

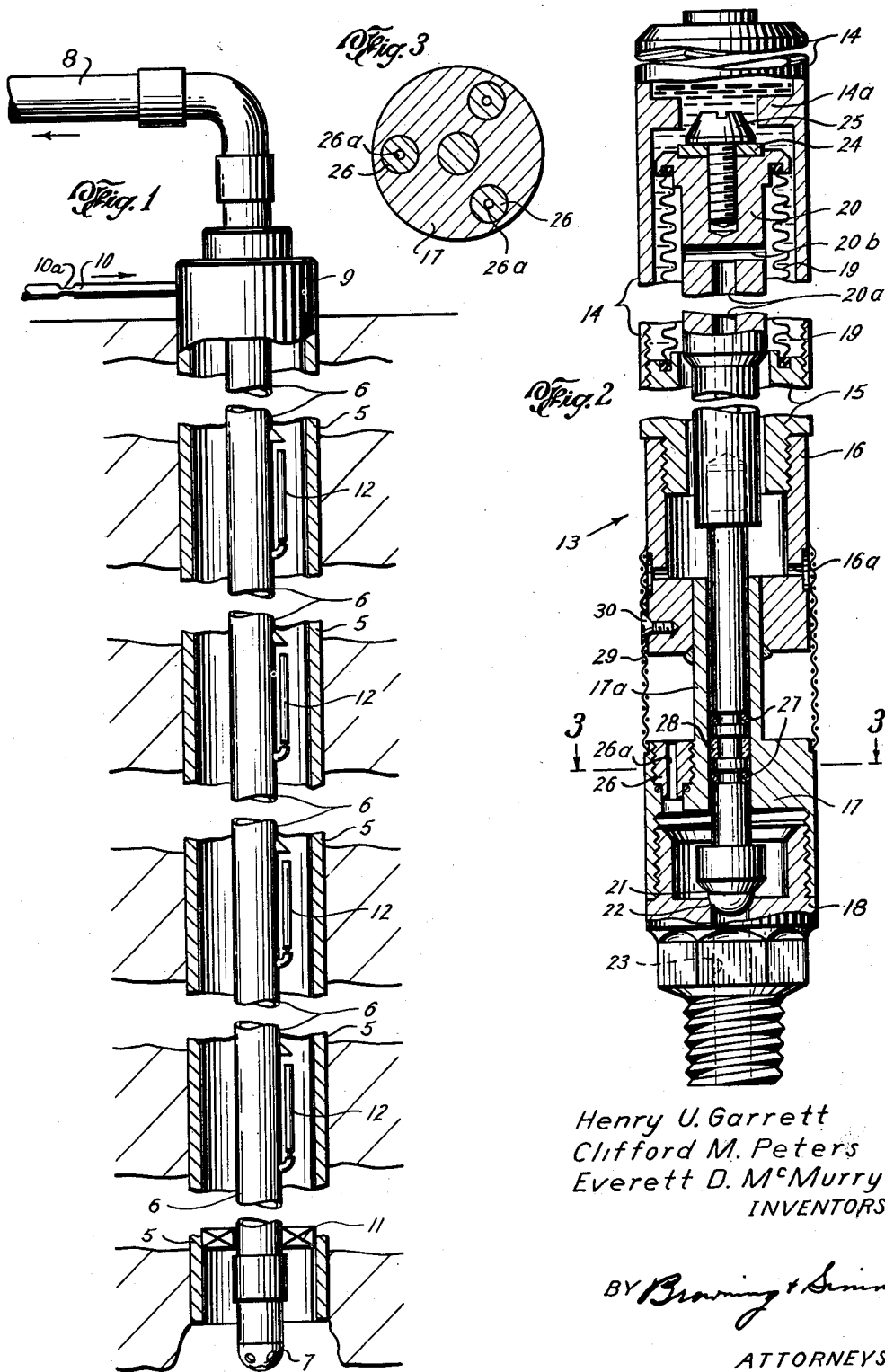
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H. U. GARRETT ET AL

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PRESSURE RESPONSIVE VALVE AND VALVE SYSTEM

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PRESSURE RESPONSIVE VALVE AND VALVE SYSTEM

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This invention relates to improvements in pressure responsive valves and a system of installation of a series of such valves, and refers more particularly to valves adapted to control the injection of fluid under pressure from one container into another container in response to variations in the pressures within the two containers.

The valve of this invention is especially adapted for use in gas lift operations as they are conducted in the oil industry. In many oil producing wells, it is the present day practice to stimulate production by the injection of gas under pressure into the pipe string which conducts the well fluids to the ground surface. This gas is injected into the string at a level well below the ground and, due to its buoyancy and expansion, forces the well liquids upwardly within the pipe string. Control of the injection of the gas into the flow string of pipe of the well has been attempted by various means, and this invention is concerned with the type of operation employing pressure responsive valves for this purpose; that is, valves that have a sealed off resilient means which hold them closed when the pressure of the gas to be injected into the flow pipe is below a predetermined amount. This means has a part exposed to the pressure of the lifting gas and when the force due to the pressure acting against this part overcomes the resilient means, the valve is opened.

In this method of lifting well fluids to the ground surface, it is desirable, in wells which have a high rate of flow of well fluids from the producing formation into the well bore, to produce the well fluids with a continuous flow. On the other hand, in wells where the well fluids feed slowly from the producing formation into the bore, it is preferred to intermittently inject the lifting gas into the flow string of pipe. Heretofore, it has been impossible to use the same valve installations for either continuous or intermittent production. Also, there has been no means whereby the wells can be produced continuously which employ pressure responsive valves adapted to positively open and close in response to pressures within the two containers or strings of pipe.

In addition, it is desirable to employ a valve installation which makes it possible to produce the well fluids through the working valves or lower valves of the installation at a high pressure. In pressure responsive equipment heretofore used, it has been necessary to successively reduce the opening pressures of successively lower level valves to prevent the untimely opening of

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the upper valves. This greatly reduces the available working pressure at the working valve.

Another problem that has confronted the industry when employing gas lift valve installations, where the pressure responsive valves employ a charge of fluid under elevated pressures acting through a bellows or other movable seal element, has been that, where the bellows of one of the dumping valves fails, the pressure charge will drop and these upper valves will then open during normal operation or working of the well. When this occurs, the well must be shut down and the upper valves repaired or replaced. It is desirable to provide a valve of this type wherein the valve will open when the pressure of the pressure charge within the dumping valves is somewhat less than the pressure of the control fluid or a gas to be injected into the flow conduit of the well. Then, if the bellows or seal element of the valve is destroyed, the pressure charge within the dumping valves will equalize with the control pressure and effectively maintain the valve closed.

An object of this invention is to provide a pressure responsive valve which is especially adapted for use in gas lift production of well fluids.

Another object is to provide a pressure responsive valve which may be employed in gas lift production of well fluids in both intermittent or continuous flow operations.

A further object is to provide a pressure responsive valve which makes it possible to equip a well for gas lift production wherein the hydrostatic head of well fluids may be dropped without substantial loss of operating pressure at the working valves of the well.

Still another object is to provide a pressure responsive valve employing a pressure charge as a resilient means for maintaining the valve closed except at predetermined pressures wherein the pressure charge is of lesser magnitude than the control pressure at which the valve will open.

A still further object is to provide a system for gas lift operations which will provide continuous flow of lifting fluid into the well at any one of several possible working valves so as to efficiently produce the well fluids.

Yet another object is to provide a gas lift system for wells for employing a series of pressure responsive valves, each having resilient means for maintaining the valve closed under predetermined ratios of pressures within the pressure or gas injection string of pipe and the flow string of pipe, whereby the well may be produced continuously from the working valve at the same

pressures used to dump the well or may be produced intermittently at substantially such pressures.

Yet a further object is to provide a gas lift valve employing a resilient means for holding the valve closed which is subjected to the pressure of the fluid to be injected into the production string of pipe to provide a force tending to open the valve and having an arrangement whereby the pressure within the production string will influence opening and closing of the valve.

Even another object is to provide a flow fitting which may be employed in conjunction with a pressure responsive motor and adapted to maintain a part of the pressure mechanism tending to maintain the valve open in a pressure zone which will be influenced by the pressure within the container into which the pressure fluid is to be injected.

Other and further objects of the invention will appear from its full description.

In the accompanying drawings, which form a part of the instant specification and are to be read in conjunction therewith, and wherein like reference numerals are used to designate like parts in the various views:

Fig. 1 is a diagrammatic view of a well installation illustrating the invention and equipped with a plurality of pressure responsive valves embodying this invention;

Fig. 2 is a fragmentary sectional view upon an enlarged scale showing the details of the pressure responsive valves shown in Fig. 1; and

Fig. 3 is a view taken along the line 3—3 in Fig. 2 in the direction of the arrows.

Referring to the drawings, in the illustration of Fig. 1, the numeral 5 designates the usual well casing and the numeral 6 indicates the usual string of well tubing. With the installation as shown, the tubing 6 constitutes the flow string of tubing and communicates through a screen 7 at its lower end with the producing formation. At its upper end, the tubing string 6 is connected with a flow line 8. The well head 9 provides a seal for the annulus between the pipe strings 5 and 6. A connection 10 is provided for supplying a lifting gas under pressure to this annulus. Usually, a packer seals off this annulus at a lower level beneath the lowest gas lift valve installation and is shown schematically at 11.

The tubing string 6 has mounted along its length a plurality of pressure responsive valves 12. These valves will ordinarily be installed with the uppermost valve just below the upper level of the accumulated well liquid or hydrostatic fluid head. The lowest valve 12 will be installed at the level where gas is to be injected into the flow string for normal working of the well, if this is known, but where this is not positively determinable, the lower valve or valves will be at a sufficiently low level to insure proper operation through one of the lower valves, that is for example, the lowest one, two or three valves of the installation.

Turning now to a description of the individual pressure responsive valves employed in the installation, reference is made to Figs. 2 and 3. The valve may be considered as made up of the usual pressure responsive motor, which may be of any conventional type employing a resilient means such as a pressure charge, a spring, or a combination of a pressure charge and spring, arranged to force the valve member toward closed position. It is preferred to use as a motor the arrangement shown in the co-pending application

of Henry U. Garrett and Clifford M. Peters for Pressure Responsive Valves, Serial No. 737,600, filed March 27, 1947, now Patent No. 2,519,242, but for further example, the arrangement shown in our co-pending applications for Valves, Serial No. 789,964, filed December 5, 1947, and for Pressure Responsive Valves, Serial No. 771,160, filed August 29, 1947, now abandoned, may be employed. In conjunction with this motor, a flow fitting is employed, which provides a pressure chamber about the valve member arranged to reflect substantially the pressure of the flow string of pipe of the well, the arrangement being such that this pressure urges the valve member toward open position.

Referring in detail to the valve, it includes a housing 13 made up of a cap or dome 14, a nipple 15 threaded thereto, a ported member 16 threaded to the nipple, and a flow fitting made up of a choke support 17 and a seated member or valve cage 18.

The motor is included within the parts 14, 15 and 16 of the housing and its function and construction is described and explained in great detail in the above-mentioned co-pending application, Serial Number 737,600, but will be described at considerable length herein. The interior of the dome member 14 houses the resilient means which, in the preferred form, constitutes a bellows 19 sealed at one end to nipple 15, and at its other end to the head of valve guide or stem 20. This stem 20 may be made up of two or more parts as indicated in the drawings. A seal is provided between the nipple 15 and cap 14 so that the bellows constitutes a movable part or element, in conjunction with the head of stem 20, sealing off a chamber in the housing. This chamber may be charged with a pneumatic fluid under predetermined pressure and the force of this fluid charge against the movable part provides a force that will urge the valve member 21 against the seat 22 in port 23. The sealed off chamber may carry an apertured partition 14a, the aperture of which is to be engaged by seal washer 24 secured to the upper end of stem 20 by screw 25. A non-compressible liquid such as water may be placed in the sealed chamber in sufficient quantity to completely fill the space between the bellows and the part of the housing beneath partition 14a when the bellows has been expanded or extended sufficiently to abut washer 24 on the underside of partition 14a to close the aperture therein. This provides a non-compressible backing for the bellows to protect it against excessive pressure differentials that may be encountered when equipping a well for gas lift.

With this arrangement, the pressure exteriorly of the device communicates with the interior of the bellows through ports 16a of ported member 16 and acts against the inner area of the bellows, which due to the thickness of the bellows, usually about eighteen thousandths of an inch, is less than the effective pressure area of the movable element which is subjected to the pressure of the pressure charge. Therefore, the pressure exteriorly of the device will of necessity exceed the pressure charge in order to open the valve. Thus, if in operation a leak should occur in the bellows, the pressure exteriorly of the valves, when increased, will bleed into the sealed off chamber to increase the pressure therein and this will effectively maintain the valves closed so that, if the bellows' failure is in one of the dumping valves, production may be continued through the work-

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ing valves without interruption for repair or replacement of the faulty dumping valve.

The valve stem 20, as heretofore indicated, carries the valve member 21 at its lower end and the motor is adapted to normally maintain the valve closed until the force of the pressure interiorly of the bellows acting against the movable element, plus the force of the pressure against the valve member across the area of seat 22, is sufficient to overcome the force of pressure within dome 14 against the other side of the movable element or the area across the top of the sealed bellows 19.

It is thus seen that the opening of the valve is a function of the ratio of pressures within the flow string of pipe 6 and the gas lift pressure within the other string of pipe 5. In order to maintain this relationship when the valve is open, it is necessary to provide a chamber for the valve member 21 in which the pressure will remain substantially that of the flow tubing. This may be accomplished by providing means for restricting the flow of the pressure fluid into the interior of valve cage 12 as compared with the cross-sectional area of port 23, by providing a constricted portion in the flow passage through the fitting. There will be a pressure drop across the constricted portion of the passage and the pressure within the cage 12 will be substantially the pressure of the tubing. This may be accomplished by providing a series of plugs 26 having choke passages 26a of predetermined total areas. The stem 20 extends through a sleeve 17a in the choke support member 17 and preferably carries seal means, which may be O-rings 27, to provide a low friction seal between the stem and sleeve. This seal should be such as to be substantially frictionless. A lubricant material may be provided in the space 28 between the seal elements 27.

The choke support member 17 has a flange-like part which carries the choke plugs 26 and preferably about three of these plugs are employed. An annular space is provided between the flange-like portion of member 17 and the lower end of the ported member 16. It is preferred to surround this space with a screen 29 which may be secured to housing 13 in any suitable manner as by screws 30. This arrangement greatly reduces the likelihood of debris clogging the choke passages 26a and even though a portion of the screen 29 should become clogged, nevertheless, ample opening will be provided for the passage of gas into the passage through the flow fitting. The upper end of screen 29 may be extended so as to cover ports 16a leading into the interior of the bellows. An external groove in ported member 16 opens into ports 16a and is covered by the screen.

It is contemplated that this arrangement of the flow fitting may be altered as, for instance, by providing restricted openings in the peripheral wall of choke support member 17 communicating with the interior of the valve cage, or by employing a loose fitting stem 20 in the sleeve 17a to provide a constricted annular flow passage therebetween. In the latter instance, of course, the seal elements 27 will be dispensed with. Any other suitable means to provide a restricted flow passage for the flow of pressure fluid through the fitting so as to give a pressure drop within the valve cage, which will be a function of the tubing pressure, may be employed. The advantage of the preferred flow fitting illustrated in the drawings resides in the freedom from clogging of the restricted portion of the

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passage and also in the fact that the passages 26a do not impinge a stream of fluid against the valve member 21 or the stem 20 which would have a deleterious cutting effect thereon.

Referring to the operation of the device and system of installation of this invention, the operation of the individual valve will be first discussed and then the mode of operating the entire installation will be taken up. The valve member is assembled so as to deliver gas from one pipe string into the other and it is contemplated that the arrangement can be such so that the tubing 6 provides the gas supply string and the annulus between the tubing and casing 5 provides the flow string. However, it is usually preferred to produce through the flow string of tubing 6.

The pressure chamber within housing 13 is filled with a predetermined pressure charge of pneumatic fluid except that sufficient liquid may be employed to completely fill that portion of the sealed off chamber of the housing residing below partition 14a when the washer 24 provides a seal between the stem and the partition upon complete opening of the valve. This liquid level is indicated in the drawings. Of course, a spring or other suitable resilient means may be employed either exclusive of a pressure charge or in conjunction with a pressure charge. The flow of the fluid from exteriorly of the housing 13 into the interior of the bellows takes place past ports 16a and the loose fitting stem extending upwardly through nipple 15 and interiorly of the bellows. This passage is constructed so as to be substantially non-restricted whereby pressure variations exteriorly of the device are quickly reflected against the movable element to affect its position within housing 13. It is desirable to provide the stem 20 with an internal axial bore 20a with radial portions 20b adjacent the connection of the stem with the bellows. This provides a passage through which a suitable lubricant such as grease may be forced into the space between the bellows and stem and the space between the nipple and stem. The grease reduces the likelihood of the space becoming clogged with debris and maintains a free or lubricated action of the valve stem whereby the motor is very sensitive.

The flow of fluid through the flow fitting takes place through the screen 29 past the restricted portion of the fitting flow passage illustrated by passages 26a in the preferred embodiment, through the interior of the valve cage and through port 23 into the flow string of the installation. With the valve 21 engaging seat 22, the forces affecting the position of the valve member and the upper end of the bellows and head of stem 20 includes the pressure of the fluid within the sealed off portion of housing 13 acting against the upper end or area across the upper end of the bellows tending to seat the valve. Opposing this is the force due to the pressure exteriorly of the flow device acting against an area equal to the interior of the bellows where it is sealed to the stem, less the diameter of that portion of stem 20 across the seals 27. An additional force tends to open the valve equal to the force of the tubing pressure against the part of the valve member 21 exposed interiorly of the seat. When these two opening pressures exceed the closing pressure, the valve will shift to open position. When this occurs, flow takes place past screen 29, the restricted portion of the passage provided by chokes 26 and through port 23.

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Inasmuch as the total cross-sectional area of the passages 26a is less than the area across port 23, there will be a pressure drop within the interior of the valve cage or flow fitting as compared to the pressure exteriorly of the device. This pressure drop will be a function of the pressure within the flow tubing adjacent the connection with the flow device. When the column of well fluid within the flow tubing becomes aerated, the force due to the pressure within the flow fitting acting against the valve member and across the stem 20 as it passes through sleeve 17 will be reduced because of the difference in weight of the less dense aerated column and the arrangement should be designed so as to produce a substantial drop in the opening force whereby the valve will be closed. It is recommended that the effective area across stem 20, as at seals 27, be such that a drop of tubing pressure of one hundred pounds will produce a reduction of twenty pounds of the force due to the pressure interiorly of the fitting which forces the valve member toward open position. Of course, this may be altered somewhat to meet particular conditions. The cross-sectional area of the port 23 preferably is equal to the cross-sectional area of the stem at seals 27 to substantially equalize the opening force due to tubing pressure with the valve open or closed.

Taking up the operation of the system, it will be assumed for purposes of discussion that each of the four valves shown in Fig. 1 has a pressure charge which, when tested at the ground, will cause the valves to open at six hundred pounds gauge pressure exteriorly of the devices. Where the preferred valve arrangement, utilizing the bellows having its interior sealed to the stem, is employed, the actual pressure within the pressure dome will be less than six hundred pounds and where the bellows has a cross-sectional area of substantially one inch and a wall thickness of eighteen thousandths of an inch, the actual pressure charge within the dome will be about five hundred twenty-five pounds gauge pressure. The temperature of the well fluids in most of the deep production of today is elevated and will in effect increase the pressure required to open the valves but each of the valves will open at substantially the same pressures. However, if pressure fluid is injected into the casing-tubing annulus, so as to raise the pressure within the annulus adjacent the well head 9 to, say, six hundred pounds, the weight of the column of fluid in the lower levels at which the valves are installed will increase the pressure at these levels where the liquid level is therebelow, to substantially evenly counteract the effect of an increase in temperature.

For purposes of describing the operation of this invention, it will be assumed that the liquid level within the casing-tubing annulus is above the first or uppermost valve 12. The pressure fluid or gas lift medium is introduced into the annulus through conduit 10, and where continuous flow is desired, the fluid will be metered through a choke 10a or other suitable means. The total cross-sectional area of the restricted portions of the passages of the flow fittings of each of the valves 12 is gradually increased at successively lower levels. This is in accordance with the well known fact that a greater volume of lifting gas is required at a lower level than at a higher level. However, the arrangement is such that when any two of the valves are open, the total cross-sectional areas of the restricted por-

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tions of the flow passages through each of the valves will be greater than the area of the choke supplying conduit 10. Thus, when two or more of the valves are open, the casing-tubing annulus pressure will reduce to close at least the uppermost one of the two open valves.

The pressure within string 5 then increases, forcing the liquid level downwardly to uncover the highest valve 12. Inasmuch as the control pressure at each of the valves is greater than six hundred pounds, all of the valves will be open, and when the uppermost valve is exposed to the gas, the gas will flow into tubing 6 aerating the column of fluid. At the same time, the liquid level will be lowered because more gas is being introduced into the casing than the single valve can accommodate. When the second valve has been uncovered, gas will pass into the tubing through both of the top two valves to aerate the column and produce the well fluids. However, this will bleed off the casing pressure until the total forces tending to open the uppermost valve are not sufficient to maintain the valve open. This closing effect will be due to both a drop in casing pressure and tubing pressure at that valve. The liquid level will then commence to drop toward the third valve. When this valve is uncovered, the casing pressure will again drop until the second valve is closed and the dumping process will continue until only the lowermost valve is open.

When the hydrostatic head has been dumped, the amount of fluid metered into the casing will be that required for producing the well at a continuous flow rate. As long as the gas introduced into the tubing maintains the proper producing condition of the fluid within the tubing 6, the valve member 21 of this lowest valve will remain unseated. However, if the well fluid within tubing 6 becomes too light, due to an excess of gas charged into the tubing, the pressure drop interior of the flow fitting and surrounding valve member 21 will be so great as to cause the valve to close. However, immediately upon an increase of the tubing pressure adjacent the valve, the valve will open. By proper regulation of the amount of gas charged into the casing, the lowermost valve 12 will operate substantially continuously to stimulate production of well fluids.

The continuous flow of well fluids is desirable in those wells having a rapid rate of production of well fluids into the bottom of the hole. On the other hand, where the rate of production of the formation is not great and it is desirable to permit time to accumulate a head of well fluids, then the device and installation of this invention may be operated on an intermittent basis. The twenty pounds reduction in closing force, due to lightening of the load within the tubing adjacent the working valve, may be relied upon to effect the intermittent opening of the lower valve. However, it is usually desirable for intermittent operations to drop the opening pressure of the valve or valves, which may be relied upon as intermitters, about twenty-five pounds in addition to this by reducing the force of the resilient means tending to close the valve. By this expedient the well may be produced intermittently with the elimination of any possibility of opening of the upper valves and with but very small reduction in operating pressure at the working valve.

Obviously, if any of the upper or dumping valves should fail so as to open and constantly admit gas to the tubing, it would throw off the

operations and require a pulling of the tubing and repair of the upper valve. Such pulling operations are very expensive and require a shutting in of the well. It is for this reason that the preferred valves are of great value, for if the bellows fails on an upper valve, the pressure within the bellows will not bleed off but rather the casing pressure will bleed into the bellows, for at the operating level, the casing pressure will be greater than the actual pressure charge within the bellows. Thus, the valve member 21 of the faulty dumping valve will be held firmly against its seat and it will not be necessary to pull the tubing string 6 and repair the valve as long as the working valve is functioning properly.

In going into a well for the first time with gas lift equipment, it is often impossible to determine in advance at just what lever the working valve should be installed. In the installations in accordance with this invention if it is determined that the well can be best produced at one of the higher lever valves, this may be accomplished at a continuous flow by metering the gas into the casing at a rate equal to the capacity of the choke passages 26a of the higher lever valve.

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

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

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

The invention having been described, what is claimed is:

1. A gas lift valve comprising a housing, an element movably mounted within the housing and sealing off a variable capacity chamber therein, resilient means within the housing urging the movable element in a direction to increase the volume of the chamber, ports in the housing between the interior and exterior of the housing on the side of the movable element remote from the chamber, an outlet port in the housing with a seat thereon axially aligned with the movable element, a valve member engageable with the seat, an actuating connection between the movable element and valve member, said outlet port communicating with the exterior of the valve with a passage having a constricted portion upstream from the valve member the size of the constricted portion, relative to the outlet port, being such that substantially all of the pressure reduction in the fluid passing through the constricted portion and outlet port takes place across the constricted portion.

2. In a valve of the gas lift type, a housing, a movable element providing a variable capacity sealed off chamber therein, resilient means urging the movable element in a direction to expand the chamber, an opening in the housing wall on the side of the movable element remote from the chamber, a second chamber in the housing spaced axially from the movable element, an outlet port therein with a seat coaxial with the movable element, a valve member controlling the seat, an actuating connection between the movable

element and the valve member, and port means providing a constriction between the second chamber and the exterior of the housing, said port means having sufficiently smaller effective area than that of the outlet port that substantially all of the pressure reduction in the fluid passing through the port means and outlet port takes place across the constriction.

3. A gas lift valve including a fitting with a passage therethrough adapted to provide for flow of fluid under pressure from the exterior of the valve into a receptacle to which the fitting may be attached, a port with a seat on its upstream side making up part of the passage, a constriction in the passage relative to the cross-sectional area of the port such that substantially all of the pressure reduction in fluid passing through the passage takes place across the constriction with the valve in operation, said constriction positioned intermediate the seat and the inlet end of the passage, a valve member adapted to engage the seat to control flow through the port, and a pressure responsive motor connected to the valve member for actuating same, said connection including a rod extending from the fitting with a sealed sliding connection therethrough, said motor having a part exposed to the pressure of fluid exterior of the valve and sensitive to variations therein to influence opening and closing of the valve member, the arrangement being such that the force of pressure within the fitting, between the port and constriction, acting against the effective area of the connecting rod at its sliding seal with the fitting, with the valve member in open position, tends to maintain the valve member in open position.

4. The valve of claim 3 wherein the cross-sectional area of the valve member included within the seat with the valve closed is substantially equal to the effective cross-sectional area of the connecting rod across the sliding seal.

5. A pressure responsive gas lift valve comprising a housing, a port with an upstream seat therein, a valve member adapted to engage the seat to control flow therethrough, resilient means within the housing and connected to the valve member to urge it toward seated position, said resilient means having a part movably mounted within the casing providing a variable capacity sealed chamber therein with one surface exposed to the fluid exterior of the valve, said port being included in a passage sealed off from the resilient means and communicating with the exterior of the valve, a constriction in the passage relative to the port such that substantially all of the pressure reduction in fluid passing through the passage takes place across the constriction, said constriction being intermediate the port seat and the exterior of the valve, the connection between the valve member and resilient means having a moving seal with the housing to seal off the passage, the arrangement being such that with the valve member in open position the pressure of fluid within the passage between the port and the constriction urges the connection, across the area of its seal with the housing, in a direction to hold the valve member open.

6. A gas lift valve including a flow fitting adapted to provide for flow of fluid under pressure from the exterior of the valve into a fluid container to which the fitting may be attached, a port with an upstream seat therein making up a part of the fluid passage of the fitting, a valve member movable interiorly of the fitting and operable with the seat to control flow there-

through, a pressure responsive motor connected to the valve member for actuating same, said motor having a resilient element urging the valve member closed and a part exposed to the pressure of fluid exterior of the valve urging the valve member toward open position under the influence of such pressure, said fitting having a constricted flow passage communicating between the exterior of the valve and the port and located upstream from the portion of the fitting housing the valve member, the size of the constricted passage, relative to the outlet port, being such that substantially all of the pressure reduction in the fluid passing through the constricted passage and the fitting takes place across the constricted passage.

7. A gas lift valve comprising a housing, a flow passage therethrough with a seated outlet port and a valve member controlling same, a pressure responsive motor means within the housing with an operable connection with the valve member, said motor means including a resilient means constantly urging said valve member toward seated position, said motor means adapted to move the valve member to seated and open positions in response to variations in a control pressure to which it is exposed, the pressure to which the valve member is subjected when seated and from downstream of the seat urging the valve member toward open position in opposition to the resilient means, said passage having a constricted portion upstream of the port whereby the pressure between the constriction and port urges the valve member toward open position when unseated the size of the constricted portion, relative to the outlet port, being such that substantially all of the pressure reduction in the fluid passing through the constricted portion and outlet port takes place across the constricted portion.

8. The value of claim 7 wherein the motor means includes a bellows sealing off a portion of the interior of the housing, said resilient means urging the bellows toward valve seating position against the pressure of control fluid to which the side of the bellows remote from the sealed off portion of the housing is exposed.

9. The valve of claim 8 wherein a charge of fluid under pressure within the sealed off portion of the housing constitutes the resilient means.

10. A gas lift valve comprising a pressure responsive motor part and a flow control fitting for injecting fluid under pressure into a flow string of well equipment, the motor part having the usual housing with an element movably sealing off a variable capacity chamber therein with a resilient means urging the element toward full capacity position and the pressure of fluid in the unsealed portion of the housing urging the element toward reduced capacity position, the flow control fitting including a valve cage with an outlet port carrying a seat, a valve member movable within the cage to control the seat, an actuating connection between the movable element of the motor and the valve member including a rod extending from the cage with the pressure in the cage urging the rod toward valve opening position when the valve is open, and port means so constricted relative to the area of the outlet port that substantially all of the pressure reduction in fluid flowing through the fitting takes place across the port means, said port means communicating between the interior of the cage and the exterior of the gas lift valve.

11. In combination inner and outer strings of well pipe, one adapted to produce well fluid and

the second adapted to supply gas under pressure into the first string of pipe at selected positions therealong to stimulate flow of the well fluids, a series of pressure actuated gas lift valves positioned at descending levels within one of the strings to control injection of fluid from the second pipe string into the first pipe string in response to pressure within both strings, each of said valves having an outlet port between the interiors of the strings with a valve member controlling same, a constricted opening between the port and interior of the second string, the size of the constricted opening, relative to the outlet port, being such that substantially all of the pressure drop in the fluid passing from the second pipe string into the first takes place across the constricted opening, a resilient means connected to and urging the valve member closed and having a part exposed to pressure within the second string and urged thereby toward valve opening position, the pressure within the first string tending to unseat the valve member when seated and the pressure between the port and constricted opening tending to prevent seating of the valve member when in open position whereby when gas is introduced into the second string at a predetermined velocity, a well so equipped will be automatically dumped of accumulated hydrostatic head of well liquid and then continuously produced from lower ones of the series of valves.

12. The combination of claim 11 wherein means is provided for metering lifting gas into the second string adjacent the ground surface and the constricted portions of the passage of each of the valves being increasingly large in descending order, the arrangement of these constricted passages being such that with any two of the valves open and passing gas, the pressure within the second string will be lowered to such extent that the uppermost of the two valves will be closed.

13. The combination of claim 12 wherein each of the valves has a charge of fluid under pressure serving as the resilient means for holding the valve members closed and each of the pressure charges for the valves are such as to cause the valve to open under identical pressures when tested under atmospheric pressure conditions.

14. A gas lift valve which comprises, in combination, a housing, a bellows mounted in the housing to provide a variable capacity sealed off chamber therein, said housing having an opening therein placing the side of the bellows situated externally of said sealed off chamber in fluid communication with the exterior of the housing so that pressure externally of the housing urges the bellows to decrease the volume of said sealed off chamber, said housing having a second chamber therein spaced axially from the bellows, an outlet port in said second chamber with a seat coaxial with the bellows, a valve member engageable with the seat, a rod extending through the housing into said second chamber and connecting between the bellows and valve member so that movement of the bellows to increase the volume of said sealed off chamber moves the valve member toward said seat, a sliding seal between the housing and rod, port means between the second chamber and the exterior of the housing having sufficiently smaller effective area than that of the outlet port that substantially all of the pressure reduction in the fluid passing through the port means and outlet port takes place across the port means, the arrangement being such that fluid pressure downstream of said valve seat, with the valve member seated, urges the valve member toward open position and, with the valve member

unseated, the pressure in said second chamber acting against the effective area within said sliding seal, likewise urges the valve member toward open position.

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Number

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2,339,487

2,342,301

2,385,316

2,465,060

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Jan. 18, 1944

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