June 23, 1953 A. I. ROBINSON 2,642,812

WELL FLOW APPARATUS

Filed June 13, 1949 2 Sheets-Sheet 1

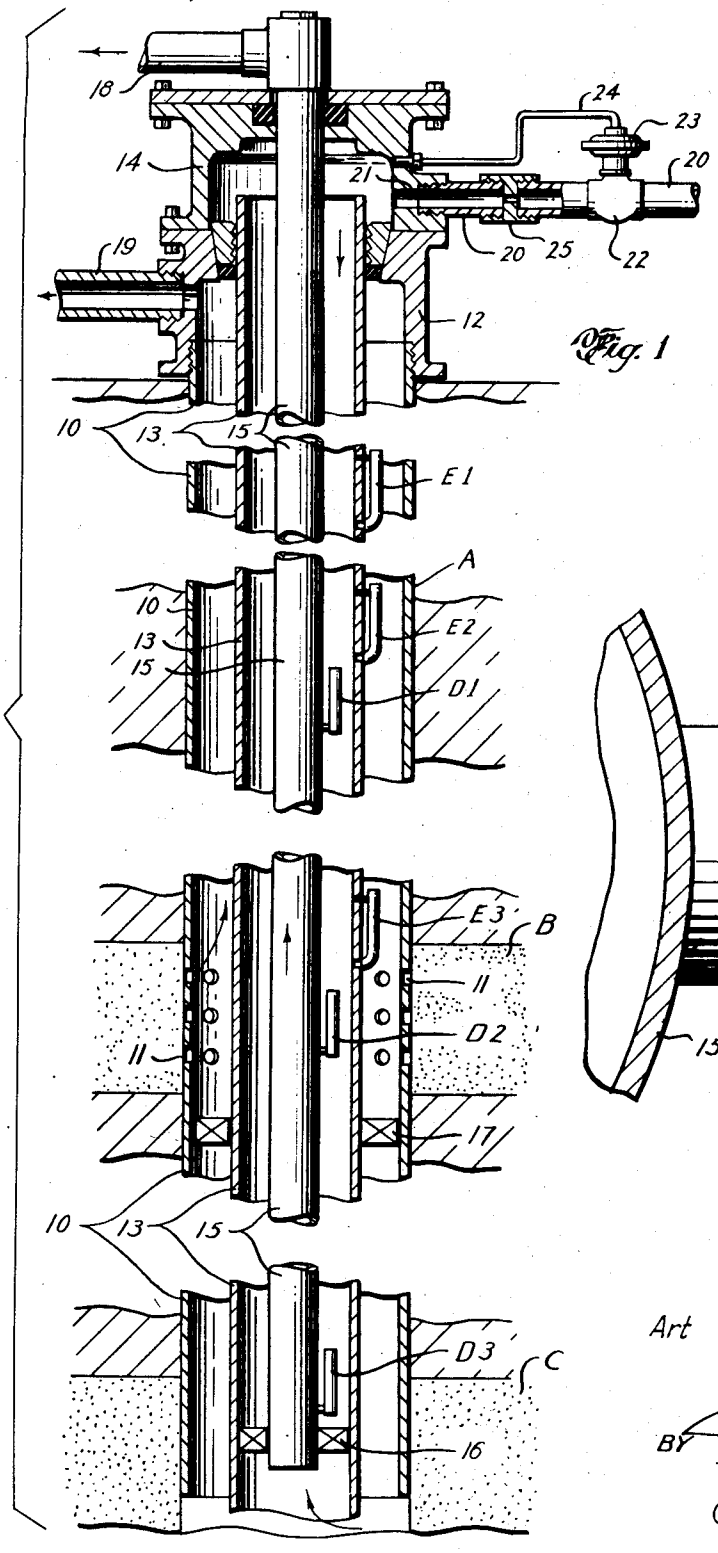


Fig. 1

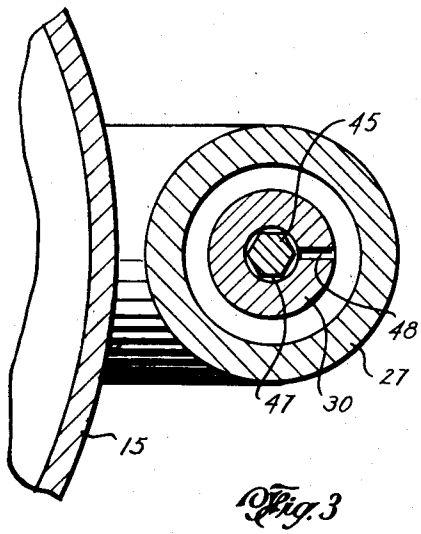


Fig. 3

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WELL FLOW APPARATUS

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Fig. 2

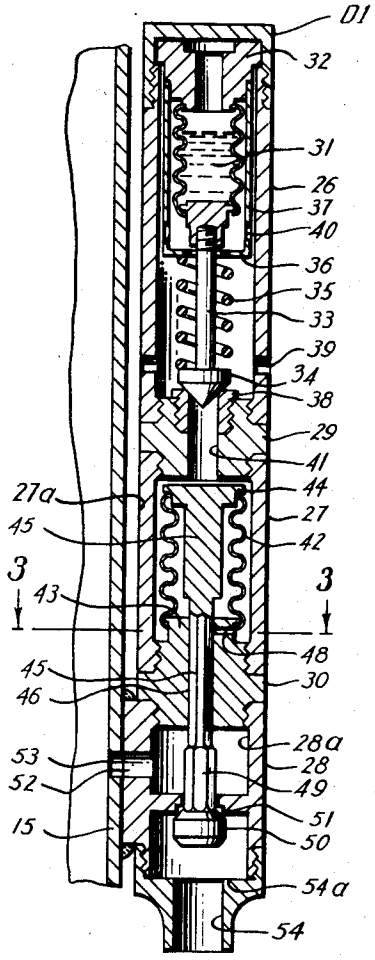
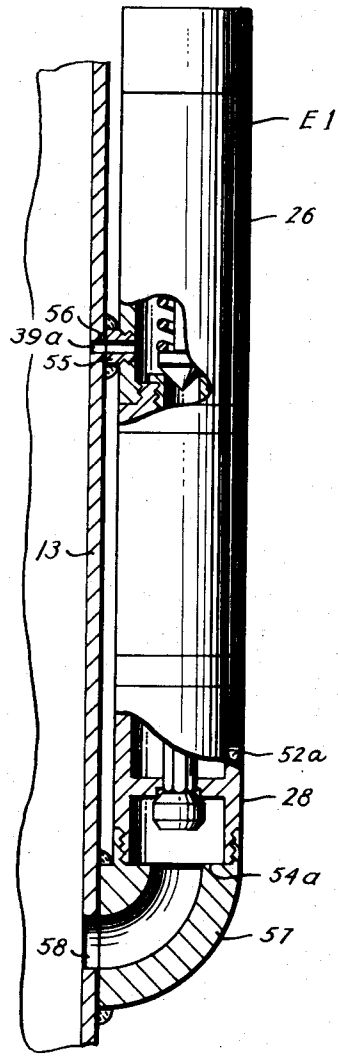


Fig. 4



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WELL FLOW APPARATUS

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11 Claims. (Cl. 103—233)

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This invention relates to new and useful improvements in a well flow apparatus.

One object of the invention is to provide an improved flow apparatus, of the intermitting type, which is particularly adapted for use in, although not limited to, multiple zone wells, whereby efficient lifting of the well fluids from the separate producing zones may be accomplished.

An important object of the invention is to provide an improved flow apparatus which employs a series of pressure-operated valves for controlling the admission of a lifting medium into a flow conductor and which has said valves arranged to close when pressure of the lifting medium is at a predetermined pressure with opening pressures of the valves being controlled by the well fluid level, whereby a fixed or constant surface pressure may be maintained in the lifting medium conductor and operation of the valves will be automatic in accordance with the well fluid conditions.

A further object is to provide a well flow apparatus for use in multiple zone wells wherein the lifting medium is conducted downwardly to the various zones through a single conductor and also wherein control of the admission of the lifting medium into each well fluid conductor is independently and automatically controlled in accordance with well fluid conditions in said well fluid conductor, whereby lifting of the well fluids from each zone is, in effect, independent of the production from the other zone or zones.

A particular object of the invention is to provide an improved well flow apparatus or system, of the character described, wherein a regulated pressure may be maintained in a common lifting fluid conductor at the upper end of the conductor and wherein all valves are arranged to close when said regulated pressure falls to a predetermined point; the apparatus contemplating compensating for the weight of the lifting fluid located between the valves which are disposed at various elevations to assure that a predetermined pressure of the lifting fluid at the surface will control the closing of all of said valves, irrespective of the elevation of said valves in the lifting fluid conductor.

Still another object is to provide a well flow apparatus, of the character described, for simultaneously lifting well fluids from a plurality of production zones wherein all valves of the apparatus are arranged to close at the same surface pressure in the lifting fluid conductor, and wherein the pressure of the lifting fluid may be controlled either by a regulator or by the usual time-cycle controller mechanism at the surface.

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A further object is to set the lifting gas admission valves at a closing pressure which will be in accordance with the elevation or position of the valve, whereby all valves will, in effect, close upon the attainment of a predetermined pressure in the lifting fluid supply conductor, with the result that the valves are operated to admit lifting fluid to the well liquid conductor in accordance with well liquid conditions.

Still another object is to provide a well flowing system for lifting well liquids from a plurality of zones in the same well, which system is constructed so that the elevation or point of admission of lifting gas into each well liquid conductor extending from each production zone will be in accordance with well liquid conditions in that conductor, whereby although the lifting gas is supplied from a common supply conductor, said gas may be simultaneously introduced into the plurality of well liquid conductors at various elevations and in the manner required by well liquid conditions.

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

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

Figure 1 is a view partly in section and partly in elevation of an improved well flow apparatus or system for carrying out the improved method in accordance with the invention,

Figure 2 is a transverse vertical sectional view of one of the control valves which control the admission of the lifting fluid to the inner well liquid conductor,

Figure 3 is an enlarged horizontal cross-sectional view taken on the line 3—3 of Figure 2, and

Figure 4 is a view partly in section and partly in elevation of one of the control valves controlling the admission of lifting fluid to the outer well liquid conductor.

In the drawings, the letter A designates a well bore which traverses two well liquid producing zones B and C. The usual well casing 10 extends through the well bore and is formed with perforations or inlets 11 opposite the upper producing zone B whereby the well liquids from this upper zone may flow upwardly through the well casing. The usual casing head 12 is mounted on the upper end of the well casing and supports an inner well pipe 13 which is disposed axially within the well casing and which functions as the lifting fluid supply conductor. A tubing head 14

is bolted on the casing head and supports an inner tubing string 15 which has its lower end open and communicating with the lower producing zone C, whereby the tubing may be referred to as the inner well liquid conductor. A packer 16 which may be of usual construction and which is indicated schematically packs off between the lower end of the tubing 15 and the well pipe 13 while a similar packer 17 packs off between the well pipe 13 and the well casing. By observing Figure 1, it will be apparent that the well liquids from the lower zone C may flow upwardly through the well tubing 15 and are discharged therefrom through a discharge pipe 18 connected with the upper end of said tubing. The well liquids from the upper producing zone B enter the inlets or perforations 11 in the well casing and flow upwardly through said casing to be discharged through a discharge line 19 connected in the side of the casing head 12.

A lifting fluid which will be referred to herein as a lifting gas although it may be air or other fluid is adapted to be conducted into the upper end of the well pipe or supply conductor 13 through an inlet pipe 20 which is connected within an inlet opening 21 in the side of the tubing head 14. The pressure and admission of lifting gas into the supply conductor may be controlled by the usual time cycle controller mechanism now in general use which will periodically admit a predetermined volume of gas under a desired pressure. However, with the flow valves which will be hereinafter described in detail, it is possible to simplify the surface controls and the arrangement illustrated includes a motor valve 22 which is connected in the inlet line 20. Opening and closing of the valve 22 is controlled by a regulator 23 which is actuated, through a pressure line 24, by the pressure which is present within the well pipe or conductor 13. The regulator may be any standard regulator which is available on the open marget and so long as the regulator functions to open and close the valve 22 in accordance with pressure conditions within the conductor or pipe 13 the purposes of the invention will be accomplished.

The regulator is so arranged that when the pressure in the well pipe or conductor 13 falls below a predetermined pressure the motor valve 22 is opened to admit additional pressure fluid; upon the attainment of a desired pressure within the conductor 13 which is in the annular space surrounding the well tubing 15 the valve 22 is closed to shut off the further admission of pressure fluid into said conductor. In order to control the volume of flow of pressure fluid into the well pipe or conductor 13 a suitable choke 25 is connected in the inlet line 20 and obviously this choke will limit the volume of admitted pressure fluid when the motor valve 22 is open.

A series of flow valves of the intermitter type, which are identified as D1, D2 and D3, are connected in the well tubing 15 at predetermined spaced levels or elevations. The construction of these valves is subject to some variation and said valves are arranged to control the admission of pressure fluid from the well pipe or conductor 13 into the well tubing 15 and when lifting gas from the pipe 13 is admitted into the well tubing said gas will function to lift the well fluids within the tubing to the surface. The valves D1, D2, and D3 are of the intermitter type and are adapted to operate intermittently at intervals to inject a "slug" of lifting gas into the well liquid column.

A second series of valves identified as E1, E2 and E3 are connected in the well pipe or supply conductor 13 at predetermined spaced levels or elevations therein and these valves are disposed in the annular space surrounding said pipe. The valves E1—E3 are adapted to control the admission of pressure fluid from the interior of the well pipe 13 into the well liquid column present within the well casing and when the lifting gas is admitted to this well liquid column, said gas functions to lift the well liquids to the surface.

As will be explained, each series of valves functions to control the admission of lifting gas into one of the well liquid conductors, the valves D1—D3 controlling flow into the inner well tubing 15 while the valves E1—E3 control the flow into the well casing. Being an intermitter type of valve the admission of lifting gas into the inner tubing 15 will be at one of the valves D1—D3, in accordance with the well liquid conditions in the tubing; similarly, the admission of lifting fluid into the well casing will be at one of the valves E1—E3, in accordance with the well liquid conditions within the well casing. The operation is entirely automatic and the single lifting fluid supply conductor 13 functions to supply gas to both of the well liquid conductors. It might be that the operation level within the well tubing may be at the valve D2, while the operating level in the well casing may be at the valve E1, which is considerably above the valve D2. Because of the manner of operation of the valve, each well liquid conductor operates at its best working level in accordance with the particular well liquid conditions in that conductor.

One type of intermitter valve which has been found adaptable for use in the present apparatus is illustrated in Figure 2 and as shown comprises an outer casing which is formed of an upper or pilot section 26, an intermediate or power bellows section 27 and a lower or main valve section 28. The sections 26 and 27 are connected by a coupling 29 while the sections 27 and 28 are connected by a similar coupling 30. The pilot valve section 26 includes a pilot bellows 31 which has its upper end connected to the lower portion of a closure 32 which closes the upper end of said section. The lower end of the power bellows is connected to the stem 33 of a pilot valve 34. A coil spring 35 surrounding the valve stem 33 has its lower end engaging the valve 34 with its upper end engaging an inwardly directed flange 36 which is formed at the lower end of a guide sleeve 37 within which the pilot bellows 31 is disposed.

The spring 35 constantly urges the valve into engagement with a valve seat 38, said valve seat being mounted within the upper end of the coupling 29. Inlet openings 39 are formed in the wall of the section 26 whereby the lifting gas from the well pipe or supply conductor 13 may enter the interior of the section 26 and may, through the lower end of the bore of the sleeve 37 as well as through radial ports 40 in the wall of said sleeve, act upon the pilot bellows 31. The pilot bellows contains a predetermined volume of liquid to protect the bellows against rupture or collapse under excessive pressure.

The pressure of the spring 35 controls the pressure at which the pilot valve 34 will open because obviously the lifting gas present within the conductor 13 enters the interior of the section 26 and acts upon the cross-sectional area of the pilot bellows. This lifting fluid pressure must build up sufficiently to overcome the force of the spring 35

to compress the same before the pilot is opened. As soon as the pilot valve 34 opens the additional area of said pilot valve which is normally within the seat 38 is immediately exposed to the pressure and the pilot valve is moved to fully open position. As the pressure in the fluid conductor or well pipe 13 drops to a point insufficient to overcome the downward force of the spring 35 said spring overcomes the action of the pressure on the cross-sectional area of the pilot bellows 31 and the pilot valve 34 closes. It will be obvious that when the pilot valve is in a closed or seated position the under side of said valve is within the axial bore 41 which extends through the valve seat and through the coupling 29 and is not exposed to the pressure of the lifting fluid within the well pipe 13; when the valve is unseated this under side area is acted upon by the lifting fluid pressure in the conductor 13. Therefore, the opening pressure, that is, the pressure necessary to open the pilot valve is greater than the pressure at which the valve closes. This difference in opening and closing pressures will be referred to herein as the range or spread of the valve units D1—D3 and E1—E3.

Within the intermediate section 27 is a power bellows 42 which has its lower end secured to an extension 43 formed on the coupling 30. The upper end of the power bellows is secured to an enlarged cap 44 which is formed integral with an elongate operating stem 45. The lower portion of the operating stem extends through the axial bore 46 of the coupling 30 and this portion of the stem is hexagonal or angular whereby by-passages 47 (Figure 3) are formed between the stem and the bore. A radial bleed port 48 extends through the wall of the power bellows 42 so that a flow from the bore 43 to the interior of the intermediate section 27 may occur, such communication being at a controlled rate in accordance with the size of the port 48.

The lower end of the operating stem extends into the lower main valve section 28 and is adapted to engage an axial shank 49 of a main valve member 50. The main valve member is arranged to seat upon an annular valve seat 51 when in its upper or raised position.

In the case of the valves D1—D3, a radial port 52 extends from the bore 28*a* of the section 28 and communicates with an inlet port 53 formed in the well tubing 15 and thus communication is established between the bore of the lower section D and the interior of the well tubing. Inlet 54 is provided in the lower end of the lower section 28 and when the main valve is open a flow from the well pipe or supply conductor 13 past the valve and through the inlet ports 52 and 53 into the inner well tubing 15 may occur.

Because the valves E1—E3 are mounted exteriorly of the supply conductor or well pipe 13 these valves must be slightly modified as illustrated in Figure 4. The internal construction of the valves E1—E3 is identical to the structure of the valves D1—D3, the only difference being in the connections whereby the gas from the conductor 13 is directed through the valves. As illustrated in Figure 4, only a single inlet 39*a* is provided in the pilot bellows section 26 of the series E valves and this inlet is connected through a nipple connector 55 with a port 56 provided in the wall of the well pipe or conductor 13. In this manner the lifting fluid may constantly enter the upper section 26 to act upon the pilot bellows 31 just as in the case of the D series valves. Each of the valves E1—E3 has an elbow 57 connected to the lower end of the lower section 28, this elbow being substituted for the inlet 54 of the D series valve. The elbow communicates through an inlet port 58 with the interior of the conductor or pipe 13. It will be evident that the valves E1—E3 will function in an identical manner to the valves D1—D3 since the lifting fluid pressure is constantly acting against the pilot bellows 31. When this pressure overcomes the pressure of the spring 35 holding the pilot valve closed the pilot valve is opened to direct the lifting fluid pressure against the upper end of the power bellows 42. Since the power bellows has a larger cross-sectional area than the area of the main valve 50 which is also acted upon by the lifting fluid pressure the main valve is lifted downwardly off of its seat to allow the lifting fluid pressure to flow through the inlet 52 in the lower valve section 28. In the case of the valves E1—E3, the lifting fluid flows through the port 52*a* directly into the well casing, whereas in the valves D1—D3 the lifting fluid flows through the inlet 52 and then through port 53 into the inner well tubing 15.

Since all of the valves are of identical construction and operate in a similar manner, it is believed that a description of one will suffice. Referring to Figure 2 which illustrates the valve D1, it will be evident that with a pressure within the well pipe 13 such pressure will act against the lower end of the main valve 50 to maintain the same seated. This pressure will also act through the ports 39 in the pilot section 26 and upon the pilot bellows, but presuming that such pressure is insufficient to open the pilot valve the main valve 50 remains closed. Any back pressure on the valve, that is, any pressure from within the inner well tubing 15 in the case of the series D valves or any pressure within the well casing 10 in the case of the series E valves, will act through the port 53 and within the bore 28*a* of the lower section 28. This back pressure flows upwardly past the angular portion of the operating stem and into the interior of the power bellows and then through the bleed port 48 in the bellows into the bore 27*a* of the intermediate section 27. The bore 27*a* of the intermediate section is in communication with the bore 41 of the coupling and thus the back pressure from the well liquid conductor will act against the cross-sectional area of the pilot valve 34 which is exposed within the bore 41 of the coupling 29. If there is no back pressure within the well liquid conductor or tubing 15 due to the absence of well liquids therein there will be no pressure acting against the under side of the pilot valve and under such a condition the pilot valve will remain closed until the pressure within the well pipe 13 is sufficient to overcome the tension or force of the coil spring 35.

For the purposes of this description and merely by way of example, it will be presumed that under atmospheric conditions the closing pressure of the pilot valve 34 is 400 pounds while opening pressure will be presumed to be 460 pounds. Under this assumption, when the pressure in the well pipe 13 reaches 460 pounds the pilot valve opens and the pressure of the lifting fluid within the pipe 13 acts on the exterior of the power bellows 42 and functions to compress or collapse said bellows to move the operating stem downwardly and thereby open the main valve 50. Opening of the main valve allows a flow of pressure fluid into the well tubing 15 when the D series valve operates or into the well casing when the E series valve operates. Just as soon as the pressure within the well pipe 13 falls below

the assumed closing pressure of 400 pounds the pilot valve **34** is closed by the spring **35**. The pressure exteriorly of the power bellows is bled off through the bleed port **48** thereby permitting the differential across the main valve **50** to move said valve to its closed position.

It will be evident that any back pressure present within the well liquid conductor will act against that cross-sectional area of the pilot valve **34** which is exposed within the valve seat **38** and this back pressure will be added to the lifting fluid pressure which is tending to open the pilot valve. Therefore, with a back pressure present within the well liquid conductor the opening pressure of the valve is altered and, as a specific example, it has been found that with a presumed opening pressure of 460 pounds at atmosphere, a back pressure of 100 pounds acting on the pilot will cause the valve to open when the pressure within the supply conductor **13** reaches 445 pounds. A back pressure of 200 pounds acting against the pilot will reduce the opening pressure to 432 pounds, while a back pressure of 300 pounds will further reduce the opening pressure to 420 pounds. This reduction in the opening pressure is, of course, based on the particular ratio between the area of the pilot valve seat **38** with respect to the effective cross-sectional area of the pilot bellows, for obviously by varying the ratio between the area of the seat **38** which is the area exposed to back pressure with respect to the cross-sectional area of the pilot bellows acted upon by the pressure within the well pipe **13**, it is possible to control the pressure which must be attained within the pipe **13** before the pilot valve opens. It is noted that the back pressure affects only the opening pressure because after the valve opens the under side thereof is exposed to the lifting fluid pressure; however, in all cases with the valves constructed identically, the closing pressures will remain the same which as presumed will be 400 pounds. Therefore, actually the operating range or spread of the valve, that is, the spread between opening and closing pressures, varies proportionately to the back pressure acting on the valve. The particular operating range or spread may, as above pointed out, be controlled accurately by varying the ratio between the diameter of the valve seat and the effective cross-sectional area of the pilot bellows.

As above pointed out the spring **35** controls the closing pressure and as will appear in the operation of the apparatus, it is desirable that the closing pressure of all of the valves in the apparatus be exactly the same. If all of the valve springs **35** were of exactly the same strength then the closing pressure under atmospheric conditions would be identical in all valves. However, it is obvious that the valves are disposed at different levels or elevations within the well bore and the volume of gas between valves has a certain weight. This weight of gas which is, of course, in proportion to the spacing between valves is added to the pressure of the lifting gas which is present within the pilot section **26** and thus, the valves which are disposed lower in the system will be actually subjected to a greater pressure than will the valves in the upper part of the system. It is, therefore, necessary to compensate for the weight of the gas which is present between valves in the system and this is done by varying the pressure of the spring **35** in direct proportion to the weight. Thus, if the valves are spaced 100 feet apart in the installation the weight of the gas above each valve is taken into consideration in setting its closing pressure. By compensating for the weight of the gas between the valve units all of said valves will close when the pressure within the pipe **13** falls to a predetermined point. In other words, when the pressure in the pipe or supply conductor **13** drops to 400 pounds all of the valves in the system will close. Each valve may not have a test block closing pressure of 400 pounds but its test block closing pressure taken with the weight of the gas thereabove makes the valve close when the actual lifting gas pressure drops to 400 pounds. The compensation for the weight of the gas is an important feature of the present invention since it assures that all valves will close when the pressure in the pipe or conductor **13** reaches a predetermined point.

In the operation of the apparatus all of the valves D1—D3 and E1—E3 will be assumed to have a presumed closing pressure which will cause said valves to close when the pressure within the well pipe or lifting fluid supply conductor **13** drops to 400 pounds. All of said valves may be constructed with their pilot bellows bearing the same ratio to their pilot valve seat. Under such a situation the operating range between opening and closing pressures on all valves would be alike with the same back pressure condition. However, if desired, certain of the valves may have different ratios between the pilot valve seat and the pilot bellows in which event the operating range or spread between opening and closing pressures of such valve under a given back pressure condition would be different from the remaining valves. At the start of the operation, fluid will be present within the well casing and will also be present within the inner well tubing so that all of the valves will have some back pressure thereon. Considering first the lifting operation which is carried out within the inner well liquid conductor formed by the tubing **15** the lifting fluid is admitted into the well pipe **13** through the supply pipe **20**. As the pressure is built up in the well pipe to a point sufficient to open the uppermost valve D1, a charge of gas is admitted into the flow tubing and the liquid above this level is lifted to the surface so that the back pressure on this particular valve becomes substantially nil. At the time that sufficient pressure has been built up to open the upper valve all of the lower valves having a greater back pressure will, of course, be open and may be in a position with the main valve **50** lowered against a back check seat **54*a*** to prevent reverse flow of well liquid from the tubing back into the well pipe.

Referring back to the uppermost valve D1, under the presumed conditions the opening pressure at atmosphere of this valve is 460 pounds while under a 100 pound back pressure the opening is 445 pounds. Therefore, assuming a 100 pound back pressure against valve D1 at the start of the operation when the pressure within pipe **13** reaches 445 pounds, the valve opens to admit lifting fluid to the tubing and thereby unload the tubing above said valve. This unloading eliminates the back pressure acting on valve D1 and immediately the opening pressure of this valve is raised to 460 pounds. Thus, the upper valve becomes inactive after it has initially opened to admit fluid and since the next valve therebelow has some back pressure on it its opening pressure is less than the pressure of the uppermost valve. The valves are operated successively

in this manner to unload the liquid in the tubing and until the working level is reached, such working level being at the point where the flowing bottom hole pressure of the well feeds past the valve at a pressure equal to or slightly less than the operating pressure of that valve. In other words, this level may be found at valve D2 or it may be at valve D3. After the well tubing is unloaded subsequent admission of lifting fluid is only through the valve at the working level and all of the valves thereabove remain inactive until such time as the back pressure conditions within the tubing change so as to bring these valves in operation. The valve at the working level will remain open until sufficient lifting fluid has passed into the well tubing to reduce the pressure in the pipe 13 to the assumed 400 pounds closing pressure of the valve. In other words, when the pressure in the pipe 13 drops to 400 pounds the valve will close and will remain closed. As soon as the pressure in the casing 13 drops to a point close to the 400 pound closing pressure, as for example, at 405 pounds, the regulator 23 will function to open the motor valve 22 and admit additional lifting fluid into the pipe 13. The choke 25 is so arranged that its capacity is less than the capacity through the valves, with the result that the lifting gas is admitted into the pipe in a volume less than that passing through the valve. Therefore, even though pressure fluid is being admitted into the pipe 13 during the time that the valve is open, it is not admitted in sufficient volume to prevent a further reduction in the pipe 13 to the 400 pound pressure which effects closing of the valve. As soon as the closing pressure is reached in the pipe 13 the valve at the working level closes but the regulator continues to hold the inlet valve 22 open until the pressure in pipe 13 has again built up to the pressure which will be required to open the valve when the fluid column has built up to the required back pressure.

If the working level is at the valve D2 and assuming that the valve D2 is operated on a 32 pound spread, the valve would reopen when the pressure within the pipe 13 reaches 432 pounds with a 200 pound back pressure exerted by the liquid within the tubing. In other words, valve D2 will close when the pressure within the pipe drops to 400 pounds and will open when the pressure in the pipe is 432 pounds with the liquid level in the tubing exerting a 200 pound back pressure. The regulator will function to shut off the pressure at 432 pounds which will be maintained in the pipe and thus the valve D1 will not reopen for the next gas admitting cycle until the well liquids have built up in the tubing to a point sufficient to exert 200 pounds back pressure on the valve.

The bleed port 48 which is provided for bleeding the interior of the power bellows enters into the operation of the device in that it controls the amount of pressure which is obtainable in the power bellows during operation. By changing the size of this bleed port 48 with respect to the size of the pilot seat bore it is possible to control or vary the amount of pressure which may be obtained in the power bellows. Thus, it will be seen that the ratio between the pilot seat and the effective cross-sectional area in the power bellows is the governing factor in controlling the operating range or spread which is had under certain pressure conditions. The ratio between the pilot seat and the power bellows bleed port 48 enters into efficient valve operation, that is, in efficient opening of the main valve 50 following unseating of the pilot valve.

The valves E1—E3 will function in exactly the same manner in lifting the well liquids within the well casing, and these valves will operate entirely independently of the valves D1—D3. Because the valve at the working level in each liquid conductor is opened in accordance with the back pressure exerted by the liquid load and because the pressure in the pipe 13 is maintained substantially constant, the working level in the tubing 15 may be different from the working level in the well casing. Thus, the valve D2 may be operating to admit lifting fluid at the proper times to the well tubing while the valve E2 which is at a considerable higher elevation may at the same time be functioning to admit lifting fluid to the well casing. Assuming the working levels in the two liquid conductors to be at the valves D2 and E2 and also assuming that the valve D2 operates first, it will be evident that the admission of lifting fluid into the well tubing will result in a lowering of the pressure in the well pipe 13 which pressure will drop below the pressure at which all valves close. Thus, the upper valve E2 cannot open during the time that the pressure in the well pipe is below 400 pounds which is the assumed pressure at which all valves close. Upon the lifting operation being completed through valve D2, valve D2 closes and immediately the regulator functions to build the pressure back up in the gas supply pipe 13 to the predetermined substantially constant pressure. As soon as this pressure is built back up and as soon as a sufficient back pressure is exerted through the casing on valve E2 this valve will open to raise the liquid in the well casing. Opening of the valve E2 reduces the pressure in pipe 13 down to 400 pounds which is the assumed pressure at which all valves close and at this point the valve D2 cannot be actuated. Thus, even though the liquid level within the second liquid conductor has built up a back pressure which would ordinarily open the valve, said valve will not open during the flowing of the other liquid conductor because of the pressure drop in the pipe 13. However, immediately upon the pressure in pipe 13 being raised the other valve can immediately operate.

From the foregoing it will be seen that an improved apparatus for lifting well liquids through two liquid conductors from a single supply source of lifting gas is provided. Each series of valves associated with a liquid conductor operates independently of the other series although both are supplied with lifting gas from the single source. An important feature of the invention is the initial setting of all valves to compensate for the weight of the gas which would create a difference due to different elevations or locations of the valves and the apparatus is such that when the pressure in the lifting gas supply conductor or pipe 13 falls to a predetermined point all valves are closed at that pressure. The regulator and choke are important in the operation of the system because the choke controls the volume of incoming pressure fluid during the operation of the valve which is functioning at the working level, whereby the pressure in the pipe 13 may fall to the predetermined point at which the valve will close before the pressure is again built up within said pipe. The use of a regulator and choke provides for a simplified arrangement but it is evident that a time cycle controller such as is now in general use with flow

valve intermitters could be employed. When a time cycle controller is employed, it will control the admission of lifting gas to the supply conductor at predetermined intervals and obviously the valves D1—D3 and E1—E3 will function in the same manner as heretofore described.

It is also pointed out that although the arrangement has been shown as applied to dual production the feature of compensating for gas weight between the valves could be employed in a single production string so that the various valves in the string would all close when the pressure in the lifting gas supply conductor falls to a predetermined point. Therefore, the invention is not to be limited to dual production, although it is readily adaptable for such use.

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

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

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

Having described the invention, I claim:

1. A well flow apparatus for lifting well liquids from a plurality of producing zones in a single well bore including, a well liquid conductor extending from each producing zone, a lifting fluid supply conductor extending within the well bore and common to all well liquid conductors, a plurality of series of pressure-actuated valves adapted to control the admission of lifting fluid to the well liquid conductors, each series of valves being associated with one of the well liquid conductors and being disposed at spaced elevations along said well liquid conductor, means for maintaining a predetermined constant lifting fluid pressure in the supply conductor, means in each valve actuated by the back pressure developed by the well liquid in each well liquid conductor for opening one of the valves in each series of valves to admit lifting fluid to the well liquid conductor associated with that series of valves, and means for adjusting the closing pressure of each valve to compensate for the weight of the lifting fluid thereabove, whereby all of the valves have the same effective closing pressure and all of said valves are thereby closed when the pressure in the supply conductor falls to a predetermined point.

2. A well flow apparatus as set forth in claim 1, wherein the means for supplying additional lifting fluid to the supply conductor is operated when the pressure falls to a predetermined point.

3. A well flow apparatus as set forth in claim 1, wherein the means for supplying additional lifting fluid to the supply conductor is operated when the pressure falls to a point just above the point at which said valves will close, and means for controlling the admission of the additional lifting fluid into the supply conductor to admit it at a volume less than the volume flowing through the open valves whereby said supply conductor pressure may fall to the closing pressure of said valves before being again built up to the desired point.

4. A well flow apparatus including, a vertical well liquid conductor for conducting well liquids from a sub-surface producing formation, a lifting fluid supply conductor extending parallel to said well liquid conductor, a plurality of communicating passages establishing communication between the lifting fluid supply conductor and the well liquid conductor and disposed at spaced elevations along the well liquid conductor, a pressure-actuated valve in each passage for controlling flow therethrough, each valve having a closing pressure which will close the valve when a predetermined pressure is present in the supply conductor and no back pressure is present in the well liquid conductor, a predetermined selected increase in the back pressure within the well liquid conductor due to a rise in well liquids resulting in opening of one or more of said valves subjected to the predetermined back pressure to admit lifting fluid to said conductor, means in each valve for initially setting the valve to a closing pressure which takes into consideration the weight of the column of lifting fluid above the valve to compensate for the difference in position or elevation of the valve, whereby reduction of the pressure in the supply conductor to a predetermined point will result in a closure of all of said valves irrespective of their elevation within the supply conductor.

5. A well flow system including, a flow conductor, a series of pressure-actuated valves connected with the conductor at various elevations therein for controlling admissions of a pressure fluid into said conductor, each valve being set to operate at progressively higher pressure range than the valve next above, whereby the highest pressure range valve is at the lowest elevation in the conductor, and means to introduce a pressure fluid into the well as a charge to open such valve or valves as will open by the fluid pressure occurring in the well due to the introduction of said charge.

6. A well flow system including a flow conductor, a series of pressure-actuated valves connected with the conductor at various elevations therein for controlling the introduction of a lifting fluid from the area exteriorly of the conductor into said conductor, each valve being set to operate at a progressively higher pressure range than the valve next above, whereby the highest pressure range valve is at the lowest elevation in the conductor, means for maintaining the pressure fluid exteriorly of the conductor at a substantially constant pressure, means in each valve controlling the operating range, and the operating range of each valve being determined in accordance with the pressure of the lifting fluid plus the weight of the column of lifting fluid above said valve.

7. A well flow system including a flow conductor, a series of pressure-actuated valves connected with the conductor at various elevations therein for controlling the introduction of a lifting fluid from the area exteriorly of the conductor into said conductor, means for maintaining a pressure fluid exteriorly of the conductor at a substantially constant pressure, means within each valve for setting the effective closing pressure thereof, whereby all of said valves have the identical effective closing pressure, said closing pressure for each valve being determined by the pressure of the lifting fluid added to the pressure exerted on the valve by the weight of the column of lifting fluid above said valve.

8. A well flow system including, a well cas-

ing extending within a well bore and having communication with a sub-surface well liquid producing zone, an inner well pipe forming a lifting fluid supply conductor extending axially within the casing, a well tubing disposed axially within the pipe and having communication with a second sub-surface producing zone, a series of pressure-actuated valves disposed at various elevations along the well pipe for controlling the admission of lifting fluid into the well casing, a second series of valves disposed at various elevations along the well tubing for controlling the admission of lifting gas from the well pipe to the well tubing, means for maintaining the lifting fluid at substantially a constant pressure in the well pipe, means within each valve for initially setting each valve of both series of valves to a closing pressure which is determined in accordance with the pressure of the lifting fluid and the weight of the column of lifting fluid above that valve whereby the differences in the elevations or positions of the valves are compensated for and all valves have the same effective closing pressure.

9. A well flow system as set forth in claim 8, wherein the means for maintaining the pressure in the well pipe is a regulator, and a choke mounted in the inlet to the well pipe for restricting the volume of lifting fluid admitted to said pipe.

10. A well flow apparatus including, a vertical well liquid conductor for conducting well liquids from a sub-surface producing formation, a lifting fluid supply conductor extending parallel to said well liquid conductor, a plurality of communicating passages establishing communication between

the lifting fluid supply conductor and the well liquid conductor and disposed at spaced elevations along the well liquid conductor, a pressure-actuated valve in each passage for controlling flow therethrough each valve having an operating means exposed to the pressure within the supply conductor for opening said valve when said pressure exceeds a predetermined point and also having an adjustable means for resisting opening of said valve and for controlling the pressure at which the valve closes, said adjustable means of each valve being adjusted to compensate for the weight of the lifting fluid in the supply conductor thereabove whereby the effective closing pressure of all valves is the same to effect closing of all of said valves when a predetermined pressure is present in the upper end of the supply conductor and no back pressure is present in the well liquid conductor.

11. A well flow apparatus as set forth in claim 4, together with a time cycle controller at the surface of the lifting fluid supply conductor for periodically admitting lifting fluid under a predetermined pressure into said conductor.

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