is provided with seal member 79 and fishing head 80. Seal member 79 is sufficiently large to provide an adequate seal against the interior of macaroni string 52 and is capable of pushing through central openings 52*a* in mandrels 54. Landing fitting 75 is provided with a plurality of ports 81 which provide fluid communication between the interior of macaroni string 52 and the interior of tubing 53.

The lower end of tubing 53 is provided with a production fitting 82 having port 83 and check valve 84 to allow the flow

of fluids upwardly into tubing 53 and to prevent the flow of fluids in the opposite direction.

Though not shown, the operation of the present invention illustrated in FIGS. 1 through 5 requires a motor member similar to motor member 76 as shown in FIG. 7. The function of such motor member is to provide the driving force for the removal of the plurality of gas lift valves from the macaroni string as will be hereinafter more fully explained.

With the well ready for a gas lift production and tubing 4, macaroni string 6 and mandrels 7 all positioned in the well casing 1 as shown in FIG. 1 then gas lift valves 31 are inserted into lubricator 17 in the form of a train with the dogs 30 of the gas lift valve 31 which is to be positioned in the lowest mandrel 7 engaging the fishing head of the motor member and having its fishing head 32 engaged in the dogs 30 of the next valve 31. In this manner all of the valves 31 are thus connected together for pumping into macaroni string 6.

With the valves 31 in lubricator 17 tubing 4 should be pressurized sufficiently to assure that spool valve 49 is positioned to block communication between central opening 20 and passageway 21 via port 28, cylinder 23 and port 26 in each of the mandrels 7. This position of spool valve 49 will also block the communication between passageway 21 and the exterior of mandrel 7 via port 25, cylinder 23 and ports 48 in plug 47. With the valve train thus installed in lubricator 17 and spool valves 49 properly positioned, valves 16 and 19 are opened and fluid pressure is delivered to pump the valve train into position within the well.

As can be seen from FIG. 3 as each of the gas lift valves 31 approaches its desired position, seal member 36 will uncover the upper opening of bypass passageway 22 into passageway 21 and allow the liquid pumping the valves to flow therethrough. In this position the gas lift valve 31 is not completely seated within mandrel 7 but the fluid pressure will be exerted upon the next lower valve or motor member and will cause the valve to be pulled down into its proper position since dogs 30 will not release the fishing head which they engage until they are properly seated in their respective recess 29.

It should be noted that while all of mandrels 7 because of simplicity of manufacture are preferred to be provided with bypass passageway 22, the lowest mandrel 7 could be made without passageway 22 without departing from the spirit of the present invention. Such a configuration would be completely operative and the only difference would be that the motor member would not be pumped to the lower end of macaroni string 6. While it is desirable to seat the motor member in the bottom of macaroni string 6 since it will provide a positive indication of the seating of all valves 31, i.e., a rise in pressure in the hydraulic fluid at the pumping unit, such seating is not necessary since the seating of the last valve 31 in its mandrel 7 without a bypass will also provide a significant pressure indication.

As mentioned, it is preferred to use a liquid for the pumping of valves 31 into position since it may be accurately measured to determine the exact location of the train of valves 31. It is suggested that the train may be pumped rapidly through macaroni string 6 until it approaches the seating position of one of the valves and then the train should be carefully and slowly pumped until the valve has seated. Seating of a valve can be detected by noting a change in pressure of the liquid.

When all of the valves 31 are properly positioned well casing 1 is pressurized with gas through line 9 and valve 10. This pressure will be sufficient to actuate spool valve 49 to the position shown in FIG. 5 for gas lift production of the well fluids through tubing 4. The casing pressure should not be sufficient to move motor member upwardly in macaroni string 6 but this may be prevented and any desired casing pressure used if valves 16 and 19 are closed whereby the hydraulic fluid used for pumping the valves 31 into position will be trapped within macaroni string 6 thereby preventing movement of the motor member and valves 31.

With spool valve 49 positioned as shown in FIG. 5, production will commence. Casing gas under pressure will flow through ports 48 into cylinder 23 through port 25 and into the chamber above seat 34. Plug 33 is controlled to allow surges of casing gas to flow into chamber 41 to inject lift gas into tubing 4 in the normal manner. The operation of the actuator-controlling plug 33 is well known and any suitable actuator may be used without departing from the spirit of the present invention. Casing gas which flows through seat 34 is conducted through chamber 41, port 26, through cylinder 23 between seals 50*b* and 50*c* and through port 28 into central opening 20 and tubing 4. With the injection of lift gas the production fluids will flow upward through tubing 4, valve 11 and into production separator 12 wherein the gas and liquids will be separated and conducted separately to their respective destinations.

At a time when it is desired to remove gas lift valves 31 from macaroni string 6 then valve 18 should be opened and casing 1 pressurized. To prevent the hydraulic fluid from bypassing macaroni string 6 and following the path of the lift gas, tubing 4 is initially subjected to sufficient pressure to cause the movement of all of the spool valves 49 into the position shown in FIG. 4. This is readily accomplished by providing a greater pressure within tubing 4 than exists within casing 1. By maintaining this tubing pressure during the removal of gas lift valves 31, spool valves 49 will be held in their desired position. This position of spool valve 49 will also block communication between central opening 20 and passageway 21 via port 28, cylinder 23 and port 26 once gas lift valve has been unseated thus preventing the flow of hydraulic fluid into tubing 4. Casing pressure will be exerted upon and admitted to the lower end of macaroni string 6 which is provided with a suitable opening and seat for its motor member (not shown). Since the motor member (similar to motor member 76 shown in FIG. 7) is provided with a seal member it will commence upward movement responsive to casing pressure. Upon reaching the lowest gas lift valve 31 the fishing head of the motor member will engage member 46 and exert an upward force thereon causing valve 31 to be forced upwardly until its seal member 36 is positioned within macaroni string 6 above the upper opening of bypass passageway 22 into central opening 20 and will reach this position prior to the uncovering of the lower opening of bypass passageway 22 by the seal member in the motor member. Dogs 30 are readily disengaged from recess 29 since the upper portion of recess 29 is tapered inwardly causing dogs 30 to retract. In this manner all of the gas lift valves 31 are finally engaged into a train and are delivered to lubricator 17 for removal. Also, the hydraulic fluid within macaroni string 6 will be discharged therefrom through line 18 and valve 19 and may be measured to provide an indication of the position of the valves 31 in macaroni string 6 as they are pumped upwardly therein.

A particular advantage of sealing macaroni string 6 with the hydraulic fluid therein after the valves 31 have been pumped into position is that only this hydraulic fluid will be in contact with seal members 36 and the other exposed portions of valves 31 thereby assisting in the preventing of deterioration of parts and the fouling which might occur due to the presence of foreign matter within macaroni string 6.

Another advantage of retaining the hydraulic fluid within macaroni string 6 is that the removal of the valves 31 can be controlled by restricting the flow of hydraulic fluid through line 18 by adjusting valve 19.

It should also be noted that after valves 31 have once been seated on macaroni string 6 and the casing 1 has been unloaded of well fluids, proper positioning of spool valves 49 during removal and reinstallation of valves 31 will prevent the filling of casing 1 with well fluids. For this reason it is suggested that gas be used to pressurize casing 1 to provide the energy needed for the removal of valves 31 but it should be understood that a liquid may be used for this purpose and it will cause the pumping of valves 31 from macaroni string 6 in the same manner except that when valves 31 are reinstalled

the casing will have to be unloaded before resuming gas lift operations. Maintaining the casing in unloaded condition during removal and reinstallation of the gas lift valves is one advantage gained by use of the present invention.

The operation of the form of the present invention shown in FIGS. 6 and 7 is substantially similar to the operation as described relating to the form of the invention illustrated in FIGS. 1 through 5. A plurality of gas lift valves 55 are inserted into macaroni string 52 in the form of a train with motor member 76 being inserted first and having its fishing head 80 engaged by dogs 71 of the valve 55 which is to be positioned within the lowest mandrel 54. The fishing head 61 of valve 55 will in turn be engaged by dogs 71 of the next higher valve 55. With the train formed and inserted into macaroni string 52 they will be pumped down the string until all of valves 55 have been seated in their proper mandrel 54 and motor member 76 is positioned on landing fitting 75. With valves 55 seated in mandrels 54 spool valve 57*a* will be positioned as shown in FIG. 7 within cylinder 57 since the pressure within macaroni string 52 which is exerted on the upper portion of valve 57*a* will be higher than the tubing pressure exerted on the lower portion of spool valve 57*a* through port 59. In this position spool valve 57*a* will provide a communication between port 58 and port 60.

Lift gas under pressure will then be applied to the interior of macaroni string 52 and will be conducted to each of the gas lift valves 55. The lift gas will enter the chamber above seat 63 through port 70. Plug 62 is the same as previously described and is designed to open when it is desired to inject lift gas into tubing 53. When plug 62 raises off seat 63 lift gas will flow through seat 63, chamber 65, port 66, port 68, cylinder 57 and port 60 into tubing 53 to provide the gas lift for the production of the well fluids upward through tubing 53.

When it is desired to remove gas lift valves 55 from macaroni string 52 then it is only necessary to pressure up tubing 53 (preferably with hydraulic fluid). The tubing pressure will act on spool valves 57*a* in each of mandrels 54 and cause them to move upward into a position blocking flow between ports 58 and 60. The pressure will be transmitted through ports 81 in fitting 75 and will move motor member 76 upward through the lower portion of macaroni string 52. Fishing head 80 of motor member 76 will engage member 74 of valve 55, causing dogs 71 to become unseated and to engage fishing head 80. In a like manner all of valves 55 will be picked up to form an upwardly moving train and they will be delivered to the surface equipment where they will be taken from the macaroni string by a suitable lubricator.

In FIGS. 8A, 8B and 9, the details of a mandrel, a gas lift valve seated in the mandrel and a shutoff valve mounted in the mandrel are shown. The mandrel 85 is adapted to be connected into a production tubing string whereby the lift gas will be supplied from the exterior of the mandrel through the shutoff valve 86, the gas lift valve 87 and into the bypass area 88 in the mandrel.

The mandrel 85 includes upper body 89 which is internally threaded to connect to the production tubing T, lower body 90 and sleeve 91. The lower end of upper body 89 fits into the upper interior of lower body 90 with its lower edge abutting internal shoulder 92 on lower body 90. The upper edge of lower body 90 abuts external shoulder 93 on upper body 89. Sleeve 91 threadedly engages body 89 near its upper extremity. Sleeve 91 extends downwardly in surrounding relation to body members 89 and 90 and at its lower end is externally threaded to connect to the lower extension of the production tubing T. The lower internal portion of sleeve 91 is provided with a shoulder 94 on which the lower end of lower body 90 abuts, whereby upon tightening of the upper threaded connection between upper body 89 and sleeve 91 body members 89 and 90 and sleeve 91 are positioned as shown in FIGS. 8A and 8B. Lock screw 95 extends through the upper edge of the upper portion of sleeve 91 into upper body 89 whereby sleeve 91 is held in position with respect to body 89. Seals 96 seal the upper threaded connection between body 89 and sleeve 91.

As best shown in FIG. 9, upper body 89 is formed to have an offset cylindrical portion 97 and a concentric cylindrical portion 98 with respect to the axis of sleeve 91. Such portions 97 and 98 are integral and are joined by island 99 to provide a housing receiving shutoff valve 86.

The lower portion of island 99 is provided with bore 100 receiving shutoff valve 86 which connects with radial bore 101. As shown in FIG. 8A, radial bore 101 is in registry with bore 102 through sleeve 91. Seals, such as O-rings, are provided in concentric cylindrical portion 98 of body 89 to seal against the interior of sleeve 91 immediately above and below ports 101 and 102. With shutoff valve 86 positioned in bore 100 it abuts shoulder 103 at its upper end and abutment 104 extending from lower body 90 at its lower end.

The upper portion of valve 86 forms a seat 105 in communication with bore 101 which is adapted to be closed by valve plug 106. The interior of valve 86 surrounding stem 107 communicates with port 108 which is in registry with port 109 extending through portion 97 of body 89. Stem 107, is provided with a transverse recess 110 receiving the motion limit pin 111. The lower portion of stem 107 is connected into piston 112 which is adapted for sliding movement within the interior of the valve 86. Piston 112 is urged upwardly by the spring 113 and, if desired, by pressure contained within the valve 86, as is hereinafter more fully explained with regard to FIG. 11, whereby piston 112 is constantly urged upwardly to maintain valve 86 in an open position. Suitable sealing is provided around the exterior of valve 86 above and below the port 108 to prevent leakage of fluids between the interior of bore 100 and the exterior of valve 86.

The interior of body members 89 and 90 are provided with an upper annular sealing surface 114, a lower annular sealing surface 115, an upper annular groove 116 and a lower annular groove 117 for receiving and seating the gas lift valve 87. The lower portion of lower body 90 is provided with slots 118 providing communication between the lower internal bore 119 of sleeve 91 and the bypass area 88 formed between the interior of sleeve 91 and the exterior of the body members 89 and 90.

Gas lift valve 87 is similar to the previously described gas lift valves in that it is to be installed in the mandrel 85 by being pumped downwardly through the production tubing T. Body 120 of gas lift valve 87 is provided with upper packing 121 and lower packing 122 which seal respectively against surfaces 114 and 115 when valve 87 is seated within mandrel 85. Neck 123 extends upwardly from the upper portion of body 120 and connects to fishing head 124. The valving mechanism indicated generally at 125 is contained within the body 120 and controls the movement of plug 126 with respect to valve seat 127. Body 120 is slotted as at 128 whereby the slots provide communication from the ports 108 and 109 into the area within body 120 above valve seat 127. The portion of body 120 below valve seat 127 provides a passageway 129 which terminates in lateral passageway 130. Lateral passageway 130 extends completely through body 120 providing communication from passageway 129 to the exterior of valve 87. Ports 131 extend through lower body 90 at a position whereby communication is established from lateral passageway 130 to bypass area 88.

Immediately below passageway 130, body member 120 provides external shoulder 132 for engagement of spring 133. Immediately below shoulder 132, body member has a reduced diameter portion 134 extending downwardly through spring 133 and terminating in upwardly facing external shoulder 135.

Sleeve 136 has its upper portion surrounding portion 134 of body member 120 in sliding engagement therewith and is provided with internal downwardly facing shoulder 137 which is in engagement with shoulder 135 when gas lift valve 87 is seated within mandrel 85. The lowermost portion of body 120 is provided with a transverse slot 138 extending downwardly to the lower end of body 120 indicated at 139. Sleeve 136 is also provided with slots 140 through its sides to allow movement of dogs 141 therethrough.

In seated position, the upper and lower ends of dogs 141 engage in the upper and lower grooves 116 and 117 respectively as shown in FIGS. 8A and 8B. Dogs 141 are pivoted about pin 142 which is suitably secured at each end in the lower extremity of body 120. Spring 143 is positioned in slot 138 and engages dogs 141 to urge them outwardly. Block 144 is positioned across the interior of sleeve 136 at its lower extremity and is secured by pin 145 extending through the sleeve 136 into block 144 or by any other suitable securing means.

In the latching position of dogs 141 the lower end of sleeve 136 is positioned between the lower end of dogs 141 to lock them in latched position. Spring 133 urges this movement of sleeve 136 as soon as dogs 141 move outwardly into grooves 116 and 117.

Valve 87 is retained in position in the mandrel 85 by the engagement of the downwardly facing shoulder 146 on the upper portion of dogs 141 coming into engagement with the upwardly facing shoulder 147 on lower body member 90. It should be noted that if desired, the space between the upper and lower portions of the dogs 141 may be set so that the shoulders 146 and 147 will not engage until the lower portion of dogs 141 are seated in the lower annular groove 117 in the mandrel in which the particular valve 87 is desired to be retained. Other suitable means for the selective seating of the gas lift valves within the mandrels such as a variation in the size of the upper and lower extremities of the dogs 141 may be used without departing from the present invention.

When the gas lift valves 87 have all been run into tubing string T and seated in their respective mandrels 85, the well will be ready for production upwardly through the tubing string T. The well fluids flowing into the lower portion of mandrel 85 will enter bore 119 of sleeve 91, flow through slots 118 and lower body 90 and upwardly through the bypass area in mandrel 85. At the upper end of bypass area 88 the production will flow through the slots 148 into the central bore of upper body 89 around neck 123 and upwardly into the upper production tubing T.

When it is desired to provide lift gas, pressure on the exterior of mandrel 85 will be raised to a sufficient extent whereby plug 126 will be lifted off of seat 127. Lift gas will flow through port 102 and radial bore 101, between valve plug 106 and seat 105, through ports 108 and 109, slots 128 into the interior of gas lift valve 87. With sufficient pressure, the valving mechanism 125 will cause plug 126 to be raised allowing the fluid to be conducted downwardly through seat 127, passageways 129, 130 and to be discharged through ports 131 into bypass area 88 whereby lift gas will assist the production of the petroleum liquids upwardly through the production tubing T.

When gas lift valve 87 is placed in the lubricator to be run into the tubing, it is incorporated with a motor and other similar valves forming a valve train. The dogs 141 will be in a retracted position and the sleeve 136 will be positioned a substantial distance upwardly from the position shown in FIGS. 8A and 8B whereby the lower portion of sleeve 136 does not engage the interior of the lower portion of dogs 141. It should be noted that spring 133 will urge sleeve 136 to the lower position only when the dogs 141 have seated in their respective grooves.

As the valves are moved downwardly through the production tubing, the uppermost valve with the valve train will seat in the uppermost mandrel and at the time its dogs 141 move outwardly into the grooves 116 and 117, they will release the fishing head 124 of the next lower valve allowing the train to move downwardly therefrom and the fluid which is used to pump the valves down will flow around the seated valves through the bypass area 88 whereby the remainder of the valve train will continue downwardly until all valves are seated in their mandrels 85. The seating of the dogs 141 within the grooves 116 and 117 allows sleeve 136 to move downwardly under force applied by the spring 133 whereby it engages the interior of the lower portion of dogs 141 thereby locking the valve 87 in position within the mandrel. Thereafter, no fluid pressure, whether above or below the valve 87, will cause the valve to be unseated.

The valves are removed by starting the motor member upwardly through the production tubing whereby the fishing head at the upper end of the motor member will engage the blocks 144 of the lowermost valve 87, causing sleeve 136 to slide upwardly to release position, allowing dogs 141 to retract and the valve 87 to become unseated and move upwardly through the production tubing T. Since the pressure external of the mandrels and production tubing T is utilized to remove the gas lift valves 87 from the production tubing T, sufficient pressure should be supplied to close the shutoff valves 86 in each of the mandrels, thereby preventing the bypassing of the fluid, which is to remove the valves from the production tubing above the motor member, into the interior of the mandrels above the valves. The shutoff valve 86 thereby effectively closes the communication between the interior and exterior of the mandrel 85 when sufficient external pressure is applied to cause the piston 112 to move downwardly against the force exerted by spring 113 until the plug 102 is seated on the seat 105.

In the form of the invention illustrated in FIGS. 10A and 10B, another form of combined mandrel, gas lift valve and shutoff valve is illustrated. The mandrel 149 includes a substantially tubular body which is provided with upper and lower external threads to provide for threaded engagement in the production tubing with the couplings C as shown. Shutoff valve 150 is installed on the exterior of the mandrel between upper and lower projections 151,152. The shutoff valve is inserted downwardly through the collar 153 formed integral with or suitably secured to the exterior member and the lower portion of shutoff valve 150 engages the upwardly facing shoulder 154. Upper projection 151 is suitably threaded to receive the jackscrew 155 which engages the upper portion of shutoff valve 150 and holds it securely in place within collar 153 against shoulder 154.

As shown the side port 156 through the body of shutoff valve 150 is in registry with the port 157 through mandrel 149 when shutoff valve 150 is properly installed and held against the shoulder 154.

The interior of mandrel 149 presents a substantially smooth cylindrical bore 158 interrupted only by annular grooves 159.

Gas lift valve 160 is generally annular in shape and is provided with an upper recess 161 receiving the sealing element 161*a* and provided with upper external threads for engagement with the annular fishing head 162. When fishing head 162 is tightened into complete threaded engagement with the body of gas lift valve 160, it also engages sealing member 161*a* to assure sealing engagement with the bore 158 of mandrel 149. Immediately below recess 161 gas lift valve 160 is eccentrically recessed externally whereby the annular space 163 is provided between the exterior of the body of valve 160 and the bore 158 in mandrel 149. Ports 156 and 157 are in communication with the annular space 163. The valve mechanism 164 is installed in the largest portion of the annular space 163 by threaded engagement at its lower end and is held by spring clip 165 at its upper end to retain it in position against the exterior of gas lift valve 160 as shown.

The annular space 163 terminates immediately below the port 157 and the body of valve 160 is provided with recess 166 to receive sealing member 167. The member 168 is threadedly engaged on the lower end of valve 160 to secure sealing member 167 within recess 166.

The dogs 169 are generally annular in shape to conform to the central bore 170 through gas lift valve 160 and member 168. Sleeve 171 is secured to member 168 and slotted to provide for movement of dogs 169 into the grooves 159. As shown the dogs 169 are pinned in their central portion to sleeve 171 with pin 172. It should be understood that pin 172 does not extend across the interior but a separate pin will be used securing the dogs 169 to the sleeve 171 at each side of the sleeve 171. The lower portion of the sleeve 171 is provided with a stop 173 projecting inwardly whereby a fishing head

coming into engagement therewith will be prevented from moving upwardly into the space between the dogs 169 and thereby allow the valve 160 to be removed from the mandrel 149 as hereinafter more fully explained. Spring 174 engages and urges dogs 169 outwardly at all times.

The valve mechanism 164 is similar to that shown in the other drawings and is provided with slots 175 which provide communication between annular space 163 and the space surrounding plug 176 above valve seat 177. Passageway 178 below valve seat 177 extends downwardly through the lower threaded portion 179 of valve mechanism 164 and provides communication into the interior of gas lift valve 160.

To install a group of valves 160 in a tubing string, the valves are first assembled with the motor member in a lubricator wherein the fishing head of the motor member is engaged by the dogs of the valve which is to be positioned in the lowermost of the mandrels 149 and each mandrel thereabove will engage the fishing head of the mandrel below. The grooves 159 and dogs 169 are designed whereby the mandrels will reject each valve passing therethrough until the valve having the proper dogs 169 to seat therein comes into seating position.

The valves 160, after being inserted in the lubricator, are pumped downwardly, it being understood that because of the internal bore through each of the valve bodies, the motor member will be essential to provide the motive force for moving the valves downwardly through the tubing. Removal of the valves is accomplished by raising the pressure on the exterior of the tubing sufficiently to cause shutoff valve 150 to close the communication between the exterior of the mandrel and the interior of the mandrel and such pressure will energize the motor to move it upwardly. As the motor moves upwardly, the motor fishing head will engage the stop 173 on the lowermost of the valves 160 forcing the valve upwardly out of seating engagement whereby the dogs 169 will be retracted by virtue of the sloping upper surfaces of the grooves 159. In like manner, the first valve 160 and the motor member will proceed up the tubing, picking up each valve with the fishing head of the next lower valve, which engages the stop 173 and forces the valve upwardly, out of seating engagement with its particular mandrel. Thus, the valve train will be delivered to the surface into a lubricator from which the valves may be readily removed for repair or replacement or the valves may be maintained in the lubricator while other operations are conducted in the tubing and then pumped downwardly into place as soon as such tubing operations are completed.

It should be noted that the central bore through each of the valves 160 will allow the operator of the well to conduct the wire line operations without the removal of the valve from the production tubing. In the design of the gas lift valve 160 shown in FIGS. 10A and 10B the central bore thereof provides the production passageway which is shown and described in the other forms of the present invention as being a bypass passageway through the mandrel.

The shutoff valve 180 illustrated in FIG. 11 is a typical shutoff valve such as shutoff valve 150 illustrated in FIG. 10A and is composed of a hollow cylindrical body member 181 which has plug 182 threadedly connected into its upper end and plug 183 connected into its lower end. The lowermost portion of the plug 183 is provided with the bore 184 having the seat 185 for the valve plug 186. Port 187 extends through the sidewall of plug 183 into bore 184 and seals 188 and 189 surround the plug 183 immediately above and below the port 187.

As previously mentioned, this port 187 will be in registry with the port in the mandrel allowing the shutoff valve 180 to control the flow of fluid through the communication between the exterior and the interior of the mandrel. Valve plug 186 is supported by valve stem 190 which is threadedly engaged into piston 191. The piston 191 as shown in FIG. 11 is made in two sections with an annular packing 192 positioned in a recess and compressed by the engagement of the two sections. Also seal 193 is provided around the upper end of piston 191 to seal against the interior of cylindrical body 181. The upper end of piston 191 is in engagement with the lower end of spring 194 which urges piston 191 downwardly thereby maintaining plug 186 off of seat 185 until such time as the pressure transmitted through the space 195 between stem 190 and the interior of plug 183 which is exerted upwardly on the lower portion of piston 191 exceeds the force urging the piston 191 downwardly.

In addition to the force exerted by spring 194, upper plug 182 is provided with a fill valve 196 in the bore 197 which bore connects into the interior of body 181. Thus it is possible to charge the interior of body 181 with air or gas to a predetermined pressure. Such pressure and spring 194 will exert a downward force on the upper portion of piston 191. Closure 198 is threadedly secured and provided with suitable seals into the interior of upper plug 182 immediately above fill valve 196.

With a shutoff valve such as is valve 180, positioned in the communication between the interior and exterior of a mandrel the force of the spring 194 and of the pressure within the valve body will maintain the communication open until such time as the pressure exterior of the mandrel becomes sufficient to overcome the spring force and the pressure whereby piston 181 will move upwardly causing plug 186 to engage seat 185 thereby closing the communication. With such a valve, it is possible to pressure up the casing to a degree whereby the shutoff valve 180 will close and thereby be assured that all communications through the mandrels will be closed. Such closure of communication is essential in the removal of the valves by pumping from the tubing string so that the fluid pressure in the casing does not bypass through the mandrel communication means to a position above the motor member or upwardly moving valve train.

In FIG. 12A and 12B a combined gas lift valve and shutoff valve 199 is illustrated. The upper portion of valve 199 is provided with the fishing head 200 which is connected through the neck 201 to the upper body portion 202, the major portion of which is not shown as it includes the necessary pressure responsive means for controlling the movement of plug 203 with respect to seat 204. Any mechanism normally used in gas lift valves which may be contained within the upper body portion 202 of valve 199 may be used for the control of plug 203.

Section 205 is threaded and sealed into the lower end of upper body portion 202 and contains a central passageway extending downwardly from seat 204 through check valve 206 and in communication with the exterior of section 205 through the upwardly inclined passageway 207. Passageway 208 extends completely through member 205 and is completely isolated from passageway 207 and provides communication from the area above seat 204 around the actuating mechanism for plug 203 to the central cavity 209 in the lower portion of member 205.

Sleeve 210 is connected to the lower end of member 205 and extends downwardly surrounding cylinder 211 in spaced relation thereto to provide an annular passageway 212 therebetween. Member 213 connects to the lower end of sleeve 210 and is suitably sealed thereto. The exterior of member 213 is recessed at 214 to receive the sealing elements 215 and the follower member 216. The lower end of cylinder 211 is sealed to the inner bore of member 213 and provides the valve seat 217 for the valve plug 218.

Cylinder 211 is provided with a port 219 in a registry with the recess 220 in member 213 above the seals between the lower end of cylinder 211 and member 213. Passageway 221 extends through member 213 providing communication between recess 220 and annular passageway 212. Immediately adjacent seat 217, member 213 is provided with a port 222 to provide communication from the exterior of valve 199 to seat 217.

Member 223 is suitably secured to the lower end of member 213 and is provided with recess 224 to receive the sealing elements 225 follower member 226 which retains the sealing elements 225 in position in the recess 224. It should be noted that the sealing elements 215 and 225 are immediately above and below the port 222 and will therefore provide a seal for valve

199 within a mandrel whereby the communication through the mandrel from the exterior to the interior will communicate directly to port 222 and be sealed off from communication immediately above and below port 222.

The lower portion of follower member 226 provides the shoulder 227 against which spring 228 abuts. Member 229 extends through spring 228 and is secured to member 223. The lower external portion of member 229 extends outwardly to provide the shoulder 230. Collar 231 is threadedly engaged to sleeve 232 and is adapted to move upwardly in sliding engagement with the exterior of member 229 but is limited in its downward travel by abutment against the shoulder 230. Spring 228 engages the upper surface of collar 231.

The lowermost portion of member 225 is provided with transverse slot 233 extending downwardly to the lower end of member 229 indicated at 234. Sleeve 232 is also provided with slots 235 through its sides to allow movement of dogs 236 therethrough.

Dogs 236 are pivoted about pin 237 which is suitably secured at each end in the lower extremity of member 229. Spring 238 is positioned in slot 233 and engages dogs 236 to urge them outwardly. Block 239 is positioned across the interior of sleeve 232 at its lower extremity and is secured by pin 240 extending through sleeve 232 into block 239 or by any other suitable securing means. The above dog and sleeve structure of FIGS. 12A and 12B is similar to the structure illustrated in FIGS. 8A and 8B.

With valve 199 seated in a suitable mandrel wherein the communication from the exterior of the mandrel to the interior of the mandrel also communicates with port 222 such communication will be limited by virtue of the upper packing 215 and the lower packing 225 sealing on the interior of the mandrel immediately above and below port 222. Thus, the valve 199 includes an integral shutoff valve and a gas lift valve which may be used in an ordinary mandrel having suitable communication means and suitable dog seating and receiving means whereby the valve 199 may be seated in the proper position within the mandrel.

When properly seated the pressure exterior of the mandrel will be communicated through port 222 through seat 217, providing the plug 218 has not been closed by the pressure. Actuation of plug 218 is responsive to movement of the piston 241 within the cylinder 211. Stem 242 connects plug 218 to the piston 241. Means opposing the pressure exerted through port 222 and seat 217 on the lower side of piston 241 is provided by spring 243 or any other suitable means. For example, pressure, as hereinbefore clearly described in relation to FIG. 11, may be used to exert a force downwardly on piston 241 and to hold valve plug 218 unseated from seat 217 until the pressure under piston 241 overcomes such force. Valve plug 218 will remain unseated at all times until the pressure under piston 241 overcomes the spring force and the pressure above piston 241. Thus, communication through the mandrel may be closed at any time by increasing the pressure on the exterior of the mandrel.

Thus, under normal gas lift conditions, valve 218 will not be seated on seat 217 and fluid pressure will be conducted through port 222, seat 217, the area surrounding stem 242, port 219, passageway 221, passageway 212 and passageway 208 into upper body portion 202 above seat 204. Such pressure, when sufficient, will actuate plug 203 to lift it off of seat 204 thereby allowing the pressure fluid to be conducted downwardly past check valve 206 and to be discharged from valve 199 through the upwardly directed passageway 207. Passageway 207 will be in communication with the interior of the production tubing whereby the fluid production may be conducted upwardly through the mandrel in a bypass passageway and into the production tubing connected to the upper portion of the mandrel.

Thus, the device illustrated in FIGS. 12A and 12B provides both the gas lift valve and a shutoff valve which, when exposed to excessive pressures will, in effect, close the communication between the interior and exterior of the mandrel. Such device may be pumped downwardly in the tubing string through the use of the motor member as hereinbefore described. Pressure on the exterior of the mandrel will be exerted against the underside of piston 241. When such pressure is sufficiently great it will cause valve plug 218 to lift into seating engagement with seat 217 thereby closing such communication.

In the structure and systems of the present invention it will at times be advantageous to have the combined gas lift valve and shutoff valve included in the unit which is pumped into the tubing string and seated in the mandrels since both valves when combined in the structure illustrated in FIGS. 12A and B may readily be removed from the production tubing by pumping.

In the FIGS. 13A, 13B, 13C and 13D, the lower end of a production tubing is illustrated showing the motor member 244 in its locked-down position therein. The production tubing T' is connected by a coupling C' to an enlarged tubing section 245 which has a larger internal diameter than the diameter of the production tubing T'. The lower end of tubing 245 is threadedly connected into the upper end of mandrel 246 as shown in FIG. 13B. The lower end of mandrel 246 is externally threaded to provide for the connection of the coupling C'' if it is desired that a tubing connection extend below the mandrel 246.

Mandrel 246 is provided with outer shell 247 and inner shell 248 held in concentric spaced relationship to outer shell 247 to provide the annular passageway 249 therebetween. Suitable means (not shown) should be provided to retain inner shell 248 in such position within outer shell 247. As shown, inner shell 248 does not extend the entire length of outer shell 247 and therefore passageway 249 is in communication with the interior of mandrel 246 above and below the ends of inner shell 248.

The lower end of mandrel 246 is provided with a reduced bore 250 having an upwardly facing shoulder 251 adapted to receive and seat valve body 252 therein.

As shown, valve body 252 has a lower central passageway extending upwardly to check valve seat 253. The area within valve body 252 above check valve 254 is in communication with the interior of outer shell 247 and annular passageway 249 through the slots 255. Valve body 252 is provided with suitable sealing elements 256 and 257 sealing in inner shell 248 above and in outer shell 247 below the slots 255. Also, valve body 252 provided with a suitable fishing head 258 at its upper extremity.

Motor member 244 includes central body 259 with fishing head 260 suitably secured to the uppermost portion thereof.

Upper sealing cups 261 and 262 are mounted between shoulders 263 and 264 immediately surrounding body 259 and are of sufficient size and resiliency to provide pressure seal against the interior of the production tubing. Lower sealing cups 265 and 266 are mounted on the lower portion of body 259 between the shoulders 267 and 268 and also have sufficient size and resiliency to seal against the interior of production tubing. It should be noted that the individual sealing cups of each pair of sealing cups are positioned facing in opposite directions whereby one cup of each pair will provide a pressure seal when pressure is exerted on motor member 244 from above and the other cup will provide pressure seal when the pressure is exerted on motor member 244 from below. Also, the spacing between upper pair of sealing cups 261 and 262 and lower pair of sealing cups 265 and 266 should be sufficiently great to provide a seal across the longest of the mandrels in the tubing string. With such spacing of the sealing cups bypass of the fluid pumping the valve train and motor member 244 into or out of the tubing will not bypass the seal cups by flowing through the bypass areas in the mandrels and thereby allow the motor member and valve train to be stalled in the tubing.

Latch body 269 is threadedly secured to the lower end of body 259 and provided with a central opening 270 in its upper portion containing piston 271 and spring 272. Spring 272 engages the upper portion of piston 271 and also the lower por-

tion of body 259 to urge piston 271 downwardly in central opening 270. Piston rods 273 connect to the piston 271 and extend downwardly through body 269 and into slot 274 in latch body 269. The lower portion of latch body 269 is provided with a central bore 275 which is internally threaded to engaged cylinder 276. Latching dogs 277 and 278 are secured to body 269 by the pine 279 which extends across the bore 275. Latching dogs 277 and 278 are pivotally mounted on the pin 279 to allow rotation of the dogs outwardly into the position as shown in FIG. 13B. Dogs 277 and 278 will be urged outwardly into engagement within the latching groove 280 on the upper interior of inner shell 248 of mandrel 246 by the downward force applied by piston 271 and piston rods 273.

The piston 281 is positioned for sliding engagement within cylinder 276 and has an upwardly extending nozzle 282 with a beveled exterior portion 283 engaging the inner side of the downwardly projecting tips 284 of the dogs 277 and 278. The interior of piston 281 is open having an orifice 285 in the nozzle 282 communicating with the interior of latch body 269. Cylinder 276 has a downwardly facing shoulder 286 at its upper extremity retaining the spring 287 at its upper extremity. The spring 287 engages upwardly facing shoulder on piston 281 to urge piston 281 in a downward direction.

Cylinder 276 is secured and sealed to member 288 at its lower extremity. Member 288 is suitably bored to receive the stem 289 of the valve plug 290 which engages on the downwardly facing seat 291 on member 288. The interior of member 288 is sufficiently large to allow the passage of fluid under pressure therethrough around stem 289 and also provides for the guiding of stem 289 in a reciprocating movement therein. Valve plug 290 is connected to the bellows assembly 292. Sleeve 293 surrounds bellows assembly 292 and is threadedly secured at its upper end to member 288 and at its lower end to member 294. Lower body member 295 is suitably secured and sealed to member 294. The interior of bellows assembly 292, member 294 and the upper portion of lower body member 295 are all open and in communication with the fill valve 296 secured in the lower end of lower body member 295. The lower exterior of lower body member 295 is recessed at 297 to receive sealing elements 298 which are adapted to seal against the interior of the inner shell 248 of mandrel 246. Cap 299 is threadedly secured to the lower end of lower body member 295 and engages the lower annular periphery of sealing elements 298 as a sealing element follower.

As best shown in FIG. 13C when motor member 244 is positioned within mandrel 246 in the latched down position, cap 299 rests against the upper portion of fishing head 258 of valve body 252 at a point immediately adjacent the port 300. Port 300 extends through shells 247 and 248 to provide communication from the exterior to the interior of mandrel 246. It should be noted that port 300 is not in communication with the annular passageway 249 between outer shell 247 and inner shell 248.

With motor member 244 positioned in the latched down position illustrated in the FIG. 13 series drawings, production will flow upwardly through valve body 252 around check valve 254, through slots 255, annular passage 249 and the space between sealing cups 266, 265, 262 and 261 and the interior of tubing 245. During normal production, the exterior of mandrel 246 below the port 300 will be packed off against the casing or formation and therefore formation pressure below such packing will not be exerted against the lower end of motor member 244 because of the upper seal 257 on valve body 252 which closes the lower interior of inner shell 248.

It should be noted that the upper end of inner shell 248 is not sealed and therefore fluid pressure within the tubing will be transmitted to the lower interior of body 269 through the space between the interior of inner shell 248 and the exterior of body 269.

The motor member 244 will be used to install the series of valves in their respective mandrels in the tubing string by first inserting the motor member into a lubricator with the fishing head 260 being engaged by the dogs of the valve which is to be positioned in the lowermost mandrel in the well and the fishing head of each valve being engaged by the dogs of the next higher valve. When all the valves have been installed in the lubricator making a continuous train, the lubricator will be closed and fluid pressure will be exerted on the train to pump the train downwardly in the tubing. The cups 262 and 266 which face upwardly will retain the pressure fluid being used to pump the valve train downwardly through the tubing and thereby provide the motor force for the movement of the train downwardly through the tubing.

As previously mentioned, as the uppermost valve in the train is seated in its particular mandrel, it will release the fishing head of the next lower valve. The seating of each valve will progress until all valves in the train have been seated and the motor member is pumped downwardly into the position as illustrated in the FIG. 13 series drawings. It should be noted that tubing 245 is substantially larger than the sealing cups and therefore the last portion of the movement of motor member 244 in the downward direction will be responsive to the pressure contained by the sealing element 298 in inner shell 248 to completely seat motor member 244 in the down position with latching dogs 277 and 278 in engagement with latching groove 280.

During the downward movement of motor member 244 through the tubing string piston 271 will be urged downwardly and such force will be transmitted through the rods 273 to urge the latching dogs 277 and 278 in an outward direction. However, the outer surface of the latching dogs coming into contact with the interior of the tubing or mandrels is sufficiently beveled to cause the latching dogs to retract allowing free passage of the motor member downwardly through the tubing string. When the motor member 244 reaches its lowermost position, the dogs will be forced outwardly into engagement with the groove 280 as shown.

Unlatching of the motor member 244 from mandrel 246 may be accomplished as follows: If desired, sufficient pressure may be exerted on the exterior of the tubing string which will be transmitted through the port 300 to the lower side of motor member 244 to shear the pin 279 allowing the piston 271 and rods 273 to force the dogs downwardly into the interior of body 269 thereby causing the dogs 277 and 278 to completely retract from the latching groove 280. Such pressure will also move the motor member 244 upwardly upon release of the latching dogs because the seal provided by sealing element 298 with the interior of inner shell 248 will be sufficient until such time as upper seal cup 261 provides sealing engagement with the interior of the tubing string. Thereafter motor member 244 will move upwardly through the tubing string with the fishing head 260 engaging the lower end of the lowermost valve and thereby moving the valve upwardly in a train until all of the valves have been picked up and are positioned in the lubricator at the upper end of the tubing string.

Also, motor member 244 may be unlatched by applying sufficient pressure on the exterior of the tubing to close all of the shutoff valves in the mandrels and then pressure is applied to the interior of the tubing. Such pressure within the tubing will be transmitted downwardly through the tubing string to the interior of body 269 where it will flow through the orifice 285 and be exerted against the valve plug 290. Bellows assembly 292 is adapted as a means of accumulating pressurized fluid whereby when the pressure on the interior of the tubing string is released, the piston 281 will move upwardly with the bevel 283 engaging the tips 284 on the latching dogs 277, 278 causing the dogs to retract out of engagement with latching groove 280. At such time the pressure on the exterior of the mandrel will be transmitted through the port 300 against the lower end of the motor member 244 causing the motor member to rise in the tubing. Such upward movement of the motor member 244 responsive to the fluid pressure exerted on the exterior of the tubing string and transmitted through port 300 to the interior of the tubing string will allow the motor member to pick up each of the valves from the mandrel in the form of a train and deliver the complete train to the lubricator at the surface.

If for any reason the motor member remains latched in its lowermost position within the tubing string then each of the valve members may be removed by individual wire line operations and the motor member may also be removed by a wire line operation. The wire line tool for removal of the motor member **244** will be lowered within the tubing string to engage fishing head **260**. Upon direct upward pull of the wire line, pin **279** will shear and upward movement of motor member **224** will cause latching dogs **277** and **278** to be retracted by engagement of the dogs with the portion of body **269** below the slot **274**. While gas lift valves have been specified as being the devices which are installed in a tubing string by the method of the present invention, it should be understood that any other device which can be made to pass through a tubing may be installed by the method of the present invention.

It should be noted that all of the gas lift valves and the motor members used with the present invention are provided with fishing heads as a precautionary measure so that in the event that any of the seal members fail to seal thereby preventing the pumping of the valves from their position in the mandrel, then each valve may be recovered by a normal fishing operation or by the pumping of a special fishing tool into the string to engage the fishing head of the top valve and recovering that valve and each other valve in sequence.

From the foregoing it can be seen that the present invention provides an inexpensive, simple method of installing and removing a plurality of valves in a well which valves may be used for production fluids from the well. In particular, the invention is shown to apply specifically to gas lift valves. Also, the method and apparatus of the present invention provides each valve be installed, properly positioned and recovered from the well and responsive to fluid pressure exerted on the tubing string from above or below. In addition, the present invention has been shown to include novel structure of the valve to be pumped into a tubing string wherein the interior of the valve may be open allowing swabbing or fishing operations through the valve even when the valve is in place in the tubing string. The present invention also discloses a novel shutoff valve for the communication through the mandrels in the tubing string which valve may be a part of the mandrel or a part of the gas lift valve which is to be seated in the mandrel. Further, a novel locking means has been disclosed for retaining the pumped down gas lift valves in position in the seat which locking means is not responsive to fluid pressure in the tubing string. A novel motor member structure which is to be used with the valves of the present invention to provide the motor power for the pumping of a train valve downwardly through the tubing string and upwardly through the tubing string has been disclosed. It has been shown also that such motor member is provided with a novel releasable latching means which may not be inadvertently released.

What is claimed is:

1. The combination gas lift valve and shutoff valve adapted to be installed into a tubing string comprising,
- a valve body,
- an inlet into said valve body,
- a shutoff valve means including means urging said shutoff valve means toward open position connected to said inlet and responsive to fluid pressure at said inlet,
- a pressure responsive gas lift valve,
- fluid communication means through said valve body connecting the outlet from said shutoff valve means to the inlet of said gas lift valve,
- an outlet extending through said valve body in communication with the outlet of said gas lift valve, and
- a pair of sealing elements positioned around said valve body for sealing engagement with the interior of the tubing string in which said combination valve is positioned,
- said sealing elements being positioned immediately above and below said inlet into said valve body.

2. A mandrel for receiving a gas lift valve comprising,
- a mandrel body,
- a pair of passageways through said mandrel body,
- means at each end of said passageways for connection of tubing thereto,
- means in one of said passageways for selectively seating a gas lift valve,
- communication means through said mandrel body between the interior of said one passageway and the exterior of said mandrel body, and
- means responsive to a pressure differential between said other passageway and exterior of said mandrel closing and opening said communication means.

3. A mandrel according to claim **2** including,
- spaced annular surfaces in said passageway for engagement with seals carried by a gas lift valve, and
- a bypass passageway through said mandrel body and communicating with said passageway above and below said spaced annular surfaces.

4. A mandrel according to claim **2** wherein said means closing and opening said communication means comprises a cylinder within said mandrel body interposed in said communication means and a spool valve movably positioned in said cylinder to open and close said communication means.

5. A combination mandrel and gas lift valve comprising,
- a mandrel body,
- said mandrel body having a passageway extending therethrough,
- a gas lift valve having a body adapted to selectively seat in said passageway in said mandrel body,
- communication means through said mandrel body between the interior of said passageway and the exterior of said mandrel body, and
- valve means positioned in said mandrel body in said communication means and closing said communication means in response to a selected high-pressure external of the mandrel body.

6. A combination tubing mandrel and valve comprising,
- a mandrel body,
- said mandrel body having a passageway extending therethrough,
- a valve having a body adapted to selectively seat in said passageway in said mandrel body,
- communication means through said mandrel body between said passageway and the exterior of said mandrel,
- said valve body positioned in said mandrel passageway,
- a first pressure responsive valve means in said valve body,
- a second valve means in said valve body,
- said first valve means adapted to close said communication means between said mandrel body and said second valve means in response to a selected high-pressure external of said mandrel and to open said communication means when pressure external of said mandrel is less than said selected high pressure,
- said second valve means adapted to open and close said communication means at a position between said first valve means and said passageway through said mandrel body,
- said first and second valve means positioned in said communication means whereby closure of one of said valve means will close said communication means.

7. A mandrel for receiving a gas lift valve comprising,
- a mandrel body,
- a passageway through said mandrel body,
- means at each end of said passageway for connection of tubing thereto,
- means in said passageway for selectively seating a gas lift valve,
- communication means through said mandrel body between the interior of said passageway and the exterior of said mandrel body,
- means closing and opening said communication means,
- spaced annular surfaces in said passageway for engagement with seals carried by a gas lift valve, and
- a bypass passageway through said mandrel body and communicating with said passageway above and below said spaced annular surfaces.

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