DIFFERENTIAL CONTROL GAS LIFT SYSTEM

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ABSTRACT OF THE DISCLOSURE

Apparatus for lifting well bore liquid through a tubing string, a differential control valve preventing the liquid level in the tubing string from rising above a predetermined height, while a differential gas lift valve controls the injection of gas under pressure from the tubing-casing annulus into the tubing string to aerate the liquid column and lift it to the top of the well bore, the differential gas lift valve being so related to the differential liquid level control valve that the differential control valve remains open during normal operation of the system, since the differential gas lift valve will open to lift the liquid column before it rises to a height at which the differential control valve closes. The differential control valve will close in the event the well is shut in or shut down to prevent the liquid level from rising above a predetermined level, so that the differential gas lift valve can begin functioning promptly when production from the well is restarted, and when aid from outside equipment, for the purpose of unloading the liquid in the tubing string above the gas lift valve.

The present invention relates to the production of fluids in a well bore, and more particularly to differential pressure control devices for determining the gas lifting of the fluid in the tubing string to the top of the well bore.

A conventional gas lift system operates by aerating the tubing fluid column with supply gas to reduce the bottom hole pressure sufficiently to induce flow of the producing zone of a well. This is done by injecting casing supply gas into the tubing fluid column through a series of carefully spaced preset gas lift valves installed along the tubing string. These valves are used to sequentially unload the fluids, such as well fluids, drilling mud, or other liquids or gases, from the tubing string, in the desired point of gas injection, employing the normally available supply gas pressure which is fed into the annulus at the top of the well bore. This usually requires a packer to be run and set in the casing for the purpose of isolating the formation from the annulus.

After the upper unloading gas lift valves have accomplished the unloading phase of the fluids in the annulus, they remain closed, the bottom gas lift valve being operative to secure elevation of the tubing fluid column to the top of the well bore under the driving force of the gas supply pressure in the tubing-casing annulus. This gas pressure may be insufficient to raise the production fluid column completely filling the tubing string, so that it has been necessary for the plurality of gas lift valves to be employed for the purpose of partially unloading the tubing fluid column to reduce its hydrostatic head sufficiently, whereupon the bottommost gas lift valve can then take over the function of supply gas, as needed, into the tubing string for the purpose of elevating the fluid column. The bottommost valve operates either continuously or intermittently, depending upon well conditions. The unloading of the tubing fluid column becomes necessary after the tubing string has been shut in, before the normally available gas supply pressure operating through the lowermost gas lift valve could begin performing its function of elevating the shorter column of fluid in the tubing string to the top of the well bore.

It has been proposed to provide a liquid level control device which will determine the level of the liquid in the tubing string after the latter has been initially unloaded, making it unnecessary to subsequently unload the tubing fluid column in the event the well is shut down or shut in, that is to say, a single gas lift valve can aerate or lift the column in the annulus without the necessity for sequentially unloading a full column of tubing fluid. Such a control device is illustrated in U.S. Pat. No. 2,599,713. That patent also proposes the employment of a gas lift valve for intermittently elevating the column of liquid in the tubing string to the top of the well bore. However, the admission of the gas under pressure into the tubing-casing annulus and through the gas lift valve is controlled by a suitable intermitter control mechanism at the top of the well bore.

By virtue of the present invention, it is unnecessary to employ a separate intermitter control mechanism at the top of the well bore, since the gas lift valve itself will determine when it is to be opened for the purpose of introducing gas into the tubing string to elevate the liquid column therewithin to the top of the hole. This gas lift valve is employed in combination with a differential control valve which determines the maximum level to which the formation fluid can rise in the tubing string in the event the well is shut in. The differential gas lift valve opens in accordance with the differential in the gas pressure in the tubing-casing annulus and the pressure in the tubing string. The differential gas lift valve is so designed and adjusted that it will open before the liquid level in the tubing string reaches the maximum height determined by the lower differential liquid level control valve. Accordingly, the lower differential control valve will normally remain open to allow continuous flow of fluid from the formation into the tubing string, while the differential gas lift valve will control the elevation of the liquid in the tubing string to the top of the hole under the impetus of the gas under pressure injected into the tubing string. If the well is to be shut in, the liquid level in the tubing string will rise for the purpose of closing the differential gas lift valve, and the level will continue rising until the differential control valve below the gas lift valve closes. The normal gas pressure in the tubing-casing annulus is sufficient to elevate the liquid in the tubing string to the top of the well bore. No auxiliary equipment is necessary.

Accordingly, by virtue of the present invention, the lower differential control valve, by remaining fully open during the normal operation of the well, does not remain in an intermediate condition at which throttling of the fluid passing therethrough occurs nor does any throttling occur during the opened condition of the gas lift valve. It is unnecessary to use any surface controls, such as intermitters. A single gas lift valve is effective to control the gas lift operation without surface controls, and a differential control valve below the gas lift valve provides a minimum casing-to-tubing restart differential pressure, so that the gas lift valve will be able to inject gas into the tubing at the initiation of the restarting operation.

This invention possesses many other advantages, and has other features which will be more clearly apparent from a consideration of the form in which it may be embodied. This form is shown in the drawings accompanying and forming part of the present specification. It will now be described in detail, for the purpose of illustrating the general principles of the invention; but it is to be understood that such detailed description is not to be taken in a limiting sense, since the scope of the invention is best defined by the appended claims.
Referring to the drawings:

FIG. 1 is a diagrammatic view of a well bore containing apparatus embodying the invention.

FIG. 2 is an enlarged longitudinal section through the lower portion of the well bore containing the differential control valve and differential gas lift valve; and

FIG. 3 is an enlarged vertical section through the differential gas lift valve.

A differential control gas lift system is disclosed in the drawings. As shown diagrammatically in FIG. 1, an oil well A has a casing string B therein with fluid from a producing zone C capable of passing through casing perforations D to the casing interior. A well packer E is set in the casing string above the perforations and a tubing string F is disposed in leakproof relation to the packer, so that formation fluid can flow upwardly through the tubing string to the top of the well bore, the tubing string extending in sealed relation through a casing head G and into a production line H under the control of a surface valve J.

A lower gas lift valve 100 is mounted on the tubing string to control the injection of gas from the casing-tubing annulus K, which is supplied from a suitable compressor or supply line through the line L into the upper portion of the casing string, there being a suitable valve M for controlling such flow of gas. The valve 100 continuously or intermittently unloads a fluid column of production fluid in the tubing string, such production fluid flowing into the casing string through a differential control valve N, which will prevent the liquid level or pressure in the tubing string F from rising to a point at which the liquid cannot be discharged in the tubing string by the supply gas in the casing-tubing annulus K.

The control valve N, in the specific form illustrated in the drawings, may form a permanent part of the tubing string F. This specific valve illustrated is both described and claimed in applicant's copending application for "Differential Pressure Liquid Level Control Apparatus," filed Sept. 19, 1968, Ser. No. 760,683, and which also illustrates other forms of differential control valves than the one specifically shown herein.

As disclosed in FIG. 2, the differential control valve N includes an outer housing or tubular member 200 adapted to be disposed within and in sealed relation to the well packer E, this packer being disclosed only diagrammatically in the drawings, since it can assume any well known form. Preferably, the well packer is of the type that will remain anchored against the action of the formation pressure tending to release it from the casing B and move it upwardly therein. The upper portion of the housing 200 is threaded so as to secure to the lower end of a lowering tubing section 201, constituting part of the tubing string F extending to the top of the well bore. Disposed within the lower portion of the housing is a valve seat member 202 threaded thereinto and having a central passage 203 into which the formation fluid can flow, passing through ports 204 into an annular space 205 surrounding the upper portion of the valve seat member, which is of smaller diameter than the internal diameter of the housing 200. Upward flow of the formation fluid in the housing is controlled by the engagement or disengagement of a valve head 206 provided on the lower end of a piston rod 207 having a central passage 208 therethrough. Elevation of the piston rod removes the valve head 206 from its seat 202 and allows flow of the formation fluid upwardly through the production passage 205 in the rod and through an upper piston 209 secured to the rod into a passage 210 in a stop and protector sleeve 211 in the upper portion of the housing 200 from where the fluid will flow into the tubing string F. The piston 209 is hollow and encompasses an upper reduced diameter portion of the rod 207, its downward movement relative to the rod being prevented by its engagement with a shoulder 212 on the rod, and its upward movement being limited and prevented by a suitable retaining ring 213 mounted in a rod groove 214 and overlying an upwardly facing piston shoulder 215. The piston is slidable longitudinally in a cylinder portion 216 in the upper end of the housing there being a suitable piston seal ring 217 slidably sealing against the wall of the cylinder, leakage of fluid between the piston and rod being prevented by a suitable seal ring 218 in the piston engaging the periphery of the rod 207.

The gas under pressure in the casing-tubing annulus K above the packer E can act upon the rod 207 and tends to elevate it and the rod 207 to effect raising of the valve head 206 from its companion seat 202. This gas can flow through one or more side ports 219 in the housing into an annular cylinder space 220 provided between the rod 207 and the cylinder wall 216, acting upon the transverse downwardly facing areas of the piston 209 and tending to elevate it in the cylinder, limited by engagement of the upper end of the piston with the downwardly facing shoulder 221 of the stop sleeve, this stop sleeve being retained in position by a slip retaining ring 222 disposed in a housing groove 223 and overlying the upper end of the sleeve. Downward movement of the stop sleeve 211 is prevented by engagement of its upper shoulder 224 with a companion upwardly facing stop shoulder 225 in the housing. Leakage of fluid between the sleeve and housing is prevented by a suitable side seal ring 226 on the sleeve engaging the housing wall. The gas pressure is prevented from moving upwardly out of the cylinder space 220 by the external and internal piston seals 217, 218. It is also prevented from leaving this space by a rod seal 227 mounted in the housing 200 and slidably and sealingly engaging the periphery of the piston rod 207.

The gas under pressure in the annulus K is acting in an upward direction on the piston 209, tending to raise it and its rod 207 for the purpose of elevating the valve head 206 from its seat 202 against the force of a helical compression spring 228 disposed in an annular space 229 between the rod and internal housing wall in the lower portion of the housing. The upper end of this spring seats against an inwardly directed flange 230 of the housing containing the rod seal ring 227, and its lower end engages an external flange 231 on the piston rod at its head portion 206, this external flange also carrying a seal ring 232 in its end face adapted to engage and seal against the transverse upper face 233 of the valve seat member. The formation fluid in the housing and the seal and the housing can enter the spring space 229 and can pass upwardly to the piston rod seal 227. The seal diameter of this latter seal 227 against the rod and the seal diameter of the valve head seal member 252 are preferably equal to one another, so that the formation fluid under pressure is acting over equal opposite areas of the piston rod 207 and will not tend to exert a force either elevating or lowering the piston rod. In other words, the valve rod 207 is balanced with respect to the formation fluid.

The pressure within the tubing string F is acting in a downward direction over the piston 209, and also over the upper end area of the piston rod 207. However, it is also acting in an upward direction over the end area of the valve head 206 of the rod between the seal diameter of the valve seal ring 232 and the internal diameter of the production passage 208 of the piston rod. Effectively, the fluid pressure in the tubing string F is acting downwardly over the annular area of the piston 209 between the seal diameter of the upper piston seal ring 217 and the seal diameter of the lower seal ring 227, and this annular area is the same as the annular area over which the lifting gas under pressure is acting in an upward direction on the piston. The gas pressure in the cylinder 220 is exerting an upward force over the annular area of the piston 209, tending to lift the piston rod 207, whereas the pressure in the tubing string F is exerting a downward force on the piston over its annular area.
area, which is supplemented by the downward force exerted by the valve closing spring 228. When the force on the piston 209 exerted by the pressure of the lifting gas, which is always at a higher unit pressure than the pressure in the tubing string F, exceeds the downward force of the fluid pressure in the tubing string F plus the force of the spring 228, the piston 209 and piston rod 207 are elevated to remove and hold the valve head 206 from its seat 202, allowing the formation fluid to flow through the valve and its production passages 208, 210 and upwardly into the tubing string F.

The formation fluid or liquid will flow upwardly through the valve N until the level of liquid in the tubing string F reaches a predetermined point or height at which the pressure of the fluid or liquid column acting downwardly on the piston 209 plus the force of the spring 228 will be sufficient to overcome the upward force of the lifting gas on the piston, the valve then shifting downwardly to its closed position. The predetermined height of the liquid column is selected so that it is substantially less than the pressure of the gas normally available in the tubing-casing annulus K. However, in the operation of the present system, the liquid level does not rise to the height or point at which the valve N will close, except when it is. During normal operations, the gas lift valve 100 functions to aerate the column of liquid thereabove and lift it to the top of the well bore, while the lower differential control valve N remains in its open condition, permitting formation fluid to flow into the tubing string F. The liquid level normally will not rise in the tubing string above the maximum level determined by the valve N (except as aerated by the lifting gas), since the differential gas lift valve 100 will open to permit gas to flow into the tubing string F substantially before such predetermined level is reached.

The differential gas lift valve 100 illustrated in the drawings may be disposed immediately above the differential control valve N. In the specific form illustrated in the drawings by way of example, it is mounted on the exterior of the tubing string F, although a similar valve arrangement may be located within the tubing string. The specific gas lift valve illustrated, and others, are described and claimed in my application for “Differential Pressure Gas Lift Valve,” Ser. No. 764,738, filed Oct. 3, 1968.

As stated above, the differential gas lift valve 100 is mounted on the exterior of the tubing string F. A fitting 20 is suitably secured, as by welding, to the exterior of the valve 100 and has its internal passage 21 communicating with the interior of the tubing string through a slotted port 22. The lower portion 23 of the fitting is internally threaded for threaded attachment of a differential gas lift housing 24 thereto, which has an upwardly facing valve seat 25 adapted to be engaged by a ball check valve element 26 to prevent reverse flow of fluid from the tubing string F into the tubing-casing annulus K. This housing also has a cylindrical valve seat 27 with an area $A_V$ adapted to be closed by the upper valve head portion 28 of a piston valve member 29 slidably mounted in the inner bore of the housing below a plurality of 30 openings or orifices 31 through the wall of the housing below the valve seat 27. Upward movement of the piston valve 29 is limited by engagement of its shoulder 31 with a companion downwardly facing shoulder 32 on the housing, at which time the valve head 28 will be disposed within the cylindrical seat 27, leakage of fluid between the head and seat being prevented by a suitable side seal ring 33 mounted in a groove 34 in the head and sealingly engaging the valve seat 27. When the valve head 28 is sealingly engaged with the seat, the head itself has engaged the ball check valve member 26 and elevated it from its companion valve seat 25 so that the fluid pressure $P_F$ in the tubing string can act in a downward direction over the area $A_Y$ of the valve head.

As illustrated in the drawings, the piston valve member 29 is shiftable downwardly to a position in which its valve head 28 is completely removed from the valve seat 27, opening the chokes 30 to the passage of gas from the tubing-casing annulus K, through the valve seat 27 and into the tubing string F. Downward shifting of the piston valve is limited by engagement of a downward facing piston shoulder 35 with a suitable stop ring 36, in the form of a split snap ring, mounted within an internal groove 37 in the lower portion of the valve housing 24. Such downward shifting of the valve head 28 occurs as a result of the combined action of the fluid pressure $P_F$ in the tubing string acting downwardly over the area $A_Y$ of the piston valve and a tension spring 38, the supper end of which is suitably connected to the lower end of the piston valve 29, the lower end of the spring being suitably connected to a spring anchor member 39 welded, or otherwise attached, to the exterior of the tubing string F, the spring being protected by a suitable enclosure 40. When the piston valve member 29 is in its downward or full port opening position, the spring 38 may have very little tension in it. However, when the valve is in its closed position, the spring may have substantial tension.

It is to be noted that the gas pressure in the tubing-casing annulus K acts in an upward direction over the area $A_P$ of the piston valve, which area is much greater than the area $A_V$ of the upper valve head portion 28 of the piston valve. When the valve is closed, the gas pressure is also acting in a downward direction over the annular area $A_K$ of the large diameter piston portion 41, which is the area between the cylindrical valve seat 27 and the larger diameter surface 42 of the cylindrical portion of the housing in which the piston slides. This pressure is designated $P_K$ in the drawings. When the valve is in the closed condition, the gas pressure can still pass through the chokes 30 to the interior of the housing above the piston shoulder 43 having part of the area $A_P$ and act downwardly on the piston valve 29. The gas pressure acting over this area $A_K$ makes the resultant area over which the gas pressure acts, with the valve in the closed condition, the same area $A_Y$, as the area $A_Y$ of the seat 27 of the gas lift valve. That is, $A_Y - A_P = A_K$.

Thus, with the valve in the closed condition, the tubing pressure $P_T$ is acting downwardly over the area $A_Y$, tending to shift the piston valve to open position. The gas pressure in the tubing-casing annulus K is acting upwardly over the area $A_K - A_P$ or $A_Y$, acting on the piston valve 29 in the closed position. The spring 38 is acting over the piston valve in a downward direction, supplementing the force of the tubing pressure and tending to shift the valve downwardly to open position. When the liquid level in the tubing string has risen sufficiently, so that its downward force on the piston valve supplemented by the spring force exceeds the force of the gas pressure acting upwardly on the piston valve, the piston valve will be shifted downwardly to an open condition, and the gas under pressure can then flow through the open ports 30 and through the valve seat 27 and past the ball check valve element 26, through the tubing port 22 to the interior of the tubing string F, lifting the plug or column of liquid ahead of it to the top of the well bore. The gas pressure $P_F$ within the valve housing 24 on the downstream side of the orifices 31, which will be $P_F - P_K$ less than the gas pressure in the tubing-casing annulus K because of the throttling action of the orifices 30, will then be acting in a downward direction on the piston valve 29 over its full area $A_Y$, this force being supplemented by the force of the spring 38, which can then be rather low, to maintain the piston valve member in the open condition. However, as the slug of liquid is discharged at the top of the well bore, the gas pressure $P_F$ passing through the orifices 30 accelerates, the gas pressure $P_F$ on the downstream side of the orifices and acting downwardly on the piston valve 28 decreasing, until it and the spring 38 are insufficient to hold the valve 29 in the down-
ward or valve opening condition, the greater gas pressure in the tubing-casing annulus K acting upwardly over the area $A_p$ of the piston valve shifting it to the closed condition.

By making the area $A_p$ over which the pressure $P_w$ acts with the valve in the open condition greater than the area $A_O$ over which the tubing pressure $P_t$ acts when the valve is in the closed condition, the area $A_p$ of the orifices or chokes 30 can be made much greater, since the larger piston area $A_p$ compensates for the smaller closing pressure drop created by the enlarged choke or orifice area $A_O$. Thus, there is still provided a differential valve that will open and close at approximately the same differential pressure.

In the operation of the gas lift valve, it is used in connection with the differential pressure liquid control valve N installed in the tubing string F just below the gas lift valve 100 and above the well packer E. It is assumed that the tubing-casing annulus K has been unloaded of liquid down to the location of the gas lift valve 100, the liquid level in the tubing string F also having reached a level in the tubing string at which the tubing pressure $P_t$ plus the spring force opens the gas lift valve 100. The gas under pressure can then flow through the orifices 30 and through the gas lift valve into the tubing string F to lift the liquid to the top of the well bore. As the liquid is being discharged, the velocity of gas through the orifices increases and the pressure $P_t$ inside the valve body 24 and on the downstream side of the orifices 30 will decrease to the point at which the gas pressure $P_g$ in the tubing-casing annulus K will shift the valve to a closed condition. Despite the use of the smaller area of chokes or orifices 30, the pressure differential required to close the valve will be approximately the same as the pressure differential between the gas pressure $P_g$ and the tubing pressure $P_t$ to open the valve, the “small spread” between the two pressure differentials being due to the fact that the greatly increased area of the orifices or orifices 30 is compensated for by the fact of the area $A_p$ of the piston valve over which the gas pressure $P_i$ acts is substantially larger than the area $A_O$ of the valve seat 27.

The gas lift valve will remain closed until the liquid level in the tubing string F has again risen to the point at which the tubing pressure $P_t$ plus the spring force exactly balances the pressure of the gas $P_g$ acting over the differential area $A_p$ of the piston valve 29 ($A_p-A_O$) when it is in the closed condition, and the foregoing cycle of operation will be repeated.

It is apparent that the differential gas lift valve 100 will open when the liquid level in the tubing string F rises to a predetermined point sufficient to exert a downward force on the piston valve 29 and shift it to a condition opening the orifices 30, aided by the tension spring 38. This level of liquid is substantially less than the level of liquid necessary for exerting a downward force on the piston 209 and piston rod 207 of the differential control valve N to shift it to closed position against the elevating force of the gas under pressure in the tubing-casing annulus K. Accordingly, when the differential gas lift valve 100 opens, the lower differential control valve N will remain open, and gas under pressure will rise through the orifice 30, in the gas lift housing 24 and through the valve seat 27 into the tubing string F to accelerate and lift the liquid in the tubing string to the top of the well bore, until the pressure in the gas lift valve on the downstream side of the orifices 30 drops to the point at which the gas pressure in the tubing-casing annulus K will shift the piston valve 29 upward to its closed position.

With the differential gas lift valve 100 closed, the lower control valve N remains open and formation fluid will continue passing therethrough and into the tubing string F, until its level reaches a point at which it can act downwardly on the piston valve 29 and shift it to open condition, aided by the tension spring 38. Thus, in the specific type of differential control valve 100 illustrated, it functions automatically to intermittently shift between opened and closed conditions, depending upon the differential between the tubing-casing annulus gas pressure $P_g$ and the pressure $P_t$ in the tubing string. Its opened and closed conditions depend purely upon the difference between the tubing-casing annulus gas pressure and the internal tubing pressure. It does not require any external control for effecting its operation. On the other hand, the lower liquid level control valve N will remain open under normal operating conditions to allow continuous flow of the formation fluid into the tubing string. It is only when the tubing-casing annulus K may drop sufficiently, as, for example, by diminishing the supply of gas to the annulus, that the liquid level in the tubing string F will rise above the normal opening condition of the differential gas lift valve 100 and up to a predetermined level, beyond which it cannot rise, that the formation fluid in the tubing string F will act in a downward direction on the differential control valve N and shift its piston and piston rod structure 209, 207 downwardly, aided by the spring 228, to engage the valve head 206 with the seat 202, thereby preventing further flow of formation fluid into the tubing string F and an increase in height of the liquid column therewithin.

In the event production from the well is to be restarted, it is only necessary to introduce gas under normal pressure into the tubing-casing annulus K. Such gas under pressure will then flow through the orifices 30, since the piston valve 29 is in its opened condition, increasing the ball check valve 26 and passing into the tubing string F to aerate and lift the liquid column to the top of the well bore. The normal gas pressure is sufficient for this purpose, since the liquid column in the tubing string F has been prevented from rising too greatly by the closing action of the lower differential control valve N. When the “slug” of liquid is discharged from the tubing string at the top of the well bore, the differential pressure across the piston valve 29 will increase to the point at which the gas pressure again shifts it upwardly to its closed condition, at which time the liquid level in the tubing string will have lowered considerably below the maximum level at which it will effect closing of the lower differential control valve. During the unloading of the liquid, the pressure acting downwardly on the piston 209 and hollow piston rod 207 of the lower liquid level control valve N will decrease, the gas under pressure in the tubing-casing annulus K acting in an upward direction on the piston 209 to shift the valve to the open condition. It will remain in such open condition, with the gas lift valve 100 intermittently opening and closing to aerate and elevate the liquid in the tubing string F, unless and until the liquid level rises to the predetermined height at which the lower control valve N closes. During the aeration and elevation of the “slug” of liquid in the tubing string, the pressure in the latter is less than the pressure necessary to effect closing of the lower differential control valve N.

Accordingly, a differential control gas lift system has been provided which prevents the liquid level in the tubing string from rising above a predetermined point after the well has been shut in or shut down, but it does not control the tubing pressure during the gas lift operation, which can be continuous or intermittent, although only an intermittent operation has been described above. The gas lift valve serves to control the gas pressure differential that is greater than the pressure differential required to close the lower valve N; that is to say, although the high pressure gas in the tubing-casing annulus K is the same for both valve 100, N, the opening of the gas lift valve 100 takes place at
a lower tubing pressure than the tubing pressure required to close the lower differential valve N. The gas lift valve 100 operates automatically in accordance with the differential pressure thereacross, and is not dependent upon surface controls for determining its opened and closed states. The gas lift valve 100, with the lower differential control valve N permits the system to operate efficiently and effectively without the necessity for employing a plurality of longitudinally spaced gas lift valves along the length of the tubing string F, since the lower differential control valve N prevents the liquid from entering above the point at which the fluid can be discharged from the tubing string by the gas pressure entering the tubing string through the open gas lift valve 100.

1. In apparatus for lifting fluid in a well bore having a producing formation: a tubular string in the well bore; a control valve for admitting fluid from the producing formation into the tubular string and embodying means responsive to the fluid pressure in the tubular string to effect closing of said control valve when such pressure reaches a first predetermined value which is substantially less than said first predetermined value, whereby said control valve remains open while said gas lift valve is open.

2. In apparatus for lifting fluid in a well bore having a producing formation: a tubular string in the well bore; a control valve for determining the admission of gas into said tubular string and embodying means responsive to the fluid pressure in said tubular string to effect opening of said gas lift valve when such pressure reaches a second predetermined value which is substantially less than said first predetermined value, whereby said control valve remains closed while said gas lift valve is open.

3. In apparatus for lifting fluid in a well bore having a producing formation: a tubular string in the well bore; a control valve for admitting fluid from the producing formation into the tubular string and embodying means responsive to the fluid pressure in the tubular string to effect closing of said control valve when the pressure reaches a first predetermined value; a gas lift valve for determining the admission of gas into said tubular string and embodying means responsive to the fluid pressure in said tubular string to effect opening of said gas lift valve when such pressure reaches a second predetermined value which is substantially less than said first predetermined value; wherein said control valve embodies means responsive to the pressure of gas in the annulus around said tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said control valve being substantially greater than said second differential.

4. In apparatus as defined in claim 2; said control valve including spring means tending to shift said control valve to closed condition; said gas lift valve including spring means tending to shift said gas lift valve to open condition.

5. In apparatus for lifting fluid in a well bore having a producing formation: a tubular string in the well bore; a control valve for admitting fluid from the producing formation into the tubular string and embodying means responsive to the fluid pressure in the tubular string to effect closing of said control valve when such pressure reaches a first predetermined value; a gas lift valve for determining the admission of gas into said tubular string and embodying means responsive to the fluid pressure in said tubular string to effect opening of said gas lift valve when such pressure reaches a second predetermined value which is substantially less than said first predetermined value; said control valve including a first valve seat, a first valve member engageable with said seat to close said control valve, said first valve member having said means which is responsive to said fluid pressure in the tubular string to engage said first valve member with said first seat, said first valve member having means responsive to the pressure of gas in the annulus around said tubular string to shift said first valve member from said seat, and means acting on said first valve member supplementing the force of the fluid pressure in the tubular string tending to engage said first valve member with said seat; said gas lift valve including a second valve seat, a second valve member engageable with said second seat to close said gas lift valve, said second valve member having said gas lift valve means which is responsive to said fluid pressure in the tubular string to disengage said second valve member from said second seat, said second valve member having means responsive to the pressure of gas in the annulus around said tubular string to shift said second valve member into engagement with said second seat, and means acting on said second valve member supplementing the force of the fluid pressure in the tubular string tending to disengage said second valve member from said second seat.

6. In apparatus as defined in claim 1; said gas lift valve including orifice means through which gas flows into the tubular string when said gas lift valve is in open condition.

7. In apparatus as defined in claim 2; said gas lift valve including orifice means through which gas flows into the tubular string when said gas lift valve is in open condition.

8. In apparatus as defined in claim 5; said gas lift valve including orifice means through which gas flows into the tubular string when said gas lift valve is in open condition.

9. In apparatus for lifting fluid in a well bore having a producing formation: a tubular string in the well bore; a control valve for determining the admission of gas into said tubular string and embodying means responsive to the fluid pressure in the tubular string to effect closing of said control valve when such pressure reaches a first predetermined value; a gas lift valve for determining the admission of gas into said tubular string and embodying means responsive to the fluid pressure in said tubular string to effect opening of said gas lift valve when such pressure reaches a second predetermined value which is substantially less than said first predetermined value; wherein said control valve embodies means responsive to the pressure of gas in the annulus around said tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said control valve being substantially greater than said second differential.

10. In apparatus as defined in claim 2; said control valve including spring means tending to shift said control valve to closed condition; said gas lift valve including spring means tending to shift said gas lift valve to open condition.
valve including a second valve seat, a second valve member engageable with said second seat to close said gas lift valve, said second valve member having said gas lift valve means which is responsive to said fluid pressure in the tubular string to disengage said second valve member from said second seat, said second valve member having means responsive to the pressure of gas in the annulus around said tubular string to shift said second valve member into engagement with said second seat, and spring means acting on said second valve member supplementing the force of the fluid pressure in the tubular string tending to disengage said second valve member from said second seat.

10. In apparatus as defined in claim 5; said gas lift valve being constructed and arranged to open at a predetermined first differential between the annulus gas pressure and tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said first differential being substantially greater than said second differential.

11. In apparatus as defined in claim 9; said gas lift valve being constructed and arranged to open at a predetermined first differential between the annulus gas pressure and tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said first differential being substantially greater than said second differential.

12. In apparatus as defined in claim 5; said gas lift valve being constructed and arranged to open at a predetermined first differential between the annulus gas pressure and tubular string fluid pressure; said control valve being constructed and arranged to close at a predetermined second differential between the annulus gas pressure and tubular string fluid pressure; said first differential being substantially greater than said second differential.

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