METHOD AND APPARATUS FOR GAS-LIFT PRODUCTION OF LIQUID FROM WELLS

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ABSTRACT

Method and apparatus for gas-lift production of fluid from wells and including a bellows controlled pressure differential responsive gas-lift valve mechanism incorporating a choke structure. The choke may be calibrated for the particular flow rate of the production zone to which the gas-lift valve mechanism is related, in order to provide the valve mechanism with optimum gas-lift capability without allowing any one valve mechanism to use excessive gas and thereby rob other gas-lift valves of sufficient gas for proper operation thereof.

15 Claims, 11 Drawing Figures
FIELD OF THE INVENTION

This invention relates generally to the flowing of wells and more particularly to a system for and method of promoting the production of liquids such as oil from wells by the introduction of gaseous fluid under pressure from the surface, and to a gas-lift valve structure for use in such a system.

BACKGROUND OF THE INVENTION

In the "gas-lift" art, the "gas" may be a hydrocarbon gas, air or any other gas (though for safety reasons it is preferably one that will not support combustion in the context of its use). In all events, in this specification "gas" should be understood to mean gaseous type fluids generally, and not just hydrocarbon gas or any other particular gas.

In the operation of oil wells, and especially in wells wherein the pressure in the formation is insufficient for the production of the well by formation pressure alone, it is customary to make use of gas-lift mechanism by which gas under pressure may be introduced into the well from the surface to promote the outflow of oil.

The gas-lift method of well operation is usually carried out by connecting into the well tubing a number of gas-lift valves which are operable to permit the inflow of gas under pressure from the interior of a gas injection conduit, usually the annulus between well tubing, well casing, into a production conduit, usually the tubing, at longitudinally spaced intervals to cause an upflow of oil and gas in the tubing. The gas-lift valves used in this method of operation are adjusted to be opened and closed upon the occurrence of approximately predetermined pressure conditions in the tubing and/or casing, so that gas is permitted to enter the tubing only at a location and under pressure conditions to most economically cause an outflow of oil.

In the operation of wells by this method, one gas-lift valve in a string may be opened continuously for long periods of "open flow," or a valve may be opened periodically to introduce gas under pressure from the annulus into the tubing.

Oil may be aerated by the gas injected continuously into the production tubing, and thereby lightened for easier flowing, or another common gas-lift technique is to introduce slugs of gas in a single bubble to act as a piston lifting a slug of oil, much as a bubble of steam in a coffee percolator lifts water upward in the percolator's tubing.

In one common application of this general production method, gas-lift valves are provided with mechanism by which the valves are held in closed position by a predetermined force and are opened when the pressure in the well annulus exceeds a predetermined pressure. Such valves are often constructed with closed bellows which are filled with gas under pressure and positioned to exert a closing force on the valve and to be acted upon the pressure in the annulus to open the valve when the pressure in the annulus reaches a predetermined pressure. By the use of suitable mechanisms for controlling the flow of gas from the surface source of gas under pressure into the well annulus, the opening of valves of this type may be regulated to introduce gas from the annulus into the well tubing continuously or at predetermined intervals to cause the outflow of oil from the well through the tubing.

At times gas-lift valves are employed which are constructed to open in response to the combined pressure in the well tubing and in the annulus when such combined pressure reaches a predetermined value. By the use of gas-lift valves of this type the combined forces of the annulus and tubing pressure maintain a value in the open position or the annulus pressure may be maintained at a predetermined value so that when the level of liquid in the tubing rises to a height to increase the pressure in the tubing on the valve by a predetermined amount, the valve will open, then the annulus pressure is allowed to decrease, causing the valve to close.

In the past the valves most commonly used in the practice of gas-lift used bellows and/or springs as the pressure responsive means therein, one company commonly using a sleeve instead of a bellows; still others in the art have used diaphragms, Bourdon tubes, pistons, etc.; but the bellows-type valve has been selected for use in illustration here because it is the most commonly used pressure responsive means in the field at the time of this application for patent and it is easily engineered by all those in the art to give the dimensional quantities of movement at preferred spring rates.

The use of the above described method of well operation, as customarily carried out heretofore, with bellows, sleeve or other type valve, is attended by the disadvantage, among others, that the vertical depth of the valve held open or caused to open or close must be as deep as possible in accordance with the amount of oil which is available to be removed from the well, or large volumes of gas at high pressure may be wasted, either in flowing smaller quantities of oil than could be efficiently obtained, or in allowing the gas to enter the tubing where there is little oil to be lifted by the gas. Thus, if the valve opens at a depth where little oil is in the tubing above the valve, the gas flows out through the tubing with only a negligible outflow of oil, and the outflow of oil will be less than the amount which could be most efficiently produced by the gas injected.

In gas-lift valve mechanisms of usual design the opening and closing movements of the valve are often relatively slow, so that at the beginning of the opening movement and just prior to the closing of the valve the valve is in a partially opened or cracked condition, which results in "throttling" and the rapid cutting or wearing away of the valve seat and other parts.

When more than one producing formation is produced through a single well, peculiar and unexpected problems arise which are often termed "valve interference," not because the valves physically interfere with one another but because the operation of the valves in one string of tubing in a well interferes with the pressure conditions that would properly operate the valves in another string of production tubing in the same well.

For example, assume two production tubings serving two different oil producing formations in the same well, and all valves are so designated to be opened by annulus pressure; and further assume that one formation produces less than the other formation. It is common to experience that the valves in the string producing the least amount of oil, stay open and maintain the annulus pressure too low to permit opening of the valves in the other string without excessive injection gas volume which causes the pressure to build up in the annulus.
Thus, pressure buildup can open a valve in the production tubing of the better producing formation but at the expense of injecting excessive gas into the production tubing of the poorer producing formation. If valves are used in both strings which open only in response to pressure in the production tubing, it is common for valves in both strings will be open on frequent occasion at the same time but the gas-lift system of the poorer producing formation will rob gas from the gas-lift system of the better producing formation, thus reducing efficiency of total well production. If one string of valves open in response to annulus pressure and the other in response to tubing pressure, it is still common to have the tubing-sensitive string use so much gas as to prejudice effective operation of valves in the other string, or to experience other forms of valve interference.

In order to overcome the disadvantages mentioned hereinabove, it is a primary object of the present invention to provide novel method and apparatus for gas-lift production of wells having singular or plural production zones and having the capability of simultaneously and automatically producing each of the production zones with optimum efficiency.

It is another object of the present invention to provide a novel gas-lift valve mechanism that is automatically opened and closed responsive to predetermined pressure differential determined by gas pressure within the annulus of the well surrounding the tubing and fluid pressure within the tubing string at the particular level at which the gas-lift valve may be located. It is an even further object of the present invention to provide a novel gas-lift valve mechanism having the capability of injecting pressurized gas into a tubing string at a rate calibrated in accordance with the production rate of the formation that is produced by the particular tubing string in order to produce the well to an optimum degree without using excessive gas.

Among the several objects of the present invention is noted the contemplation of a novel gas-lift valve mechanism, several of which may be interconnected in spaced relation in a tubing string and may be individually and automatically actuated by pressurized gas introduced into the gas-lift valve structures of a common annulus.

It is an even further object of the present invention to provide a novel gas-lift valve mechanism that is readily adaptable for use in multiple well completions where production fluid may be produced from two or more production zones and which valve structure will not permit gas-lift valves of one tubing string to rob excessive gas from the system and prevent operation of the gas-lift valves of another tubing string producing a separate production zone.

It is also an object of the present invention to provide a novel gas-lift valve mechanism having the capability of being automatically moved to the closed position in the event casing pressure within the annulus of the well should suddenly decrease below a predetermined minimum level.

Another object of the present invention contemplates the provision of a novel gas lift-valve mechanism wherein the valve mechanism includes the capability of moving to the closed position thereof upon a predetermined decrease in the fluid pressure within the tubing string.

It is an even further object of the present invention to provide a novel gas-lift valve mechanism that will effectively close to shut off the flow of annulus gas upon establishment of a predetermined pressure differential between gas within the casing and fluid pressure within the tubing.

It is another feature of the present invention to provide a novel gas-lift valve mechanism having the capability of movement to the closed position thereof upon a predetermined increase in the temperature of either the production fluid or the gaseous actuating medium.

It is an even further object of the present invention to provide a novel gas-lift valve mechanism that may be moved from its open position to the closed position thereof responsive to any combination of decrease in fluid or gas pressure within the casing or tubing and any predetermined increase in the temperature of either the production fluid or the pressurized actuating fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the manner in which the above recited advantages and objects of the invention are attained, as well as others, which will become apparent, and can be understood in detail, more particular description of the invention, briefly summarized above, may be had by reference to the specific embodiment thereof, which is illustrated in the appended drawings, which drawings form a part of this specification. It is to be understood, however, that the appended drawings illustrate only a typical embodiment of the invention and therefore, are not to be considered to be limiting of its scope, for the invention may admit to other equally effective embodiments.

In the drawings:

FIG. 1 is a diagrammatic illustration of a dual completed well producing from two different production formations and further illustrating each tubing string of the well to be provided with a plurality of gas-lift valve mechanisms constructed in accordance with the teachings of the present invention.

FIG. 2 is a fragmentary sectional view of one of tubing strings of FIG. 1, illustrating one of the gas-lift valve mechanisms thereof in greater detail.

FIG. 3A is a fragmentary sectional view of the gas-lift valve structure of FIGS. 1 and 2 showing details of the construction of the upper portion of the valve and its operating mechanism.

FIG. 3B is a fragmentary sectional illustration of the lower end portion of the valve of FIG. 3A, this figure being a downward continuation of the structure illustrated in FIG. 3A.

FIG. 4 is a cross sectional view taken along line 4—4 of FIG. 3B and looking in the direction indicated by the arrows.

FIG. 5 is a fragmentary sectional view of a gas-lift valve mechanism representing a modified embodiment of the present invention.

FIG. 6 is a fragmentary sectional view of the upper portion of a gas-lift valve mechanism representing a further modified embodiment of the present invention.

FIG. 7 is a fragmentary sectional view of the upper portion of the valve mechanism of FIGS. 2 and 3A and showing the valve mechanism in the open position thereof prior to unloading of the well.
FIG. 8 is a fragmentary sectional view of the upper portion of the gas-lift valve structure illustrating the internal movable parts of the valve in the positions the parts will occupy immediately upon closure of the valve.

FIG. 9 is also a fragmentary sectional view of the upper portion of the gas-lift valve mechanism, illustrating the internal movable parts of the valve mechanism in the positions the parts will occupy during cocking movement prior to opening of the valve structure.

FIG. 10 is also a fragmentary sectional view of the upper portion of the gas-lift valve structure, illustrating the internal movable parts thereof in the positions the parts will occupy when the valve mechanism is fully cocked.

SUMMARY OF THE INVENTION

The present invention is directed to a method and apparatus for gas-lift production of the fluid from a well having one or more production strings of tubing disposed therein for production of fluid such as crude oil from one or more production zones beneath the surface of the earth. At least one and preferably a plurality of gas-lift valves, constructed in accordance with the present invention, may be provided at spaced intervals in each of the tubing strings each valve being operative to inject a pressurized actuating gas, such as air, for example, into the tubing string under such conditions as to move fluid from the production zone to well head structure located at the surface of the earth where the fluid may be transported by any convenient means to a suitable storage facility.

Each of the gas-lift valve mechanisms may include a valve mechanism that is capable of controlling movement to the open or closed positions thereof to control injection of gas into the tubing string. The valve mechanism may be controlled by the urging means, which may, for example, be an internally pressurized bellows that is capable of compression and expansion responsive to pressure conditions within the valve housing.

The valve mechanism may also include a biasing means, such as a compression spring, for example, that may be calibrated to allow movement of the valve to the open position thereof under normal automatic valve operation in response to the development of a predetermined pressure differential established by the difference between pressurized gas within the valve housing and the pressure created by the hydrostatic head of production fluid disposed within the tubing.

An important aspect of the present invention resides in means for controlling the flow of pressurized gas into the tubing from individual gas-lift valve mechanisms in accordance with calibration determined by the optimum rates of production from any particular production zone and by the particular location of individual gas-lift valve at various levels within the tubing string. This feature effectively prevents any of the gas-lift valve mechanisms from utilizing excessive amounts of the available pressurized actuating gas and thereby preventing other valves of the tubing string or of other tubing strings from being actuated at all or being actuated to an optimum degree.

The gas-lift valve mechanism of the present invention is intended to have the capability of being automatically moved to the closed position thereof upon a predetermined decrease in casing pressure, upon a predetermined decrease in tubing pressure, upon establishment of a predetermined pressure differential between the casing and tubing, upon a predetermined increase in the temperature of either the operating gas injected into the annulus of the well of the production fluid being produced from the well or upon any combination of pressure or temperature responsive valve closing features.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawings and first to FIG. 1 there is illustrated a fragmentary sectional view of a well such as an oil well having a well casing or liner C positioned in the well bore, within which at least one and frequently two or more tubing strings T and T' are located. The tubing strings each extend downwardly through the casing to a position at the level of production zones Z and Z' and are sealed with respect to the casing and with respect to other tubing strings by packers P and P' located within the casing immediately above the respective production zone and establishing a seal between the exterior surfaces of the tubing and the interior surfaces of the casing. The casing is typically perforated, as shown at S and S' at the level of each production zone thereby allowing fluid from the production zone to enter the casing and come into contact with the lower extremity of the tubing string associated with the particular production zone.

The tubing strings T and T' are typically opened at the lower extremity thereof to permit the inflow of fluid from the production zone, and are connected at the upper extremity thereof to suitable outlet lines L and L' through which the produced fluid is conducted to any desired facility for storage or handling. The casing C is typically closed at the upper extremity thereof by a casing head structure of conventional design and is provided with an inlet conduit 10, which is disposed in communication with the interior of the casing and which leads to a suitable source of gas under pressure, such as a pressure tank or compressor, generally designated 12, from which gas under high pressure may be supplied to the casing. The inlet conduit 10 may be provided with a choke 14 that may be calibrated in accordance with the desired flow rate of the well and may serve to control the amount of pressurized gas transmitted from the source 12 into the casing for gas-lift production of the production zone. It will generally be practical to provide a source of pressurized gas capable of exceeding the requirements of the well. The choke 14 may be changed out for a choke of different calibration, in the event the flow rate of the well should change or different operational characteristics are desired. It is necessary, when employing the present invention, only to supply sufficient pressurized gas for efficient operation of both production zones. The valves will automatically compensate for variation in the rate of production flow from the formations.

The space 18 between the casing C and the tubing strings T and T' is typically referred to in the industry as the "annulus" of the well and that portion of the annulus above the uppermost packer P, within the casing, forms a gas reservoir or pressure chamber within which may be maintained a quantity of gas at a predetermined minimum operating pressure that is sufficient to allow the gas-lift valves of the gas-lift system to function properly. A gas injection control valve 20 may be employed to compensate for variations in the pressure of
the gas supply 12, thereby maintaining in the conduit 10 upstream of the choke 14. In accordance with accepted principles of gas-lift production of oil wells, crude oil will flow from the production formation or zone through the perforations in the casing and is capable of producing to a particular level within the tubing string associated with the particular production formation involved. After the oil has risen to the particular level in the tubing string, the gas-lift valve injects pressurized gas into the tubing as deep as possible below the level to which the oil has risen. The injected gas will serve to aerate or lighten the column of oil above the valve and cause the oil to flow until the oil reaches the casing head and exits through an outflow line and is transported to a storage or handling facility.

For the purpose of introducing gas under pressure from the annulus into the tubing strings at various levels within the tubing string, a number of gas lift valves, generally designated 16 and 16' may be connected into the tubing T at vertically spaced locations within the pressure chamber or annulus 18 of the casing, which valves may be calibrated to open and close upon the occurrence of predetermined differential pressures in the tubing and casing.

It may be desirable to utilize the annulus for production of fluid from one or more of the production zones and utilize at least one tubing string for injection of gas into the annulus of the well. It is most common practice, however, to utilize the annulus as a pressure chamber and to inject operating gas from the pressure chamber into the tubing string in the manner generally set forth herein. In either case, it is necessary that there be provided a pressurized chamber, which may either be the annulus or a tubing string, from which gas is injected into either the tubing string or the annulus for production of the fluid disposed therein. Gas-lift valves constructed in accordance with the present invention will function quite efficiently when either the annulus or one or more tubing strings are utilized to transport produced fluid to outflow lines connected to the wellhead structure of the well.

The valves 16 and 16' in tubing strings T and T' are preferably of a type, such as those described hereinafter, designed to open in response partly to gas injection conduit pressure and partly in response to production conduit pressure, the valve being cocked or set in response to predetermined pressure differential across the valve element of the valve and being opened when the pressure differential decreases to a predetermined or calibrated level or closed when the pressure differential increases to a predetermined or calibrated level.

As will be explained in detail hereinbelow, after a valve has been opened, it may close immediately upon development of any one or any combination of several developments which function to modify pressures sensed by the valve apparatus. If casing pressure or tubing pressure should suddenly decrease the valve will automatically close, thereby shutting down the system until proper pressure conditions have been restored. The valve mechanism will also automatically close upon the sensing of a predetermined differential pressure established by any one of a number of factors including casing pressure and tubing pressure. The valve will also be closed in the event the temperature of the injected gas or the produced fluid should increase to a predetermined maximum level.

With reference now particularly to FIG. 2 and FIGS. 3A, 3B and 4, each of the gas-lift valves, illustrated generally at 16, may take any number of suitable forms one such form being disclosed herein and incorporating a valve housing, illustrated generally at 22, which may include a generally tubular upper housing section shown generally at 24, having externally threaded upper and lower extremities 26 and 28, respectively. An upper connector element 30, having an externally threaded portion 32, may be threadedly received by the upper threaded extremity 26 of the tubular housing element 24 to form an upper closure or the valve housing and to establish fluid communication between the gas-lift valve structure and the tubing string with which the gas-lift valve may be associated.

As illustrated in FIGS. 2 and 3A, the connector element 30 may be provided with an externally threaded upper extremity 34 that may be received by internal threads 36 defined with the lower extremity of a coupling element 38 that may, if desired, have an upper threaded extremity 40 received in threaded engagement within the internally threaded lower extremity 42 of an upper valve connector lug 44. The lug 44 may be connected in any desirable manner to a tubular section 46 of conduit that may be provided with upper and lower internal or external threads for appropriate connection thereof to sections of tubing defining the tubing string of the well.

The upper connector lug 44 may be provided with a counterbore 48, the lower extremity of which may be internally threaded, as shown at 58, for connection to the coupling 38. A plurality of ports 50 may be formed in the wall structure of the upper connector lug 44 and may be disposed in registry with a similar number of ports 52 formed in the tubular conduit section 46, which ports serve to define flow passages through which pressurized gaseous medium may be injected from the gas-lift valve mechanism into the tubing string. A bore 54 may be formed in the coupling element 38 and may serve to conduct the gaseous medium from the gas-lift valve mechanism into counterbore 48 for injection into the tubing string through the flow passages defined by registry of the ports 50 and 52.

A lower housing section 56 may include an externally threaded upper extremity 58 that may be threadedly received by the internally threaded extremity 28 of the upper tubular housing section 24 and may cooperate with the upper tubular housing section to define the valve housing 22. The lower extremity of the valve housing may be enclosed by a closure plug 60 that may be provided with an upper threaded extremity 62 that is threadedly received within the internally threaded lower extremity 64 of a counterbore 66 defined within the lower housing section 56.

The upper connector element 30, the upper tubular housing section 24, the lower housing section 56 and the closure element 60 cooperate to define an internal pressure chamber 68 within the valve housing that may be disposed in communication with the annulus 18 by a plurality of ports 70 formed in the wall structure of the upper tubular housing section 24. Within the pressure chamber 68 may be moveably disposed a valve carrier unit or cage, illustrated generally at 72, that may include an elongated tubular element 74 having an upper end wall 76 provided with a centrally located...
bore 80 through which may extend an elongated stem 82 of a valve element 84 capable of movement to the open or closed positions thereof. The stem portion 82 of the valve element 84 may be provided with a lower threaded extremity 86 to which may be threadedly connected an adjustment nut 88 that may be retained in immovable assembly with the stem 82 by means of a set screw 90 or any other suitable locking element. The purpose of the adjustment nut 88 is to modify the degree of compression of a compression spring 92 that surrounds the stem portion 82 of the valve element and is interposed between upper and lower shoulders 94 and 96 defined by the end wall 76 of tubular element 74 and by the upper surface of adjustment nut 88.

It will be desirable to provide means for imparting movement to the valve element 84 between the open and closed positions thereof and, depending upon the nature of valve actuation desired, such valve movement can be responsive to pressure conditions within the well or responsive to surface control equipment. The structure of the embodiments incorporated herein are particularly suited to pressure responsive actuation and therefore surface controlled actuation need be employed only under circumstances when such is preferred.

One suitable means for imparting opening and closing movement to the valve element 84 may conveniently take the form illustrated particularly in FIG. 3A, which discloses an expansible actuator element or bellows 98 that may be connected at the lower extremity thereof to a vertically extending projection or flange 100, provided at the upper extremity 58 of the lower housing section 56. The lower extremity of the bellows 98 may be bonded to the vertically extending projection or may be connected in any other suitable manner to achieve permanent sealed connection of the bellows to the lower housing section. Likewise, the upper extremity of the bellows 98 may be bonded or otherwise suitably fixed in field engagement to a downwardly extending projection or flange 102 depending from an actuator connector element 104. Connection between the actuator connector element 104 and the valve carrier unit 72 may, if desired, be conveniently established by upper threaded extension 106 that may be formed integrally with or otherwise connected to the actuator connector element 104 and may be threadedly received by an internal threaded bore 108 of an actuator coupling 110. The actuator coupling in turn may be provided with an externally threaded portion 112 that may be threadedly received by a lower internally threaded portion 114 of a counterbore 116 defined within the tubular portion 74 of the valve carrier unit.

The expansible actuator element or bellows 98 thus forms, with the lower housing section 56, the actuator connector element 104, and the closure element 60, an expansible pressure chamber or dome 118. The expansible pressure chamber or dome 118 may be filled with a gas, such as air or nitrogen, for example, that is maintained at any desired pressure that serves to urge the valve carrier unit or cage 72 toward the closed position thereof.

It will be desirable to limit axial movement of the valve carrier unit 72 in order to prevent damaging the valve element 84 or the valve seat in the event the differential pressure across the bellows should increase above a predetermined level. One suitable means for limiting movement of the valve carrier unit in one direction may conveniently take the form of an elongated stem 120 the upper extremity of which may be secured about a depending extension 122 formed integrally with the actuator connector element 104. The stem 120 may extend in moveable relation through a guide bore 124 formed through the lower housing section 56.

The tubular guide stem 120 may extend downwardly as shown in FIG. 3B, with its lower extremity 132 positioned for contact with an annular stop surface 134, defined within the closure element 60, when the stem has been moved to its desired full open position, thereby limiting movement of the valve element 84 in a direction away from the valve seat.

As indicated above, the bellows 98, the lower housing section 56, the actuator connector element 104 and the closure element 60 cooperate to define an expansible pressure chamber or dome 118. The pressure chamber 118 is charged with a gas such as air or any other gaseous medium by connecting suitable gas filling equipment to an internally threaded bore 136 defined within the lower extremity of the closure element 60. A check valve 138, or other suitable valve device, may be suitably received within a smaller diameter threaded bore 140, also defined within the closure element 60, and may serve to allow introduction of the gaseous medium into the expansible pressure chamber or dome 118. In this regard, it should be borne in mind that the space within which the tubular stem 128 is received and the space within the tubular stem itself becomes part of the expansible pressure chamber or dome 118.

After the expansible pressure chamber has been charged with the proper amount of compressed gaseous medium, an externally threaded closure element 144 may be threadedly received within the internally threaded bore 136 of the closure element 60. An annular sealing element 146, which, for example, may be an O-ring, may be disposed within an annular groove 148 for sealing engagement with a cylindrical surface 150 defining the outer extremity of the passageway into the expansible pressure chamber.

It will be desirable to provide means defining a valve seat against which the valve element 84 seats to control flow of pressurized gaseous medium from the gas-lift valve into the tubing string. According to the present invention, such seat forming structure may conveniently take the form illustrated in the upper portion of FIG. 3A, where the connector element 30 is shown to be provided with a generally cylindrical bore 152 and a slightly larger generally cylindrical bore 154 that cooperate to define an annular shoulder 156. A seal element 158 may be received within the bores 152 and 156 with a shoulder 160 thereof bearing upon the annular shoulder 156. The seal element 158 may be retained in proper assembly within the connector element 30 by any suitable means of retention, such as a snap ring 162, for example, retained within an annular groove 164 defined within the connector element 30. The seal element 158 may be disposed in sealed engagement with respect to the internal surface of the connector element 30 by means of an annular sealing element 166, such as an O-ring or the like, that may be retained within a groove 168 formed about the periphery of the seal element 158. The seal element 158 may be provided with an annular sealing shoulder 170 disposed for engagement by a generally spherical surface.
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172 defined at the upper extremity of the valve element 84.

When gas-lift valves, constructed in accordance with the present invention, are connected to the tubing string, as illustrated in FIG. 2, and with the valve element 84 in the closed position thereof, as shown in FIG. 8, pressurized gaseous medium, within the annulus between the tubing and the casing, will be introduced into the pressure chamber 68 of the gas-lift valve structure, thereby developing a force that tends to compress the bellows 98, thereby reducing the dimension of the expansible pressure chamber or dome 118. As the bellows 98 is compressed by the gaseous medium, the valve carrier unit 72 will be moved downwardly thereby applying, through the compression spring 92, a force acting downwardly upon the valve element 84 and tending to move the valve element away from its engagement with the seat surface 170.

As the seat carrier unit 72 is moved downwardly, away from the seat element 84 along with the collapsing bellows 96, the lower extremity 132 of the stop tube 128 may move a distance X, shown in broken line in FIG. 3B, into engagement with the stop surface 134. This movement however will be insufficient to achieve compression of the spring 92 to the degree necessary to develop a force, acting upon the valve element 84, of sufficient magnitude to overcome the differential pressure acting across the valve element and move the valve element away from its seating engagement with the seat element. As fluid pressure within the pressure chamber 68 increases, causing the bellows 98 to compress, the valve carrier unit 72 will be moved downwardly, but the valve element 84 will remain in engagement with the seat element by virtue of the force developed by pressure differential across the valve element. Downward movement of the valve carrier unit, therefore, merely serves to compress, cock, or load the compression spring 92, but, so long as the pressure differential across the valve 84 produces greater closing force than the opening force of the compression spring 92, the valve 84 will remain closed.

It is similarly apparent that, if the force of the spring 92 is not sufficient to overcome the force of the pressure differential across the valve element 84, the valve will remain closed no matter how high the pressure on the outside of the bellows 92 may be raised; unless and until the hydrostatic pressure within the tubing string reaches the necessary magnitude to decrease the differential pressure across the valve element 84 sufficiently to permit the compression spring 92 to open the valve. Hence, the valve is truly responsive not just to casing pressure on the exterior of the bellows, but to casing pressure in combination with hydrostatic pressure within the tubing string, that is transmitted from the tubing through the ports 50 and 52 and into the counterbore 48 where it is caused to bear upon the valve element. Casing pressure, acting within the pressure chamber upon the valve element 84 and the hydrostatic head, also acting upon the valve element, determines the pressure differential across the valve element 84 which works against the force of the spring or other urging means to determine the pressure at which the valve element 84 automatically opens.

After the hydrostatic head has increased to the degree that the force developed by pressure differential acting upon the valve element will no longer overcome the compression of the spring 92, the valve element will move quickly to its open position and will allow the pressurized gaseous medium within the pressure chamber to be injected through the counterbore 48 and through ports 50 and 52 into the production conduit 46 defined by the tubing string.

It will be desirable, in order to prevent injection of excessive gas from the gas-lift valve mechanism into the production conduit 46, to provide a means for metering the gas into the production conduit in accordance with the rate of flow of the particular production zone being produced. One suitable means for achieving optimum metering of gaseous medium into the production conduit may conveniently take the form illustrated in detail at the upper portion of FIG. 3A. The seat element 158 may be provided with an internal axial bore 174 within which may be movably received a piston element 176 having a plurality of spaced annular grooves 178 formed in the periphery of the upper portion of the piston which grooves establish a dynamic sealing restriction with the cylindrical surface defined by the bore 174.

The piston element 176 may be connected to the valve element 84, in the manner illustrated in FIG. 3A, where the lower portion 180 of the piston is shown to be of generally cylindrical configuration and is received within a blind bore 182 formed axially within the valve element 84. A roll pin 184 may extend through aligned transverse bores formed in the valve element 84 and piston 176 and may retain the piston and valve element in assembly. A sealing element 186, such as an O-ring or O ring, may be retained within an annular groove 187 formed in the piston element 176 and may serve to establish sealing engagement with the generally cylindrical wall defining the bore 182.

To provide for metered flow of gaseous medium from the gas-lift valve structure into the tubing string or production conduit, a calibrated bore 188 may be formed axially of the piston and may intersect a transverse bore 190, thereby defining a calibrated flow passage bypassing the sealing elements of the piston and allowing controlled injection of gaseous medium from the gas-lift valve into the production conduit when the valve element 84 is disposed in the open position thereof. The upper extremity of the bore 188 may, if desired, be provided with internal threads 192, which threads may receive an orifice fitting 194 that may be interchanged as desired to modify the calibration of the passage extending through the piston element 176.

If the rate of flow of the production zone being produced should change after the gas-lift valves have been installed, it may be desirable to modify the calibration of the passage extending through the piston element. This can be accomplished simply by removing the orifice fitting 194 and replacing it with an orifice fitting of different calibration.

If a piston has been employed that is not provided with an internally threaded upper extremity, such as shown at 192 in FIG. 3A and the calibration of the flow passage through the piston is established solely by the dimension of the axial bore 188 or the transverse bore 190 of the piston, it may be desirable to remove the piston from the valve element 84 and substitute a piston having an appropriately calibrated flow passage for the particular production rate of the producing formation. The operational characteristics of the gas-lift valve structure, therefore, may be altered simply by replacing...
the piston element 176 with a piston element of different calibration.

With reference to the upper portion of FIG. 3A, it should be borne in mind that the seating surface 170 of the seat element 158, that is engaged by the curved sealing surface 172 of the valve element 84, may, if desired, be of substantially identical cross-sectional dimension as compared with the cross-sectional dimension of the piston element 176. As shown descriptively at the upper portion of FIG. 3A, the dimension D1 of the piston and the dimension D2 of the seat, being substantially identical, cause the forces, acting upon the piston and valve element, to be substantially balanced in all relative positions of the piston and valve element. Balancing of the forces acting upon the piston and valve element effectively eliminates any extraneous forces acting upon the compression spring 92 and therefore allows the compression spring to positively control opening and closing movement of the valve element without interference by other pressure responsive forces.

It may be desirable to provide a gas-lift valve mechanism capable of operating solely in response to differential between the casing pressure and pressure in the tubing string and which valve mechanism does not employ a bellows or other mechanism for imparting closing and opening movement to a valve carried in response to variation in casing pressure. A gas-lift valve mechanism that is solely responsive to such differential pressure, may conveniently take the form illustrated particularly in FIG. 5, where a valve housing structure is shown generally at 200 which comprises a connector element 201 having upper and lower threaded extremities 202 and 203. A generally cylindrical tubular body section 204 may be threadedly connected to the lower threaded extremity 203 of the connector element 201 and may in turn be provided with a lower internally threaded extremity 205. A valve carrier unit, illustrated generally at 206, may be provided with an externally threaded portion 207 that may be threadedly received by the lower threaded extremity 205 of the tubular housing section 204, thereby fixing the valve carrier element in immovable relation with the housing structure of the gas lift valve assembly for the purpose of introducing through the calibrated flow passage of the piston and into the tubing string to lighten the column of fluid.

The valve carrier unit may comprise an externally threaded valve carrier housing 208 having a closed upper wall 209 within which may be formed a valve stem aperture 210. A valve element 211 may be movably disposed within the tubular housing section 204 and may include a generally spherical sealing surface 212 adapted for sealing engagement with a seat surface 213 defined on a seat element 214. The seat element may be of similar configuration as compared with the seat element 158 illustrated in FIG. 3A and may be retained in fixed assembly with the connector element 201 in the manner illustrated in FIG. 3A.

The valve element 211 may be provided with an elongated stem 216 that may extend through the stem aperture 210 and into the seat carrier body 208. A compression spring 218 may be disposed within the seat carrier unit and may be interposed between a stop shoulder 219, defined by the closed end wall 209, and a stop surface 220 defined by the upper extremity of an adjustment element 221 that may be threadedly received by a lower threaded extremity 222 of the stem element 216. A lock element 223 may be carried by the adjustment element 221 for the purpose of locking the adjustment element in immovable assembly with the valve stem 216.

The valve carrier housing 208 may be provided with an annular flange 224 defining an upper annular surface the may be brought into abutment with the lower extremity of the tubular housing section 204 during assembly. The flange 222 also defines a lower surface 225 to which the upper surface of a valve carrier cap 226 may be abutted as the cap is threadedly assembled to an externally threaded axial extension 227 of the valve carrier housing 208. If it becomes desirable to adjust the compression of the spring 218 after the gas-lift valve mechanism has been assembled, access to the adjustment element 221 may be gained simply by unthreading the cap 226 from the externally threaded extension 227. The locking element 223 then may be loosened and the adjustment element may be rotated to increase or decrease the compression of the spring. After this has been accomplished, the lock element 223 may again be tightened to secure the adjustment element in immovable assembly with the stem and the cap 226 may be threadedly assembled to the valve carrier housing to again close the same. Annular sealing elements 228 and 229 may be employed to prevent leakage along the threaded connections between the valve carrier housing and the tubular body section and between the valve carrier housing structure and the cap structure 226.

The valve structure, illustrated in FIG. 5, will be operative solely in response to pressure differential between casing pressure and tubing pressure. The compression spring 218 will be operative to develop a force acting upon the valve element that tends to urge the valve element 211 in an open position thereof with the spherical sealing surface 212 thereof disposed in seating engagement with the seat surface 213. Casing pressure introduced from the annulus of the well into a pressure chamber 230 by means of ports 231 formed in the tubular housing section 204 will, in the closed position of the valve, act upon the surface area of the valve defined by the dimension of the seat surface 213 engaging the valve element. Simultaneously, pressure from the tubing string will act upon the cross-sectional dimension of the piston 212 and develop a force, acting through the piston upon the valve element, that opposes the force developed by annulus pressure on the valve element. Annulus pressure will always be higher than tubing pressure and therefore will develop a force differential acting upon a valve element depending upon the relative values of annulus and tubing pressure.

Opening movement of the valve element 211 will occur when a predetermined pressure differential is reached that develops a net force acting on the valve element that is sufficiently low that the compression spring 218 will overcome the net force and urge the valve element 211 to its open position. When opening pressure differential is reached, the valve element 211 will be moved rather quickly to its open position, thereby allowing pressurized gas, introduced into the pressure chamber 213, to be injected through the calibrated injection passage 232 of the piston element 212 and into the tubing string.

After the valve 211 has been opened for a time and a sufficient volume of pressurized gas has been introduced through the calibrated flow passage of the piston and into the tubing string to lighten the column of fluid
in the tubing string and transport the lightened fluid upwardly toward the well head, the pressure differential between the casing pressure and tubing pressure will be modified to the extent that the valve will again be caused to close because the compression spring 218 will be compressed by forces acting upon the piston to the extent that the valve element is moved into closely spaced relation with the seat surface 213.

When this occurs, the valve element will define a restriction to the flow of fluid through the seat aperture and a pressure differential will be developed across the valve seat itself, tending to further compress the spring 218 to the maximum compressed condition thereof and thereby moving the valve element quickly to the fully closed position. The valve element then will remain closed until liquid production fluid flowing into the tubing string above the gas lift valve mechanism reaches a level where the predetermined opening pressure differential is again created within the valve mechanism.

When the valve element illustrated in FIG. 5 is employed in a gas-lift production operation, the valve element will in most cases remain open a majority of the time and injection of gas into the column of liquid in the tubing string will be virtually continuous. Valves constructed in accordance with FIG. 5 may thus be employed in the deeper portions of the well to cause substantially continuous aeration of the production fluid as it enters the tubing string. When the production fluid is aerated in a substantially continuous manner, the substantially continuous flow of fluid from the production zone to the surface is produced essentially as a stream of aerated fluid rather than being produced in slugs of pure liquid.

If it is desired to provide an unbalanced force acting upon the piston and the valve element, which force is greater against the valve element than against the piston, a gas-lift valve construction to produce this effect may conveniently take the form illustrated in FIG. 6, where a piston 234 may be employed that is of smaller cross-sectional dimension than the cross-sectional dimension of the valve seat surface 236 and within which is defined a calibrated passage 242 through which gaseous medium may be controllably injected into the tubing strings. The seat element 236, defining the valve seat 236, will be constructed of proper dimension to receive the piston 234 in close fitting moveable relation therein. The gas-lift valve construction, illustrated in FIG. 6, is otherwise constructed identically with respect to the gas-lift valve construction illustrated in FIG. 3A. When the valve element 240 is in the closed position thereof with the curved sealing surface bearing upon the valve seat 236, casing pressure within the gas-lift valve will act upon the cross-sectional dimension of the valve element 240 encompassed by the valve seat 236. Tubing pressure will also act upon the surface area of the valve element 240, encompassed by the valve seat 236, and will produce a resultant force acting upon the valve element, depending upon the relative magnitudes of the casing and tubing pressures. After the valve element 240 has moved away from its sealing engagement with the valve seat 236, casing pressure, being injected into the tubing string, will act upon the lower surface area of the piston and will develop a resultant force acting upon the piston that will be effective to modify the valve controlling capability of the compression spring 244.

With reference now to FIGS. 7–10, a gas-lift valve construction of the nature set forth in FIG. 3A and 3B is shown in the various operative positions thereof. FIG. 7 the gas-lift valve construction is shown in the open position thereof while the closed position of the gas-lift valve is depicted in FIG. 8. FIG. 9 depicts the gas-lift valve construction with the valve carrier element being moved relative to the valve element during cocking movement thereof. In FIG. 10 the gas-lift valve construction is shown with the moving parts thereof in the fully cocked position with the valve carrier element being shown in the lowermost position thereof.

The valve element 84 of the gas-lift valve construction of the present invention is ordinarily maintained with the spherical seating surface 172 thereof in seating engagement with the seat surface 170 of the seat element 158 by the bellows 98. The bellows 98 will expand responsive to the charge of pressurized gas disposed within the dome, and will urge the valve element against the seat surface in absence of casing pressure. Casing pressure overcomes the pressure of the bellows and tends to compress the bellows and retract the valve element from the seat. Operation of the gas-lift valve, therefore, may be controlled in large degree by the pressure within the dome. As indicated above, operating pressure within the dome may be increased simply by connecting suitable pressurized gas supply apparatus to the internally threaded bore 136 and injecting the pressurized gas past the check valve 138. To reduce the pressure within the dome, the check valve 138 may be manually manipulated to release a quantity of gas from the dome after the closure plug 144 has been removed.

In the operation of the apparatus, with the valve element 84 in the closed position thereof, a force is exerted by the pressure of gas in the expansible pressure chamber or dome 118 that urges the valve carrier element 72 and the valve element 84 and piston 176 carried thereby, in a direction to urge the valve element into sealing engagement with the annular sealing surface 170. Simultaneously, a force is exerted on the valve elements by the pressure of gas in the annulus that opposes the force developed by pressurizing gas within the dome and therefore tends to compress the bellows and move the valve carrier element, controlled thereby, in a direction tending to move the valve element 84 toward the open position thereof. The valve element 84, therefore may be biased toward the open or closed position thereof, depending upon the pressure differential established by annulus pressure and pressure within the dome 118. With the valve element in the closed position thereof, a closing force is exerted on the valve element by the pressure of gas communicated from the annulus to the pressure chamber 68. An opening force is exerted on the valve by the pressure of the column of fluid in the production tubing 46 above the level of the valve. The direction and the role of gravity and frictional forces is obvious and hence these forces are disregarded in further discussion of the present invention.

Assuming that the valve is in the closed position and that a column of fluid is present in the tubing above the level of the valve which is exerting a certain opening pressure on the valve, but that the combined pressure of the gas in the pressure dome 118 and the closing pressure exerted on the valve by the gas in the annulus between the casing C and the tubing T is sufficient to
hold the valve closed, then upon the admission of additional gas under pressure into the annulus 18 from the source 12 through the choke 14, the pressure in the casing will increase until it exceeds the pressure on the down 15 side by an amount sufficient to cause the bellows 98 to contract, and the valve carrier unit 72 to be moved away from the valve seat element 158 and thereby compress the spring 92. FIG. 9 illustrates movement of the valve carrier unit in the direction compressing the spring 92. This movement may be referred to as a “cocking” movement that takes place immediately prior to seating of the valve element and injection of gas into the tubing string. As shown in FIG. 10, the valve carrier unit has moved downwardly to the full extent thereof i.e., the fully cocked position, thereby compressing the spring 92 to the maximum degree possible. In this particular position the lower extremity 132 of the stop tube 128, shown in FIG. 3B, will be disposed in engagement with the stop surface 134, thereby restraining the spring 92 against further compression. The compression spring 92, when fully compressed, or cocked as shown in FIG. 10, will not be capable of transmitting sufficient force to the stem 82 and valve element 84 to overcome the force exerted on the valve element by annulus pressure and unseat the valve. It is necessary, therefore, that the valve element, in addition be subjected to opposing hydrostatic pressure exerted by the column of fluid in the production tubing T above the gaslift valve.

A further increase in the pressure of the gas in the annulus combines with the opening pressure on the valve member, exerted by the column of fluid in the tubing, causes the valve members to be moved away from the valve seat. As soon as the valve is in a partially opened or cracked condition, fluid from the annulus may flow past the seat surface 170 of the seat element 158 and may enter the piston chamber 177. Restriction to the flow of fluid caused by the calibrated passage 188 and 190 through the piston element 176 will cause the forces acting upon the valve element 84 to be substantially the same in the open as in the closed position by equalization of pressure across the valve element as illustrated in FIG. 7.

With the valve in the open position, pressurized gas will flow from the annulus 18 into the tubing to move the liquid in the tubing above upward toward the wellhead and ultimately to the appropriate flow line for transportation to a storage or fluid handling facility.

After the valve element 84 has moved to the open position thereof, annulus pressure will be communicated into the piston chamber 177 and will act upwardly against the effective cross-sectional area of the piston substantially equalizing or balancing the effect of annulus pressure on the piston or the valve element in either the closed or open position. The balanced effect, created by cooperating between the piston 176 and the valve element 84, causes the compression spring 92 to be subjected to a net force of predetermined magnitude that can be modified by simple adjustment of the compression spring 92. It should be borne in mind that the balancing effect of the cooperative relationship between the piston and the valve element is operative regardless of the particular position of the valve element, thereby preventing pressure differential responsive variation in the forces transmitted through the moveable valve parts to the compression spring. This feature effectively allows the compression spring to be easily adjusted for actuation of the valve element solely in response to pressure differential across the valve element.

The upward flow of gas in the tubing, when the valve 84 is open, causes a reduction of the pressure of gas in the annulus and causes consequent reduction of gas pressure within the pressure chamber 68. The bellows 98, in response to reduction of pressure, will be caused to expand or move upwardly as pressurized gas within the expansible pressure chamber or dome 18 expands to equalize with annulus pressure. When annulus pressure has fallen to a point at which the bellows 92 has expanded to move the valve carrier unit 72 along with the valve element 84 and piston element 176 sufficiently to bring the spherical sealing surface 172 of the valve element into juxtaposition with the sealing surface 170 of the seat element, a differential pressure will be developed across the valve element. When the valve element is almost in seating engagement with the seat, there will be developed a decrease in pressure on the downstream side of the valve element, thereby giving rise to an increase in the net closing force thereon, so that final closing of the valve takes place suddenly with a snapping action. Because of the sudden opening and closing movements of the valve, it is apparent that the valve does not remain in a partially open, or cracked position and does not chatter as is common with other valves. This feature effectively prevents and development of excessive wear or erosion of the valve and the valve seat due to the action of abrasive materials and the cutting capacity of throttled gas does not take place. The valve element, being moveable relative to the valve carrier unit and being controlled by the compression spring 92, will be capable of moving suddenly to the closed position thereof by slight compression of the spring 92 responsive to the force developed on the valve element by pressure differential. The bellows and the valve carrier unit, under such circumstances, are not caused to move suddenly and therefore the life of the bellows is enhanced materially.

The spring 92 is of sufficient stiffness that when the differential between the pressures in the casing and tubing is less than the force of the spring, the valve moves with the bellows without compressing the spring. By this means the valve may be used for either intermittent or continuous flow depending on well conditions.

The strength of the spring may also be varied in accordance with the differential in pressure that may exist between the pressure in the casing and in the tubing to permit the operation of the valve in a manner to cause intermittent or continuous flow of the well in accordance with the well conditions and production demands.

As explained above, historically, production of a well might be regulated by carefully controlling the flow of fluid from a source of pressurized gas through a choke and into the annulus of the well. If the amount of gas injected into the annulus was excessive, a large amount of the gas would be wasted and efficiency of the production facility would be adversely affected. Likewise, if too little gas was injected into the annulus, one or more of the gas-lift valves of a particular tubing string might be prevented from operating. One production zone of a multiple completion well might be produced while production from the other zone might be prevented because sufficient gas for operation thereof may
be robbed by the valves of another string. Also gas-lift valves at certain levels within the well might be prevented from operating if the supply of gas is insufficient. The present invention effectively overcomes this disadvantage by providing each gas lift valve in each of the tubing strings with calibrated flow passages through which the gas must flow to be injected into the tubing string. Each of the valves may be separately calibrated to compensate for differences in desired valve operation due to the production rate of the particular zone being produced by the valve and by differences in pressure within the well due to the particular elevation at which the valve may be disposed. Each of the valve, therefore, may be designed, by use of pistons with properly calibrated flow passages formed therein, to provide optimum operational characteristics and thereby provide for optimum overall production of each of the zones of the well. The calibrated flow passages of the gas-lift valve effectively prevents any of the valves from using excessive amounts of gas and thereby robbing other valves of sufficient gas for operation thereof.

As indicated above, it has been very difficult in the past to insure that each of the valves of a single or multiple completion well begin to operate when operation is begun following a period of down time. It is necessary that the well be completely unloaded of fluid that has risen within the tubing string from the various production zones thereof. Historically, it has been necessary to start well operation in a prescribed manner in order to insure that all of the gas-lift valves begin sequential operation properly. The present invention however effectively eliminates the necessity for employing specific production initiating procedures. It is simply necessary to inject into the annulus a sufficient volume of pressurized gas to enable all of the strings of the well to unload simultaneously. Each of the valves of each of the strings will then function in accordance with the individual calibration thereof and will inject a sufficient volume of gas into the tubing string to move a slug of produced fluid located above the valve upwardly toward the well head where it may be conducted away from the well by flow lines. After the well has been properly unloaded, each of the production zones will continue to flow in accordance with the established flow rate thereof and each of the gas-lift valves will function automatically in response to the rate of fluid being produced. In the event the production rate of the well should increase and there is sufficient annulus pressure to compensate for more rapid valve operation, the gas-lift valves of the present invention will simply and automatically decrease the amount of time between each operational sequence thereof.

Gas-lift valves manufactured in accordance with the present invention will be capable of automatically closing in response to various pressure conditions, in response to predetermined increases in temperature of either the fluid being produced or the fluid being injected into the well or upon any combination of various pressure and temperature conditions. If the temperature of fluid within the well should rise, the pressurized gas within the dome, defined by the bellows, will expand responsive to the increased heat, thereby increasing the pressure within the bellows. The increased bellows pressure will alter the pressure differential at which the valve is designed to close and will cause the valve element to be moved to its closed position well below the designed operating pressure.

It should be borne in mind that gas-lift valve of the present invention are capable of closing responsive to a differential pressure that is determined by the pressure of injected gas within the annulus of the well and the hydrostatic pressure of liquid within the tubing string at above the particular gas lift valve concern. In the event the pressure of gas within the annulus should decrease suddenly, such as by closing of a gas supply valve or by rupture of a gas supply line, fluid pressure within the pressure chamber 68 will likewise diminish thereby allowing the pressurized gas within the expandable pressure chamber 118 to expand the bellows thereby moving the valve element to the closed position thereof.

If the valve is initially in closed position and tubing pressure remains below the operating level thereof, the differential between the pressures in the casing and the tubing will be sufficient to maintain the valve element in the closed position, thereby preventing the upper valves from operating under low tubing pressure conditions.

With the system thus arranged and conditioned for operation, it is apparent that oil entering the casing from the formation located below the packer of the tubing string concerned, rises within the tubing until the pressure exerted by the oil therein is sufficient to cause one or more of the valves in the tubing to open. Gas under pressure in the annulus may then enter the tubing into the oil to cause the oil to flow upwardly out of the tubing.

In the operation of the valve, it should be particularly noted that the valves are not opened by the pressure in the annulus alone, but the force exerted by the internal pressure change of the bellows in the direction of closing movement of the valves is opposed by the pressure in the annulus, so that the springs are compressed to apply a force tending to open the valves, thus placing the mechanism in cocked or loaded condition for the valve to open when the opening pressure on the valve exerted by the column of liquid in the tubing rises to a predetermined value.

It will be readily apparent that by properly adjusting the valves in each of the tubings the well may be produced simultaneously from both of the formations by gas from the same conduit without objectionable valve interference that occurs quite frequently in multiple completed wells produced by prior gas-lift equipment and methods.

The invention is disclosed herein in connection with specific embodiments of the gas-lift valve mechanism, but it will be understood that this is intended by way of illustration only and that various changes can be made in the structure and arrangements of the parts within the spirit and scope of the invention.

It is therefore seen that my invention is one well adapted to attain all of the objects and advantages hereinabove set forth, together with other advantages, which will become obvious and inherent from a description of the apparatus itself. It will be understood that certain combinations 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 present invention.

I claim:

1. A valve mechanism comprising:
a valve housing defining a valve chamber and having inlet and outlet passage means in communication with said valve chamber;
valve seat means being defined within said valve housing;
a valve carrier being movably disposed within said housing upstream of said seat means;
a valve element being movably disposed within said carrier and being movable between open and closed positions relative to said seat means to control the flow of fluid through said valve chamber;
a piston bore being defined in said housing downstream of said seat means;
a piston of substantially the same diameter as the internal diameter of said seat means, said piston extending downstream from said valve element and being movably received within said piston bore, said piston having choke passage means defined therethrough, said choke passage being of smaller diameter than the internal diameter of said seat means and said choke passage defining the smallest flow area in the valve mechanism in the wide open position of the valve element and communicating said inlet and outlet passage means, said valve element remaining sensitive at all times to the difference between upstream and downstream pressures; and
pressure responsive means disposed within said valve mechanism and being capable of imparting a variable force to said valve element, said variable force establishing the necessary difference between upstream and downstream pressures required to maintain the valve element in either open or closed position.

2. A valve mechanism as recited in claim 1;
gas supply means being communicated to said inlet passage means to supply said valve chamber with pressurized gaseous medium;
said outlet passage means being communicated to a source of downstream pressure; and
said piston means transmitting the force induced thereto by said source of downstream pressure to said valve element, thereby rendering said valve element responsive to a net force developed by the differential between tubing pressure downstream of said valve element and pressure within said valve housing.

3. A valve mechanism as recited in claim 2;
said choke passage being calibrated according to the particular rate of gas flow desired in the open position of said valve element.

4. A valve mechanism as recited in claim 3;
said pressure responsive means being a bellows charged with gaseous medium at a predetermined pressure, said bellows being responsive to variation in pressure of said gas supply means for varying the position of said valve carrier within said housing.

5. A differential pressure responsive valve mechanism adapted to be disposed in a pressurized gas environment and being automatically operative to allow flow of gas from said pressurized gas environment through said valve mechanism responsive to predetermined pressure conditions comprising:
valve housing means defining a valve chamber and having inlet and outlet passage means disposed in communication with said valve chamber;
means within said valve housing means defining a valve seat;
a valve carrier element being movably disposed within said valve housing;
pressure responsive means disposed within said housing and causing movement of said valve carrier element responsive to the pressure of said pressurized gas environment;
a valve element being movably supported by said valve carrier element within said valve chamber and being engagable with and movable relative to said valve seat for controlling the flow of fluid through said valve mechanism from said inlet passage means to said outlet passage means;
urging means being disposed within said valve housing and urging said valve element toward the open position thereof;
said valve housing defining a piston bore disposed downstream of said valve seat;
piston means of substantially the same dimension as the internal dimension of said seat means extending from said valve element and being movably disposed within said piston bore, said piston means being capable of movement with said valve element independently of said pressure responsive means; and
a choke passage being formed through said piston means and establishing communication between said inlet and outlet passage means and controlling the flow of fluid past said piston means, said choke passage means being of smaller dimension than the internal dimension of said seat means and said choke passage defining the smallest flow area in the valve mechanism in the wide open position of the valve element.

6. A differential pressure responsive valve mechanism as recited in claim 5 wherein:
said choke passage is calibrated in accordance with the desired rate of flow of gaseous medium through said valve mechanism in the open position of said valve element.

7. A differential pressure responsive valve mechanism as recited in claim 5:
said means defining said valve seat being a seal element being retained within said valve housing and having a flow port defined therein and defining a seat surface disposed for engagement by said valve element in the closed position thereof;
said piston bore being formed within said seat element; and
said flow port and said piston bore being of substantially identical cross-sectional configuration and dimension.

8. A differential pressure responsive valve mechanism as recited in claim 7 wherein:
said choke passage is calibrated in accordance with the desired rate of flow of fluid through said valve mechanism in the open position of said valve element.

9. A differential pressure responsive valve mechanism as recited in claim 8:
said urging means comprising a compression spring means interposed between said carrier element and said valve element.

10. A differential pressure responsive valve mechanism as recited in claim 9:
means for adjusting the compression of said compression spring means and thereby adjusting the necessary differential pressures for controlling opening and closing movement of said valve element.

11. A differential pressure responsive valve mechanism as recited in claim 9:

said valve carrier unit being supported within said valve housing means and having a transverse wall defining a valve stem passage;
said valve element having an elongated valve stem thereon extending in moveable relation through said stem passage;
a spring abutment element being adjustably carried by said valve stem and being adjustable to vary the compression of said spring; and
said compression spring being disposed about said valve stem and being interposed between said transverse wall of said valve carrier unit and said spring abutment element.

12. A differential pressure responsive valve mechanism adapted to be connected to the production tubing of a well and disposed within the casing of the well where the valve mechanism is automatically operative responsive to the differential between casing pressure and tubing pressure, said valve mechanism comprising:

valve housing means defining a valve chamber and having inlet and outlet passage means disposed in communication with said valve chamber, said inlet passage means communicating casing pressure to said valve chamber, said outlet passage means communicating said valve chamber with said production tubing;
means within said valve housing means defining a valve seat;
valve carrier means being movably disposed within said valve housing;
a valve element being carried in movable relation with said valve carrier element;
means supported by said valve carrier element and urging said valve element in a direction away from said valve seat;
pressure responsive means being connected to said valve housing means and connected to said valve carrier means and being responsive to pressure upstream of said valve carrier element toward and away from said valve seat;
said valve housing means defining a piston bore disposed downstream of said valve seat;
piston means carried by said valve element and being movably disposed within said piston bore, said piston means being of substantially the same dimension as the internal dimension of said seat means; and
a choke passage being formed in said piston means and establishing communication between said inlet and outlet passage means and controlling the flow of fluid past said piston means, the area of said choke passage being of smaller dimension than the area defined by said seat means and said choke passage defining the smallest flow area in the valve mechanism in the wide open position of the valve element.

13. A differential pressure responsive valve mechanism as recited in claim 12:
said means defining said valve seat being a seat element being retained within said valve housing and having a flow port formed therein and defining a seat surface disposed for engagement by said valve element in the closed position thereof;
said piston bore being formed within said seat element; and
said flow port and said piston bore being of substantially identical cross-sectional configuration.

14. A differential pressure responsive valve mechanism as recited in claim 12:
said valve carrier means defining an enclosure having a valve stem passage formed therein;
said valve element having elongated stem means extending through said stem passage and into said enclosure and terminating in a free extremity;
said urging means being a compression spring disposed within said enclosure and being interposed between said enclosure and said stem means; and
said piston means extending from the free extremity of said valve element.

15. A differential pressure responsive valve mechanism as recited in claim 14:

means for adjusting the compression of said compression spring means and thereby adjusting the necessary differential pressure for controlling opening and closing movements of said valve element.

* * * * *
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,834,414 Dated September 10, 1974

Inventor(s) Everett D. McMurry

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 11, "productio" should read --production--.
Col. 14, line 5, "face the" should read --face that--.
Col. 17, line 57, "cooperating" should read --cooperation--.
Col. 23, line 47, "of" should read --to--.

Signed and sealed this 24th day of June 1975.

(SEAL)
Attest:

RUTH C. HASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks