

Jan. 9, 1968

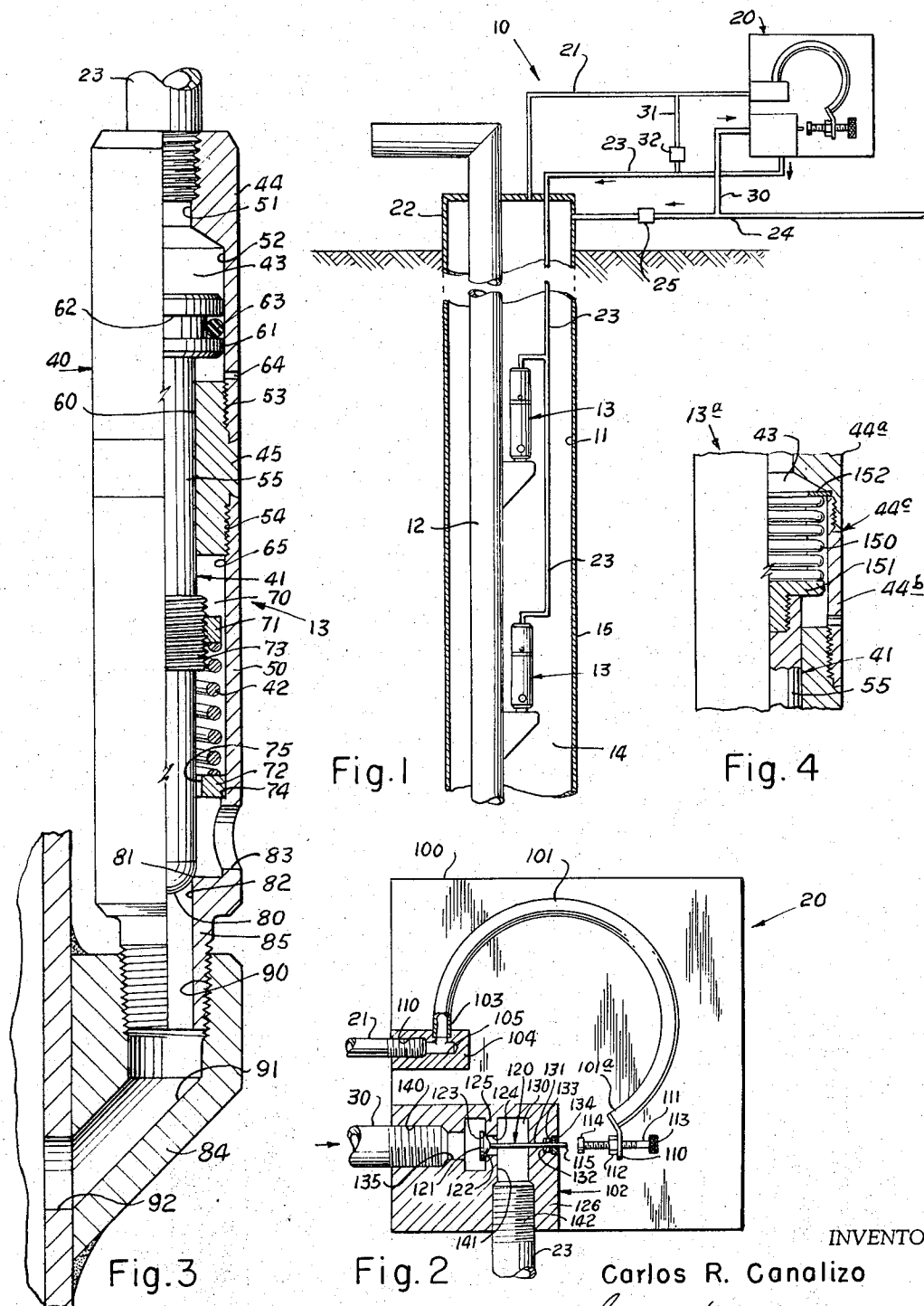
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3,362,347

GAS LIFT SYSTEMS AND VALVES

Filed Jan. 5, 1966

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

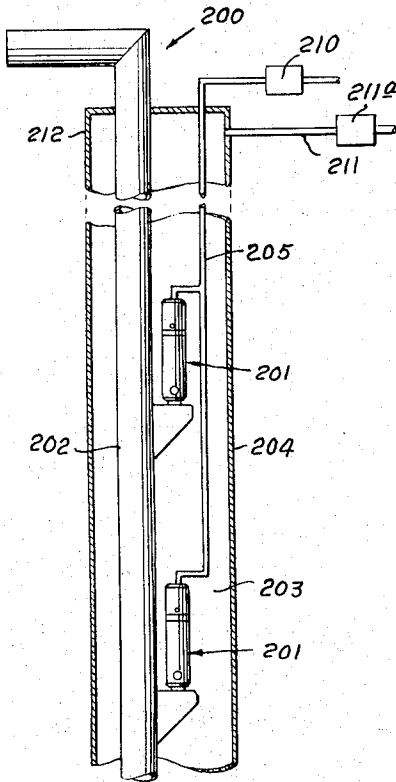


Fig. 5

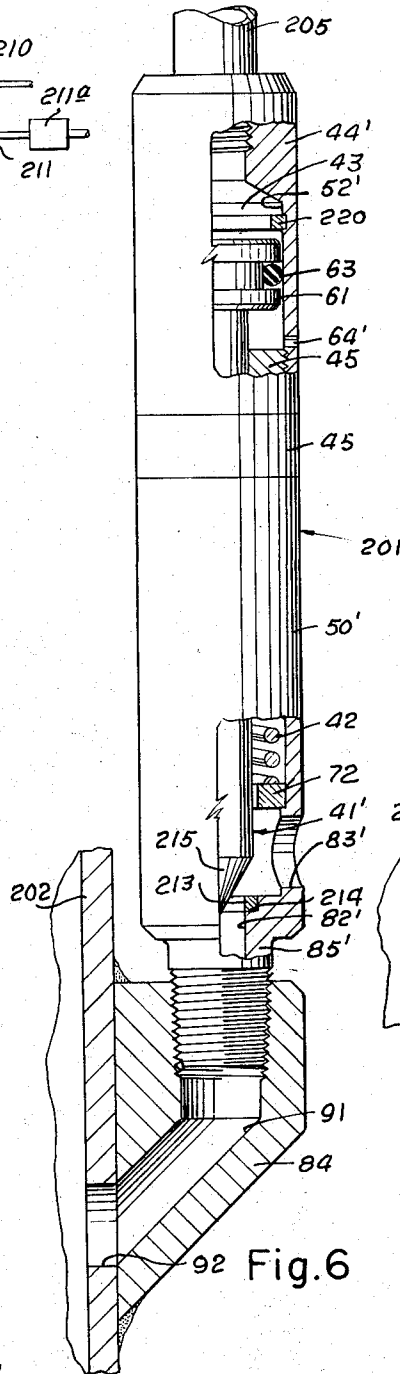


Fig. 6

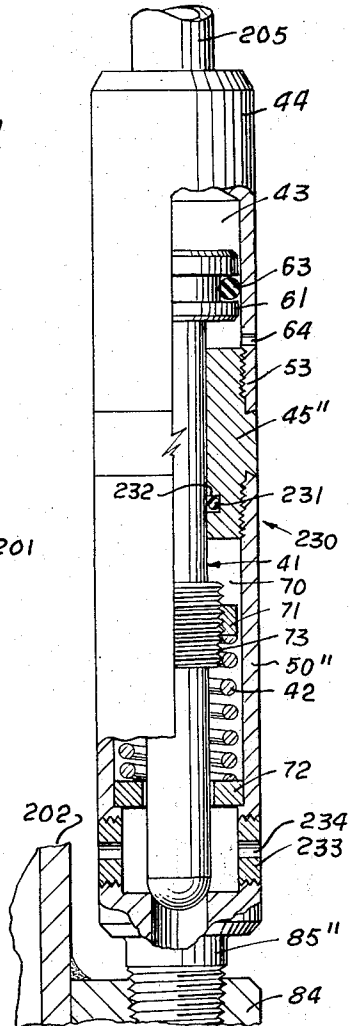


Fig. 7

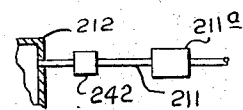


Fig. 5-A

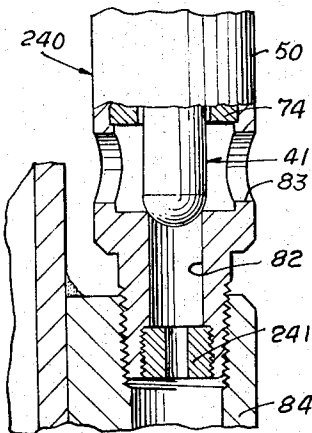


Fig. 8

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GAS LIFT SYSTEMS AND VALVES

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ABSTRACT OF THE DISCLOSURE

A gas lift system and a valve for use therein having a surface controlled pressure sensitive valve actuating structure providing for opening and closing the valve in response to a control fluid pressure controlled from the well surface in opposition to the lift fluid pressure, the pressure of the fluid in the eduction tubing and resilient means in the valve biasing the valve toward open position.

This invention relates to systems for producing well fluids and more specifically relates to gas lift systems and valves useful therewith.

It is an object of this invention to provide a new and improved gas lift system.

It is another object of this invention to provide a new and improved valve for admitting fluids into a tubing disposed in a well bore.

It is a particularly important object of this invention to provide a new and improved gas lift valve.

It is a further object of this invention to provide a new and improved gas lift system for removing liquids through a well tubing disposed in a well casing wherein gas within an annular flow passage between the casing and the tubing provides a lifting force for removing the liquids to the surface through the tubing.

It is another object of the invention to provide a gas lift valve which is operable responsive to the liquid level within the well tubing.

It is a particularly important object of the invention to provide a gas lift valve which is biased toward a closed position by dome gas pressure which is controllable from the surface.

It is an additional object of the invention to provide a well tool for automatically removing liquid from a well bore including a valve which opens intermittently to permit gas to flow from an annular flow passage within the well casing around the tubing into the tubing to transport liquids present in the tubing above the valve to the surface through the tubing.

It is another object of the invention to provide a gas lift system wherein each time the casing pressure drops below a predetermined level the dome pressure is raised to a level in excess of the casing pressure to close the valve which subsequently is held in closed position by dome pressure equal to the casing pressure.

It is a still further object of the invention to provide a gas lift system including a surface control unit having means operable responsive to the casing pressure for controlling the valve dome pressure so that the dome pressure is increased when the casing pressure is decreased below a predetermined value.

It is a still further object of the invention to provide a gas lift valve which opens responsive to a predetermined pressure within the well tubing and closes responsive to a predetermined pressure within the casing annulus around the tubing.

It is another object of the invention to provide a gas lift valve which is biased toward a closed position by dome gas pressure and biased toward an open position by the force of a spring and the pressure of fluid in the tubing string of the well.

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It is still a further object of the invention to provide a gas lift valve having a valve member provided with a piston which is reciprocable in a dome gas chamber to bias the valve member toward a closed position.

5 It is a further object of the invention to provide a new and improved gas lift system including one or more lift gas injection valves which remain open continuously responsive to predetermined pressure conditions for introducing lift gas into a tubing string from a surrounding casing annulus.

10 It is another object of the invention to provide a gas lift system including lift gas injection valve means for continuous introduction of lift gas into a tubing string which has means for biasing the valve means toward a closed position by a force from gas under pressure supplied to the valve from the surface.

15 It is a further object of the invention to provide a new and improved gas lift system having one or more lift gas injection valves each including a dome gas chamber continuously supplied with gas at a regulated pressure from the surface for biasing the valve toward a closed position.

20 It is still a further object of the invention to provide a valve for injecting lift gas into a tubing string from a casing annulus which includes a valve member having a throttling tip for reducing the pressure of the lift gas from the casing annulus into the tubing string.

25 It is another object of the invention to provide a gas lift system for continuous injection of lift gas from a casing annulus into a tubing string including one or more injection valves biased toward a closed position by fluid under pressure supplied from the surface, each of the valves including a choke in an outlet passage leading from the valve to the tubing string and a choke in a lift gas supply flow line leading into the casing annulus at the surface.

30 It is another object of the invention to provide an injection valve for a gas lift system which includes choke means for reducing the pressure of lift gas from a casing annulus into a chamber around a valve member of the injection valve at a location upstream from a seat surface engageable by the valve member.

35 Additional objects and advantages of the invention will be readily apparent from the reading of the following description of a device constructed in accordance with the invention, and reference to the accompanying drawings thereof, wherein:

40 FIGURE 1 is a diagrammatic view partially in section and partially in elevation illustrating a gas lift system in a well which includes a gas lift valve embodying the present invention;

45 FIGURE 2 is an enlarged schematic view partly in section and partly in elevation of a surface control unit employed in the gas lift system illustrated in FIGURE 1;

50 FIGURE 3 is a longitudinal view partially in elevation and partially in section of a gas lift valve included in the system of FIGURE 1;

55 FIGURE 4 is a fragmentary view partially in section and partially in elevation illustrating a modified form of gas lift valve of FIGURE 3;

60 FIGURE 5 is a diagrammatic view partially in section and partially in elevation illustrating a gas lift system embodying the invention for continuous injection of lift gas into a tubing string;

65 FIG. 5A is a fragmentary diagrammatic view illustrating a modified form of the gas lift system shown in FIGURE 5;

70 FIGURE 6 is a fragmentary view partially in section and partially in elevation of a gas lift valve used in the gas lift system of FIGURE 5;

FIGURE 7 is a fragmentary view in section and eleva-

tion of another form of gas lift valve utilized in the gas lift system of FIGURE 5; and,

FIGURE 8 is a fragmentary view in section and elevation of a further form of gas lift valve employed in a modified gas lift system similar to that of FIGURE 5.

Referring to the drawings, a gas lift system 10 embodying the invention is installed in a well 11 to supply lift gas intermittently into a tubing string 12 for displacing well fluids through the tubing string to the surface. The gas lift system includes a plurality of gas lift valves 13 at spaced intervals to control the admission of lift gas into the tubing string from the casing-tubing annulus 14 between the well casing 15 and the tubing string, herein-after referred to as the casing annulus. A surface control unit 20 is connected with the casing annulus and the gas lift valves for supplying dome gas to the gas lift valves to close the valves when the pressure within the casing annulus is reduced to a predetermined value.

The control unit 20 senses the pressure within the casing annulus through a line 21 which is connected from the control unit into the well casing through a well head 22 on the surface end of the casing. Dome gas is supplied to each of the gas lift valves through a line 23 which is connected from the control unit through the well head downwardly in the casing annulus 14 to each of the gas lift valves. Lift gas is supplied to the casing annulus through a line 24 which is connected from a gas supply, not shown, into the well head. The line 24 contains a choke 25 for reducing the pressure of the lift gas supplied into the annulus. The dome gas is supplied to the control unit through a line 30 which extends from the line 24 upstream of the choke 25 to the control unit. A line 31 containing a choke 32 is connected between the lines 21 and 23 to provide a balance of pressure between the dome chambers of the gas lift valves and the casing annulus as will be explained hereinafter.

Each of the gas lift valves 13 includes a generally tubular body 40 housing a longitudinally reciprocable valve member 41 which is moved upwardly by the pressure of fluids in the tubing string 12 and by a spring 42 to admit lift gas from the casing annulus 14 into the tubing string. The valve member is moved downwardly to a closed position to prevent admission of the lift gas to the tubing string by dome gas pressure admitted through the dome gas supply line 23 into a dome gas chamber 43 within the valve body above the valve member.

The valve body 40 includes an upper body section 44, a central body section 45, and a lower body section 50. The dome gas supply line 23 is connected into an internally threaded bore 51 in the upper body section 44 communicating with the dome gas chamber 43 formed in the upper body section by the enlarged bore 52. The upper and lower body sections 44 and 50 are secured, respectively, on a threaded reduced upper end section 53 and a threaded reduced lower end section 54 of the central body section.

The valve member 41 has a valve rod 55 supported in sliding relationship through a longitudinal bore 60 of the central body section 45 which provides a bearing and guiding surface for the valve rod. A piston 61 is mounted on the valve rod for longitudinal sliding movement within the dome gas chamber 43. The piston has an external annular groove 64 to receive a piston ring 63, which may be an O-ring seal, to provide a sealing relationship between the side wall of the piston and the internal wall of the upper body section defining the bore 52. The upper body section has a laterally extending vent port 64 communicating through the body section into the dome gas chamber below the piston.

The lower body section 50 has a bore 65 which is sufficiently larger than the valve rod 55 to provide an annular space or spring chamber 70 around the valve rod within the body for the spring 42. The spring 42 is confined around the valve rod within the annular spring chamber between an adjustable upper retainer ring 71 and a fixed

lower retainer ring 72 to apply a force to the valve rod biasing it upwardly relative to the valve body. The upper retainer ring is threaded on an external enlarged central section 73 of the valve rod 55 while the lower retainer ring 72 is supported within the lower body section against downward movement by an internal annular shoulder 74 provided within the body section. The upper retainer ring is rotatable on the valve rod to adjust its position for varying the compression of the spring 42. The outside diameter of the upper retainer ring is sufficiently less than the diameter of the bore 65 while the bore 75 through the lower retainer ring is sufficiently larger than the valve rod 55 that pressure differentials will not be created within the annular spring chamber 70 which might interfere with the proper functioning of the valve.

A lower end surface 80 on the valve rod is engageable with an annular valve seat surface 81 formed in the lower body section 50 around its outlet flow passage 82 to control flow through the valve. An inlet port 83 is provided in the lower body section 50 above the valve seat surfaces 81 for the admission of lift gas from the annular casing annulus into the gas lift valve.

Each gas lift valve 13 is supported on an injection lug 84 which is suitably secured, such as by welding, to the tubing string 12. A threaded reduced lower end section 85 on the lower body section 50 is attached in a threaded upper end section 90 of an injection flow passage 91 through the injection lug communicating with a port 92 in the tubing string to permit lift gas to be injected through the lug into the tubing string.

The admission of dome gas to the chamber 43 is controlled by the control unit 20 responsive to the pressure within the casing annulus 14. The control unit includes a mounting plate 100 on which is secured a Bourdon tube 101 and a dome gas valve 102. The Bourdon tube is supported on the mounting plate from a short fixed end section 103 which is secured in the fitting 104 connected to the mounting plate so that the free end 101a of the tube moves relative to the dome gas valve as the tube expands and contracts. The fitting 104 has an L-shaped flow passage 105 and is internally threaded along an end section 110 around the flow passage into which is connected the line 21 so that fluid pressure from the casing annulus 14 is communicated through the line 21 and the fitting 104 into the Bourdon tube.

A bracket 110 is secured on the free end of the Bourdon tube supporting an adjustable dome gas valve push rod 111 threadedly engaged through the bracket and lockable by a lock nut 112 threaded on the push rod adjacent the bracket. The push rod has a knurled knob 113 on one end so that it can be readily grasped by an operator's fingers to rotate it to adjust its position in the bracket. The other end of the push rod has an enlarged head 114 which engages one end of a valve stem 115 of a valve member 120 to control the flow of dome gas to the dome gas chamber of each gas lift valve. The valve member 120 includes the valve stem 115 and an enlarged head member 121 provided with a conical seat surface 122 engageable with an annular seat surface 123 formed around a bore 124 through a valve seat 125 formed integral with or secured to the valve body 126 within its valve chamber 130. The valve stem 115 is slidably fitted through a bore 131 which extends through the valve body and is enlarged along its outer end section to provide an internal annular recess 132 for an O-ring seal 133 to seal between the valve stem and the valve body. The O-ring seal is held in the recess 132 by a retainer ring 134 threaded into the outer end section of the bore 131 around the valve stem.

An inlet flow passage 135 in the dome gas valve body permits dome gas to flow from the supply line 30 into the valve. The valve body is internally threaded around the bore 135 along a section 140 for the connection of the supply line 30 into the valve body. An outlet flow passage 141 in the valve body provides fluid communication between the line 23 and the chamber 130. The valve body

is internally threaded along a section 42 around the passage 141 so that the line 23 may be connected into the body 102 to allow dome gas to flow from the valve to the dome gas chamber of each gas lift valve.

When the Bourdon tube 101 contracts moving the free end 101a toward the valve stem 115 and the head 114 engages the valve stem moving the head 121 away from the seat 123, fluid flows through the valve from the line 30 into the line 23. When the Bourdon tube expands until the head 114 no longer holds the valve member away from its seat, the gas pressure in the chamber 130 acting across the valve stem 115 moves the valve to a closed position at which the head 121 engages the seat 123.

The gas lift system 10 embodying the invention is employed in a well for recovering fluids flowing into the well from earth formations penetrated by the well when the native reservoir energy derived from such sources as water drive or gas cap is depleted to the extent that additional energy is needed for lifting desired quantities of the fluids to the surface. Unless the well was initially equipped with the gas lift system in anticipation of its ultimate depletion, it will be necessary to pull the tubing string 12, install the gas lift valves 13 in the tubing string along with the flow line 33 for supplying dome gas to the gas lift valves, and re-install the tubing string in the well.

Each of the gas lift valves is adjusted prior to assembly and installation so that it will open for admitting lift gas into the tubing string when the pressure within the tubing string reaches a predetermined value dependent upon the fluid column within the tubing string which is to be displaced to the surface by the lift gas entering the valve. Three forces act to raise the valve member 41 from its lower closed position illustrated in FIGURE 3 to its upper open position, not shown, wherein the lower end surface 80 is displaced above the seat surface 81 to allow fluid flow from the casing annulus 14 inwardly through the ports 83 and downwardly through the flow passage 91 and into the tubing string through the port 92. One upward force on the valve member results from the pressure of the fluids in the tubing string acting through the injection passage 91 upwardly against an effective area of the valve member within the line of sealing engagement of the lower end surface 80 with the seat surface 81. A second upward force is provided by the spring 42. The third upward force on the valve member is provided by the fluid pressure within the casing annulus acting through the ports 83 and the vent ports 64 upwardly on the valve member over an effective annular area between the line of sealing engagement of the lower end surface 80 with the seat surface 81 and the line of sealing engagement of the O-ring 63 and the wall surface defining the bore 52 of the upper body section 44.

The single force which moves the valve member 41 downwardly to the closed position shown in FIGURE 3 is provided by the pressure of the dome gas in the chamber 43 above the piston 61. Considering all of the factors which affect the opening and closing of the valve member, each of the gas lift valves is adjusted by varying the compression in the spring 42 as determined by the position of the adjustable retainer ring 71 on the threaded section 73 of the rod 55 so that the valve will open when a column of fluid of the desired height rises through the tubing string 12 above the valve.

The gas lift valves are installed at depths which are consistent both with the remaining native reservoir energy in the formations producing into the well and the pressure at which lift gas is available for operating the gas lift system. Fluids flowing from the formations penetrated by the well will rise in the well tubing to a level largely dependent upon the energy available in the formation from such sources as gas cap and/or water drive pressure in the formations for displacing the fluids into the well bore and upwardly toward the surface. Obviously, the gas lift valves must be placed below the level to which the fluids will inherently rise without the aid of energy

added from outside sources so the lift gas may be injected below the column to be lifted. The extent to which the gas lift valves are positioned below the level to which the fluids will normally rise depends upon the height of the column of fluids desired to be raised during each cycle by the lift gas which in turn is affected by the pressure at which the lift gas is available for injection into the casing annulus.

After the tubing string with the gas lift valves is installed in the well, the necessary surface connections are made to provide the casing annulus 14 with lift gas through the gas supply line 24 and the control unit 20 is interconnected with both the well casing and the gas supply line as illustrated in FIGURE 1 for sensing the casing annulus pressure and supplying dome gas to the gas lift valves in accordance with such pressure.

The control unit 20 of the gas lift system is adjusted with the push rod 111 preparatory to initiating operation of the system based upon the casing annulus pressure at which it is desired that the gas lift valves close. The Bourdon tube 101 of the control unit is connected through the fitting 104 and the line 21 into the casing annulus so that the casing annulus pressure is applied directly into the Bourdon tube. It is well known that a Bourdon tube tends to expand or straighten out with the free end moving away from the fixed end as the pressure within the tube increases and when the pressure decreases in the tube it contracts with the free end moving toward the fixed end. An increase in the pressure in the casing annulus 14 expands the Bourdon tube with the free end 101a supporting the bracket 110 and the push rod 111 moving away from the valve stem 115 of the dome gas valve 102. The head 114 of the push rod 111 is engageable with the right or outward end of the valve stem 115 to push the valve 120 toward the left moving the surface 122 away from the valve seat surface 123 to allow flow to the dome gas valve from the supply line 30 into the line 23 extending to the dome gas chambers 43 of the gas lift valves. A decrease in pressure within the casing annulus permits the Bourdon tube to contract to open the dome gas valve so the dome gas is supplied into the chambers 43 effecting closure of the gas lift valve while an increase in pressure in the casing annulus expands the Bourdon tube moving the push rod head 114 away from the valve stem 115 to allow the dome gas valve to close to shut off flow of dome gas to the gas lift valves. It is, therefore, necessary that the push rod 111 be adjusted by rotation of the knob 113 to properly position the push rod head 114 relative to the valve stem 115 so that at the desired casing annulus pressure the Bourdon tube will contract sufficiently to open the dome gas valve to admit dome gas to the dome gas chambers of the gas lift valves to effect their closing.

After the gas lift system is installed and before it is operated to produce fluids from the well the casing annulus and the tubing string are normally full or partially full of liquids from the formations penetrated by the well to an elevation at which the hydrostatic heads from the columns of liquid substantially equal the formation pressure pushing the liquids into the well bore. Generally, both the casing annulus and the tubing string are full of liquid substantially above the gas lift valves. Prior to starting the gas lift operation, the gas lift valves, which are immersed in liquid, are in open position since the only pressure biasing each valve toward the closed position is the pressure within the dome 43 which is essentially atmospheric as the only fluid connection into the dome gas chamber extends to the surface components which are at atmospheric pressure before the flow of lift gas is initiated to effect an increase in the gas pressure within the casing and the dome gas chamber. The forces acting upwardly to push each gas lift valve to the open position include the hydrostatic pressure within the tubing string 12 acting on the lower end of the valve member 41 through the injection flow passage 91, the spring 42, and

the hydrostatic pressure within the column of liquid in the casing annulus 14 at the gas lift valve acting on the valve member 41 below the piston 61. Since the hydrostatic pressure within the liquid columns at the gas lift valves and the spring 42 provide forces substantially in excess of the force of the pressure within the dome gas chambers, the valve member 41 of each of the gas lift valves is biased upwardly to the open position.

The first or initial step in the operation of the gas lift system and one which must be effected prior to the system's beginning its normal intermittent cycling is the displacement of the liquid from within the casing annulus 14 through the gas lift valves and the tubing string 12 to the surface until the liquid level in the annulus is about at the uppermost gas lift valve. The uppermost gas lift valve is utilized so long as the formation pressure lifts the well fluid to an adequate height above the upper valve. When such condition ceases to exist the next lower gas lift valve functions. The operation of the system will therefore be discussed in terms of the operation of the uppermost gas lift valve. The hydrostatic head in the tubing and casing annulus will maintain the lower valves open for reasons previously explained.

Lift gas is injected into the casing annulus through the supply line 24 and the choke 25. The gas enters the casing annulus through the well head 22 to exert pressure on the column of liquid within the casing annulus displacing the liquid downwardly causing it to flow through the gas lift valves into the tubing string 12. The liquid enters each gas lift valve through the port 83 flowing downwardly around the lower end surface 80 of the valve member 41 which is raised to an open position and through the injection flow passage 91 into the tubing string through the port 92.

The lift gas being supplied to the system through the line 24 also flows through the line 30 to the dome gas valve 102 in the control unit 20. The push rod 111 on the Bourdon tube 101 is generally adjusted so that the tube contracts to open the dome gas valve at a pressure appreciably above atmospheric and thus during the initial stages of activating the gas lift system when gas injection first starts, the tube is contracted so that the head 114 on the push rod is holding the valve stem 115 to the left maintaining the surface 122 on the valve head 121 spaced from the seat surface 123 so that the dome gas valve is open and the gas flowing from the supply line 24 through the line 30 passes through the dome gas valve to flow through the line 23 to the dome chambers 23 in each of the gas lift valves. Since the gas flowing to the dome gas valve through the line 30 passes from the line 24 upstream of the choke 25, the pressure of the dome gas is higher than the pressure of the lift gas entering the casing annulus at the head. So long as the gas pressure within the casing annulus at the head 22 remains below the predetermined level at which the Bourdon tube is adjusted to expand to allow the dome gas valve to close, the dome gas valve will remain open allowing the higher pressure gas upstream of the choke 25 in the line 24 to be applied into the dome gas chamber of each gas lift valve. It will be understood, as previously pointed out, however, that the pressure in the tubing string and casing annulus at the gas lift valves is the hydrostatic pressure of the columns of liquid above the valves plus the pressure of the lift gas being injected into the casing annulus. The force of the hydrostatic pressure of the liquid columns tending to hold the valve members 41 in their upper open positions will generally sufficiently exceed the force of higher pressure of the gas within the dome gas chambers which tends to move them to their lower closed positions so that the gas lift valves will remain open until the column of liquid has been displaced downwardly in the casing annulus to the levels of the upper gas lift valve and the lift gas has entered the tubing string 12 displacing the column of liquid within the tubing string upwardly to the surface above the gas lift valves.

During the raising of the lift gas pressure in the casing annulus above the column of liquid within the annulus the lift gas pressure increases to a valve above the lower valve of the pressure within the casing annulus at which the dome gas valve 102 in the control unit is adjusted to open and close. During this pressure increase the casing annulus pressure is applied through line 21 into the Bourdon tube causing the tube to expand with the free end 101a moving away from the valve stem 115 of the dome gas valve. When the head member 114 on the push rod ceases to engage the outward end of the valve stem 115 the force of the pressure of the dome gas passing through the line 30 and to the dome gas valve moves the head 121 of the valve member into engagement with the seat 123 closing the valve and preventing further supply of gas into the dome gas chamber 23 of each of the gas lift valves. The higher dome gas pressure then is bled down through the choke 32 and the line 31 until the dome gas pressure equals the casing annulus pressure. The equalizing of the pressures in the dome gas chambers with the pressure in the casing annulus occurs rapidly due to the relatively small volume of the dome gas chamber.

As the liquid column is lifted in the tubing string by the lift gas, the hydrostatic pressure exerted by the column through the gas lift valve into the casing annulus decreases causing the pressure within the Bourdon tube 101 as sensed through the line 21 to correspondingly decrease. The lift gas flows from the casing annulus through the ports 83 in the gas lift valve at a more rapid rate than it is being replenished in the casing annulus through the supply line 24. When the liquid column in the tubing string being displaced by the lift gas is lifted to displace a predetermined volume of the column from the tubing at the surface, the hydrostatic head of the column within the tubing string decreases resulting in a decrease in the casing annulus pressure effecting a reduced pressure in the Bourdon tube which contacts to open the dome gas valve 102 admitting dome gas to the dome gas chamber of the gas lift to close the valve.

At the time in the process of operating the gas lift system immediately before the dome gas valve opens the pressure within the casing annulus 14 is substantially equal to the pressure within the dome gas chambers 43 as previously discussed, and since the gas lift valve is still open with the valve member 41 being at its upper position the pressure below the piston 61 of the valve as applied through the ports 83 and 64 is equal to the pressure within the casing annulus which is equal to the pressure within the dome gas chambers so that the gas lift valve is being held at an open position by the spring 42. As soon as the higher pressure of the dome gas is applied to the piston 61 of the gas lift valve, the valve member 41 is displaced downwardly against its spring 42 and when the force of the spring 42 is exceeded by the force of the dome gas pressure acting on the piston 61 the valve member 41 is forced downwardly so that the lower end surface 80 on the valve member engages the seat surface 81 to prevent further flow through the gas lift valve. At the instant of closing the gas lift valve, the dome gas pressure is applied above the piston 61 over an effective area within the line of sealing engagement of the O-ring 63 with the inner wall of the upper body section 44 defining the bore 52. The valve member is being biased upwardly by the spring 42 along with the force of the casing annulus pressure acting over an area of the valve member 41 between the line of sealing of the surface 80 with the seat 81 and the line of sealing of the O-ring 63 with the wall defining the bore 52 plus the force of the tubing string pressure acting on the lower end surface 80 of the valve member within the line of sealing with the valve seat 81. The gas lift valve and the control unit are so designed and adjusted that the force of higher dome gas pressure effects rapid closing of the valve and holds the valve closed against the above defined upwardly acting forces.

With the gas lift valve closed lift gas cannot flow through the valve into the tubing string and the continued flow of lift gas into the casing annulus from the supply line 24 increases the pressure of the lift gas within the casing annulus at a more rapid rate than the increase of the pressure at the gas lift valve from within the tubing string 12 due to the rising column of liquid in the tubing string from the producing formations. When the increasing lift gas pressure within the casing annulus reaches the value at which the control unit 20 is adjusted to close the dome gas valve 102, the Bourdon tube expands allowing the valve to close preventing a further supply of the higher pressure dome gas to the dome gas chamber. The dome gas pressure then bleeds down through the choke 32 and the line 31, as previously explained, until the dome gas pressure substantially equals the casing annulus pressure. At this stage, the gas lift valve remains in the closed position because the casing annulus pressure is sufficiently above the pressure within the tubing string 12 to retain the valve member 41 in the lower closed position against the forces of the spring 42, the tubing string pressure on the lower surface 80, and the casing annulus pressure below the piston 61 acting on an area between the line of sealing of the surface 80 with the seat surface 81 and the sealing engagement of the O-ring 63 with the inside wall defining the chamber 52. The gas lift valve is thus held closed and the lift gas pressure within the casing annulus continuous to rise until it is at the maximum desired value.

Starting at the time that the gas lift valve closes and continuing simultaneously with the increase of the lift gas pressure in the casing annulus, the liquids and gases from the formations producing into the well 11 are flowing upwardly in the casing string 12 due to the previously discussed various forms of native reservoir energy which cause the flow of the fluids into the well bore. The fluids rise within the casing string 12 until the column of liquid within the string has risen to a level above the gas lift valve which provides a column of the height which the gas lift system is designed and adjusted to lift to the surface.

The column of liquid above the gas lift valve exerts hydrostatic pressure on the gas lift valve and when such pressure reaches a predetermined value, as explained below, the valve opens to admit lift gas from the casing annulus into the tubing string to lift the column of liquid to the surface. The force of the hydrostatic pressure of the liquid column in the tubing string above the gas lift valve is applied upwardly to the valve member 41 of the gas lift valve on the lower end surface 80 within the line of sealing engagement with the seat surface 81. Also applying an upward lifting force to the valve member 41 is the spring 42. Since the dome gas pressure is equalized with the casing annulus pressure, as previously discussed, dome gas pressure at a value of the casing annulus pressure applies a downward force to the valve member 41 above the piston 61 within an area defined by the line of the sealing engagement of the O-ring 63 with the inside wall of the valve body defining the bore 52. Also, casing annular pressure is being applied to the valve member 41 below the piston 61 through both the ports 64 and 83 so that an upward force from the casing annulus pressure is applied to the valve member over a net annular area between the line of sealing engagement of the seat surface 81 with the lower end surface 80 and the line of sealing engagement of the O-ring 63 with the inner wall of the upper body section 44. The net effect of the pressure applied to the valve element from the dome gas chamber and the casing annulus is thus a pressure within the dome gas chamber equal to the casing annulus pressure applied downwardly to the piston 61 over an area equal to the area within the line of sealing engagement of the lower end surface 80 with the seat surface 81, while the upward force on the valve member is the combination of both the force of

the spring 42 and the force of the hydrostatic pressure within the casing string 12 from the column of liquid above the gas lift valve applied to the same area of the lower end surface 80. It is, therefore, clear that since the spring 42 supplements the upward force of the hydrostatic pressure in the tubing string against the lower end of the valve element a hydrostatic pressure within the tubing string less than the casing annulus pressure when combined with the force of the spring 42 lifts the valve member 41 to open the gas lift valve and permit the lift gas to be admitted to the tubing string. Obviously, the gas lift valve must be designed and adjusted to open when the pressure within the tubing string is lower than the lift gas pressure within the casing annulus so that the higher lift gas pressure will displace the column of liquid within the tubing string to the surface.

Thus, when a column of liquid of the desired height has accumulated in the tubing string above the gas lift valve, the force of the hydrostatic pressure of the liquid acting through the injection passage 91 of the gas lift valve applied to the lower end of the valve member moves the valve member upwardly to the open position permitting the higher pressure lift gas to enter the gas lift valve through the port 83 flowing downwardly through the injection passage 91 into the column of liquid within the tubing string. The flow rate of the lift gas into the tubing string is preferably sufficiently great that rather than simply mixing with the liquid in the tubing string so as to lower its density and lighten the liquid column, the gas enters the tubing string in a body forming a continuous gas bubble within the liquid column below the length of the column extending above the gas lift valve causing the liquid column to be lifted toward the surface. The lift gas flows from the casing annulus into the tubing string lifting the liquid column to displace it from the well at the surface until all of the column has been produced from the tubing string or until a predetermined quantity of the column has been displaced from the string. The reduced hydrostatic pressure of the column as applied through the gas lift valve into the casing annulus 14 reduces the casing annulus pressure to the predetermined value at which the control unit 102 is designed and adjusted to allow the dome gas valve to open by contraction of the Bourdon tube. The higher pressure dome gas flows into the dome gas chamber of the gas lift valve to effect a rapid, positive closing of the valve.

The gas lift valve is thus closed by the higher dome gas pressure to permit additional formation fluids to accumulate in the tubing string 12 above the gas lift valve and allow the lift gas pressure within the casing annulus to again increase to a sufficient value to lift another column of liquid from the tubing string to the surface. The lift gas system repeats the previously described cycles during which the dome gas valve closes due to the expansion of the Bourdon tube, the lift gas pressure increases in the casing annulus while the fluids accumulate in the tubing string to a level to again open the gas lift valve and produce another quantity of fluid from the well.

During the repeated operational cycles of the gas lift system described above, the upper gas lift valve performs the function of admitting lift gas into the tubing string 12 while the lower gas lift valve remains open continuously due to the hydrostatic pressure of the column of liquid remaining in the tubing string and casing annulus above the lower gas lift valve between the lower valve and the upper valve. For various reasons which has been discussed above, this hydrostatic pressure at the lower valve exceeds the dome gas pressure in the lower valve even when it is raised to the higher value by the dome gas valve in the control unit. To some extent there is a transfer of liquid back and forth through the lower gas lift valve. As the column of liquid in the tubing string is

raised and lowered during the operation of the system and the pressure fluctuates in the casing annulus the fluids within the tubing string and casing annulus will move back and forth in a manner often referred to as "U-tubing." If desired, a suitable "velocity" check valve may be in the flow passage 91 of the valves 13 to close at a predetermined velocity of flow from the tubing string into the annulus to prevent the "U-tubing."

When the well is produced by the gas lift system to the extent that the native reservoir energy in the formations is so depleted that it will not lift a column of liquid in the tubing string above the upper gas lift valve to a height adequate to open the valve, the valve then ceases to serve a primary function of being the first of the gas lift valves to admit lift gas into the tubing string to initiate upward movement of each of the columns of liquid. The liquid level in the casing annulus is then lowered from the upper gas lift valve to the lower valve by displacing the liquid to the surface through the lower gas lift valve. The liquid level within the casing annulus is lowered to a level about at the lower edge of the port 83 leading into the valve in accordance with the above described procedure for lowering the liquid level from above the upper gas lift valve. The lower valve then functions by opening and closing responsive to the hydrostatic pressure from the column of liquid within the tubing string in exactly the same manner as described for the upper gas lift valve to intermittently admit lift gas into the tubing string through the lower gas lift valve for raising liquids to the surface in the tubing string.

Each time that a column of liquid being raised in the tubing string from the lower gas lift valve passes the upper gas lift valve and rises above the upper gas lift valve sufficiently it may exert a hydrostatic pressure on the valve of a value high enough to open the valve. If the valve moves to the open position, it remains open admitting lift gas into the upwardly moving column of liquid until the column has been displaced from the tubing sufficiently to reduce the hydrostatic pressure on the upper gas lift valve sufficiently to effect its closing. Thus, the upper gas lift valve after serving a primary function initially in the operation of the gas lift system may perform a secondary function of admitting lift gas into the moving column of liquids assisting the gas admitted through the lower valve in lifting the column to the surface.

The gas lift system 10 may include a substantial number of gas lift valves connected with the tubing string and surface control unit as described above to provide both for lowering the fluid level in a well bore down to a normal working level for the particular well which is the level to which the fluids in the tubing string will continue to rise between lift gas injection cycles. For example, as many as 8 or 10 of the gas lift valves may be incorporated in the system so that the fluids in the well may be removed to lower their level to the working level of the well at which one of the intermediately positioned valves will generally be the functioning valve so that there will be several valves below the functioning valve at the working fluid level of the well to provide the additional lower valves which may be required for continued production of the well by gas lift as its reservoir pressure is depleted causing a future lowering of the working fluid level.

The adjustability features of the control unit 20 provides flexibility in the operation of the gas lift system which is not found in conventional systems employing the gas dome chambers which are charged and sealed at the surface prior to their installation of gas lift valves. Leakage which may occur from a permanently sealed gas dome chamber presents no problem in the present system due to the ability to charge and discharge the dome chamber of each of the valves from the surface. The casing pressure at which it is desired that the gas lift valves close is readily adjustable, as previously discussed, with the push rod 111 on the Bourdon tube 101 of the control

unit. For example, it may be desired that the closing pressure of the gas lift valves be varied in the event that a different source of lifting gas becomes available at a different pressure. Since the opening pressure of each of the gas lift valves is directly correlated with the pressure of the lift gas in the casing annulus and each gas lift valve is opened by the force of the hydrostatic pressure of the liquid column in the tubing string above the operating gas lift valve, a change in the pressure at which lift gas is supplied into the annular space effects a change in the liquid column necessary for opening the gas lift valve. An increase in the gas lift pressure in the annular space will permit the liquid column in the tubing string to rise to a higher level prior to the opening of the operating gas lift valve. Similarly, a reduction in the lift gas pressure in the annular space will permit the operating valve to be opened by a liquid column exerting a lower hydrostatic fluid pressure on the valve.

It will now be seen that a new and improved gas lift system has been described and illustrated.

It will be also seen that a new and improved valve for admitting fluids into a tubing disposed in a well bore has been described and illustrated.

It will be further seen that a new and improved gas lift valve has been described and illustrated.

It will be seen that the gas lift system provides a new and improved well tool for removing liquids through a well tubing disposed in a well casing wherein gas within an annular flow passage between the casing and tubing provides a lifting force for removing liquids to the surface through the tubing.

It will also be seen that the gas lift system provides means for automatically removing liquid from a well bore which includes a valve adapted to open intermittently to permit gas to flow from an annular flow passage in the well casing around the tubing into the tubing to transport liquids present in the tubing above the valve to the surface through the tubing.

It will also be seen that the gas lift system includes a gas lift valve which is operable responsive to the liquid level within the tubing of the well.

It will be seen that the gas lift valve of the system is biased toward a closed position by dome gas pressure controllable from the surface.

It will be seen that when the casing pressure drops below a predetermined level the dome gas pressure in each gas lift valve is raised to a value in excess of the casing pressure to rapidly close the valve which is then held at a closed position by dome gas pressure which is reduced to a level equal to the casing pressure.

It will also be seen that the gas lift system includes a surface control unit having means operable responsive to the casing annulus pressure for controlling the pressure within the dome of each of gas lift valve in the system so that the dome pressure is increased when the casing pressure is decreased below a predetermined value.

It will also be seen that the system includes a gas lift valve which opens responsive to a predetermined pressure within the well tubing and is closed responsive to a predetermined pressure within the casing annulus around the tubing.

It will also be seen that the gas lift valve is biased toward a closed position by dome gas pressure and biased toward an open position by the force of a spring and when the valve is closed the force of the pressure of fluid in the tubing string of the well.

It will also be seen that one form of the gas lift valve includes a reciprocable piston supported on the valve rod of the gas lift valve within the dome gas chamber.

It will also be seen that the opening pressure of the gas lift valves of the system are varied from the surface by changing the lift gas pressure.

It will be further seen that the closing pressure of the gas lift valves is varied by changing the dome gas pressure control unit at the surface.

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As illustrated in FIGURE 4, an alternative form of gas lift valve 13a which may be employed in the system of FIGURE 1 includes a bellows 150, instead of the piston 61 mounted on the upper end of the valve rod 55 within the dome gas chamber. The bellows, which preferably is formed of relatively thin flexible metal, is suitably secured, as by welding, to a head member 151 threaded into the upper end of the valve rod 55 of the valve member 41. The lower end of the bellows is thus sealed with the head member 150 so that fluid pressure may not be applied from around the bellows into its lower end while the upper end of the bellows is open to admit fluid pressure from above the bellows and thus a pressure differential may be developed across the bellows. The upper end of the bellows is suitably secured as by welding to a ring member 152 an outer peripheral portion of which is clamped between an upper section 44a and a lower section 44b of an upper body section 44c of the gas lift valve body 40. The interior of the bellows is thus in communication with the dome gas chamber 43.

The upper body section 44c is identical to the upper section 44 illustrated in FIGURE 3 in all respects other than being separable into the sections 44a and 44b for purposes of securing the upper end of the bellows to the valve body. The ring member 152 preferably is formed of a suitable metal, such as brass, which is sufficiently soft that when the member is clamped between the body sections 44a and 44b a sealed relationship is established between the body sections and the ring member preventing leakage of fluid around the upper end of the bellows so that the desired pressure differential for operation of the gas lift valve may be applied across the bellows. The upper end of the bellows is thus clamped in sealed relationship and held against movement relative to the valve body while the lower end of the bellows is secured to and movable with the upper end of the valve rod 55 so that when the higher dome gas pressure is applied into the dome chamber 43 the pressure differential effected across the bellows displaces the valve member 41 downwardly to close the gas lift valve 13a. In a similar manner when the upward forces on the valve member exceed the dome gas pressure within the bellows the valve member moves upwardly to open the gas lift valve. The gas lift valve 13a is identical in all respects to the gas lift valve 13 of FIGURE 3 other than in the use of the bellows 150 and the described and illustrated altered forms of the related components necessary to incorporate the bellows in the valve. A gas lift system employing the gas lift valve 13a operates in exactly the same manner as the system above described and illustrated using the gas lift valve 13.

It will now be seen that an alternative form of gas lift valve embodying the invention includes a bellows connected at one end to the upper end of the valve rod of the valve member while the other end of the bellows is secured in fixed relationship with the valve body whereby dome gas is introducible into the bellows to effect a pressure differential across the bellows for actuating the valve member between open and closed positions.

A gas lift system 200 embodying the invention, as illustrated in FIGURE 5, is utilized to produce well fluids by continuous injection of lift gas. The gas lift system 200 includes a plurality of gas lift valves 201 supported from a well tubing 202 for controlling the injection of lift gas into the well tubing from an annular space 203 within a well casing 204 around the tubing string. The gas lift valves are supplied with dome gas for biasing them toward a closed position through a line 205 which extends from a source of dome gas, not shown, at the surface. A suitable pressure regulator 210 is connected in the line 205 to control the pressure of the dome gas supplied to the gas lift valves. Any suitable form of pressure regulator which will supply the dome gas at the desired pressure level may be employed. Lift gas is conducted into the annulus 203 through a line 211 having a suitable pressure regulator 211a for supplying gas into the annulus at a

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fixed pressure. The tubing string, the dome gas supply line, and the lift gas supply line are all connected into the surface end of the casing 204 through a suitable head 212.

The gas lift valve 201 is a modified form of the valve 13 shown in FIGURE 3 including identical components designated by the same reference numerals as used in FIGURE 3 and modified components referred to by the same reference numerals with a prime (') mark added. Referring to FIGURE 6, the lower body section 50' includes an annular valve seat member 213 which is tightly fitted in an upward and inwardly opening annular recesses 214 formed in the body section around its outlet flow passage 82'. The longitudinally reciprocable valve member 41' has a lower end throttling tip comprising a conical lower end surface 215 which coacts with the valve seat 213 to regulate flow through the gas lift valve into its outlet flow passage 82'. A split stop ring 220 is engaged within the upper body section 44' to limit the upward movement of the piston 61 so that the throttling tip of the valve member remains sufficiently close to the seat 213 to provide a continuing throttling effect through the valve even when it is at its maximum open position. All other details of the valve 201 are identical to the previously described valve 13.

The lift gas valve 201 is biased toward a closed position by dome gas supplied through the regulator 210 and line 205 into the dome gas chamber 43 above the piston 61. The valve is biased upwardly toward an open position by the spring 42 and the forces of fluid pressures within the tubing string as applied through the injection lug 84 to the lower end surface 215 of the valve member 41' and within the annulus 203 as applied to the valve member through the ports 64' and 83'.

In operation the gas lift system 200 functions to inject lift gas into a column of well fluids within the tubing string 202 at a rate which is insufficient to establish a large continuous gas bubble as utilized in intermittent injection but yet sufficient to introduce an adequate quantity of gas in the form of small bubbles into the liquid column to reduce the density of the fluids sufficiently that the formation pressure will displace them from the well through the tubing string. A sufficient number of the lift gas valves 201 are connected into the tubing string spaced along its length over a distance adequate to provide a gas lift valve at each depth at which it is anticipated that lift gas injection may be required through the life of the well, taking into consideration the necessary initial unloading of the well when gas injection starts and the normal gradual lowering of the working level of the well throughout its life which progressively requires gas injection at lower levels within the well. As previously discussed with reference to the gas lift system 10, the tubing string and casing annulus are normally initially partially full to full of liquids to a level at which the hydrostatic heads of the two columns substantially equal the formation pressure pushing the fluids into the well bore. Thus, prior to starting the gas lift operation, all of the gas lift valves are in an open position, that is, with their valve members 41' at an upper end position, since there is atmospheric pressure within the dome chamber 43 of each valve while the hydrostatic pressures within the tubing string and the casing annulus together with the spring 42 are exerting upward forces on the valve members to hold them each at an upper end position.

As in the case of the intermittent gas lift system, the initial step in the operation of the system 200 is the displacement of the fluids from the casing annulus and tubing string until the liquid levels in the tubing string and casing annulus have been reduced to a "working level" which reduces the liquid levels to a depth at which one of the gas lift valves, preferably one of the upper valves, is above the liquid to permit initiation of continuous lift gas injection into the tubing string. The liquid is displaced from the well in the same manner as described in the intermittent system by lift gas being introduced through the

line 211 into the casing annulus 203 exerting pressure on the fluids within the casing annulus displacing them through the open gas lift valves into the tubing string 202 and through the tubing string to the surface.

The dome gas pressure within the chambers 43 of the gas lift valves is raised by transmission of dome gas through the regulator 210 and line 205 into the chamber of each of the gas lift valves. The regulator 210 is adjusted to establish the dome gas pressure at a desired predetermined value so that the gas lift valves react responsive to the hydrostatic pressure of the column of fluids within the tubing string as in the case of the intermittent gas lift system previously discussed.

The dome gas pressure in the gas lift valves is established at the desired value prior to or simultaneously with the raising of the lift gas pressure in the annulus 203 so that as the liquid level in the annulus and the tubing string is reduced to the "working level" there is a biasing force being applied to the valve member of each of the lift valves tending to close the valves responsive to predetermined pressure conditions established at the valves above the one nearest the surface of the liquid in the annulus. While all of the valves at the initiation of the process are submerged in liquid in the annular space, the hydrostatic pressure of the liquids coupled with the pressure of the lift gas in the annulus above the liquids is sufficient to hold each of the valves in the open position against the dome gas pressure. As the liquid is reduced in the annulus, the surface of the liquid is successively displaced below gas lift valves which previously were submerged in the liquid. For example, initially the liquid is displaced below the uppermost of the gas lift valves with the lift gas then being introduced through the uppermost valve into the tubing string reducing the density of the fluid column in the tubing string to aid in displacement of the fluid column through the string to the surface. The lift gas enters the uppermost gas lift valve as soon as the inlet ports 83' of the valve cease to be submerged below the liquid level in the casing annulus. The lift gas flowing into the gas lift valve through the entry ports 83' flows downwardly around the lower end surface 215, through the flow passages 82' and 91 into the tubing string 202. The throttling tip of the valve member 41' is so positioned relative to the valve seat 213 that the pressure of the lift gas is reduced as it passes the throttling tip to enter the tubing string at a reduced pressure where bubbles of the lift gas mix with the fluid column in the tubing string.

The forces holding the valve member 41' at an upper open position against the dome gas pressure in the chamber 43 include a force from the pressure of the lift gas in the annulus 203 applied through the entry ports 83' and the port 64' in an upward direction on the valve member 41' above the seat 213 and below the piston 61 within the line of sealing engagement of the ring seal 63 with the wall of the bore of the upper body section 44'. The valve member 41' is also biased upwardly by the pressure of the fluid within the outlet passage 82' below the throttling tip of the valve member as applied to the lower end surface 215 over an area determined by the position of the valve member relative to the seat 213. The pressure within the outlet flow passage 82' is essentially equal to the hydrostatic pressure of the column of fluids within the tubing string 202 above the gas lift valve. The coaction between the valve member 41' and the valve seat 213 serves a regulating function as the valve member is longitudinally reciprocable to regulate the gas admitted into the tubing string through the gas lift valve responsive to the hydrostatic pressure in the tubing string. Since the pressure is maintained constant in both the annulus 203 and in the dome chamber of the gas lift valve and the force of the spring 42 remains constant, the changes in the density of the fluid column in the tubing string above the valve raises and lowers the valve member admitting more or less gas into the tubing string in accordance with the density of the fluids in the tubing string above the

valve. For example, if water is produced through the tubing string, its greater density in the fluid column above the gas lift valve increases the hydrostatic pressure at the gas lift valve through the flow passage 82' against the conical surface 215 causing the valve member 41' to be lifted to admit of an increased quantity of lift gas into the tubing string for more effectively lifting the fluids column containing the water to the surface. Similarly, a quantity of gas in the tubing string serving to lower the density of the fluids column above a gas lift valve reduces the hydrostatic pressure against the valve member allowing the valve member to move downwardly lowering the quantity of lift gas admitted into the string.

The lock ring 220 limits the upward movement of the valve member 41' by contacting the upper end of the piston 61. The lock ring is positioned relative to the piston to prevent the valve member from moving above a throttling position relative to the valve seat 213 so that the valve member will remain responsive to the column of fluids in the tubing string. If the valve member were permitted to move to a fully open position at which it effected no throttling of the lift gas introduced through the passage 82', the valve member would be responsive only to the casing annulus pressure, the spring 42 and the dome gas pressure, with no effect from the pressure in the tubing string.

Lift gas is introduced into the tubing string as described above until the liquid level in the annulus is reduced to the next lower gas lift valve at which time the lift gas begins entering such valve. For a short time lift gas enters both the uppermost and the next lower gas lift valves increasing the quantity of gas entering the fluids column and reducing its density. When the density of the column of fluids in the tubing string above the uppermost gas lift valve is reduced to a predetermined level the reduced pressure on the surface 215 permits the dome gas pressure to close the valve with the valve member 41' moving downwardly until the surface 215 engages the seat 213 preventing further admission of lift gas through the valve into the tubing string from the casing annulus. At this stage the next lower gas lift valve nearest liquid level in the casing annulus serves to continuously admit lift gas into the tubing string until the liquid level in the casing annulus is again reduced to the next lower valve at which time the immediately described procedure of the next upper valve closing occurs with the newly opened valve continuously admitting lift gas.

Illustrated in FIGURE 7 is an alternative form of gas lift valve 230 which may be substituted for the gas lift valve 201 in the gas lift system 200. The valve 230 is a modified form of the gas lift valve 13 and thus all identical components are designated by the same reference numerals and modified components by the same reference numerals with a double prime (") mark added. The central body section 45" supports a ring seal 231 within an internal annular recess 232 for sealing within the body section around the valve member 41 to permit operation with different pressures within the chamber 43 below the piston 61 and the chamber 70 below the central body section 45". A choke 233 having a port 234 is secured in lower body section 50" provides inlets for the valve 230 to reduce the pressure of the lift gas flowing from the annulus 203 into the valve body around the valve member 41 below the seal ring 231. With the exception of the just described structure all other details of the gas lift valve 230 are identical to the gas lift valve 13 as described above.

The valve 230 is biased toward the closed position by dome gas supplied into the dome gas chamber 43 through the line 205 while the valve is biased upwardly toward an open position by forces resulting from the pressure of the lift gas within the annulus 203 as applied through the port 64 into the chamber 43 below the piston 61 and the pressure of the gas within the valve body 50" around the valve member 41 below the ring seal 231, which pres-

sure is substantially equal to the pressure of the fluids within the tubing string 202 at the injection lug 84 into which the valve 230 is connected. Thus, the valve 230 is responsive to the pressure within the tubing string of the valve in the same manner as the valve 201. More specifically, the gas lift valve 230 is biased toward a closed position by the force of the dome gas pressure in the chamber 43 acting over an area on the piston 61 within the line of sealing engagement between the seal ring 63 and the inside wall of the upper body section 44 defining the chamber 43. The valve is biased upwardly toward an open position by the forces of the casing annulus pressure applied through the ports 64 into the chamber 43 below the piston 61 around the valve member 41 within the line of sealing engagement of the seal ring 63 with the chamber wall, the fluid pressure within the spring chamber 70 acting over an area of the valve member 41 within the line of sealing engagement between the seal ring 231 and the valve member, and the spring 42. The fluid pressure within the chamber 70 acting upwardly on the valve member is substantially the same as the fluid pressure within the tubing string 202 applied into the lower end of the chamber through the injection lug 84.

The gas lift system 200 when utilizing the gas lift valves 230 functions substantially identically to the system when using the gas lift valves 201, as described above. The lift gas is metered from the casing annulus 203 through the chokes 233 into the gas lift valves. The lift gas flows downwardly through the injection lug 84 into the tubing string in the manner described above. The operation of the system with the valves 230 differs from the system with the valve 201 only to the extent that the valve 230 does not regulate the lift gas flow responsive to the tubing pressure as does the valve 21. The gas lift valves 230 close responsive to the hydrostatic pressure of the column of fluids in the tubing string as described with respect to the valves 201. The pressure within the chamber 70 below the seal ring 231 is reduced as the fluids become less dense with the introduction of additional gas into the tubing string during the transition of moving to a lower gas lift valve so that after the gas lift valve nearest the liquid level in the casing opens the lift valve above it closes.

A modification to the gas lift system 200 is illustrated in FIGURE 5A utilizing gas lift valves 240 as shown in FIGURE 8. The valve 240 is identical in all respects to the gas lift valve 13 except that a fluid flow choke 241 is secured in a lower end section of the lower body section 50 below the valve seat 81 within the outlet flow passage 82 from the valve. Lift gas flows from the casing annulus 203 into the body of the valve 240 through the inlet ports 83 and downwardly through the outlet flow passage 82 when the valve member 41 is in an upper open position. The pressure of the lift gas is reduced as it flows through the choke 241 into the injection lug 84 to enter the tubing string. The gas lift system 200 as modified in FIGURE 5A includes a choke 242 in the lift gas supply line 211 to permit flow into the annulus 203 at substantially the same rate as the flow capacity of each of the gas lift valves 240. The regulator 211a is optional in the system shown in FIGURE 5A. Each valve 240 is responsive to the tubing string pressure only when its valve member 41 is at a lower closed position so that the pressure equalizes across the choke 241 to the pressure in the tubing string. When the valve member 41 is at its open position the pressure in the chamber 70 below this valve member above the choke 241 is equal to the pressure in the casing annulus 203.

The gas lift valves 240 close responsive to pressure fluctuations within the annulus 203 since the effect of the hydrostatic pressure within the fluid in the tubing string is essentially eliminated when the valve is in the open position by the choke 241 in each of the valves. The valves 240 are therefore each provided with a spring 42 which when acting against a predetermined dome gas pres-

sure within the chamber 43 will close each of the gas lift valves at a predetermined casing annulus pressure as applied upwardly to the valve member through the inlet ports 83 over an effective area within the line of sealing engagement between the ring seal 63 and the wall of the chamber 43. The design of the springs 42 in the gas lift valves 240 are so related that the uppermost of the gas lift valves closes at a maximum annulus pressure while each consecutive gas lift valve down the tubing string closes at a slightly lower annulus pressure than the one above it.

Each valve 240 is biased toward a closed position by the dome gas pressure and toward an open position by the forces of the spring 42 and the pressure of the lift gas in the casing annulus 203. The uppermost valve is provided with the weakest spring 42 so that a maximum casing annulus pressure is required to hold the valve in the open position. Each succeeding gas lift valve down the tubing string is provided with a stronger spring so that each valve is held open by a reduced casing annulus pressure. By way of example, an uppermost valve biased downwardly by dome gas pressure providing a force 100 pounds may be counterbalanced by upward forces provided by a spring 42 providing a force of ten pounds with the remaining 90 pounds of force being provided by the pressure of the lift gas in the casing annulus. The next valve down the tubing string has the same dome gas pressure providing a downward force of 100 pounds while the spring 42 may provide an upward force 20 pounds with the remaining force necessary to hold the valve in the open position being 80 pounds provided by the pressure of the lift gas in the casing annulus. Thus, it will be obvious that by increasing the force provided by the spring 42 of each lower gas lift valve a lesser casing annulus pressure is required to hold the valve in the open position. When each gas lift valve closes, it remains biased downwardly by the force of the dome gas pressure above the piston 61 and biased upwardly by the sum of the forces provided by the spring 42, the casing annulus pressure acting on the valve member around the line of sealing engagement between the lower end surface 80 with the seat 81 within the line of sealing engagement of the ring seal 63 with the wall of the chamber 43 and the fluid pressure within the outlet flow passage 82 acting within the line of sealing engagement between the lower end surface 80 and the seat 81. The pressure acting within the passage 82 on the valve member substantially equals the fluid pressure in the tubing string since with the valve member at the lower closed position the pressures stabilize across the choke 241 in the absence of flow through the choke so that the pressures above and below it are equal. The pressure within the outlet flow passage 82 is lower than the casing annulus pressure of the lift gas and within the design limits of the valves for a particular gas lift system utilizing the valves once a closed gas lift valve does not reopen with increases of the lift gas pressure within the annulus 203 within normal operating limits.

A gas lift system employing the gas lift valves 240 with the choke 242 in the lift gas supply line leading to the casing annulus is initially operated in a manner identical to that described in connection with the previously discussed and illustrated gas lift systems through the step during which the uppermost of the gas lift valves allows entry of the lift gas into the tubing string. The operation of this modified system varies somewhat, however, when the liquid level in the casing annulus is lowered to the second gas lift valve. When the fluids in the casing annulus are displaced downwardly to the extent that the liquid level moves below the inlet ports 83 of the second gas lift valve from the top, the lift gas from the casing annulus enters the inlet ports of the second gas lift valve so that lift gas is flowing from the annulus into the tubing string through both the uppermost and the second of the gas lift valves. Since the choke in each of the gas lift valves is sized to pass about the same volume of gas as

the choke 242, the flow of lift gas from the annulus into the tubing string abruptly is doubled with the supply of lift gas through the choke 242 remaining substantially the same and a consequent rapid reduction of pressure within the casing annulus. The reduction of annulus pressure allows the dome gas pressure in the uppermost gas lift valve to shut the valve as soon as the annulus pressure drops below the valve required to hold the valve in the open position. Since the second gas lift valve has a stronger spring 42 and thus is holdable at open position by a lower casing annulus pressure, it will remain open while the uppermost valve closes. When the uppermost valve is closed, the next valve or second valve down remains open so that lift gas continues to flow into the tubing string to displace the fluids in the tubing string to the surface. The procedure continues with consecutive gas lift valves down the tubing string opening and closing as the liquid level in the casing annulus is lowered.

It will now be seen that an improved continuous gas lift system has been described and illustrated including gas lift valves which function responsive to predetermined pressure conditions for permitting flow of gas from a casing annulus into the tubing string.

It will be further seen that one of the continuous gas lift systems described and illustrated includes lift gas injection valves which are each biased toward closed position by a force provided by the pressure of gas supplied into a dome gas chamber of each valve from the surface.

It will additionally be seen that one form of gas lift valve utilized in a continuous gas lift system embodying the invention includes a valve member having a throttling tip for regulating flow of lift gas from the casing annulus into the tubing string through the gas lift valve.

It will also be seen that another modified form of gas lift system embodying the invention includes gas lift valves having choke means in inlet ports leading from the casing annulus into the valve body of each valve for metering the lift gas from the casing annulus into each gas lift valve.

It will also be seen that a further modified form of continuous gas lift system described and illustrated herein includes a choke in a lift gas supply line leading to a casing annulus for limiting the supply of lift gas to the annulus and a choke in the outlet flow passage from each of the gas lift valves in the system, the choke in each gas lift valve being sized to pass about the same gas volume as the choke in the lift gas supply line.

It will be further seen that each of the gas lift valves in this last mentioned system is closable responsive to a predetermined casing annulus pressure controlled in part by a spring and the springs of the gas lift valves in the system each have different strength characteristics with the weakest spring being positioned in the uppermost valve and the strength of the springs progressively increasing in each lower gas lift valve in the system.

The foregoing description of the invention is explanatory only, and changes in the details of the construction illustrated may be made by those skilled in the art, within the scope of the appended claims, without departing from the spirit of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. A gas lift system for displacing well fluids in a well bore to the surface through a tubing string in the well bore by injection of lift fluids from an annular space in the well bore around the tubing string into the tubing string comprising: injection valve means connected with said tubing string within said well bore for admitting fluid from said annular space into said tubing string; and means located at the surface interconnected with said injection valve means for remotely controlling said injection valve means; said injection valve means including a valve member and a dome gas chamber receiving a portion of said valve member, said valve means being connected with

said tubing string at a predetermined depth within said well bore, spring means in said valve means biasing said valve member toward open position, said valve member being biased to an open position responsive to fluid pressure in said tubing string at said valve means, said spring means and the pressure in said annular space, said movable to a closed position responsive to fluid pressure in said dome gas chamber; and said means located at the surface connected with said injection valve means including control means adapted to permit dome gas to flow to said injection valve means at a pressure in excess of the pressure of lift gas flowing into said annular space to close said valve means when the pressure in said annular space decreases below a predetermined value, said control means being further adapted to suspend flow of dome gas to said injection valve means when the pressure in said annular space exceeds said predetermined value; and means for substantially equalizing the dome gas pressure in said injection valve means with the pressure in said annular space.

2. A gas lift system as defined in claim 1 including a Bourdon tube and dome gas flow control means in said control means, the interior of said Bourdon tube being exposed to the pressure in said annular space whereby said tube moves between expanded and retracted positions responsive to the pressure within said annular space, and the free end of said tube is engageable with said dome gas flow control means for controlling the flow of dome gas from said control means to said injection valve means.

3. A gas lift system as defined in claim 2 wherein a flow conduit extends from said control means to said injection valve means, a flow conduit extends from said control means into said annular space, and said means for equalizing said dome gas pressure with said pressure in said annular space comprises a choke in a flow conduit extending between said conduits extending from said control means to said valve means and said annular space.

4. A gas lift system in accordance with claim 3 wherein said injection valve means comprises: a tubular body having an upper dome gas chamber, a lower spring chamber, and a central bore connecting said chamber; said body being further provided with a lower outlet flow passage, an annular seat surface around said outlet flow passage, and a lateral port opening into said body above said outlet flow passage; a longitudinally slidable valve member movably supported through said bore between said dome gas chamber and said spring chamber; said valve member including pressure responsive means positioned within said dome gas chamber permitting pressure within said chamber to bias said valve member downwardly; the lower end of said valve member including a seat surface adapted to engage said seat surface around said outlet flow passage from said body for controlling fluid flow through said outlet flow passage; and resilient means operatively connected between said valve member and said body biasing said valve member upwardly relative to said body.

5. A gas lift system as defined in claim 4 wherein said pressure responsive means comprises a piston at the upper end of said valve member and sealing means supported on said piston for sealing between said piston and the inside wall of said body defining said dome gas chamber.

6. A gas lift system as defined in claim 4 wherein said pressure responsive means comprises a bellows secured at the lower end in fluid tight relationship with said valve member and secured at the upper end around its periphery to said body member within said dome gas chamber whereby pressure is applied within said dome gas chamber above said bellows for affecting a pressure differential across said bellows.

7. A gas lift system as defined in claim 4 including in addition a supply gas line connected into said annular space, a dome gas line connected from such supply gas line to said dome gas flow control means, and a choke

in said supply gas line downstream from the connection of said dome gas line into said supply gas line.

8. A gas lift system as defined in claim 7 wherein said control means includes a dome gas valve connected between said dome gas line and said line extending from said control means to said injection valve means, said dome gas valve being adapted to be held in open position when said Bourdon tube is contracted responsive to a predetermined pressure level in said annular space to permit flow of dome gas to said injection valve means, and said dome gas valve being adapted to be moved to a closed position by said dome gas when said Bourdon tube is expanded by annular space pressure above said predetermined value until the free end of said tube releases said dome gas valve.

9. A gas lift valve comprising: a body having an upper dome gas chamber, a lower spring chamber, and a central bore connecting said chambers; said body being further provided with a lower outlet flow passage, an annular seat surface around said outlet flow passage, and a lateral port opening into said body above said outlet flow passage; a longitudinally slidable valve member movably supported through said bore between said dome gas chamber and said spring chamber; said valve member including pressure responsive means positioned within said dome gas chamber permitting pressure within said chamber to bias said valve member downwardly; the lower end of said valve member including a seat surface adapted to engage said seat surface around said outlet flow passage from said body for controlling fluid flow through said outlet flow passage; and resilient means operatively connected between said valve member and said body biasing said valve member upwardly relative to said body.

10. A gas lift valve as defined in claim 9 wherein said pressure responsive means comprises a piston at the upper end of said valve member and sealing means supported on said piston for sealing between said piston and the inside wall of said body defining said dome gas chamber.

11. A gas lift valve as defined in claim 9 wherein said pressure responsive means comprises a bellows secured at the lower end in fluid tight relationship with said valve member and secured at the upper end around its periphery to said body member within said dome gas chamber whereby pressure is applied within said dome gas chamber above said bellows for affecting a pressure differential across said bellows.

12. A gas lift system for displacing well fluids in a well bore to the surface through a tubing string in the well bore by injection to lift fluids from an annular space in the well bore around the tubing string into the tubing string comprising: injection valve means connected with said tubing string within said well bore for admitting fluid from said annular space into said tubing string; and means located at the surface interconnected with said injection valve means for remotely controlling said injection valve means; said injection valve means being adapted for continuous injection of lift fluids from said annular space into said tubing string and adapted to close responsive to a pressure reduction in said tubing string.

13. A gas lift system for displacing well fluids in a well bore to the surface through a tubing string in the well bore by injection of lift fluids from an annular space in the well bore around the tubing string into the tubing string comprising: injection valve means connected with said tubing string within said well bore for admitting fluid from said annular space into said tubing string; and means located at the surface interconnected with said injection valve means for remotely controlling said injection valve means; said injection valve means being adapted for continuous injection of lift fluids from said annular space into said tubing string and adapted to close responsive to a reduction of the pressure within said annular space below a predetermined value.

14. A gas lift system for displacing well fluids from

a well bore continuous gas injection comprising: means providing a tubing string in said well bore for conducting well fluids therefrom; an annular space being provided within said well bore around said tubing string; lift gas injection means supported from said tubing string for controlling continuous injection of lift gas from said annular space into said tubing string for displacing well fluids in said tubing string to the surface; said lift gas injection means having a valve member movable between open and closed positions and a dome gas chamber for receiving a piston portion of said valve member whereby said valve member is biased toward a closed position by fluid pressure within said dome gas chamber; conduit means extending to the surface end of said well bore; fluid pressure regulating means in said last mentioned conduit means for regulating the pressure of dome gas to said dome gas chambers; and means for supplying lift gas under pressure into said annular space; said lift gas injection means comprising a body having an upper dome gas chamber, a lower chamber, and a central longitudinal bore connecting said chambers; said body also having a lower outlet passage communicating with said lower chamber, an annular seat surface around said outlet flow passage, and lateral port means comprising a choke opening into said lower chamber above said outlet flow passage; a longitudinally slidable valve member through said bore between said dome gas chamber and said lower chamber; said valve member including pressure responsive means positioned within said dome gas chamber permitting pressure within said chamber to bias said valve member downwardly; a lower end of said valve member including a seat surface adapted to engage said seat surface around said outlet flow passage from said body for controlling fluid flow through said outlet flow passage, seal means around said valve member between said dome gas chamber and said lower chamber; and said body having a port opening into said dome gas chamber below said pressure responsive means.

15. A gas lift system as defined in claim 14 wherein said means for supplying lift gas into said annular space includes pressure regulating means.

16. A gas lift system as defined in claim 14 wherein said means for supplying lift gas to said annular space includes choke means for controlling the fluid flow rate of said lift gas into said annular space.

17. A gas lift comprising: a body having an upper dome gas chamber, a lower chamber, and a central longitudinal bore connecting said chambers; said body also having a lower outlet passage communicating with said lower chamber, an annular seat surface around said outlet flow passage, and lateral port means comprising a choke opening into said lower chamber above said outlet flow passage; a longitudinally slidable valve member through said bore between said dome gas chamber and said lower chamber; said valve member including pressure responsive means positioned within said dome gas chamber permitting pressure within said chamber to bias said valve member downwardly; a lower end of said valve member including a seat surface adapted to engage said seat surface around said outlet flow passage from said body for controlling fluid flow through said outlet flow passage, seal means around said valve member between said dome gas chamber and said lower chamber; and said body having a port opening into said dome gas chamber below said pressure responsive means.

18. A gas lift valve as defined in claim 17 including spring means in said lower chamber confined for expansion and contraction between said valve body and said valve member for biasing said valve member upwardly toward an open position.

19. A gas lift system as defined in claim 16 wherein said gas lift injection means comprises: a tubular body having an upper dome gas chamber, a lower chamber, and a central longitudinal bore connecting said chambers; said body being further provided with a lower outlet flow

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from said lower chamber, an annular seat surface around said outlet flow passage, and a port opening into said body above said outlet flow passage; a longitudinally slidable valve member supported through said bore between said dome gas chamber and said lower chamber; said valve member including pressure responsive means positioned within said dome chamber permitting pressure within said chamber to bias said valve member downwardly; the lower end of said valve member including a seat surface adapted to engage said seat surface around said outlet flow passage from said lower chamber for controlling fluid flow through said outlet flow passage; resilient means operatively connected between said valve member and said body biasing said valve member upwardly relative to said body; and said outlet flow passage having a restriction limiting flow through said passage to a lower rate than permitted through said lateral port into said body.

20. A gas lift system for displacing well fluids in a bore to the surface through a tubing string in the well bore by injection of lift fluids from an annular space in the well bore around the tubing string into the tubing string comprising: injection valve means connected with said tubing string within said well bore for admitting fluid from said annular space into said tubing string; said valve means including a pressure chamber, pressure responsive means in said valve means exposed to the pressure in said chamber biasing said valve means to closed position, resilient means in said valve means biasing said valve means toward open position, and means communi-

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cating lift fluid pressure from said annular space to said pressure responsive means opposing the pressure in said chamber, whereby said valve is biased toward open position by a combination of the pressure in said pressure chamber, said resilient means, and the pressure in the tubing string at said valve means; and control fluid pressure means located at the surface interconnected with said pressure chamber of said valve means for controlling the pressure in said pressure chamber of said injection valve means for remotely controlling said injection valve means.

15 21. A gas lift valve as defined in claim 17, wherein said outlet flow passage is provided with flow restriction means limiting flow through said outlet passage to a lower rate than permitted through said lateral port into said body.

References Cited

UNITED STATES PATENTS

2,278,532	4/1942	Crickmer	103—233
2,345,865	4/1944	Boynton	103—233
2,465,060	3/1949	Carlisle et al.	137—155
2,556,867	6/1961	Carlisle et al.	137—155
2,633,086	3/1953	Zaba	103—233
2,658,460	11/1953	Davis	103—233
2,725,014	11/1955	Pryor	103—233
2,761,465	9/1956	Garrett et al.	137—155
3,139,040	6/1964	Roach	103—232

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,362,347

January 9, 1968

Carlos R. Canalizo

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 72 "levels" should read -- level --.
Column 8, lines 3 and 4, "valve", each occurrence, should read -- value --; line 37, "contacts" should read -- contracts --; line 39, after "lift" insert -- valve --.
Column 9, line 28, "continuous" should read -- continues --.
Column 12, line 17, "exering" should read -- exerting --; line 26, "seeen" should read -- seen --. Column 15, line 11, "volumn" should read -- column --. Column 19, line 5, "The" should read -- This --; line 6, "uppormost" should read -- uppermost --. Column 21, line 50, "to" should read -- of --. Column 22, line 1, after "bore" insert -- by --; line 46, after "lift" insert -- valve --; line 75, after "flow" insert -- passage leading --. Column 23, line 7, after "dome" insert -- gas --. Column 24, line 13, after "outlet" insert -- flow --.

Signed and sealed this 19th day of August 1969.

(SEAL)
Attest:

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