

Jan. 20, 1959

R. A. BOBO
CONTROL SYSTEM

2,869,475

Filed Dec. 21, 1951

2 Sheets-Sheet 1

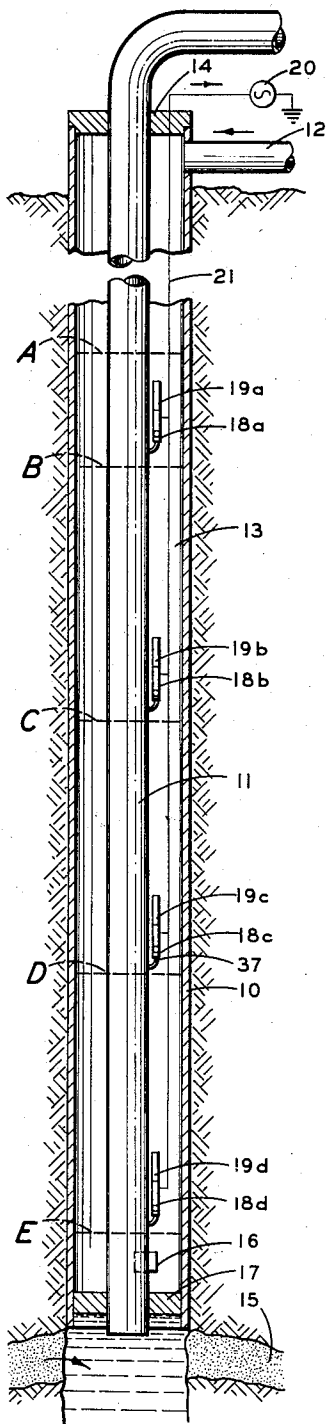


FIG. 1

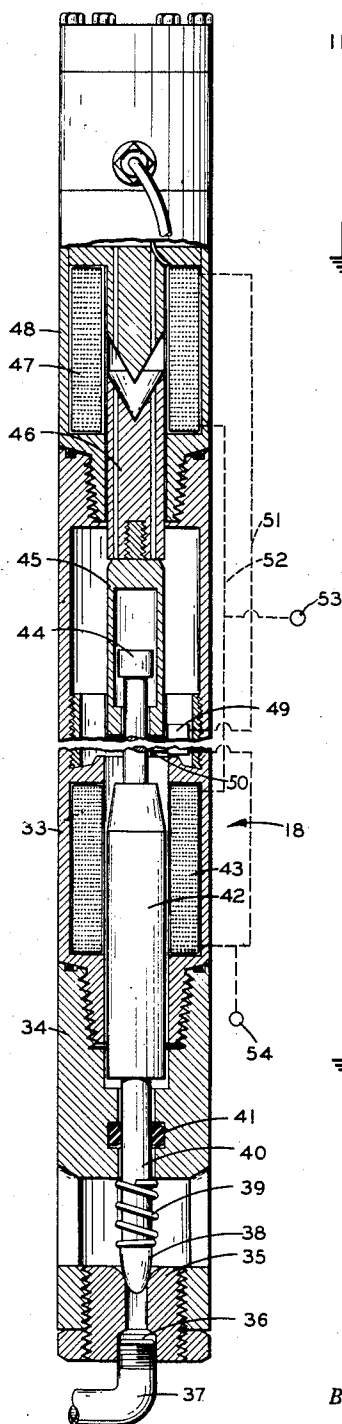


FIG. 4

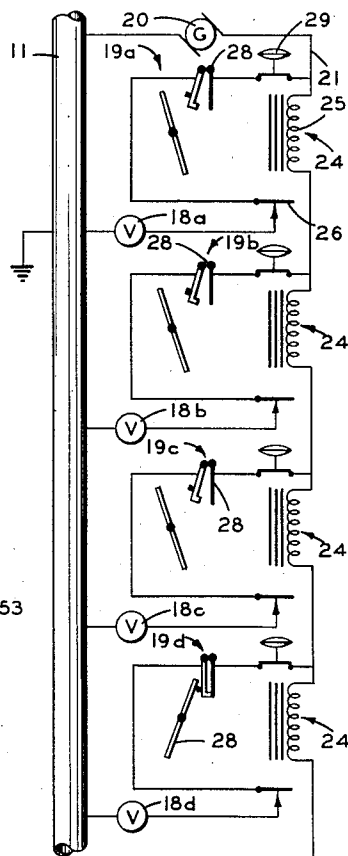


FIG. 2

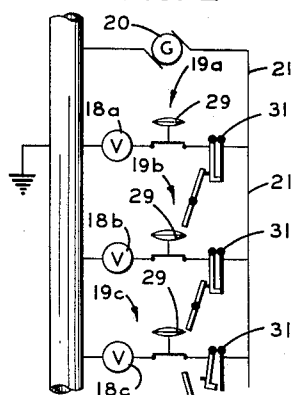


FIG. 3

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2 Sheets-Sheet 2

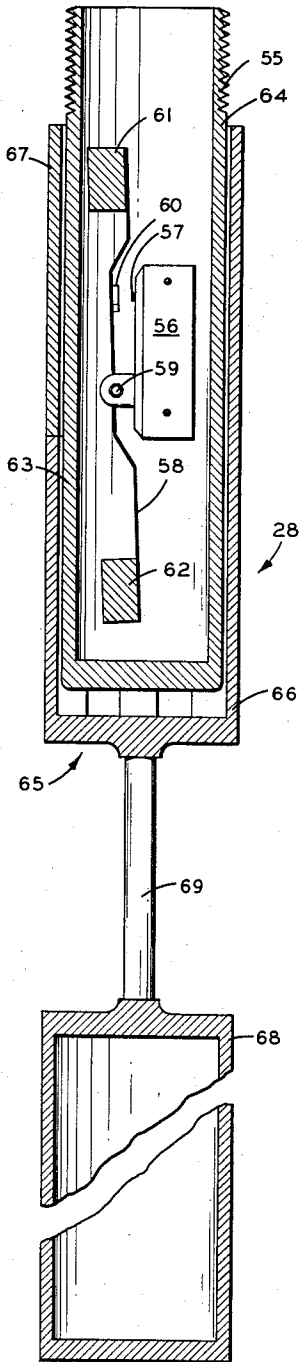


FIG. 5

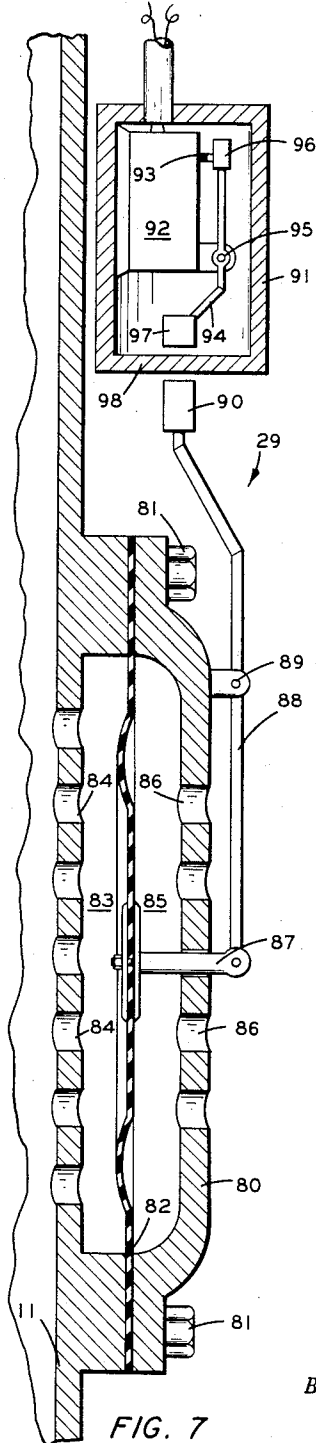


FIG. 7

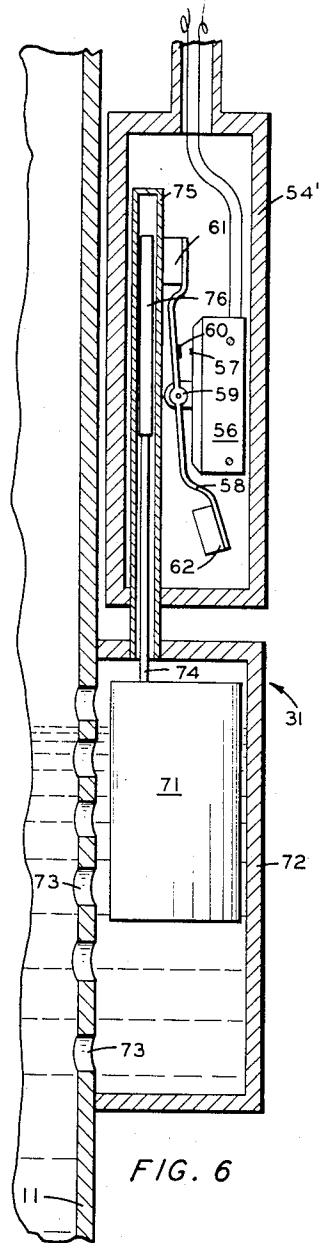


FIG. 6

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2,869,475

CONTROL SYSTEM

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14 Claims. (Cl. 103—233)

This invention relates to an improved control system for gas lift valves. In another aspect, it relates to an improved float switch for operating gas lift valves. In still another aspect, it relates to an improved valve construction. In still another aspect, it relates to an improved diaphragm-actuated switch.

In gas lift operations, a well having a string of tubing and a casing has a plurality of valves spaced along the tubing to admit gas under pressure which is pumped into the annulus between the tubing and casing to the tubing, thereby to aerate the oil in the tubing and cause it to rise to the surface.

In such a system, it is desirable that the valve be open which is immediately above the liquid level, and all valves above this valve to be closed. In the present system, I accomplished this automatically without the necessity of manually controlling each valve from the surface. This purpose is accomplished by a combination of novel elements including the gas lift valves, magnetically-operable float switches, and magnetically-operable diaphragm switches.

It is an object of the invention to provide an improved gas lift control system.

It is a further object to provide an improved gas lift valve.

It is a still further object to provide improved magnetically-operable float switches and diaphragm-actuated switches.

Various other objects, advantages and features of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawings, in which:

Figure 1 is a vertical sectional view of a well incorporating the gas lift system of this invention;

Figure 2 is a schematic circuit diagram of the control circuits of the invention;

Figure 3 is a schematic circuit diagram of a modified control circuit;

Figure 4 is a vertical sectional view, partially in elevation, of an improved gas lift valve;

Figure 5 is a vertical sectional view, partially in elevation, of an improved magnetically-operable float switch;

Figure 6 is a vertical sectional view, partially in elevation, of a modified float switch; and

Figure 7 is a vertical sectional view, partially in elevation, of a magnetically-actuated differential-pressure diaphragm switch.

Referring now to Figure 1, I have shown a well having a casing 10 with a string 11 of tubing mounted concentrically therein. Gas under pressure is fed through a conduit 12 to the interspace or annulus 13 between the tubing and casing, this region being sealed from the atmosphere by a casing head 14. The tubing 11 has a check valve 16 opening into the annulus 13, a packer 17 being provided, as an optional feature, to seal the annulus 13 from the producing formation. Oil entering the tubing 11 is aerated by gas admitted from the an-

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nulus 13 to the interior of tubing 11 through one of a series of gas lift valves 18a to 18d, inclusive, which are spaced vertically along the tubing 11. Associated with the valves 18 are respective control mechanisms 19a to 19d, inclusive, which will be more fully described hereinafter. Each such control mechanism may incorporate a current-actuated relay, a magnetically-actuated float switch, a magnetically-actuated diaphragm switch or a subcombination of these parts. The electrically-actuated devices are supplied with current by a generator 20 which impresses an alternating voltage between ground and a conductor or line 21 extending from the surface to the lowermost control mechanism. A source of direct current can be substituted for the generator, if desired.

Referring now to Figure 2, in which parts already described are indicated by like reference characters, it will be noted that the control mechanism associated with each valve includes a current-actuated relay 24 having an operating winding 25 connected in series with the line 21, each relay being provided with a set 26 of normally closed contacts. Connected in series between line 21 and ground at each valve station are the actuating windings of the valve, the normally closed contacts 26, a float-actuated switch 28, and a diaphragm operated switch 29.

Each switch 28 is constructed in accordance with Figure 5 and is controlled by a float which is positioned within the annulus 13, Figure 1. The diaphragm-operated switch 29 can be of the construction shown by Figure 7 and is responsive to the pressure differential between the interspace 13 and the interior of the tubing 11.

In operation, assuming that the interspace 13 and tubing are both filled with oil or water, or a combination of the two, to the level A, Figure 1, and that no check valve 16 nor packer 17 is utilized, each diaphragm switch 29 is closed, the pressure in the interspace opposite each valve being equal to or exceeding that within the tubing at that point, and each of the switches 28 is open. Therefore, no current is supplied to the operating winding of any valve, and all of such valves are, therefore, in closed position. The gas pressure forces a portion of the oil upwardly in the tubing and depresses the level of the fluid within the interspace 13. When this level drops to the point B, the float switch 28 of control mechanism 19a is actuated, thereby closing the switch and opening valve 18a to admit gas under pressure to the tubing. This aerates the fluid in the tubing and causes it to rise toward the surface with a resultant additional lowering of the fluid level within the interspace 13. When this fluid falls to the level C, either from drop in bottom hole pressure due to flow which is initiated by gas injection through valve 18a, or from continued depression due to gas pressure applied to the interspace, the switch 28 of control mechanism 19b is closed and, accordingly, valve 18b is opened. The valve-operating current of unit 18b passes through the winding 25 of control mechanism 19a thereby energizing this relay and causing contacts 26 to open. This interrupts the supply of current to the associated valve and causes valve 18a to close. The fluid within the tubing is, accordingly, aerated only by gas under pressure passing therein through valve 18b. Due to flow which is now controlled by gas injection, the liquid level in the annulus will continue to drop until an equilibrium is reached where all pressure and flow conditions concerned are satisfied. If equilibrium is not attained with stabilized flow, the liquid level in the annulus will drop successively to the positions D and E with successive opening of valves 18c and 18d. When valve 18c is energized, the energizing current passes through the relay windings of control mechanisms 19a, 19b thereby breaking the valve-actuating circuits and causing valves 18a and 18b to close. Similarly, when valve 18d is open the relays of control mechanisms 19a,

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19b and 19c are energized and, accordingly, valves 18a, 18b and 18c are closed.

In summary, therefore, the system operates to maintain the first valve above the liquid level in the interspace 13 in open position, all valves above this open valve being closed through operation of the current relays 25. The diaphragm-actuated switches 29 associated with each control mechanism is an important feature. Its function is to open any valve-actuating circuit when the pressure in the tubing at a valve station is greater than the pressure in interspace 13. This effectively prevents any flow of liquid from the tubing into the interspace.

Where the pressure gradient in the tubing is steeper than that in the annulus 13, the differential switches 29 can be eliminated. Thus, since the annulus pressure and tubing pressure are equal at the bottom of the well, at the first valve station above the liquid level in the annulus, the annulus pressure will be greater than the tubing pressure, so that gas will enter the tubing at this point.

Conversely, if the pressure gradient in the annulus 13 is steeper than that in the tubing, the float-actuated switches 19 can be eliminated for, in this case, the pressure in the casing will exceed the pressure in the tubing at the top valve before this condition prevails at any lower valve. Similarly, as the operation continues, the lower valves are sequentially operated because the tubing pressure at successively lower valves becomes greater than the annulus pressure.

It is preferred, in most cases, however, to use the float switches in combination with the differential switches.

Where a packer 17 is utilized, all liquid in the casing is displaced with salt water before the packer is set. The liquid level in the casing cannot rise again when it has been once displaced through check valve 16 by the gas, since all other means of entry from the tubing into the casing are prevented. In this case the operation can be carried out by the differential switches alone by raising the annulus pressure to a sufficient level to operate the desired valve, all valves above this being closed by the current relays.

In Figure 3, I have shown a modified form of operation which is particularly adapted for use in wells not provided with a packer 17, Figure 1. In this modification, each control mechanism 19 includes a float-actuated switch 31 of the type shown by Figure 6 and, optionally, a diaphragm-actuated switch 29, both sets of switch contacts being connected in series with the valve-operating winding. In this case, each switch 31 is actuated by a float which is responsive to the density of the fluid in the tubing 11, Figure 1, below the associated valve. The float is lowered and the switch is opened when the oil within the tubing is reduced in density by aeration thereof with gas passed through one of the valves, the float being raised, and the switch closed when the oil is not so aerated. Assuming the level of dense non-aerated oil in the tubing to be at A, Figure 1, each of the switches 31 is closed and accordingly, each of the valves 18 is opened. Gas under pressure is admitted to annulus 13 and the operation proceeds in the normal manner until the valve 18b begins to admit gas to the tubing. When this occurs, the fluid flowing past control mechanism 19a is aerated with the result that the switch 31 of this control mechanism is opened and valve 18a is closed. When gas is admitted through valves 18c or 18d, the column of fluid in the tubing above these valves is aerated with the result that the float-actuated switches of each valve above the lowermost actuated valve are open and the corresponding valves are closed. In this embodiment, the diaphragm-actuated switches 29 are utilized to cause their associated valves to close should the tubing pressure exceed the pressure in the interspace 13. It will be noted that the current relays can be eliminated in this embodiment of the invention.

The valves 18 are of novel construction, as shown by

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Figure 4. In this figure, it will be noted that each valve has an elongated generally cylindrical casing 33, an extension 34 of which is provided with a valve seat 35 having a passage 36 therein communicating with the interior of the tubing 11 through a conduit 37. Cooperating with the seat 35 is a valve head 38 which is urged into engagement with the seat by a spring 39. The region just above the valve head is provided with openings communicating with the annulus or interspace 13. The valve head is carried by a rod 40 which extends longitudinally within the casing 33. A sealing gasket 41 is provided to prevent well fluids from entering the interior of casing 33. Rod 40 carries an enlarged armature 42 which is encircled by a solenoid winding 43 of relatively low power. At the end thereof remote from the head 38, the rod 40 has an enlarged portion 44. Slidably mounted upon the rod 40 just below the enlarged portion 44 is a fitting 45 which cannot slide past the enlarged portion 44. Fitting 45 is secured to a second armature 46 which is encircled by a solenoid winding 47 of relatively high power mounted in an extension 48 of the casing 33.

Mounted within the casing is a limit switch 49 having an actuating member 50 which is engaged by armature 42 when the valve head moves to open position. This limit switch is normally closed and is connected in series with winding 47. The operating circuit for winding 47 includes terminal 53, lead 52, winding 47, lead 51, limit switch 49 and terminal 54. Winding 43 is connected directly to terminals 53 and 54. Thus, winding 43 is independent of limit switch 49. Terminals 53 and 54 are used to connect the valve in the circuit as shown in Figure 2 or 3.

When operating current is supplied to the valve, winding 47 is energized with the result that fitting 45 moves sharply into engagement with enlarged portion 44, thereby giving the enlarged portion a jarring blow which causes the valve head to be lifted from seat 35. Winding 43 is also energized, and maintains the valve in open position through attraction of armature 42 after the valve has been opened in the manner described. As the valve moves into open position, armature 42 engages the actuating arm 50 of limit switch 49, thereby opening the switch contacts and opening the operating circuit of winding 47. Thus, after the valve is open, it is maintained in open position by a relatively light current passing through the winding 43, it being understood that the more powerful winding 47 draws substantially more current. When the current is interrupted, the valve is, of course, moved to closed position under the influence of spring 39.

Referring now to Figure 5, I have shown a float switch of novel construction, as denoted by reference numeral 28 in Figure 2. This switch includes a fluid tight housing 64 which is provided with threads 53 for attachment to the rest of the control mechanism. Mounted within the housing 64 is a switch 56, preferably of the snap action type, this switch having an actuating pin 57. A control lever 58 is pivoted at 59 to the switch casing, this lever having a stop 60 adapted for engagement with contact pin 57. Mounted at the respective ends of lever 58 are a pair of magnetic members 61 and 62 which are both positioned close to one wall 63 of the housing 64.

A float assembly 65 includes a casing 66 which is slidably mounted relative to housing 64 and has a magnetic segment 67 positioned adjacent the housing wall 63. The float assembly 65 further comprises a float 68 which is attached to the casing 66 by a rod 69.

When the float is in a fluid of high density, it rises and the casing 66 moves upwardly to a position where there is a magnetic attraction between segment 67 and magnetic member 61, thereby causing lever 58 to swing in a counterclockwise direction, Figure 5, with resultant opening of switch 56. When the float is positioned in a fluid of low density, it moves downwardly with the result that magnetic segment 67 moves to a position adjacent magnetic member 62, the resultant magnetic at-

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traction between these parts causing lever 58 to swing in a clockwise direction, Figure 5, with resultant engagement of stop 60 with pin 57 and closure of the switch. It will be observed that, when the switch is positioned in the annulus 13, Figure 1, as illustrated, the float is immersed in the fluid within the annulus.

The modified float switch of Figure 6 is of generally similar construction as regards the housing, operating lever, and switch, so that these parts will not be described in detail. In this modification, a float 71 is positioned within a casing 72 which communicates with the interior of the tubing 11 through openings 73. Attached to the float 71 is a rod 74 which extends through a partition member 75 of non-magnetic material into the housing 54'. The rod carries a magnetic member 76 which co-operates with the magnetic members 61, 62 in the same manner as described in connection with Figure 5. The partition member 75, in effect, forms a wall of the housing 54' and it will be noted that both magnetic members 61, 62 cooperate with the magnetic member 76 through this wall.

The operation of the float switch of Figure 6 is similar to that of Figure 5 except that the position of the float is determined by the density of the fluid within the tubing rather than by the density of the fluid within interspace 13, Figure 1. Thus, when the tubing 11, and hence the casing 72 is filled with non-aerated oil of comparatively high density, the float and magnetic member 76 rise, thereby causing switch 56 to close. When the fluid in the tubing 11 in casing 72 is aerated, its density decreases thereby causing the float 71 and magnetic member 76 to drop with resultant actuation of switch 56.

In Figure 7, I have illustrated a diaphragm switch, such as that indicated by reference numeral 29 in Figures 2 and 3. This switch includes a casing member 80 which is secured by bolts 81 to the tubing 11. The bolts 81 also secure a diaphragm 82 between suitable flanges on the tubing 11 and casing 80, the diaphragm dividing the interior of the casing into a chamber 83 communicating with the interior of the tubing 11 through openings 84 and a chamber 85 communicating with the interspace 13, Figure 1, through openings 86. A rod 87 secured to the diaphragm 82 is pivoted to an operating lever 88 which, in turn is pivoted at 89 to casing 80, the rod carrying a control member 90 of magnetic material. Member 90 is positioned adjacent a fluid tight housing 91 within which is mounted a switch 92 having an actuating pin 93. A lever 94 is pivoted at 95 to the switch casing and carries, at one end, an abutment 96 which is engageable with pin 93 and, at its other end, a magnetic member 97 positioned adjacent a wall 98 of the housing 91 in proximity to the magnetic member 90.

When the pressure in the interspace 13 is greater than the tubing pressure, the parts are in the position shown and the switch 92 is closed. Should the tubing pressure become greater than the pressure in the interspace, the diaphragm 82 moves rightwardly, Figure 7, thereby causing lever 88 to pivot in a counterclockwise direction, Figure 7. As a result of the magnetic attraction between members 90, 97, this causes lever 94 to pivot in a clockwise direction, Figure 7, with the result that abutment 96 moves out of engagement with contact pin 93, thereby opening the switch 92. As explained in connection with Figures 2 and 3, this causes the valve associated with the diaphragm switch to close. When the tubing pressure becomes less than the pressure in interspace 13, the parts are restored to the positions shown by Figure 7.

It will be apparent that I have achieved the objects of my invention in providing an automatic gas lift system of improved character which does not require any manipulation of controls at the surface of the well to effect its operation. Further, in this gas lift system, I have provided gas lift valves, float-actuated magnetic switches, and diaphragm magnetic actuated switches of improved construction. Finally, the system is completely automatic; 75

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and utilizes only a single wire extending from the surface to the valves.

While the invention has been described in connection with present, preferred embodiments thereof, it is to be understood that this description is illustrative only and is not intended to limit the invention.

I claim:

1. In combination, a well having a casing and tubing mounted therein, a metal housing secured to said tubing, a diaphragm mounted in said housing and dividing it into two diaphragm chambers, means for effecting communication between one chamber and the interior of said tubing, means for effecting communication between said other chamber and the interspace between said tubing and said casing, a member of magnetic material, linkage connecting said member to diaphragm so that said member moves in response to movement of said diaphragm, a fluid tight housing secured to said tubing, a switch mounted therein, an actuating member for said switch pivotally mounted in said last-mentioned housing, and a magnetic element carried by said actuating member arranged to follow the movement of said magnetic member and thereby open or close said switch responsive to movement of said diaphragm.

2. In combination, a well having casing and tubing mounted therein, a metal housing secured to said tubing, a diaphragm mounted in said housing and dividing it into two diaphragm chambers, means for effecting communication between one chamber and the interior of said tubing, means for effecting communication between said other chamber and the interspace between said tubing and said casing, a pivoted control rod connected at one end thereof to said diaphragm, a magnetic member carried at the other end of said control rod, a fluid tight housing secured to said tubing and having one wall thereof positioned adjacent said magnetic member, a pivoted control lever in said fluid tight housing, an element of magnetic material carried by said control lever adjacent said wall of said fluid tight housing and in the field established by said magnetic member, and a switch mounted within said fluid tight housing and actuated by said control lever.

3. A valve comprising, in combination, a valve seat, a valve head, means for urging said head into engagement with said seat, an elongated armature of magnetic material secured to said valve head, a solenoid winding of low power encircling said armature, a second solenoid winding of high power, a control member movable within said second winding in response to energization thereof, a rod protruding from said armature having an enlarged head portion, and a fitting carried by said control member and slidably mounted upon said rod, said fitting engaging said enlarged head upon energization of said second winding to move said valve head to open position.

4. A gas lift valve comprising, in combination, an elongated generally cylindrical casing, a valve seat in said casing, a rod positioned axially within said casing, a valve head carried by said rod and adapted for engagement with said seat, a spring urging said valve head into engagement with said seat, a gasket sealing the region between said casing and said rod, an armature carried by said rod, a solenoid winding of relatively low power encircling said armature, and an enlarged portion formed on said rod at the end thereof remote from said valve head, a gripping device encircling said rod and engageable with said enlarged portion, a second armature secured to said gripping member, and a second solenoid winding of relatively high power encircling said second armature, a limit switch, an actuating member carried by said rod to move said limit switch to open position when said valve is open, means for connecting said solenoid windings in parallel, and means connecting said limit switch in series with said second solenoid winding.

5. In a gas lift system, in combination, a well including a tubing, a series of gas lift valves spaced along said tubing, each controlling the flow of fluid between the exterior

and interior of said tubing, control means operatively connected to each valve, and sensing means disposed within the well and operatively connected to the control means of each valve and responsive to a variable of the gas lift system within the well to operate the control means of each valve above the lowermost open valve so as to close each such valve.

6. In a gas lift system, in combination, a well including a tubing, a series of gas lift valves spaced along said tubing, each controlling the flow of fluid between the exterior and interior of said tubing, an electrical switch connected to and controlling the operation of each such valve, and a float-actuated device connected to each switch and responsive to the density of a liquid adjacent each valve to open and close said switch.

7. In a gas lift system, in combination, a well including tubing and casing, a series of gas lift valves spaced along said tubing, each controlling the flow of fluid between the exterior and interior of said tubing, a circuit including an electrical switch controlling the operation of each such valve, a float-actuated device connected to each switch and responsive to the density of a liquid adjacent each valve to open and close said switch, a current-sensitive relay operatively connected to each valve, each relay having an operating winding and a set of normally closed contacts, and means connecting the operating windings of said relays in series whereby, when current is drawn by a current relay at a selected valve station, the current relays above such station are energized, one set of said normally closed contacts being connected in each valve-operating circuit.

8. In a gas lift system, in combination, a well including tubing and casing, a series of gas lift valves, each having an operating winding actuable by passing current therethrough, spaced along said tubing at one of a plurality of valve stations, each valve controlling flow of fluid between the exterior and interior of the well tubing, a conductor extending from the surface to the lowermost valve of said series, an operating circuit at each valve station including said conductor, the operating winding of the valve at said valve station and a switch, a float-controlled magnetic means responsive to the density of a liquid adjacent each valve, and means connecting said magnetic means to said switch to actuate same.

9. In a gas lift system, in combination, a well including concentrically disposed tubing and casing in spaced relationship, a series of solenoid-actuated gas lift valves spaced along said tubing, each valve controlling flow of fluid between the exterior and interior of the well tubing at one of a plurality of valve stations, a conductor extending from the surface to the lowermost valve of said series, an operating circuit at each valve station including said conductor, the solenoid winding of the valve at said station and a switch having a magnetic actuating member, a float located adjacent each valve and responsive to the density of liquid in the interspace between the tubing and casing, and magnetic means connected to and actuated by said float and magnetically coupled to said member to open said switch when liquid is present in said interspace and to close said switch when no liquid is present in said interspace.

10. In a gas lift system, in combination, a well including concentrically mounted tubing and casing in spaced relationship, a series of gas lift valves spaced along said tubing, each having an operating winding and actuable by energization of said operating winding, each valve controlling flow of fluid between the exterior and interior of the well tubing at one of a plurality of valve stations, a conductor extending from the surface to the lowermost valve of said series, an operating circuit at each valve station including said conductor, the operating winding of the valve at said station, and a switch having a magnetic actuating member, a float located adjacent each valve and responsive to the density of liquid in the interspace between the tubing and casing, and

magnetic means connected to and actuated by said float and magnetically coupled to said member to open said switch when liquid is present in said interspace and to close said switch when no liquid is present in said interspace, a current-sensitive relay at each valve station having its operating winding connected in series with said conductor below such valve station, each relay having a set of normally closed contacts connected in the operating circuit of the associated valve.

11. In a gas lift system, in combination, a well including concentrically mounted tubing and casing in spaced relationship, a series of electromagnetically operated gas lift valves spaced along said tubing, each having an operating winding, each valve controlling flow of fluid between the exterior and interior of the well tubing at one of a plurality of valve stations, a line extending from the surface to the lowermost valve of said series, an operating circuit at each valve station including said line, the operating winding of the valve at said station, and a switch having a magnetic actuating member, a float located adjacent each valve and responsive to the density of liquid in the interspace between the tubing and casing, and magnetic means connected to and actuated by said float and magnetically coupled to said member to open said switch when liquid is present in said interspace and to close said switch when no liquid is present in said interspace, a current-sensitive relay at each valve station having its operating winding connected in series with said line below such valve station, each relay having a set of normally closed contacts connected in the operating circuit of the associated valve, a second normally closed switch connected in the operating circuit of each valve, a diaphragm member connected to the tubing and disposed in the interspace between the tubing and casing, said diaphragm member being responsive to the difference in pressure between the tubing and the interspace between the tubing and casing, and magnetic control linkage connecting said diaphragm with said switch so as to open said switch when the tubing pressure is greater than the pressure in said interspace.

12. In a gas lift system, in combination, a well including concentrically disposed tubing and casing in spaced relationship, a series of electrically-actuated gas lift valves, each having an operating winding, spaced along said tubing, each controlling the flow of fluid between the exterior and interior of said tubing, a line extending from the surface to the lowermost valve of said series, means for supplying current to said line, and an operating circuit for each valve including its operating winding, said line and a normally closed switch, a diaphragm-actuated switch having a diaphragm connected to the tubing and disposed in the interspace between the tubing and casing, said diaphragm being responsive to difference in pressure between said tubing and the interspace between said tubing and casing, and magnetic control linkage connecting said diaphragm with said normally-closed switch so as to open said normally-closed switch when the tubing pressure becomes greater than the pressure in said interspace.

13. In a gas lift system in combination, a well including concentrically mounted tubing and casing in spaced relationship, a series of gas lift valves spaced along said tubing, each valve having an operating winding and controlling the flow of fluid between the exterior and interior of said tubing, a conductor extending from the surface to the lowermost valve of said series, means for supplying current to said conductor, an operating circuit for each valve including the operating winding of said valve, a switch and said conductor, said switch having a magnetic actuating member, float-actuated magnetic means having a float magnetically coupled to said member for operating said switch, said float being responsive to the density of the fluid in said tubing to close said valve by means of said switch when the den-

sity of said float is that of the oil to be produced and to open said valve through operation of said switch when the density of said fluid decreases due to aeration thereof.

14. A gas lift system in accordance with claim 13 in which each float is mounted within a protective chamber in the interspace between said tubing and said casing, said chamber communicating with the interior of said tubing.

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