April 8, 1941. E. K. BURGHER 2,237,408

WELL PUMPING APPARATUS

Filed Nov. 18, 1938 3 Sheets-Sheet 1

Fig. 1.

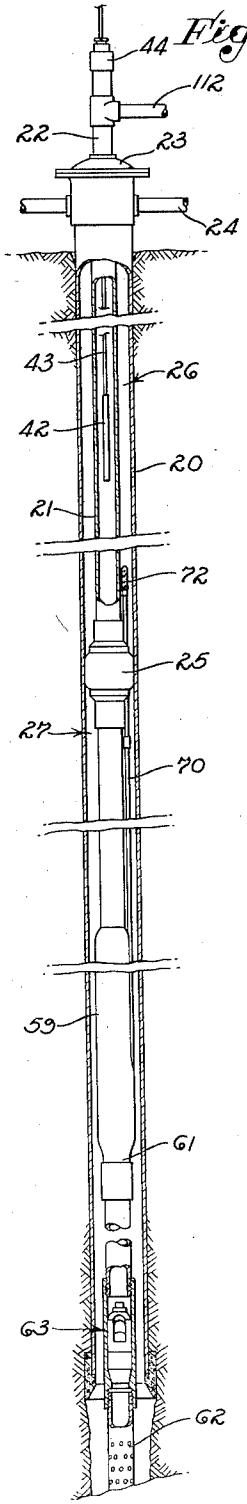


Fig. 8.

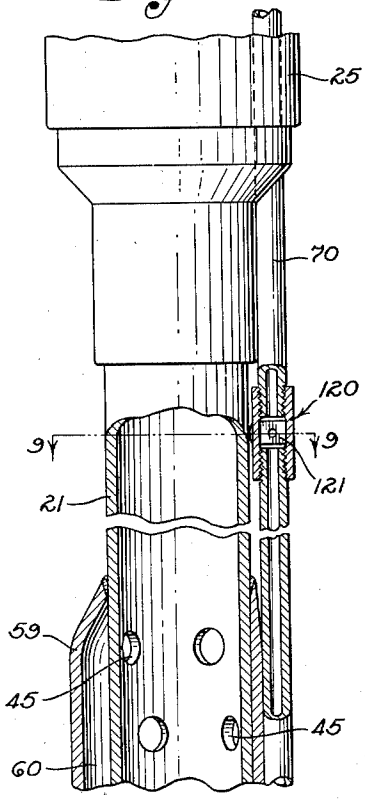


Fig. 9.

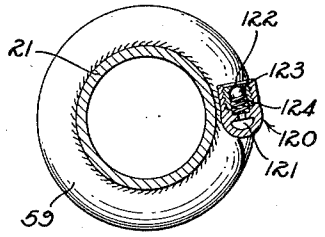


Fig. 7.

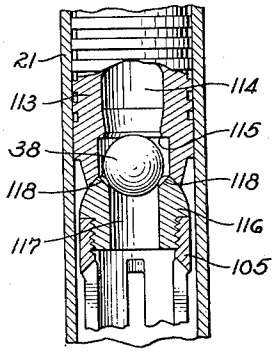
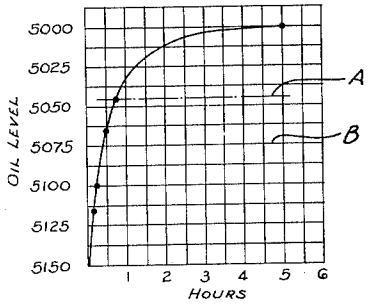


Fig. 12.



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Filed Nov. 18, 1938 3 Sheets-Sheet 2

Fig. 2.

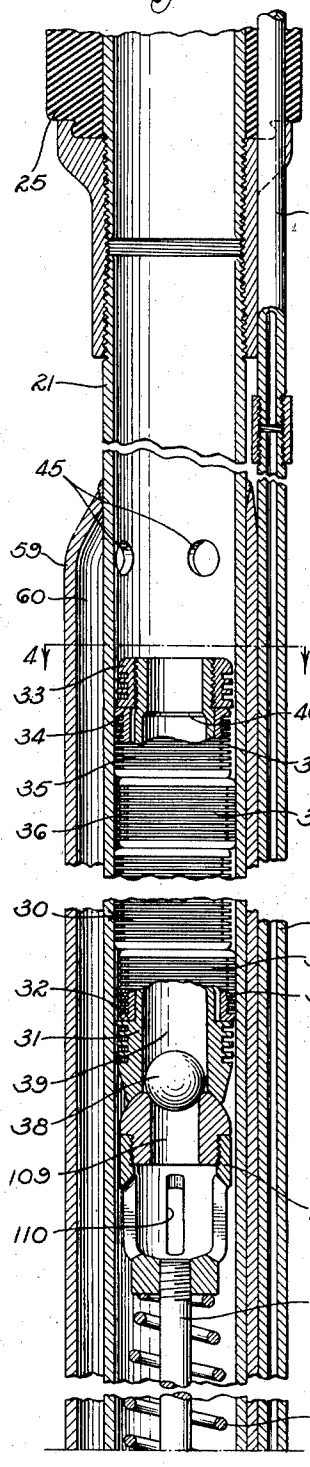

Fig. 3.

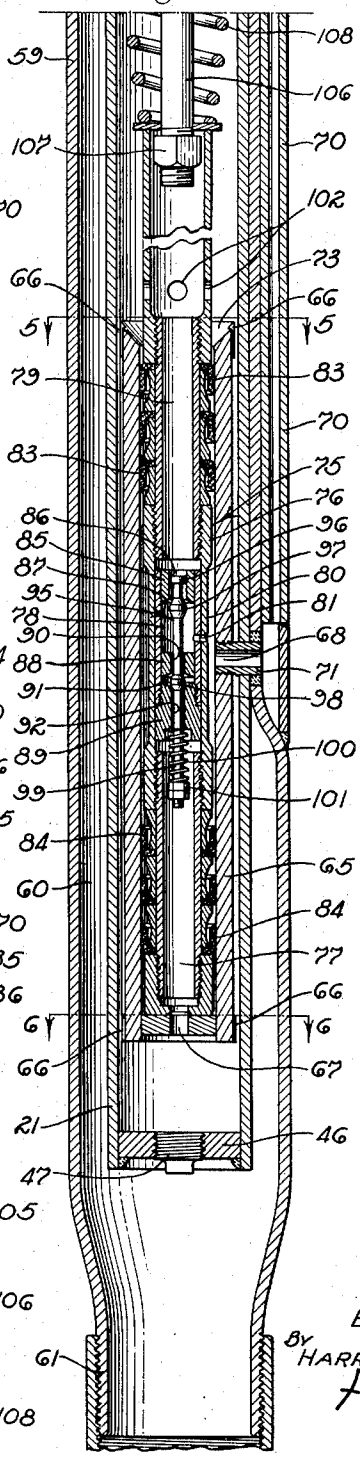

Fig. 4.

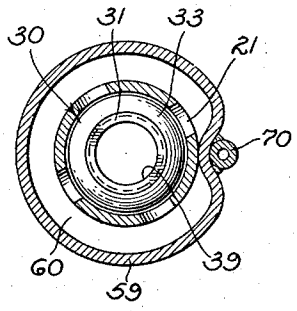

Fig. 5.

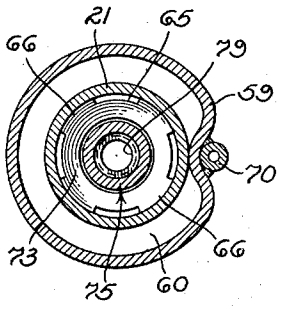

Fig. 6.

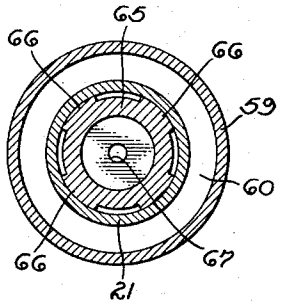

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Fig. 10.

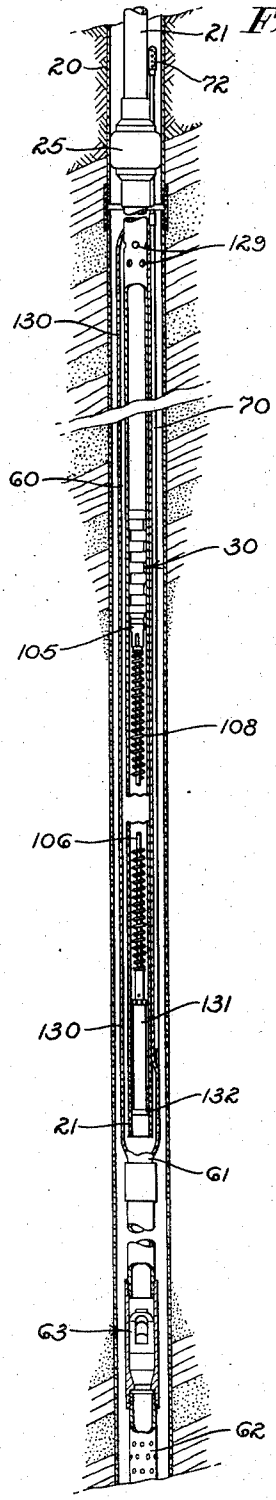
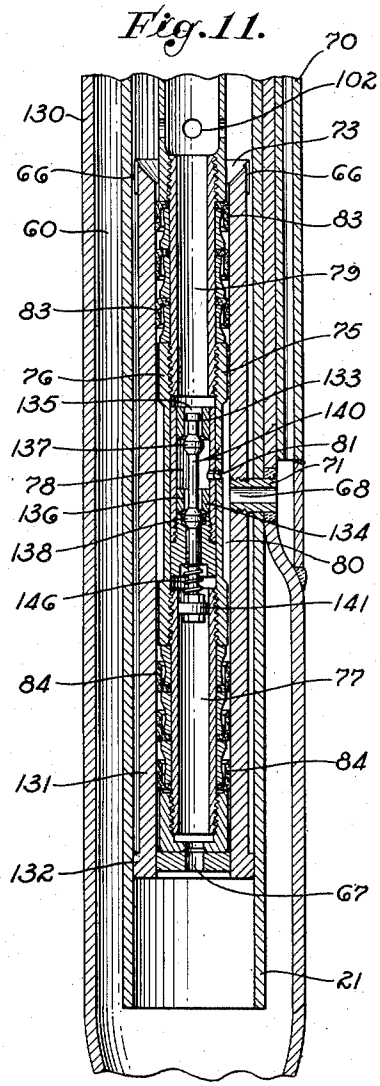


Fig. 11.



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Patented Apr. 8, 1941 2,237,408

UNITED STATES PATENT OFFICE

2,237,408

WELL PUMPING APPARATUS

Everett K. Burgher, Manhattan Beach, Calif.

Application November 18, 1938, Serial No. 241,207

14 Claims. (Cl. 103—52)

My invention relates to gas-lift apparatus for pumping deep wells, with special reference to devices for intermittently propelling a body of liquid upwardly through a well tube by the introduction of a body of compressed gas under the liquid body.

It has heretofore been proposed in the art to introduce gas continuously into a liquid column at the lower end of a lift tube and to place in the tube a suitable swab having a valve controlled passage therethrough. Gas accumulating rapidly under such a swab, the swab being at its lowermost position with its passage closed, immediately forces the swab upwardly to carry the superimposed liquid column to the surface of the well, whereupon the swab passage is opened automatically to permit the swab to gravitate downwardly against upwardly flowing gas and finally through the liquid column, the swab passage being closed by automatic means as soon as the swab reaches its lowermost position. The disadvantages of such an arrangement arise from the fact that the continuously introduced gas is wasted except during the intervals of lift, and from the fact that the swab continually reciprocates at an uncontrolled rate that is rarely the optimum frequency for the rate of oil flow in a given well. As a result, the life of the swab is shortened by unnecessary traverses of the well tube and necessarily the ratio of the gas released in the lift tube to the quantity of oil flowing from the well is inordinately high.

Another practice known to the art is to introduce gas under pressure periodically into a liquid body at the lower end of a lift tube to blow a quantity of the liquid to the surface of the well, the periods of gas introduction being spaced at sufficient time intervals to permit the accumulation of an economical volume of liquid for each blowing operation. By virtue of a gas valve suitably responsive to conditions in the well, such an arrangement is usually automatic, the operating cycle being repeated as often as a predetermined quantity of liquid accumulates in the lower end of the lift tube. The disadvantage of this second pumping method is that the gas blowing the liquid body upward tends to puncture or form channels through the propelled oil body so that gas is wasted and a substantial portion of the lifted oil gravitates back to the bottom of the well. The inefficiency of this practice increases with the depth of the well to such an extent that the cost of operation would be prohibitive for many wells.

The broad object of my invention is to provide a gas lift apparatus of the general type under consideration that will operate more efficiently and economically than either of the two practices mentioned above. The invention herein described may be applied at a profit to low production wells of relatively great depth that could be pumped only at a loss by an uncontrolled reciprocating swab or by gas blown directly into a liquid column through an automatically intermitting gas valve.

Broadly described, my invention is based on the conception of employing a lift piston in combination with automatic means below the piston responsive to pressure from above the piston to admit compressed gas under the piston for periods of controlled duration and at controlled intervals of time. I propose to employ in a lift tube a piston having a longitudinal passage controlled by a piston valve, to employ cooperatively with the piston a pressure-responsive gas valve under the piston for controlling the introduction of lifting gas, and to transmit pressure from above the piston to the gas valve below the piston for control of the gas valve. Under this broad conception it is my object to save gas in the lifting operation by cutting off the introduction of gas while the piston is gravitating downwardly in the tube and subsequently while liquid is accumulating in the tube above the piston. It is my purpose also to save gas by carrying out the lifting operation only as often as loads of economical size accumulate above the piston and by employing the piston to prevent gas from blowing through the propelled body of liquid.

Another object of my invention is to eliminate opposition to the gravitational movement of the piston by upwardly flowing gas and to minimize the extent to which the piston must work its way through liquid to reach its lowermost position in the well tube.

A further object in mind is to reduce wear both on the piston and the well tube by reducing the number of piston traverses for a given quantity of delivered oil.

Another purpose in mind is to employ a gas-actuated piston for lifting oil from a well without imposing the pressure of the actuating gas on the well formation. In one of the specific forms of my invention, I have the further object of drawing on the well gas to assist extraneous gas in the lifting operation without permitting the pressure of the extraneous gas to be transmitted to the well formation.

A further object of my invention is to arrange

such a pumping apparatus in such a manner that the piston will not only force oil to the surface of the well, but will also serve as a receptacle for solids carried into the lift tube from the well formation as well as positive means to elevate such solids to the surface of the well.

Other objects of my invention relate to the problem of arranging a valve below a piston to respond to pressure exerted above the piston. In one form of my invention it is my object to provide a piston that will form with the surrounding tube walls a labyrinth passage whereby static pressure may by-pass the piston but gas propelling the piston upwardly will not escape past the piston to any effective extent. In other forms of my invention I propose to have the piston valve at least partially open while the piston is stationary at its lowermost position whereby static pressure may be transmitted downwardly through the piston and whereby minor flow upward through the piston will be permitted to prevent leakage from the gas valve lifting the piston prematurely. In this regard a feature of my invention is the conception that a piston valve that is partially closed while the piston is stationary at the bottom of the well may be closed automatically by the initial rush of gas when the intermitting gas valve opens. In one form of my invention I propose to employ for the piston valve a valve member freely movable in the well tube below the piston, and I contemplate providing support means in the bottom of the well to receive the valve member and the piston in sequence, the support means being adapted to hold the piston and valve in spaced relation and to direct inflow of gas against the valve member for closing the passage through the piston at the inception of a lifting operation.

An object of a preferred form of my invention is to provide a combined shock absorber and valve assembly in the well tube that is adapted to be removed as a unit whereby either the shock absorber or the valve assembly may be replaced, repaired, or adjusted without disturbing the well tubing.

Other objects and advantages of my invention will be apparent in the course of the following detailed description considered with my accompanying drawings.

In the drawings:

Fig. 1 is a schematic view of one form of my apparatus installed in an oil well;

Fig. 2 is an enlarged axial section through a portion of the apparatus shown in Fig. 1;

Fig. 3 is a continuation downwardly of Fig. 2;

Fig. 4 is a transverse section taken as indicated by the line 4—4 of Fig. 2;

Fig. 5 is a transverse section taken along the line 5—5 of Fig. 3;

Fig. 6 is a transverse section taken along the line 6—6 of Fig. 3;

Fig. 7 is a fragmentary section to indicate a modification of one detail in my invention;

Fig. 8 is a view of a portion of my apparatus partly in section to indicate how a check valve may be incorporated therein;

Fig. 9 is a transverse section taken as indicated by the line 9—9 of Fig. 8;

Fig. 10 is a view similar to Fig. 1 indicating the construction of a second embodiment of my invention;

Fig. 11 is an enlarged axial section of a portion of Fig. 10 showing the construction of a valve for controlling the admission of gas into the well tube; and

Fig. 12 is a graph indicative of the rate of subterranean flow in a typical oil well.

Fig. 1 shows diagrammatically an oil well having a casing 20 through which extends a string of tubing 21 hereinafter to be termed the "lift tube." At the surface of the well the lift tube has a terminal nipple 22 protruding upwardly from the casing head 23 and has a lateral branch 24 through which oil is delivered by the pumping action in the well. At an intermediate depth above the inherent oil level of the well, a packer 25 embracing the lift tube seals the annular space between the lift tube and the casing to form an annular pressure chamber 26 above the packer and a lower annular space 27 that communicates directly with the producing formation. Gas from the well or from a second well or from a compressor on the surface, or from more than one of these sources, is maintained at a required pressure in the upper chamber 26.

Slidingly mounted in the lift tube 21 is a lift piston, generally designated 30, which, as indicated in the drawings, is constructed in accordance with my Patent No. 2,001,012, issued May 14, 1935. One feature of such a piston is that special tubing is not required for efficient cooperation therewith, and a second feature is that the piston keeps clear an ample passage through the tubing without permitting any substantial escape of gas past the piston in the course of a lifting operation. The piston 30 has a cylindrical body 31 that is enlarged at the lower end to provide a shoulder 32 and that carries a collar 33 at its upper end to provide a second shoulder 34. Mounted on the piston body 31 between the two shoulders 32 and 34 are a number of rings 35, each of which has a plurality of peripheral fins 36. The rings 35 are smaller in over-all diameter than the inside diameter of the lift tube 21 and larger in inside diameter than the piston body 31 so that each of the rings is free to shift laterally both with respect to the inner walls of the lift tube and with respect to the piston body. A feature of such a piston, as pointed out in my Patent No. 2,001,012, is that the rings are small enough to provide liberal clearance in the lift tube and yet by virtue of their fins and their random eccentric positions the clearance space they form with the lift tube is of such labyrinth character as to retard to an exceedingly high degree any high velocity flow past the piston. The retardation is so efficient that the piston may be said to form a seal against gas from below when a large volume of gas of relatively high pressure is released to lift the piston.

A further feature of such a piston of importance in the present invention is that the retardation effect is selective in the sense that it blocks high velocity gas flow past the piston thereby to cause the piston to rise to the top of the well, but offers substantially no hindrance to any low velocity flow past the piston that may be incidental to pressure equalization on the opposite ends of the piston. In other words, the piston does preclude high velocity flow, but does not preclude pressure communication.

A piston of the type under consideration has a longitudinal passage therethrough controlled by a valve that opens to permit the piston to gravitate downwardly in the lift tube and closes to permit the piston to carry upwardly a liquid column superimposed thereon. In my preferred construction, shown in Fig. 2, the valve com-

prises a ball member 38 that is free to drop away from the piston, the ball member being adapted to close an axial passage 39 through the piston. I prefer to make the major portion of the passage 39 of sufficient size to permit substantial clearance for the ball and to place a seat 40 toward the upper end of the piston for cooperation with the ball in sealing the passage. As taught by my above-mentioned patent, the means for unseating the ball member 38 as the piston approaches the top of the well may comprise a suitable bar 42 suspended by a cable 43 that adjustably passes through a packing gland 44 at the top of the lift tube.

At some point a suitable distance below the inherent oil level of the well, the lift tube 21 is provided with one or more oil inlet ports 45. The lift tube proper extends a sufficient distance below the inlet ports 45 to accommodate the piston 30 and control means associated therewith. The lower end of the lift tube is sealed by an end wall 46 and removable plug 47 in the preferred form of my invention. A wall 59 of cylindrical character is attached at its upper end to the periphery of the lift tube 21 just above the inlet ports 45 to form a space 60 of more or less annular configuration around the lower end of the lift tube. Below the end of the lift tube, the wall 59 is reduced in diameter and forms an intake tube 61, the intake tube terminating in a perforated portion 62 and having above the perforated portion a check valve or standing valve, generally designated 63 to prevent downward flow therethrough.

Mounted in the lower end of the lift tube 21 in spaced relation to the end wall 46 is a cylindrical valve housing 65. To permit vertical fluid movement between the valve housing 65 and the surrounding wall of the lift tube, the valve housing is of smaller diameter than the interior of the lift tube and is attached to the lift tube by radial extensions 66 at the upper and lower ends of the valve housing. The valve housing 65 has a fluid port 67 in its lower end and has a central gas inlet port 68 in its peripheral wall for the admission of gas into the tube 21 to lift the piston 30. Since, in the preferred form of my invention the gas for lifting the piston is stored under pressure in the upper chamber 26, some means is required to convey such gas from the pressure chamber to the port 68. For this purpose I provide a pipe 70 alongside the lift tube extending downwardly from the pressure chamber 26 through the packer 25 to the level of the port 68 where a short nipple 71 connects the pipe with the interior of the lift tube. The drawings show the inlet end of the pipe 70 extending a short distance above the packer 25 and equipped with a suitable strainer 72.

The upper end of the valve housing 65 is open and is chamfered to provide a conical surface 73 to guide into the valve housing a removable valve assembly, generally designated 75. The valve assembly 75 includes a valve body 76 formed of various interjoined cylindrical members, the valve body providing a lower chamber 77, a central chamber 78, and an upper chamber 79. The central portion of the valve body 76 is reduced in diameter to form with the valve housing 65 an annular space 80 opposite the gas inlet port 68, and the wall of the valve body is provided with one or more apertures 81 to provide communication between the annular space 80 and the central valve chamber 78. The valve body 76 carries a series of sealing cups 83 above the annular space 80 and a second series of oppositely disposed sealing cups 84 below the annular space whereby gas in the annular space may neither escape upwardly around the valve body nor escape downwardly into the lower end of the valve housing 65.

The central chamber 78 of the valve assembly is separated from the upper chamber 79 by a tubular member 85 forming a cylindrical discharge passage 86 and a valve seat 87 at the inner end thereof. The valve chamber 78 is separated from the lower chamber 77 by a tubular member 88 and spaced therebelow a second tubular member 89. The tubular member 88 provides an axial passage 90 with a valve seat 91 at the lower end thereof and the tubular member 89 provides a second axial passage 92. A valve member 95 of substantial length has an annular flange 96 at its upper end loosely fitting in the discharge passage 86 and carries a valve head 97 in the valve chamber 78 adapted to cooperate with the upper valve seat 87. The valve member 95 extends through the passages 90 and 92 below the chamber 78 and carries a secondary valve head 98 adapted to cooperate with the valve seat 91, the spacing of the two valve heads being such that both heads may seat simultaneously. Below the tubular member 89 the valve member 95 is continued as a valve stem 99, and in the preferred form of my invention a suitable helical spring 100 embracing the valve stem in compression between the tubular member 89 and suitable nuts 101 on the stem urges the valve member downwardly out of engagement with the two valve seats. When this gas valve is in open position, gas flows from the gas inlet port 68 into the annular space 80, thence through the aperture 81 into the central valve chamber 78, and then upwardly through the discharge passage 86 past the valve flange 96 into the upper valve chamber 79, finally passing into the lift tube through suitable apertures 102 in the wall of the chamber 79.

It is contemplated that the piston 30 will be supported by the valve assembly 75 prior to the admission of gas into the lift tube to force the piston upward. In the preferred form of my invention I mount shock-absorbing means on the upper end of the valve assembly to stop the fall of the piston and to support the piston while liquid is accumulating in the lift tube above the piston. Such a means may comprise a support head 105 on the upper end of a plunger 106 that retractibly extends from the upper valve chamber 79, a suitable nut 107 being provided on the lower end of the plunger to limit its upward movement. The required yielding action is provided by a suitable spring 108 surrounding the plunger 106 in compression between the support head 105 and the top of the valve assembly. The particular support head 105 shown in the drawings has a passage 109 at its upper end that communicates with radial ports in the support head opening on the space below the support head.

In the normal inactive disposition of my apparatus, the piston 30 is at the bottom of the well and oil pouring in the ports 45 is accumulating in the form of a column superimposed on the piston 30. It is important to note that the inlet ports 45 are spaced above the piston 30 so that solids heavier than the oil, such as sand and rock particles carried into the lift tube, may gravitate out of the incoming stream directly onto the piston to form a deposit thereon or

therein during the oil accumulation period. During this inactive accumulation period the piston **30** rests on the support head **105** and the valve member or ball **38** rests on the support head **105** at the upper end of the passage **109** out of contact with the piston. During this accumulation period the valve member **95** is in its upper closed position in opposition to force exerted by the spring **100**, the effect of the spring being counteracted by the fact that the diameter of the discharge passage **86** above the valve head **97** is larger than the diameter of the passage **90** above the secondary valve head **98** to create an upwardly directed pressure differential.

The progressively increasing static pressure exerted by the accumulating column of oil above the piston is transmitted along the labyrinth passage between the periphery of the piston and the tubing wall, gradually increasing the pressure on both the upper and lower ends of the valve member **95**. Since the greater area of the valve member is acted upon from above, the effect of that pressure plus the effect of the spring **100** eventually predominates over the gas pressure differential in the central valve chamber **78**, whereupon the valve member **95** snaps downward to permit gas supplied through the pipe **70** to pass into the lift tube under the piston **30**. It is apparent that the head of oil that must accumulate above the piston **30** to cause the gas valve to open will depend upon the force exerted by the spring **100** and the area differential in the valve chamber **78** affecting the valve member **95**, and since the valve assembly is removably mounted in the valve housing **65** the valve assembly may at any time be brought to the surface by a suitable tool for adjustment with respect to these factors. It may also be pointed out that by mounting my shock-absorbing means directly on the valve assembly, I provide for servicing or repairing the shock-absorbing means at the same time.

Any substantial leakage of gas through or around the valve assembly during the accumulation period might, in the absence of some provision for release, cause the piston **30** to be lifted prematurely to the extent of cutting off oil inflow through the ports **45**. A feature of the preferred form of my piston in the described structural combination is that not only does the piston permit static pressure to be transmitted downwardly past the periphery of the piston, but also the piston will permit appreciable flow at low velocities upward past the piston. As a further safeguard against premature lifting of the piston by leakage gas, attention is directed to the fact that the ball **38** is normally supported in spaced relation to the piston and the further fact that the piston passage **39**, especially the lower end thereof, is sufficiently larger than the ball to permit minor flow upwardly past the ball without carrying the ball to the seat **40**. Excessive leakage gas, then, will simply lift the ball **38** slightly from its normal position and escape past the ball and through the piston into the lift tube above the piston.

As soon as the gas valve opens, gas is admitted to the lift tube under the piston at such a high rate that the ball **38** is immediately carried upward into sealing contact with the valve seat **40** and the piston is forced upwardly to carry the superimposed oil column to the surface of the well. It should be noted that I insure seating of the ball prior to piston movement by concentrating the force of initial gas flow on the ball and at the same time not only shielding the piston from the force of that flow but also reducing the area subjected to pressure at the lower end of the piston. In other words, the support head **105** serves as a nozzle to direct gas flow against the ball from below but at the same time not only diverts flow from the annular lower end of the piston but also by surface-to-surface contact prevents fluid pressure from acting on the lower end of the piston.

As the piston approaches the top of the well, the ball **38** encounters the depending bar **42** and is dislodged thereby to fall downwardly through the tube to its normal position on the support head **105**. Dislodgment of the ball permits the free flow of fluid through the piston passage necessary for the piston to gravitate freely to the bottom of the well. I have found that the ball may be dislodged from its seat when the piston is a considerable distance below the top of the well since the oil column is then moving upwardly with considerable momentum and may be carried the last few feet by gas flow alone. As the piston moves upwardly, it serves not only as a carriage for sand deposited thereon during the accumulation period, but also serves as a receptacle for paraffin and other solids or semi-solids scooped from the walls of the lift tube. As soon as the ball **38** is dislodged from the piston, gas from below the piston surges through the piston with such force and velocity that all the material carried by the piston is blown into the superimposed oil body and flushed out of the well.

Gas streaming through the discharge passage **86** from the central valve chamber **78** when the gas valve is open tends to close the gas valve in opposition to the spring **100**, especially since the flow through the discharge passage impinges against the under face of the annular valve flange **96**. So long as considerable pressure is maintained in the lift tube under the traveling piston acting upon the upper end of the valve member **95**, the effect of the gas flow through the valve is not sufficient to cause the valve member **95** to close, but when the ball **38** is dislodged from the piston by the bar **42** to permit gas to flow freely upward through the piston passage, the gas pressure in the lift tube below the piston drops to such an extent that it can no longer withstand the tendency of the gas stream to close the valve member **95**, whereupon the valve closes. An important feature of my invention resides in this causal relationship between opening of the piston passage and closing of the gas valve, since gas flow does not continue in a wasteful manner when the piston passage is open and does not continue for any substantial period to oppose gravitation of the ball **38** and the piston **30**. It is further to be noted as an important feature of my invention that the piston carries to the surface substantially all of the oil in the lift tube so that it is not necessary for the piston to work its way downward through a long column of oil to its lowermost normal position. A certain desirable quantity of oil will, however, flow into the lift tube through the inlet ports **45** while the piston is elevated and will serve as a liquid cushion for partially decelerating the downward movement of the ball and piston. It is to be further observed that any rise above well pressure in the lift tube will cause the standing valve **63** to close so that throughout the lifting operation the gas introduced into the lift tube for pumping the oil is not exerted against the well formation to retard well flow.

Whenever it is desired to retrieve the lift piston at the surface of the well for servicing or replacement, the lift bar 43 is withdrawn through the packing gland 44 and passage for oil flow is opened through an upper pipe 112 branching from the nipple 22. In the subsequent lifting operation the piston passage will remain closed and the piston will be forced upward into an accessible position in the nipple 22.

Fig. 7 suggests how the piston and support head in the arrangement just described may be slightly modified. The piston 113 has a longitudinal piston passage 114, but the valve seat 115 for the ball 38 is relatively near the lower end of the piston. Normally the ball 38 rests on the support head 116 with substantial clearance between the sides of the ball and the surrounding walls at the lower end of the piston passage, but in this construction the walls of the support head 116 at the upper end of its axial passage 117 are cut away to form grooves 118 for fluid flow past the normally positioned valve ball 38. The important feature of this construction is that I do not depend upon any passage along the exterior of the piston for the transmission of static pressure from above the piston to below the piston. I may, therefore, as indicated in Fig. 7, employ a piston that fits the tubing 21 in a fluid-tight manner. While the piston 113 and the ball 38 are in their normal stationary positions, static pressure is transmitted downwardly through the piston passage 114 past the ball 38 and then through the grooves 118 and the axial passage 117 into the lift tube below the piston. Along the same channel of communication any gas leaking from the gas valve below may pass upwardly through the piston without causing the piston to be lifted prematurely during the accumulation period.

A refinement of the preferred form of my invention that will have utility in many installations may be understood by referring to Figs. 8 and 9. In some wells, considerable gas is released from the formation at substantial pressure but not in sufficient quantity or at sufficient pressure to serve alone as means to force the piston to the top of the lift tube. I have discovered, however, that after extraneous gas employed in the manner heretofore described has overcome the initial inertia of the piston and the super-imposed oil column, the amount of pressure required to keep the piston and oil column moving, especially as the piston nears the upper end of the well, may be within the range of pressure offered by the well formation. I propose, therefore, to provide an inlet in the pipe 70 for well gas to enter the pressure system from the lower annular casing chamber 27. For this purpose I provide a fitting 120 for the pipe 70 preferably at a point just below the packer 25. The fitting 120 has a vertical passage 121 continuous with the passage provided by the pipe 70, and has a laterally disposed inlet 122 controlled by a check valve. The check valve may comprise a ball 123 and a spring 124 pressing the ball outwardly to close the inlet. Whenever the pressure in the pipe 70 drops materially below the well pressure, gas in the annular space 27 passes into the pipe 70 and to that extent reduces the amount of extraneous gas necessary to complete the lifting operation.

A second form of my invention shown in Figs. 10 and 11 is similar in most respects to the preferred form heretofore described, corresponding numerals being employed to designate unchanged parts. The essential differences involved are, first, that the well fluid inlets 129 of the lift tube are spaced a substantial distance above the normal position of the piston 30, a distance at least as great as the height of the liquid column it is proposed to carry to the surface of the well in one lifting operation, and, second, that a gas controlled valve is employed that is responsive to the pressure differential between the liquid column above the piston and the formation pressure near the lower end of the lift tube. To carry the oil upwardly from the standing valve 63 to the relatively high inlets 129 the annular wall 130 corresponding to the wall 59 in Figs. 1 to 6 will, of course, be of greater height than heretofore suggested.

In this embodiment of my invention the lower end of the lift tube 21 is open, but otherwise the lift tube is the same. The valve housing 131 is the same as the previously described valve housing 65, but is provided with an annular flange 132 at the bottom that seals off the annular space around the housing. The valve assembly 75 is unchanged but in this embodiment I may use tubular members 133 and 134 corresponding respectively to tubular members 85 and 88, the substituted members having axial passages 135 and 136 of equal diameter adapted to be closed by identical valve heads 137 and 138. The valve member 140 that carries the valve heads 137 and 138 is of the same construction as heretofore described but carries at its lower end a piston 141 that cooperates with the walls of the lower valve chamber 77.

It will be apparent that the valve member 140 is acted upon from above by the pressure of liquid accumulating in the lift tube above the piston and is also acted upon by formation pressure transmitted upward through the open lower end of the tube 21 and through the fluid port 67 in the bottom of the valve housing. Oil in the annular space 60 around the lift tube exerts pressure against the lower face of the piston 141. Normally, the annular column of oil in the space 60 extends to the overflow level at the inlets 129 and consequently produces sufficient pressure against the under face of the piston 141 to hold the gas valve closed against force exerted by a spring 146 that acts against the upper face of the piston. Since the two valve passages 135 and 136 are of equal diameter, the relatively high gas pressure in the central valve chamber 78 has substantially no effect on the valve member in either direction.

As oil pours through the inlets 129, a column accumulates on the piston 30. As the oil column in the lift tube approaches the height of the inlets 129, the pressure per unit area on the upper end of the valve member 140 approaches the pressure per unit area on the lower face of the piston 141. Although the area of the piston acted on from above is considerably less than the area of the piston acted on from below, the spring 146 is designed to exert sufficient force to more than compensate for the area differential when the accumulated oil column reaches the desired height, whereupon the gas valve is tripped and the piston with the superimposed oil load is forced toward the surface of the well. Gas flowing through the gas valve and pressure against the bottom of the piston 141 tend to move the valve member 140 to closed position, but that tendency is opposed not only by the spring 146 but also by gas pressure exerted against the upper face of the piston 141. As soon as the piston

is carried to a level at which the ball **38** is dislodged from the piston, the gas pressure in the lift tube drops to such an extent that the gas valve closes under the action of the gas flow and the liquid pressure against the lower face of the piston **141**. The ball **38** and piston **30** then gravitate to the bottom of the well to pause while oil accumulates for another cycle of operation.

The optimum adjustment for a gas valve of my apparatus will depend upon the character of a given well. For example, consider a well having the flow characteristics indicated by the curve in Fig. 12. The inherent oil level of this particular well is at 5000 feet and the curve in Fig. 12 indicates the rate at which the oil level will be restored if the well is pumped or bailed out to the 5150 foot level. In approximately fifteen minutes the oil level will rise 50 feet to the 5100 foot level. In another fifteen minutes the oil will reach the 5065 foot level and at the end of half an hour will have climbed to the 5045 foot level, a total rise of 105 feet. From that point, designated level A in Fig. 12, the rate of oil flow will gradually drop off and it will require a total of five hours for the inherent oil level to be attained. If the normal inactive position of the lift piston of my apparatus is at the 5150 foot level and the gas valve is adjusted to open when a liquid column of 105 feet is imposed, the oil then being at the 5045 foot level, the lifting cycle will be repeated every forty-five minutes. Oil will flow from the well formation continuously at the maximum rate and each lifting operation will be performed upon an economical volume of oil. As a result, the maximum quantity of oil attainable will be recovered from the 5150 foot level and the recovery will be had with the minimum quantity of lifting gas.

If the same oil well were pumped with a swab continually intermitting at an uncontrolled rate, the amount of oil brought to the surface on each reciprocation of the swab would depend upon the duration of each reciprocation. If, for example, it would require ten minutes for the swab to move up and down in the lift tube, only approximately 35 feet of oil would accumulate for each lifting operation. If the swab were to reciprocate every fifteen minutes, only 50 feet of oil would accumulate. Such a pumping procedure in the situation indicated by Fig. 12 would require more than twice as much gas for a given quantity of oil pumped.

If a pressure-responsive intermitting valve were employed to control gas for blowing the oil to the surface of the well periodically and such a valve were set to open at pressure corresponding to the oil level A, the lifting operation would start with an oil column of 105 feet but in the course of 4000 feet, the gas would blow channels through the oil and a substantial quantity of the oil would drop back into the well. The net quantity lifted, for example, might be the equivalent of a column 75 feet long measuring to the level B, the equivalent of a 30 foot column dropping back into the well. Such a procedure would require considerably more gas than the method set forth herein, not only because of gas escaping through the oil but also because oil dropping back into the well would increase the frequency of the lifting cycle for a given volume of production.

The selected forms of my invention described in specific detail for the purpose of disclosure and to illustrate the principles involved will suggest to those skilled in the art various changes and modifications that do not depart from the essence of my concept, and I specifically reserve the right to all such changes and modifications that properly come within the scope of my appended claims.

I claim as my invention:

1. In a well pump, the combination of: a casing; a lift tube therein having an inlet spaced above the lower end thereof for the admission of well fluids; a lift piston freely movable in said tube; means to support said piston at rest below said inlet for a period to permit liquid accumulation in the tube above the piston; and means responsive to the pressure rise of said accumulated liquid to introduce pressure fluid under the stationary piston to force the piston upward to deliver said accumulated liquid to the surface of the well, said means being adapted to cut off said introduction of pressure fluid in the tube when the flow of the pressure fluid through said means attains a predetermined velocity.

2. In a well pump, the combination of: a lift tube therein having a first inlet spaced above the lower end thereof for the admission of well fluid and a second inlet below the first inlet for the admission of pressure fluid; a lift piston freely movable in said tube, said piston having a passage longitudinally therethrough; a valve member for controlling said piston passage, said valve member being separable downwardly from the piston; means to support said piston stationary in the tubing between said first inlet and said second inlet for the accumulation of liquid on the piston and to support said valve member in spaced relation to said piston passage to permit minor flow and transmission of pressure through said piston passage; means to supply pressure fluid to said tube through said second inlet to lift said piston and superimposed liquid, said support means being adapted to direct said fluid against said valve member to force said valve member into position closing said piston passage; and a pressure-responsive valve controlling the introduction of the pressure fluid through said second inlet, said valve being set to open in response to pressure in the tube below said piston when said accumulated liquid reaches a desired quantity and to close when the valve member in the piston is separated therefrom, thereby permitting unrestricted pressure fluid flow through the piston passage.

3. In a well pump, the combination of: a lift tube therein having a first inlet spaced above the lower end thereof for the admission of well fluid and a second inlet below the first inlet for the admission of pressure fluid; a lift piston freely movable in said tube, said piston having a passage longitudinally therethrough; a valve member below said piston freely movable in said tube independently of said piston and adapted to close said piston passage; means to supply pressure fluid to said tube through said second inlet to force said piston upwardly to lift liquid to the surface of the well; means near the top of the well to dislodge said valve member from said piston passage to cause the valve member and piston to fall independently; support means to receive the falling valve member and to support the valve member in said tube between said first and second inlets and to receive said falling piston and to support said piston in the tubing between said inlets and sufficiently above said valve member to permit pressure transmission and minor flow through said piston passage; and a pressure-responsive valve controlling the intro-

duction of the pressure fluid through said second inlet, said valve being set to open in response to pressure in the tube below said piston when said accumulated liquid reaches a desired quantity and to close when the valve member in the piston has been dislodged from the piston passage, thereby permitting unrestricted pressure fluid flow therethrough.

4. In a well pump, the combination of: a lift tube therein having a first inlet spaced above the lower end thereof for the admission of well fluid and a second inlet below the first inlet for the admission of pressure fluid; a lift piston freely movable in said tube, said piston having a passage longitudinally therethrough; a valve member for controlling said piston passage; means for actuating said valve member; means to support said piston stationary in the tubing between said inlets to permit well fluid flowing into the tube through said first inlet to accumulate above the piston, said piston being of a configuration to form with the surrounding tube a labyrinth passage for the transmission of pressure from above the piston to below the piston; means to supply pressure fluid to said tube through said second inlet to lift said piston and liquid superimposed thereon; and a pressure-responsive valve controlling the introduction of the pressure fluid through said second inlet, said valve being set to open in response to pressure in the tube below said piston when said accumulated liquid reaches a desired quantity and to close when the valve member in the piston passage is actuated to permit unrestricted pressure fluid flow therethrough.

5. In a well pump, the combination of: a lift tube therein having a first inlet spaced above the lower end thereof for the admission of well fluid and a second inlet below the first inlet for the admission of pressure fluid; a lift piston freely movable in said tube, said piston having a passage longitudinally therethrough; a valve member for controlling said piston passage; means to support said piston stationary in the tubing between said inlets to permit fluid accumulation on the piston and to hold said valve member simultaneously in open position to permit minor flow through the piston passage, said piston being of a configuration to form with the surrounding tube a labyrinth passage for the transmission of static pressure from above the piston to below the piston; means to supply fluid to said tube through said second inlet to force said valve member into position closing said piston passage and to lift said piston to deliver said superimposed liquid to the top of the well; means rigidly affixed within the lift tube near the upper end thereof for actuating said valve member to permit unrestricted fluid flow through said passage; and a pressure-responsive valve controlling the introduction of the pressure fluid through said second inlet, said valve being set to open in response to pressure in the tube below said piston when said accumulated liquid reaches a desired quantity and to close when said passage through the piston has been opened to unrestricted fluid flow.

6. In a gas lift system, a lift tube having an inlet spaced above the lower end thereof for the admission of well fluids, a lift piston freely movable in said tube, means to support said piston at rest below said inlet, for a period to permit a well liquid accumulation in the lift tube, means to admit pressure fluid to the space below the piston to force said piston upwards, means to release the pressure fluid from the space below the piston, and valve means to control the admission of the pressure fluid, said means being actuated into an open position by the pressure rise of said accumulating liquid, and into a closed position upon the release of the pressure in the space below said piston.

7. In a gas lift system, a lift tube having an inlet spaced above the lower end thereof for the admission of well fluids, a lift piston freely movable in said tube, means to support said piston at rest below said inlet for a period to permit a well liquid accumulation in the lift tube, means to admit pressure fluid to the space below the piston to force said piston upwards, a normally closed passage in the piston, means to open said passage to permit a discharge of the pressure fluid through the liquid accumulating above said piston, and valve means to control the admission of the pressure fluid, said means being actuated into an open position by a pressure rise of the liquid accumulating in the lift tube, and into a closed position upon the discharge of the pressure fluid through the liquid above the piston.

8. In a gas lift system, the combination of a casing, a lift tube in said casing, means dividing the space between the casing and the tube into an upper annular chamber and a lower annular space open to well fluids, a pressure fluid confined in said upper chamber, said lift tube having a first inlet spaced above the lower end thereof for the admission of well fluids from said lower annular space and a second inlet below the first inlet, passage means for transmitting pressure fluid from said upper chamber to said tube through said second inlet, a lift piston freely movable in said tube, a normally closed passage through said piston, means responsive to a predetermined upward displacement of said piston to open said passage, means to support said piston in a stationary position in said tube between said first and said second inlets for a period to permit liquid accumulation in the lift tube above the piston, leakage means to permit a restricted flow of said liquid from the space above said piston to the space below said piston, and pressure responsive valve means to control the admission of the pressure fluid through said second inlet, said means being actuated into an open position by the pressure in the tube below said piston when said accumulating liquid reaches a predetermined quantity and into a closed position when the pressure fluid admitted to the space below the piston is released to the space above the piston by the opening of the passage through said piston.

9. In a gas lift system, the combination of a casing, a lift tube in said casing, means dividing the space between the casing and the tube into an upper annular chamber and a lower annular space open to well fluids, a pressure fluid confined in said upper chamber, said lift tube having a first inlet spaced above the lower end thereof for the admission of well fluids from said lower annular space and a second inlet below the first inlet, passage means for transmitting pressure fluid from said upper chamber to said tube through said second inlet, a lift piston freely movable in said tube, a normally closed passage through said piston, means responsive to a predetermined upward displacement of said piston to open said passage, means to support said piston in a stationary position in said tube between said first and said second inlets for a period to permit

liquid accumulation in the lift tube above the piston, leakage means to permit a restricted flow of said liquid from the space above said piston to the space below said piston, pressure responsive valve means to control the admission of the pressure fluid through said second inlet, said means being actuated into an open position by the pressure in the tube below said piston when said accumulating liquid reaches a predetermined quantity, and into a closed position when the pressure fluid admitted to the space below the piston is released to the space above the piston by the opening of the passage through said piston, a check valve in communication between said space open to well fluids and said passage between the upper chamber and the second inlet, and spring means normally holding said valve in closed position, said valve being adapted to open against the action of said spring means when the pressure in said space exceeds materially pressure in said passage.

10. An oil flowing apparatus for raising a column of oil artificially introduced into a string of tubing, comprising a string of tubing and a piston adapted to be acted upon and urged by pressure fluid in one direction in the said tubing, the said column of oil extending above the said piston, means beneath the said piston automatically regulating the flow of the said pressure fluid, the said means actuated by the weight of the said column and the velocity of the said pressure fluid.

11. In combination with a string of tubing in an oil well, an oil flowing apparatus for raising a column of oil previously introduced into the said tubing, comprising a traveling plug operatively arranged in the said tubing and below the said column adapted to be operated upon and moved against the said column by pressure fluid exerted therebelow and means situated beneath the said plug and the said column automatically controlling the said pressure fluid, the said means actuated by the liquid column and the peak velocity of the said pressure fluid in its passage therethrough.

12. In combination with a string of tubing, a well flowing apparatus for raising a column of oil artificially inducted into and confined within the said string of tubing comprising a traveling plug adapted to be urged upwardly in the said tubing by pressure fluid introduced from the earth's surface against the said column and descending by gravity, a valve controlling the flow of the said pressure fluid cooperating with the said plug and operated by the weight of the said oil and the velocity of the pressure fluid.

13. In combination with a string of tubing in an oil well, a flowing apparatus for raising a column of oil comprising a piston slidably arranged within the said tubing and urged upwardly against the said oil by pressure fluid exerted therebelow, a valve assembly cooperating with the said piston controlling the said pressure fluid, the said valve assembly opened by the weight of the said oil and closed by the velocity of the said pressure fluid.

14. In a well flowing apparatus operating in a string of tubing, a go-devil slidably disposed within the said tubing and adapted to raise a column of liquid thereabove by pressure fluid exerted thereagainst from below, a regulating means controlling the flow of the said pressure fluid cooperating with the said go-devil, the said means acted upon and motivated by the weight of the said column and by the velocity of the said pressure fluid.

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