United States Patent

[11] 3,617,152

[72] Inventor **Leslie L. Cummings**
Houston, Tex.
[21] Appl. No. **825,538**
[22] Filed **May 19, 1969**
[45] Patented **Nov. 2, 1971**
[73] Assignee **Otis Engineering Corporation**
Dallas, Tex.

[54] **WELL PUMPS**
55 Claims, 15 Drawing Figs.

[52] **U.S. Cl.** **417/54,** 417/120, 417/122
[51] **Int. Cl.** **F04f 1/06,** F04f 3/00
[50] **Field of Search** 103/234, 231, 232, 235, 240; 417/118, 120, 122, 54

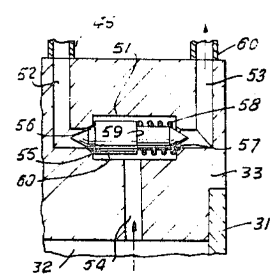
[56] **References Cited**

UNITED STATES PATENTS

2,942,552	6/1960	Wayt	417/390 X
3,415,199	12/1968	Elliott et al.	417/127
2,034,798	3/1936	Clark	103/234
2,142,481	1/1939	Stephens et al.	103/234
2,339,487	1/1944	King	103/231
2,400,651	5/1946	Marsh	103/234
2,777,399	1/1957	Clark, Jr.	103/234
2,948,232	8/1960	McCarvell et al.	103/232
3,106,170	10/1963	Gray	103/234
3,260,308	7/1966	Cryer	103/234
3,288,081	11/1966	McMillan	103/234

Primary Examiner—Carlton R. Croyle
Assistant Examiner—Richard E. Gluck
Attorney—E. Hastings Ackley

ABSTRACT: Methods of and means for the artificial lifting of well fluids; and, more particularly an automatic well pump utilizing compressed power air or gas to displace well production fluids from the well bore to the earth's surface, and systems and methods utilizing such pumps wherein the power gas exhausted from the pump is collected in a chamber at a desired predetermined superatmospheric pressure to reduce the energy required to compress the same for reuse in the pump.



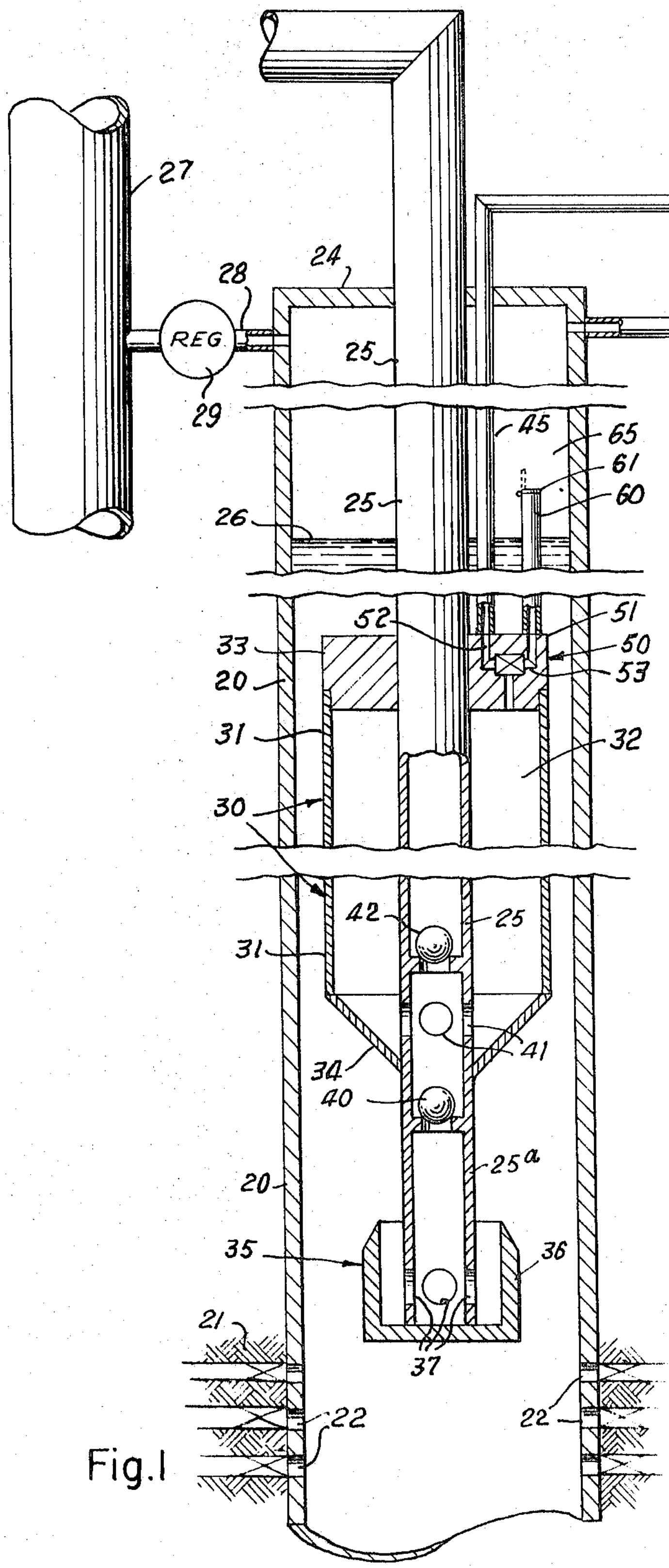


Fig.1

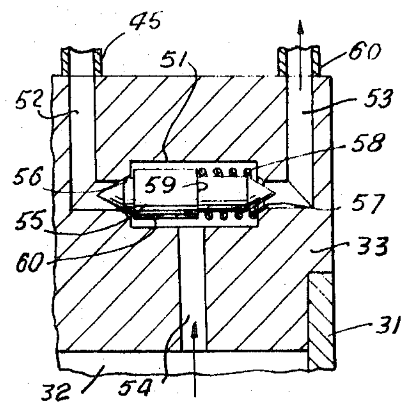


Fig.2

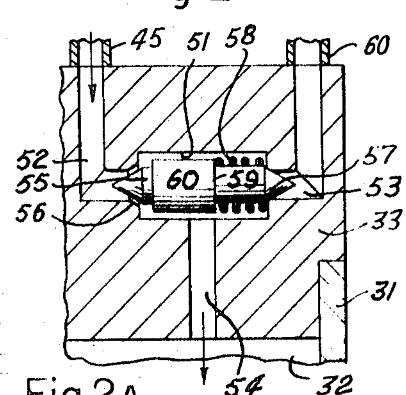


Fig.2A

INVENTOR.
Leslie L. Cummings

BY C. Hastings Ackley

ATTORNEY

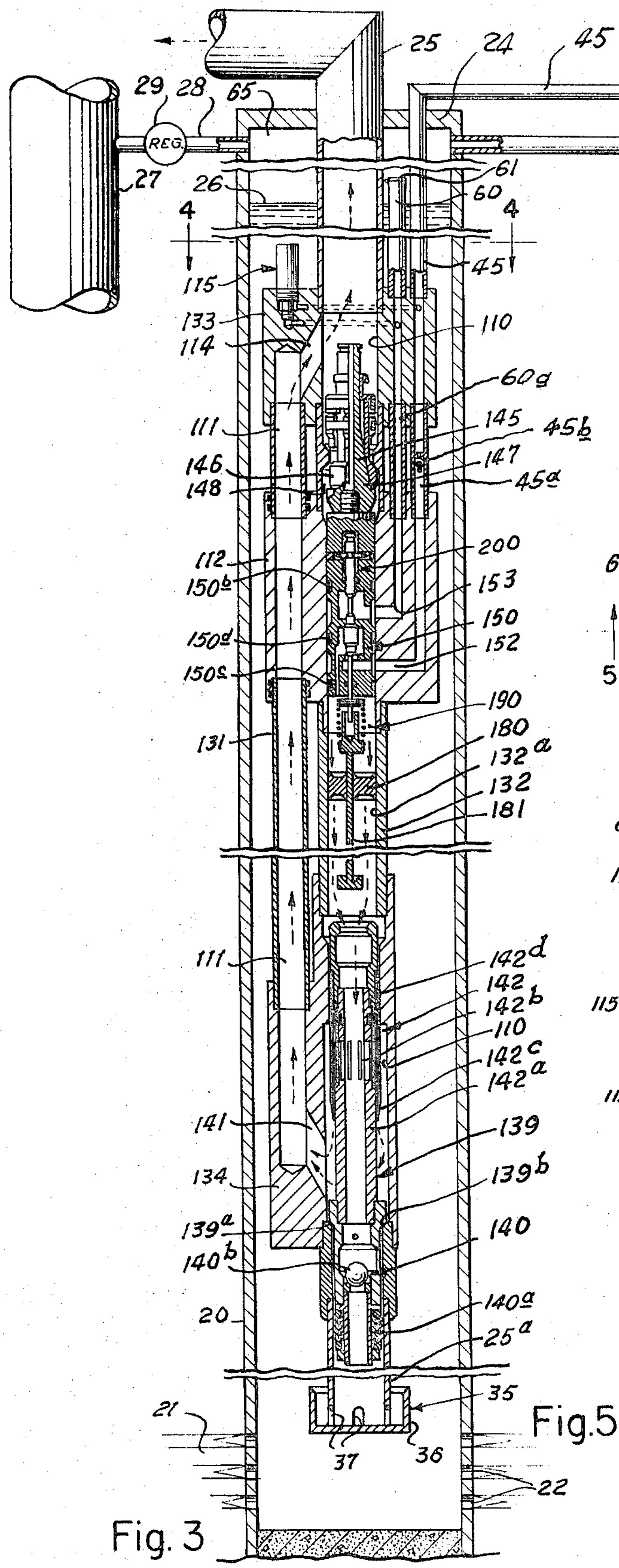


Fig. 3

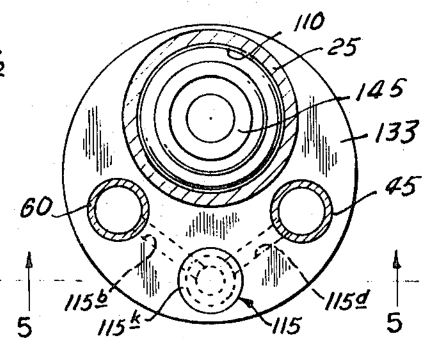


Fig. 4

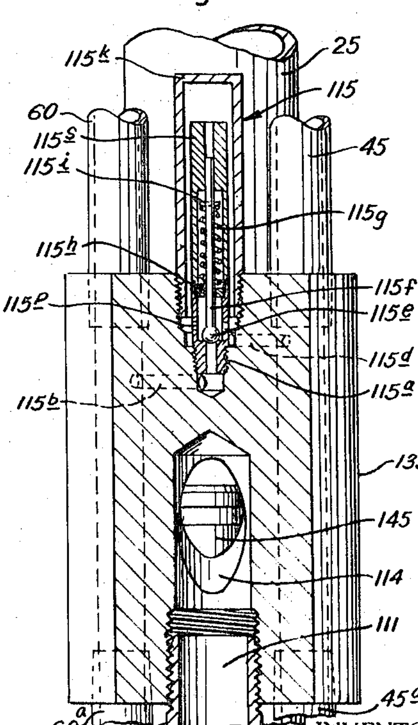


Fig.5

INVENTOR.

Leslie L. Cummings

BY E. Hastings Ackley

ATTORNEY

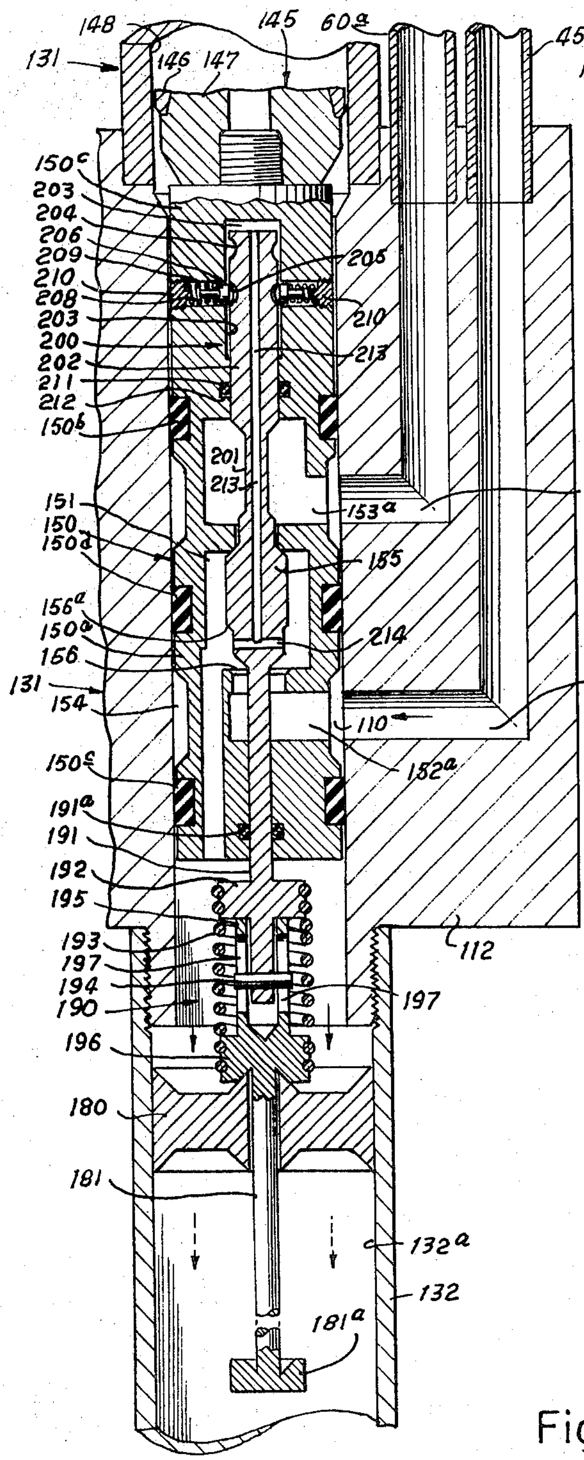


Fig. 6

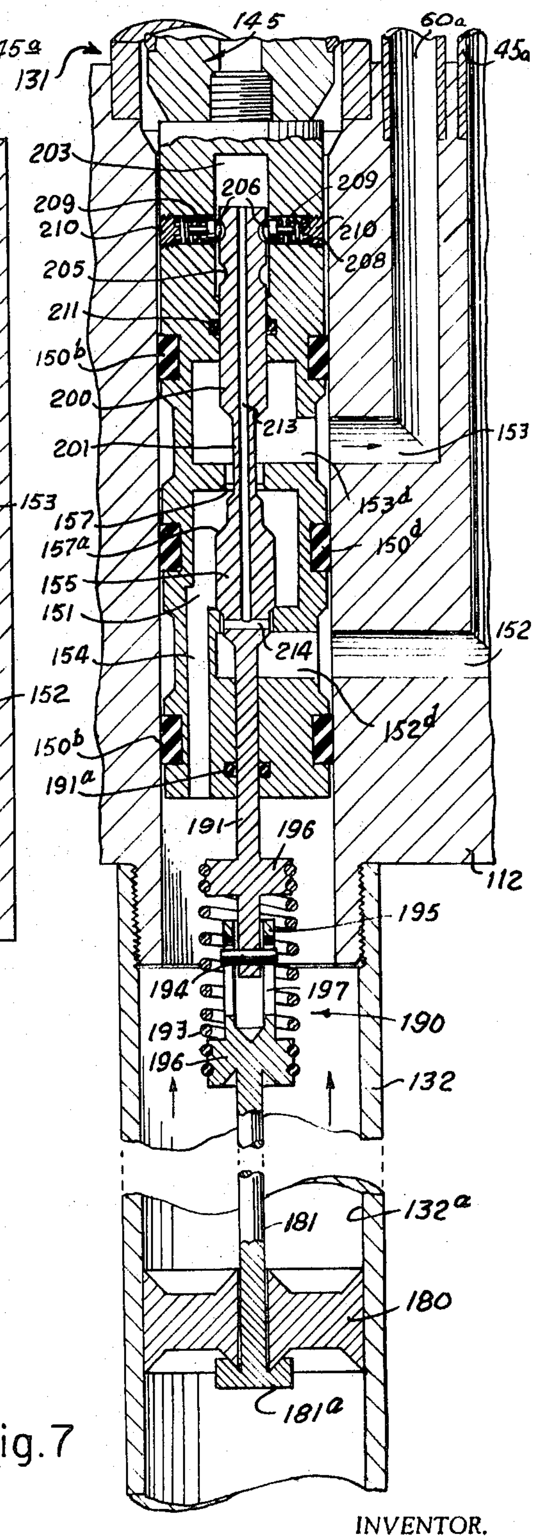


Fig. 7

INVENTOR.
Leslie L. Cummings
BY E. Hastings Ackley
ATTORNEY

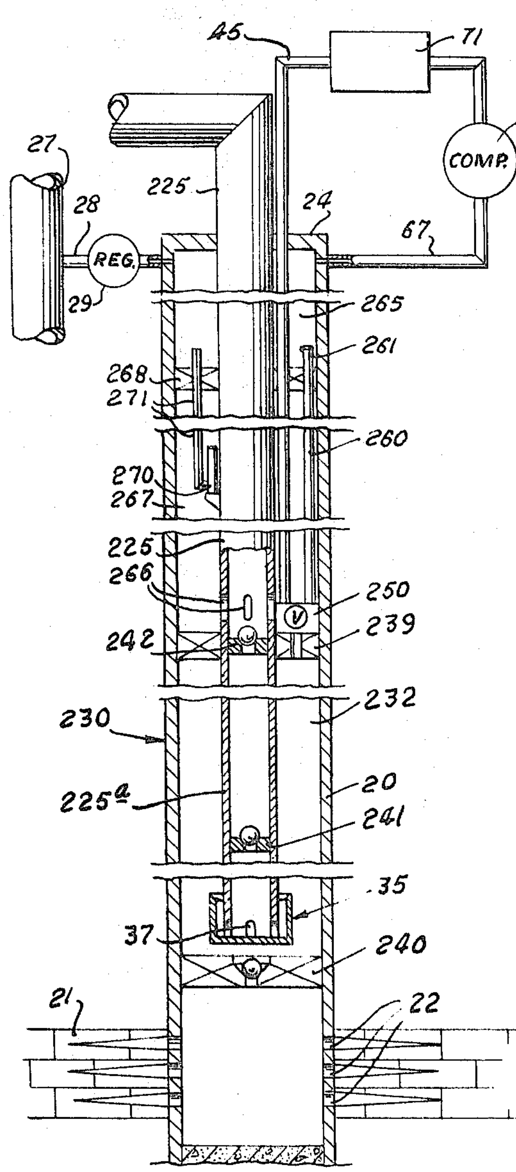


Fig. 8

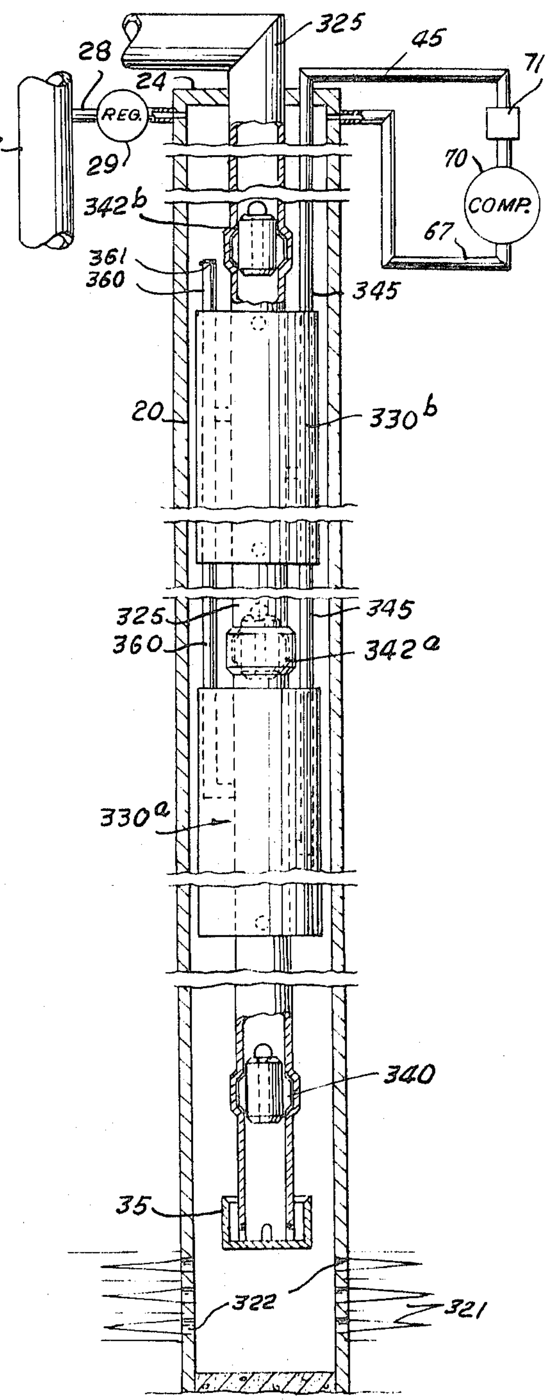


Fig. 9

INVENTOR.
Leslie L. Cummings
BY
Hastings Ackley
ATTORNEY

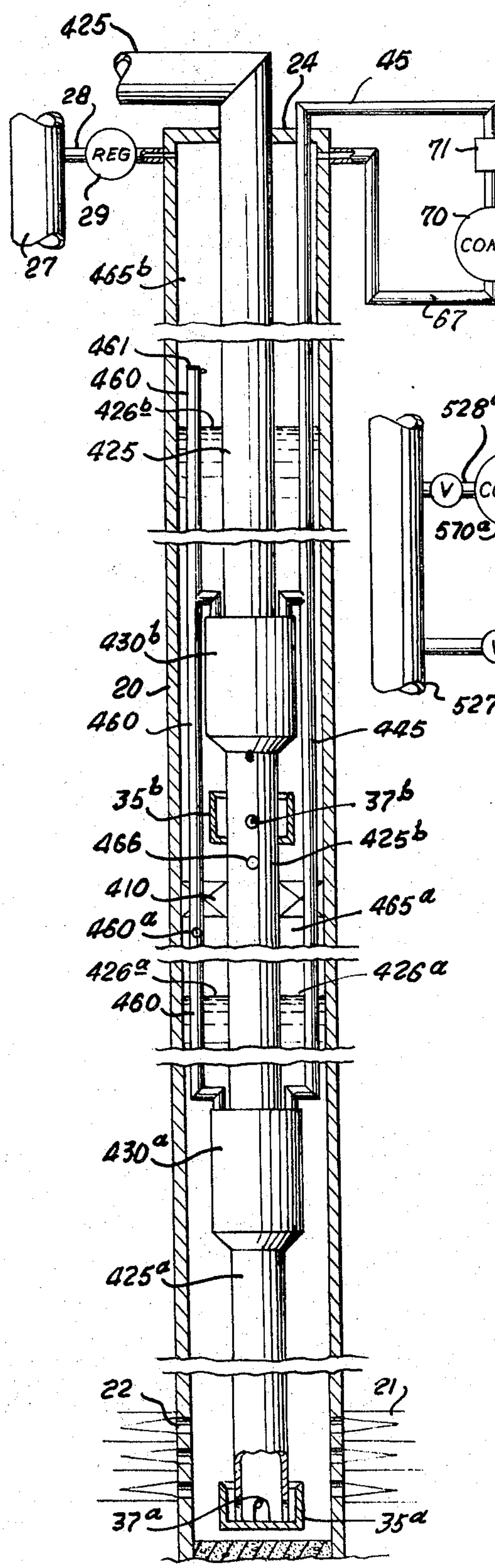


Fig.10

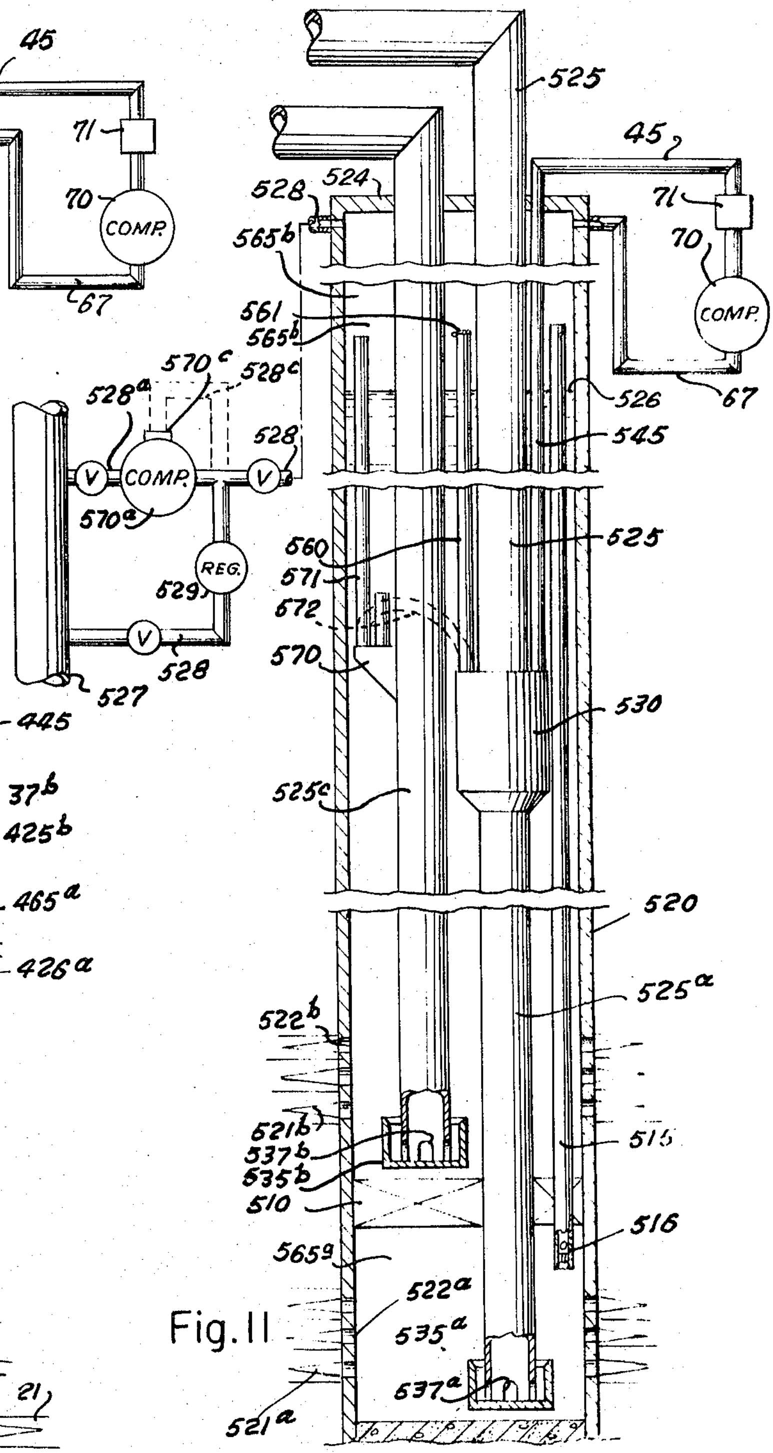


Fig.11

INVENTOR.
Leslie L. Cummings
BY
C. Hastings Ackley
ATTORNEY

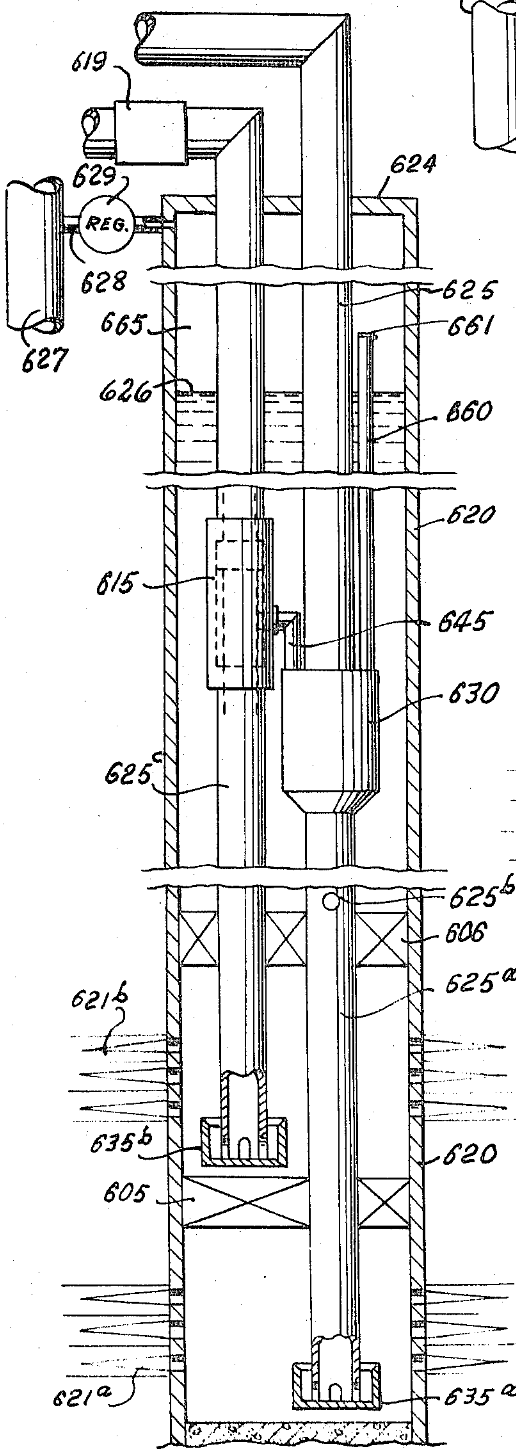


Fig. 12

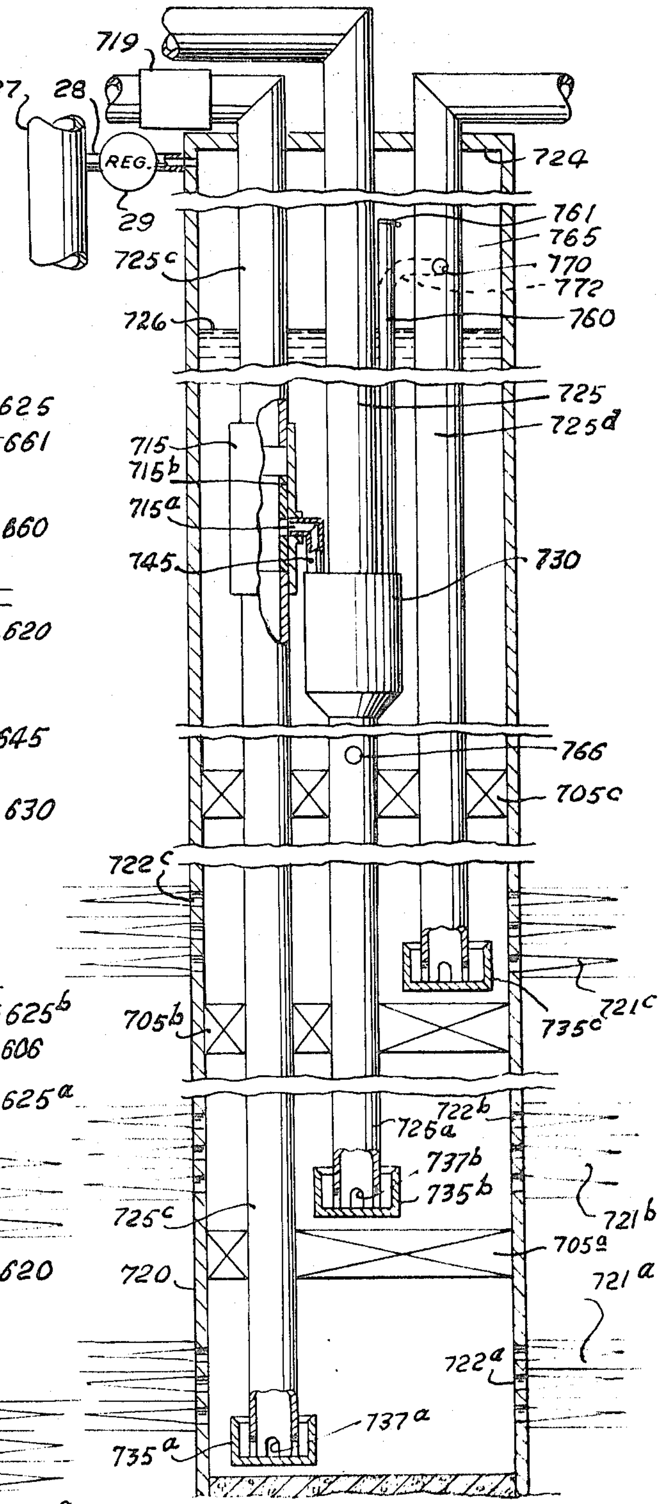


Fig. 13

INVENTOR.
Leslie L. Cummings
BY
Hastings Ackley
ATTORNEY

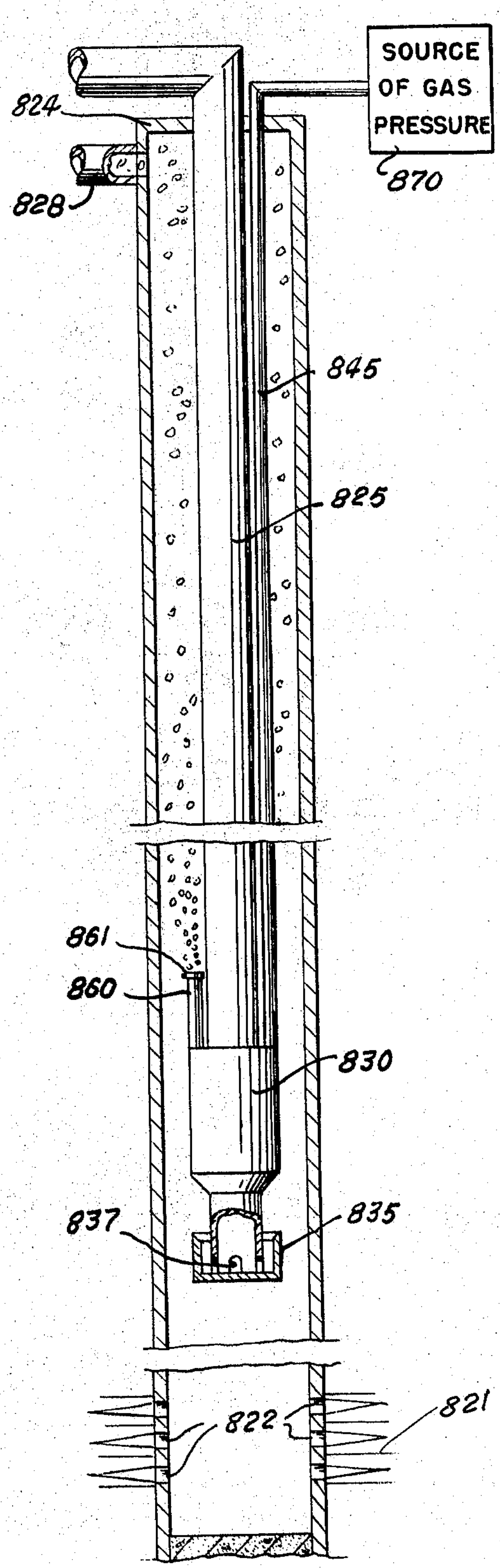


Fig.14

INVENTOR.
Leslie L. Cummings
BY E. Hastings Ackley
ATTORNEY

WELL PUMPS

One object of the invention is to provide an improved air- or gas-operated pump means for lifting well fluids to the surface with an efficiency greatly in excess of conventional gas lift or other means, thus providing substantial economic savings in lifting costs.

Another object of the invention is to provide a system for and method of artificial lift utilizing pump means operated by high-pressure gas and having a chamber in which the exhaust gas is accumulated at a pressure in excess of atmospheric pressure to conserve the potential energy of such gas and to reduce the cost of recompression for further use in the pump, whereby the method can be practiced and the system can be operated by means of a single-stage compressor rather than requiring a multistage compressor, resulting in substantial reductions in lifting costs.

A still further object is to provide a system and method of the character set forth wherein the well fluids are maintained under substantially constant pressure conditions while in the pump so that the efficiency of the system will not be reduced by releasing entrained gas from the well fluid or liquid in the pump.

Another object is to provide systems or methods of the character set forth wherein gas-powered pumps are utilized to move the well fluids a part of the way to the surface and then are lifted the remainder of the way by other means such as gas lifting, rod pumping, hydraulic pumping, or the like.

A further object is to provide an artificial well lift system or method of the character set forth well casing the exhaust power gas from the pump is further utilized to aid in disposed in to backflow surface well fluids either from the pumped zone or from another and separate producing formation.

Still another object is to provide a system utilizing a plurality of gas-operated pumps embodying the invention wherein fluids from a plurality of production zones are lifted separately to the surface.

A further important object is to provide systems or methods of artificial lift for wells using compressed gas wherein a plurality of pumps actuated by such compressed gas are disposed at different depths in a well to lift well fluids to the surface in stages.

Another object is to provide a lift system and method of the character described wherein gas entrained in the well production fluids is allowed to break out of solution exterior of the pump and is collected in a chamber, together with the exhaust from the pump, under predetermined pressure conditions; and also to provide in such a system a fluid flow regulator through which the excess gas is allowed to bleed from the chamber into a flow line or other conductor in order to maintain the chamber pressure at a substantially constant value.

A particular object of the invention is to provide a gas-operated pump assembly for lifting well fluids to the surface having a pump chamber in which well fluids are accumulated and having positive pressure-actuated plunger means slidably disposed in said chamber and directly responsive to the fluid pressure within the chamber to shift the valve means to alternately introduce power gas into and exhaust it from said chamber to sequentially reciprocate the plunger in the chamber to fill the chamber with and empty it of well fluids automatically to pump such fluids to the surface.

Yet another object is to provide apparatus of the character set forth which comprises a chamber for collecting well fluids, a plunger in the chamber substantially defining the gas-liquid interface, and valve means operated by the plunger to control the admission of power gas into the chamber and the exhaustion of gas therefrom to cause the chamber to be sequentially filled with and emptied of well fluids which are moved to the surface by the power gas and wherein the plunger is always acted upon by positive forces due to fluid pressures in the chamber.

Also an object of this invention is to provide gas-operated pump means for lifting well fluids to the surface having working parts installable and retrievable from the well flow conductor by means of conventional wire line tools and methods without removing the flow conductor.

An important object of this invention is to provide a gas-powered pump for lifting well fluids to the surface which is so constructed that its working parts are not easily fouled by solid particles which may be carried by the production fluids.

Another object of this invention is to provide a method and system of artificial lift powered by compressed gas wherein the pressure of the power gas is prevented from bearing against the producing formation to permit entry of production fluids into the well bore from the production zone under predetermined desired conditions.

A further object is to provide a method and system for lifting well fluids to the surface wherein a plurality of gas-powered pumps of the character set forth are connected in parallel to operate independently of one another to lift the well fluids to the surface in stages, the pumps exhausting their used power gas into interconnected exhaust gas collection chambers.

A still further object is to provide methods and systems for lifting well fluids to the surface through a plurality of flow conduits each communicating with a separate production zone, wherein fluids from at least one zone are lifted by a pump powered by gas conducted thereto from the surface and wherein the used power gas exhausted from the pump is collected together with gas coming out of solution in a chamber at superatmospheric pressure for gas-lifting fluids from at least one other production zone and for recompression and reuse as power gas for the pump, and wherein excess gas is dumped through a pressure regulator into a disposal conduit and lack of gas is made up by withdrawing it from the disposal conduit for recompression and reuse.

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

FIG. 1 is a schematic view, partly in elevation and partly in section, of a well pump installation embodying the invention;

FIG. 2 is a fragmentary sectional view showing a differential value used for controlling introduction and exhaust of lifting gas in the pump installation, showing the gas exhausting position of the valve;

FIG. 2A is a view similar to FIG. 2 showing the gas introducing position of the valve;

FIG. 3 is a schematic sectional view of a well installation having a removable well pump assembly installed therein;

FIG. 4 is a horizontal cross-sectional view taken on the line 4—4 of FIG. 3;

FIG. 5 is an enlarged view, partly in elevation and partly in section, of the differential valve used in the installation of FIG. 3;

FIG. 6 is an enlarged vertical sectional view of the control valve of the pump assembly, showing the same in position for the production stroke of the pump;

FIG. 7 is a view similar to FIG. 6 showing the control valve in position for the exhaust stroke;

FIG. 8 is a schematic view, partly in elevation and partly in section, of a modified form of well pump installation;

FIG. 9 is a schematic view, partly in elevation and partly in section, of a tandem well pump installation;

FIG. 10 is a schematic view, similar to FIG. 9, of a modified form of tandem well pump installation;

FIG. 11 is a schematic view, partly in elevation and partly in section, a dual zone, dual string, well pump installation;

FIG. 12 is a schematic view, similar to FIG. 11, of a modified form of dual zone, dual string, well pump installation;

FIG. 13 is a schematic view, partly in elevation and partly in section, of a triple zone, triple string, well pump installation; and,

FIG. 14 is a view, partly in elevation and partly in section, showing a well pump installation in a high productivity well.

In the drawings, FIG. 1 illustrates schematically a liquid pump constructed in accordance with the invention and installed in a well. Well casing 20 extends downwardly through a producing formation 21 and a plurality of perforations 22 are formed in the casing to provide for admission of liquids from the formation to the bore of the casing for production from the well. A casing head or other closure 24 closes the upper end of the casing and a production tubing string 25 extends downwardly into the well from the surface through the closure in the usual manner to a point adjacent the producing formation, or to a point substantially below the upper level 26 of the liquids in the casing. A surface flow line 27 of the usual type is connected by means of a lateral flow line 28 to the upper end of the casing below the closure and a fluid pressure regulator 29 is connected in said lateral flow line for controlling the pressure of the gas or other fluids flowing from the casing through said flow line.

The pump of the invention is indicated generally by the numeral 30 and is shown connected to the lower end of the tubing string 25 in flow communication therewith. The pump includes a housing 31 surrounding the tubing string and providing an annular liquid chamber 32 between the tubing string and the housing which is closed at its upper end by a cap or closure 33 and at its lower end by a closure member 34 welded or otherwise secured to the tubing and to the lower end of the housing. Below the housing 31 an extension tubing 25*a* extends downwardly a desired predetermined distance to a gas anchor 35 in the form of an upturned cup 36 surrounding the lower end of the tubing in spaced relation thereto and closing the lower end of the tubing, with lateral ports 37 formed in the wall of the tubing within the cup, so that gas produced from the formation 21 will pass upwardly around the cup and will not enter the tubing openings 37. The pump 30 includes a lower check valve 40 which is disposed at the lower end of the housing 31 or in the extension tubing 25 below the housing between the pump and the openings 37 communicating with the producing formation in the well. Also, lateral ports 41 are formed in the wall of the tubing above the lower closure 34 communicating with the bore of the pump chamber 32 to admit liquids from the well producing formation to flow into said chamber. Above the lateral openings 41, the tubing string is provided with a second check valve 42 which is disposed downstream in the tubing of the openings 41 and which prevents backflow of fluids from the tubing string thereabove downwardly to the openings 41 communicating with the pump chamber 32.

Liquids from the well producing formation are permitted to pass inwardly through the inlets 37, upwardly through the extension tubing 25*a*, past the lower check valve 40 and outwardly through the lateral ports 41 into the chamber 32 of the pump. The liquids are then displaced from the chamber 32 through the ports 41 into the tubing string 25 and upwardly past the upper check valve 42, and then upwardly through the tubing string 25 thereabove to the surface of the well.

For displacing the liquids from the chamber 32, a supply of pumping gas or power gas of compressed air or gas is introduced into the chamber 32 above the liquid contained therein. The power gas is conducted into the chamber by means of a power gas conduit 45 extending downwardly from the surface of the well through the closure 24 at the upper end of the casing to the cap 33 at the upper end of the pump housing 31 and communicates at that point with a gas control valve 50, shown as disposed in the closure or cap at the upper end of the pump. The valve includes a valve chamber 51 having an inlet port 52, an outlet port 53, and a passage 54 communicating with the chamber 32 of the pump. Within the valve chamber is disposed a valve closure member 55 which is movable between an inlet seat 56 and an outlet seat 57 in said chamber to engage said seats for the purpose of controlling the flow of the power gas into and out of the chamber 32 in a manner which will be hereinafter described.

The valve is shown to be a differential valve which is biased toward a position closing the inlet port 56 by means of a spring 58 surrounding the valve closure member 55 between a shoulder 59 formed by a flange 60 on said closure member and the wall of the chamber 51 adjacent the outlet seat 57. Thus, the valve closure is biased toward a position closing the inlet seat 56 at all times by the spring 58. An exhaust conduit or tube 60 is connected to the outlet port 53 of the valve and the gas exhausted from the chamber 32 of the pump is conducted by said conduit 60 to an accumulator chamber 65 formed by the upper portion of the casing annulus between the tubing string 25 and the casing 20 closed by the well head 24 and above the liquid level 26. A backflow check valve 61 is provided on the upper end of the exhaust conduit or tube 60 to prevent backflow of liquids or gas down said conduit to the valve.

For supplying the pressure or power fluid or gas to the pump 30, a compressor 70 is connected on its exhaust or high pressure side to the power supply conduit 45 and is connected on its intake or suction side with the accumulator chamber 65 by means of a suction conduit line 67 having an inlet to the accumulator chamber through the wall of the casing below the closure or well head 24. A variable choke or flow control device 71 is provided in the power gas conduit 45 between the compressor and the pump 30 for controlling the volume of flow of compressed gas from the compressor into the pump.

In operation, power gas from the compressor 70 is conducted by means of the power supply conduit 45 to the valve 50 through the inlet port 52 and will move the valve closure 55 to the position shown in FIG. 2A against the force of the spring 58, and will flow through the passage 54 into the pump chamber 32 to displace liquids accumulated in said chamber. The lower check valve 40 will prevent the liquids from flowing back down the extension tubing 25*a* to the producing formation, while the upper check valve 42 will open to permit such liquids to be displaced upwardly in the tubing 25 to the surface. The power gas entering through the valve 50 forces the closure member 55 to the right to engage the outlet seat 57 as shown in FIG. 2A, and thus close the exhaust passage 53 to direct the gas flow inwardly from the inlet 52 past the closure member 55 and outwardly through the passage 54 into the chamber 32 of the pump. When the pressure in the pump chamber 32 declines, as a result of the restriction of flow by the variable choke 71 and the exhaust of gas and fluids from the pump chamber upwardly through the tubing, the spring 58 will bias the valve closure member 55 to the left in the chamber 51 to engage the inlet seat 56 to close the inlet port 52 and open the exhaust port or passage 53 to permit the gas within the pump chamber to flow outwardly through the passage 54 past the valve closure member 55 and then outwardly through the exhaust port 53 and upwardly through the exhaust conduit 60 to the accumulator chamber 65 in the casing annulus above the liquid level 26 in the casing. Such exhausting of the gas from the pump chamber 32 will permit liquids from the well formation 21 to again flow inwardly through the ports 37 in the tubing, upwardly past the lower check valve 40 and into the chamber 32 of the pump. The upper or downstream check valve 42 will be closed due to the hydrostatic head of the liquids sanding in the tubing string, which is at a value in excess of that of the liquid within the casing, so that the liquid entering from the producing formation will enter the pump chamber 32 and flow upwardly therein until the pressure in the supply conduit 45 builds up to a value sufficient to overcome the spring 58 and move the valve closure member 55 to the position shown in FIG. 2A to again admit gas into the chamber 32 of the pump to displace the liquids from such chamber.

Obviously, if desired, an intermitter and motor valve timer device may be used at 71 in the supply conduit line 45 to control admission of power gas through the supply conduit into the chamber 32 to displace the liquids therefrom, using the same valve 50.

Since the gas which is exhausted from the pump chamber 32 is trapped in the accumulator chamber 65 in the annular space or annulus of the casing above the liquid level 26 in the casing, and since the regulator 29 in the lateral flow line 28 produces a back pressure or maintains a back pressure in said accumulator chamber dependent upon the setting of the regulator, the power gas exhausted through the exhaust line 60 into the accumulator chamber 65 is trapped or accumulated therein at an elevated or superatmospheric pressure, and is conducted through the intake suction line 67 to the compressor at such elevated or superatmospheric pressure for compression to the desired operating pressure for operating the pump. Thus, a greater efficiency of operation is obtained in that a reduced amount of energy is required at the compressor 20 to elevate the power gas from the superatmospheric pressure at which it is trapped in the accumulator chamber 65 to the operating pressure at which it is admitted into the pump chamber to displace the liquids to the surface. Since the pressure in the accumulator chamber 65 is regulated or controlled by the regulator 29 in the lateral flow line 28, the gas accumulating in the accumulator chamber 65 at a pressure in excess of the value at which the regulator 29 is set will pass through the regulator and through the lateral flow line to the surface gathering line for flowing line 27 in the usual manner for transportation to any desired storage or remote point for disposition, use or sales.

It will be seen, therefore, that the pump provides for lifting liquids by utilization of power gas, which is then conducted from an accumulator chamber wherein it is trapped or accumulated at a superatmospheric pressure to a compressor for recompression to the desired higher operating power pressure, and is then reintroduced into the pump to again displace liquids from the pump. Since a great amount of energy is utilized in compressing gas from atmospheric pressure to a superatmospheric pressure, such as 500 pounds per square inch, as compared to the energy utilized in compressing the gas from the superatmospheric pressure of 500 pounds per square inch to an operating power pressure of, say, 1,500 pounds per square inch, it will be readily apparent that a substantial saving in power use, and a greater efficiency and reduced costs are provided by the utilization of the pump and system of this invention.

If desired, as has been explained, the variable choke designated as 71 in the supply line 45 may be substituted for by a timer intermitter of the standard gas lift type which intermittently actuates a motor valve for admitting the power gas to the valve 50 for actuating the pump. The intermitter and motor valve construction may be of the standard variety which functions at predetermined intervals, which may be controlled by adjustment of a timer wheel on the intermitter, and the interval of injection and the injection period also may each be controlled by adjustment of timer wheel of the intermitter. One such structure could be that shown in the 1968–1969 Composite Catalog of Oil Field Equipment and Services, at pages 3,856 and 3,857.

A preferred embodiment and commercial form of the pump of the invention is illustrated in FIGS. 3 through 7, inclusive. In this form of the device, the pump housing assembly 131 is connected by screw threads or the like in the usual manner to the lower end of the tubing string 25 and is supported thereby in the casing 20 at a desired depth below the upper liquid level 26 in the annulus in said casing. An extension tubing 25*a* is connected by threads to the lower end of the housing and extends downwardly therefrom to the gas anchor 35. Well liquids entering the perforations 22 in the casing 20 will flow upwardly through the inlet openings 37 through the extension tubing 25*a* and through the housing to the tubing 25 thereabove, from whence it will flow to the surface of the well. In this form of the device, the housing assembly 131 is formed with an upper head or cap member 133, a control valve housing and landing nipple section 122, a pump chamber section 132, a lower closure and check valve housing 134, an elongate laterally offset bypass passageway 111 and an elongate principal bore or through passageway 110; and, the valve structure, displacement means and check valve structures of the pump are removably disposed within the elongate through bore 110 of the housing assembly, which is aligned axially with the tubing string 25. The lateral bypass passageway 111 is connected at its lower end by means of an inclined lateral port 141 with the bore of the housing 110 at the lower end of the housing, and at its upper end is connected by an inwardly and upwardly inclined port 114 with the bore 110 of the housing in the cap 133 above the valve structure and below the point of connection of the housing cap to the tubing string 25. Obviously, the bypass passage 111 provides for flow of well fluids from the producing formation upwardly therethrough to the tubing 25 above the valve assembly when the valve 150 is positioned in the landing nipple 112, as will be hereinafter more fully explained.

The power gas conduit 45 is connected to the cap 133 at the upper end of the housing in the same manner as in the form first described, and the variable choke or intermitter 71 is connected in the power gas conduit between the compressor 70 and the well head 24. The suction or intake conduit 67 is connected in the same manner as in the form first described to the accumulator chamber 65 in the upper portion of the annular space between the casing and the tubing below the well head 24 and above the liquid level 26 in the casing. The lateral flow line 28, regulator 29 and the surface gathering line 27 are also identical to those first described.

A double check valve structure 139 is mounted in the lower portion of the bore 110 in the check valve housing 134 of the housing assembly. The double check valve comprises a lower check valve 140 having a sealing mandrel 140*a* and a ball closure 140*b* which function to close off backflow of fluids through the extension tubing 25*a* from the housing to the producing formation. The lower check valve 140 is connected at its upper end to an upper check valve 142 having an elongate spacer mandrel 142*a* provided with longitudinal ports 142*b* formed in the wall thereof and closed by an elongate elastomeric seal sleeve 142*c* surrounding the mandrel and confined at its upper end on a seal mandrel 142*d* at the upper end of the upper check valve 142. The upper check valve 142 is disposed above the lateral port 141 in the check valve housing 134 communicating with the bypass passage 111, and prevents backflow of fluids from the bypass passage 111 inwardly through the port 141 to the pump chamber 132 in the bore 110 of the housing assembly above the upper check valve. Thus, the resilient elastomeric sleeve 142*c* closes the ports 142*b* to prevent backflow to the pump chamber 132, and the lower check valve 140 prevents backflow to the tubing extension. The elastomeric sleeve 142*c* of the upper check valve flexes to permit fluids to flow outwardly from the pump chamber through the bore of the mandrel 142*a* of the check valve, through the lateral ports 141 and upwardly through the bypass 111 and the upper ports 114 to the tubing 25 thereabove. The double check valve assembly 139 is supported by a shoulder 139*a* on the upper end of the lower check valve mandrel 140*a* which engages the upwardly facing stop shoulder 139*b* at the upper end of the tubing extension 25*a* connected to the lower end of the housing and supporting the gas anchor 35. The double check valve assembly 139 corresponds in function to the two check valves 40 and 42 of the form first described, and functions in the same manner and for the same purposes.

The control valve 150 for controlling passage of power gas from the supply line 45 to the pump chamber 132 is supported by a suitable anchoring and sealing mandrel assembly 145, which may be Otis Type N locking mechanism or mandrel such as is illustrated in the 1968–69 Composite Catalog of Oil Field Equipment and Supplies at page 3,768, though any other suitable locking or anchoring means operable by wire line tools may be utilized for positioning and anchoring the valve assembly in the landing nipple section 112. The locking mechanism 145 includes a plurality of expansible and contractable locking dogs 146 slidable on the expander mandrel 147 for expansion into a locking recess 148 formed in the upper portion of the bore 110 of the landing nipple 112 of the housing assembly. The valve body 150*a*, as best seen in FIGS. 6 and 7, is provided with external annular seal means 150*b* and 150*c* above and below the inlet and exhaust ports 152 and 153, respectively, to which the supply conduit 45 and the exhaust conduit 60 are connected, and an intermediate seal ring

150*d* is also mounted on the housing 150*a* and seals between the housing and the bore wall in the bore 110 of the landing nipple 112 between the inlet port 152 and the exhaust port 153. The inlet and exhaust ports extend upwardly in the landing nipple 112, and are connected by an inlet conduit nipple 45*a* having a back flow check valve 45*b* therein and an exhaust conduit nipple 60*a* with the cap member 133 of the housing through passages laterally offset from the bore 110 to the upper end of the housing assembly, where they are connected to the supply conduit 45 and the exhaust conduit 60, respectively. In FIGS. 4 and 5 the details of the upper portion of the housing are shown, together with the manner in which the inlet and exhaust conduits are connected. The upper portion 150*c* of the valve body 150*a* is closed so that well liquids in the tubing string 25 above the valve cannot flow back downwardly through the bore 110 of the housing landing nipple 112.

A spring loaded differential pressure operated unloading valve 115 is mounted on the upper cap member 133 in flow communication with the power gas conduit 45 and the exhaust gas tube 60, as best shown in FIG. 5. A tubular seat member 115*a* has its lower end communicating by a lateral passage 115*b* with the exhaust tube 60, and its upper end above a seat 115*c* therein communicating by a lateral passage 115*d* with the power gas conduit 45. A ball closure 115*e* engages the seat 115*c* to close off flow through the seat until liquid pressure in the exhaust tube rises sufficiently to open the valve and permit power gas from the conduit 45 to blow the liquid out of the exhaust tube. The ball closure has an elongate stem 115*f* connected thereto, and a spring 115*g* confined between an adjusting spacer washer 115*h* and a pin 115*i* surrounds the stem to bias the valve toward an open position. The upper end of the stem is slidable in a guide sleeve 115*s*, and a cap or enclosure 115*k* forms a chamber in which the valve is contained under power gas pressure. Parts 115*p* permit gas to flow past the ball closure through the seat member 115*a* where the valve is open. Liquid accumulating in the exhaust tube 60 can be blown out of it by power gas by means of this valve.

The elongate tubular pump chamber 132 is disposed in the landing nipple section 112 of the housing assembly 131, and a separator member or piston 180 is slidable longitudinally in the bore 132*a* of such chamber 132. The piston is formed with external and internal annular lip seal means engageable with the bore wall 132*a* of the chamber 132 and with the exterior surface of an elongate operator rod 181 which extends downwardly in the chamber 132 through the piston 180, as is clearly shown in FIGS. 3, 6 and 7. The valve body 150*a* is provided with an elongate compartmented chamber 151 in which an elongate valve closure member 155 is longitudinally slidable. The valve closure member and the housing 150*a* are schematically illustrated in FIGS. 3, 6 and 7 and will, of course, be formed in sections which may be suitably joined together by screw threads, welding or the like, to assemble the same into the relationship shown in these figures of the drawings.

The inlet passage 152 in the housing communicates with an inlet port 152*a* in the valve body 150*a* which is disposed between the external sealing members 150*c* and 150*d*, so that the power gas entering the inlet port 152*a* will flow into the chamber 151 through the seat 156 surrounding the inlet port 152*a* and will flow through the passage 154 downwardly into the pump chamber 132 therebelow. The valve chamber 151 also communicates at its upper end with the exhaust port 153*a*, and the valve seat 157 surrounding the inner end of the outlet port is adapted to be engaged by the closure member 155 of the valve to close off the flow of the power gas outwardly from the chamber 151 to the outlet port 153*a* and the exhaust port 153 and exhaust conduit 60*a* when the valve is in the position shown in FIG. 6. When the valve closure member 155 is in the lower position shown in FIG. 7, the closure member engages the seat 156 and closes off admission of power gas into the chamber 151 and permits exhaust of gas from the pump chamber through the outlet and exhaust ports 153*a* and 153. The functioning of the valve in this respect is the same as that of the valve of the form first described.

The gas entering the pump chamber 132 acts downwardly on the interface separator or piston 180 to move the same downwardly in the chamber 132 to displace liquid in the chamber below the piston outwardly through the lateral ports 142*b* in the upper check valve 142 and thence through the inclined lateral port 141 into the bypass passage 111, from whence the liquids are pumped upwardly through the upper lateral port 114 into the tubing string 25 thereabove.

The elongate operator rod 181 is connected with the valve closure member 155 by means of a snap action lost-motion linkage 190, whereby the valve closure member is actuated by the piston 180 for movement between the valve seats 156 and 157 to control the flow of power gas into and out of the chamber pump chamber 132. The lost motion linkage comprises an elongate stem 191 connected at its upper end to the lower end of the valve closure member 155, and having an external annular flange 192 near its lower end to which the upper end of a coil spring 193 is connected. The elongate operator rod 181 is provided with a cylindrical sleeve 195 at its upper rod 191 below the flange 192, and an external annular flange 196 formed on the lower portion of the cylindrical sleeve is connected to the lower end of the helical coil spring 193, whereby the rod 191 and the operator rod 181 are resiliently coupled together by means of said spring. The end coils of the spring are disposed in helical grooves formed in the external cylindrical surfaces of the flanges 192 and 196. In addition, a cross pin 194 is disposed in a transverse opening formed in the lower end of the rod 191 and extends outwardly on each side of the rod into elongate longitudinal slots 197 formed in the cylindrical sleeve 195 to provide a positive operating connection between the operator rod 181 and the valve rod 191 connected to the valve closure 155. The engagement of the rod in the slots also prevents rotative movement about their longitudinal axis between the elongate rod 181 and the valve rod 191, so that the spring 193 remains connected to the flanges on such rods and thus prevents disengagement of the spring ends from the flanges 192 and 196.

A detent mechanism 200 is connected to the upper end of the valve body closure 155 by means of an elongate stem 201 which extends upwardly from the closure member to an enlarged head portion 202 slidably disposed in an elongate bore 203 formed in the upper portion 150*c* of the valve body 150*a*. A pair of longitudinally spaced upper and lower annular detent grooves 204 and 205; respectively, are formed on the exterior of the head 202 and are adapted to be engaged by the inwardly projecting noses of detent plungers 206 mounted in substantially radially extending apertures 208 formed in the body 150*a*. The detent plungers are biased inwardly to engage the detent head 202 by springs 209 disposed between the heads of the plungers and retaining screw 210 threaded into the outer portion of each of the radial bores. The screws 210 have a sealing engagement with the body to prevent fluid leakage outwardly or inwardly therepast. An O-ring or other seal member 211 is disposed in an internal annular groove 212 formed in the wall of the lower reduced portion of the bore 203 in the valve body and seals between the body and the head 202 at the lower portion of the head to provide means for equalizing the fluid pressure areas of the valve closure member and the detent head 202, so that fluid pressure may be introduced into the chamber bore 203 above the detent head to offset pressure in the valve chamber 151 acting on the lower portion of the head. An elongate bypass passage 213 is formed axially of the head, the stem 201 and the valve closure member 155, extending to a point below the seat 156*a* on the closure member 155 which engages the inlet seat 156 in the valve chamber, whereby power gas may be therethrough to the chamber bore 203. A lateral or transverse opening 214 is formed transversely of the valve closure member below the seat 156*a* and communicates with the elongate axial bypass passage 213 and the valve chambers 151. The transverse opening 214 and the elongate bypass passage 213 provide means for conducting power gas from the port 152*a* in the body 150*a* below the seat 156, when the closure member of the valve is in the closed position, as shown in FIG. 7, whereby fluid pressure from the inlet port acts on the upper end of the detent head 202 within the bore 203 to offset the effect of the power gas pressure acting on the valve closure member below the inlet port seat 156, so that the valve will remain in the closed position with a minimum of restraining force applied thereto. The detent plungers 206 engaged in the annular detent grooves in the detent head 202 provide a restraining means for restraining the valve closure member in the two positions shown in FIGS. 6 inner 7. When the detent plungers are engaged in the upper groove 204, as shown in FIG. 7, the valve closure member 155 engages the inlet seat 156 to close the inlet port 152*a*. When the detent plungers are engaged in the lower detent groove 205, as shown in FIG. 6, the valve closure member 155 engages the exhaust seat 157 and closes the exhaust port 153*a* to prevent the escape of gas through the exhaust passage and conduit.

It is believed obvious that, when the operating rod 181 is moved downwardly with respect to the valve 191, until the transverse pin 194 engages the upper end of the slots 197, the spring will be stretched or extended, and further downward movement of the operator rod 181 by the piston 180 will then move the valve closure 155 downwardly away from the outlet or exhaust port seat 157 against the restraining force of the detent plungers 206 engaged in the lower detent groove 205, and when the restraining force of the detent plungers engaged in the grooves is overcome the valve will move quickly, or snap, from the position shown in FIG. 6 to the position shown in FIG. 7, due to the force of the spring 193 acting to contract and draw the valve rod 191 downwardly. This snap action prevents the valve closure member 155 from stopping intermediate its engagement with the seats 156 and 157 and provides for a positive complete opening and closing of the inlet and exhaust ports, respectively. The spring and the lost motion connection provide such snap action movement of the valve closure member as the detents are released.

In the operation of the device, liquid is permitted to enter through the check valve assembly 139 into the pump chamber 132 below the piston or interface separator 180 and fill said chamber, moving the piston or interface separator upwardly in the chamber until the upper surface of the piston engages the under side of the flange 196 on the upper end of the operator rod 181 to move the rod upwardly so that the sleeve 195 moves upwardly with respect to the valve rod 191 until the lower ends of the slots 197 engage the transverse pin 194 and move the pin and the valve rod 191 upwardly to quickly move the valve closure member 155 off the seat 156 and into engagement with the upper outlet seat 157 at the exhaust port 153*a*. The detent plungers 206 are moved out of the upper detent grooves 204 and into the lower detent grooves 205 by such action. The spring 193 causes a quick snap-action movement of the valve closure without affecting the movement of the operator rod 181. The spring 193 biases the valve rod 191 and the valve closure member quickly upwardly from the lower to the upper position during such actuation.

With the valve closure member 155 closing the exhaust port, power gas enters through the inlet port 152 and the passage 152*a* in the body 150*a* and enters the valve chamber 151 below the outlet seat 157 and above the O-ring seal 191*a* around the valve rod 191, and then passes downwardly from the valve chamber through the passage 154 into the chamber 132 above the interface separator or piston 180 to force the piston downwardly in the chamber and displace the liquid therebelow outwardly through the elongate slots 142*b* in the upper check valve past the elastomeric sleeve 142*c* and through the upwardly inclined lateral port 141 into the bypass passage 111, from which the liquids are forced upwardly through the upwardly and inwardly inclined lateral port 114 into the bore of the tubing 25 above the pump and then to the surface.

When the liquid has been displaced from the chamber 132, the piston 180 will again engage the flange 181*a* at the lower end of the rod 181 and move the rod downwardly to again move the valve closure member 155 downwardly to a position closing the inlet port and opening the exhaust port. When the valve is in this lower position, liquid from the well may enter the pump chamber to repeat the operation cycle just described.

The undercut surfaces of the flanges 196 and 181*a* are engaged by corresponding beveled lip sealing surfaces on the piston 180 to provide a seal between the piston and the rod at that point. The flexible annular lips on the upper and lower faces of the piston or interface separator member provide a flexible seal between the separator member and the bore wall 132*a* of the pump chamber 132. While a seal or piston is not required to effect movement of displacement of the liquid from within the chamber 132, the provision of the piston or interface separator 180 provides for separation of the power gas and liquid and an accurate and positive actuating means for the valve 150, and likewise prevents aeration of the liquid and loss of operating or power gas during actuation of the pump.

A modified form of the pump installation is illustrated in FIG. 8, wherein a lower check valve 240 in the form of a packer having a ball check is mounted in the well casing 20 below the anchor 35 at the lower end of the tubing string. The annular space in the casing above the packer and check valve 240 and below an intermediate packer 239 sealing between the tubing and the casing defines a pump chamber 232 into which the liquids are directed for accumulation and from which they are exhausted by admission of gas from the valve 250. An upper check valve 241 is provided in the bore of the tubing above the lateral openings 37 in the gas anchor 35 to prevent back flow of fluids from the tubing through the ports 37 into the pump chamber 232 so that the liquid displaced from the pump chamber by the power gas controlled by the valve 250 will be pumped upwardly through the tubing 225 past the upper check valve 241 to lateral ports 266 formed in the wall of the tubing string 225 above the check valve and above the intermediate packer 239. The liquids displaced from the pump chamber flow outwardly through the ports 266 into the annular space between the tubing string 225 and the casing above the intermediate packer 239 and below an upper packer 268 sealing between the upper portion of the tubing string 225 and the casing 20 and defining an upper liquid collection chamber 267. A gas lift valve 270 is connected in the usual manner to the tubing string 225 above the lateral ports 266 and is operated by gas from the annular accumulator chamber 265 above the upper packer 268 in which the power gas discharged through the discharge conduit or exhaust conduit 260 from the pump 230 accumulates, and such gas will flow downwardly through a gas lift conduit 271 to the gas lift valve 270 to pass through the gas lift valve and aerate the column of liquid contained in the tubing 225 above the upper check valve 241 to assist in lifting the liquid from the well through such tubing string.

This installation is adapted for use in deep wells wherein the liquid level is low and a long vertical lift of such liquids is required. The gas admitted into the pump may be controlled by an adjustable choke or by means of an intermitter and motor valve 71 in the manner already described. Other details and operation of the pump are the same as the form first described. The liquid pumped upwardly in the tubing is aerated by means of the gas lift valve 270 to facilitate the production of the liquid to the well surface from great depths with a single pump.

It is obvious that more than one gas lift valve may be utilized in the tubing string 225 above the packer 239 and the pump 230, and that a check valve may be provided between each pair of adjacent gas lift valves, if desired, to assure lifting of the liquid with a minimum amount of gas.

While the gas lift valves have been used in conjunction with a single pump in the installation illustrated in FIG. 8, a tandem pump installation is illustrated in FIG. 9 for lifting liquids from great depths in a low fluid level well. In this system, a first pump 330*a* is connected in the tubing string 325 for elevating liquids from the producing formations 321 upwardly in the tubing string past an upper check valve 342*a* into the pump chamber of an upper pump 330*b*, from which the liquids are displaced by gas power gas past a second check valve 342*b* into the tubing string 325 thereabove, from which they are discharged at the surface. In this form of the device, the lower pump 330*a* is operated until the pump chamber of the upper pump 330*b* is filled with liquid, whereupon the upper pump is operated to discharge the liquids from the pump chamber of the upper pump past the upper most check valve 342*b*. When the pump chamber of the upper pump 330*b* is emptied, or the liquid displaced therefrom, liquid from the lower pump may then enter the chamber of the upper pump to repeat the cycle.

The lower pump 330*a* will stop operation during operation of the upper pump, and the upper pump will not operate until the pump chamber therein has been filled with liquid sufficiently to cause actuation of the control valve controlling admission of power gas into the pump chamber to displace the liquid therefrom. It will be seen that the pumps will actually function in the same manner as the forms first described, but that the pump chamber of the upper pump will be filled directly from the lower pump rather than from the producing zone or the casing communicating therewith. Power gas from each of the pumps discharges through an elongate common exhaust conduit 360 into the accumulator space 365 at the upper end of the annular space between the casing 20 and the tubing 325, and the gas pressure in the accumulator chamber is regulated or maintained at the desired superatmospheric value by the regulator 29. The superatmospheric gas from the accumulator chamber is drawn through the suction line 67 to the compressor 70 and is compressed therein, and then passes through the variable choke or intermitter and motor valve 71 to the supply line 45 for conduction by means of a common elongate power gas supply conduit 345 to the pumps for actuating the same.

The details of construction of the two pumps are the same as those first described, and other than the lower pump 330*a* discharging directly into the pump chamber of the upper pump 330*b*, and the use of a common supply line of power gas 345 and a common discharge line 360, the pumps function in the same manner as those first described.

In FIG. 10 a slight modification of the installation using tandem pumps is illustrated. In this well installation, a packer 410 is installed to seal between the tubing 425 and the casing 20 in the annular space between the lower pump 430*a* and the upper pump 430*b*. The gas anchor 35*a* is provided on the lower end of the tubing extension 425*a* below the lower pump 430*a*, and the liquids from the lower pump 430*a* are discharged through a lateral port 466 formed in the wall of the tubing string 425*b* above the packer 410 between the lower pump 430*a* and the upper pump 430*b* into the annular space above the packer 410 where such fluids will accumulate until lifted by the upper pump 430*b*. The liquids discharged through the lateral port 466 into the casing annulus chamber above the packer 410 will then be lifted by the upper pump 430*b* in the same manner as the individual pump first described functions. The pumps 430*a* and 430*b* will function independently of each other, the lower pump 430*a* continuing to pump the well liquid from the producing formation into the casing annulus above the packer 410, while the upper pump 430*b* independently pumps the well liquids from the casing annulus above the packer 410 upwardly and out through the tubing string 425. The discharge conduit 460 from the lower pump 430*a* is provided with a lateral opening 460*a* below the packer 410 which permits gas discharged from the lower pump to accumulate in the annular space above the liquid level 426*a* in the casing below the packer 410, and at the same time such gas is permitted to flow upwardly through the common discharge conduit 460 to pass the upper pump 430*b* into the upper casing annulus accumulator 465*b* above the upper liquid level 426*b*. The pressure in the lower accumulator 465*a* will be substantially the same as that in the upper accumulator 465*b*, differing only by the hydrostatic head of the column of gas. The power gas will be pumped downwardly through the common power conduit 445 to the two pumps for actuating the same in the manner already described.

Should the lower pump deliver a sufficient column of liquid into the annular casing annulus above the packer 410 to create a hydrostatic head acting through the lateral port 466 and the tubing string 425*b* on the lower pump 430*a* to create a pressure head sufficient to prevent the lower pump 430*a* from lifting the liquids from the producing formation into the annular casing space above the packer 410, the lower pump will cease to operate until the upper pump 430*b* has operated independently sufficiently to lift the liquids from the casing chamber annulus above the packer 410 upwardly through the tubing string 425 to a sufficient degree to lower the hydrostatic head pressure acting on the check valve downstream of the lower pump 430*a* to a value low enough to permit the pump to again function. The pumps of this installation function independently of each other and, acting in tandem, provide for lifting the liquid through a substantial distance vertically from deep wells where the liquid levels are low.

The pump of the invention may also be used in well installations in which a plurality of producing zones are traversed by the well bore and the casing is perforated at each producing zone. Such an installation is shown in FIG. 11, wherein the pump 530 is connected in a first tubing string 525, extending to the lower producing formation, a tubing extension 525*a* extends downwardly through a packer 510 which seals between the tubing extension and the casing 520 in the annular space between the lower and upper producing zones 521*a* and 521*b*, respectively. A gas anchor 535*a* is provided on the lower end of the tubing extension 525*a* and admits well liquids into the bore of the extension tubing through the usual lateral ports 537*a* formed in the tubing extension. A vent tube 515 extends from the accumulator chamber 565*a* at the upper end of the annular space below the packer 510 and upwardly to the upper accumulator space 565*b* at the upper end of the casing below the casing head 524. A check valve 516 is disposed in the vent tube below the packer 510 to prevent backflow of any liquids or gases from the upper accumulator chamber 565*b* to the lower accumulator chamber 565*a*. The pump 530 is operated by power gas transmitted to the pump through a power gas conduit 545 and discharged from the pump through a discharge or vent conduit 560 and check valve 561 to the accumulator space 565*b* in the same manner as the pump of the forms first described. Liquid is therefore pumped upwardly from the lower formation 521*a* through the tubing string 525 to the well surface.

A second tubing string 525*c* is suspended in the casing 520 parallel to the tubing string 525 and provided with a gas anchor 535*b* at its lower end with lateral inlets 537*b* in the tubing within the anchor for admitting liquid from the upper producing formation 521*b* into the bore of the tubing. A gas lift valve 570 is connected to the tubing string 525*c*, and a gas conduit tube 571 extends from the accumulator space 565*b* downwardly to the gas lift valve for conducting gas from the accumulator space to the gas lift valve for operating the gas lift valve to aerate and lift the liquid from the upper producing formation upwardly through the tubing string 525*c* to the well surface. The pump 530 functions in exactly the same manner as the form first described. However, the upper zone in in the installation just described is lifted by gas lift by means of gas from the accumulator chamber 565*b*.

Gas from the upper producing formation accumulates in the upper accumulator chamber 565*b*, as does the gas from the lower formation through the tube 515, and the regulator 529 in the lateral flow line 528 maintains a predetermined superatmospheric pressure in the accumulator chamber 565*b*. The compressor 70 and the variable choke or intermitter controlled motor valve 71 would control the supply of power gas to the pump through the supply conduit 45 in the manner already described. Of course, should the gas pressure in the accumulator chamber 565*b* not be sufficiently high to aerate the column of liquid in the tubing string 525*c*, a compressor 570*a* may be provided in the lateral flow line 528*a* for compressing gas from the surface gathering line 527 and introducing such gas into the accumulator chamber 565*b* to supply lift gas to the gas lift valve 570, and to the compressor 570 for operating the pump 530.

It appears readily apparent that, in accordance with good gas lift practices, the location of the gas lift valve 570 on the tubing string 525c may be a depth in the well which would permit proper operation thereof by the gas from the discharge line of the pump conduit of the pump, and that such elevation or depth in the well may be above or below the pump 530, as such conditions dictate. It is also believed apparent that, if desired, a plurality of gas lift valves may be connected in the tubing string 525c for operation by the gas discharged into the accumulator zone or chamber 565b from the discharge conduit 561 from the gas-operated pump 530.

Suitable valves may be connected in the lateral flow lines 528 and 528a for controlling the direction of flow through the compressor 570a and the regulator 529 connected in said lateral flow line. It is also believed readily apparent that a pressure switch 570c may be connected to the compressor and a conduit 528c, shown in dotted lines, be directed to the pressure switch from the lateral flow line 528 for controlling actuation of the compressor 570a to provide for automatic control of the compressor, and the automatic provision of power gas in the accumulator chamber 565b at all times. Thus, the compressor will be actuated to maintain a sufficient supply of gas to the accumulator chamber 565b automatically, should the gas lift valve 570 utilize a greater volume of gas from the chamber than is discharged thereinto from the pump 530 and the well formation alone. Similarly, the regulator 529 acts to release any excess pressure accumulated in the accumulator chamber 565b from the producing formations or from the discharge conduit of the pump or both.

It is also possible to connect the discharge conduit 560 of the pump 530 by means of a gas conduit 572, shown in dotted lines in FIG. 11, with the gas inlet of the gas lift valve 570 whereby the discharge gas from the pump 530 is conducted directly to the gas lift valve for operating the same to aerate the column of liquid in the tubing string 525c for lifting the same to the surface. In this case, the gas discharged from the pump would not be conducted to the accumulator chamber from the pump. However, the discharge conduit 572 from the pump connected to the gas lift valve must be of sufficient length to maintain a desired predetermined gas pressure head on the control valve of the pump to assure proper operation of the pump, and a check valve may be provided in the line 572 to prevent back flow of fluids from the gas lift valve to the pump through the line, if desired.

In FIG. 12, a modified form of the well installation is illustrated wherein a multiple zone well produces predominantly oil from a lower zone 621a and predominantly gas from an upper producing formation 621b. A packer 605 is installed in the well to seal between the tubing extension 625a and the casing 620 to separate the two zones. A dual string packer 606 is installed in the well above the upper producing formation 621b for sealing between the casing and the tubing extension 625a and the second tubing string or power gas supply tubing string 625c. A sliding side door valve 615 is shown connected in the second tubing string 625c above the dual string packer 606, but may be located at any desired elevation in said second tubing string. The sliding side door valve may be of the type illustrated in the 1968–69 Composite Catalog of Oil Field Equipment and Services, at page 3,775, with the lateral port thereof connected to the power gas supply line 645 to the pump 630. In this installation, the oil or other liquids from the lower producing formation 621a are conducted upwardly through the tubing extension 625a and outwardly through a lateral port 625b into the annular space between the tubing extension 625a and the casing 620 above the dual string packer 606. The pump 630 then picks up the liquids from the annular space through the port 625b and lifts the same upwardly through the tubing string 625 to the surface. The power gas is supplied to the pump from the upper formation 621b through the second tubing string 625c and will pass outwardly through the lateral ports of the sliding side door valve 615 to the power gas supply conduit 645 connected to the pump. A regulator 629 is provided in the lateral flow line 628 connected to the surface gathering line 627 in the manner already described. Since the gas pressure in the upper formation in this well is at a substantially elevated pressure, a regulator or choke 619 in the second tubing string 625c at the surface may be utilized to maintain a proper operating pressure in the second or power gas tubing string for actuating the pump. It is, therefore, readily apparent that the pump may be utilized in wells in which a high-pressure gas formation is present to supply the power gas for operating the pump 630 for lifting the liquids from a lower pressure primarily liquid producing formation.

Obviously, of course, the liquid producing formation may be at a higher elevation than the gas producing formation, in which case the longer tubing extension 625a with the sliding side door valve 615 therein would be connected to the gas producing formation and the second tubing string 625c with the pump 630 therein would be connected to the liquid producing formation for operation as already described.

A still further modification of well installation, in which the pump of this invention is utilized for pιoducing liquids from the well, is illustrated in FIG. 13 wherein a triple zone well is shown as traversed by the well casing 720 and perforations are provided in the casing communicating with each of the producing formations. As shown in this figure, a predominantly oil or liquid producing formation 721b producing through perforations 722b is located in the intermediate zone, while a formation predominantly producing gas at a higher pressure through perforations 722a, similarly to that of the form of FIG. 12, is shown in the lower producing formation 721a. The upper producing formation 721c may be producing predominantly liquid through perforations 722c, and each of the formations is separated from the other by a packer. The gas-operated pump 730 of the invention is connected in a tubing string 725 and the tubing extension 725a extends downwardly through a triple string packer 705c sealing between the tubing string 725, a second gas-producing string 725c and a third liquid-producing tubing string 725d. The tubing extension 725a and the tubing string 725c also extend downwardly through a dual string packer 705b between said tubing strings and the casing 720 at a point between the upper and intermediate producing formations 721c and 721b, respectively. The gas-producing tubing string 725c also extends downwardly through a lower single string packer 705a which seals between said tubing string and the casing at a point between the intermediate producing formation 721b and the lower producing formation 721a. A gas anchor 735a with inlet openings 737a is provided on the lower end of the gas-producing string 725c and gas from the lower zone is conducted upwardly through the tubing string 725c to the surface through a surface choke or variable flow control device 719 which maintains a suitable back pressure in the power gas tubing string for actuating the pump 730 in the manner described in connection with the form illustrated in FIG. 12. The sliding side door valve 715 has its lateral port 715a connected with the power gas supply conduit 745 leading to the pump 730 connected in the tubing string 725. The sliding sleeve member 715b of the side door valve is slidable in the valve to open and close the side port 715a to control the admission of power gas to the pump 730 for actuating the same. The exhaust or vent conduit 760 from the pump opens through the check valve 761 into the accumulator chamber 755 in the annular space between the tubing strings and the casing 720 below the well head 724 in the manner already described, and the pump is actuated by the power gas from the lower zone to lift liquids from the intermediate zone which flow through the openings 737b into the extension 725a upwardly through said tubing extension and outwardly through lateral ports 766 to the casing annulus above the upper packer 705c, and then are pumped upwardly from such casing annulus through the tubing string 725 to the surface by means of the pump 730. As shown in te drawings, a lateral port or gas lift valve 770 may be provided in the tubing string 725d for aerating the liquids in said tubing string for lifting the liquids from the upper formation to the surface. Of course, if desired, a gas lift valve similar to the valve **570** shown in FIG. **11** may be provided in the tubing string instead of the port **770** for aerating the liquid therein to lift the same. Gas from the chamber **765** would be utilized for operating the gas lift valve for aerating the liquid in the tubing. Also, if desired, as shown in dotted lines, a discharge conduit **772** from the pump **730** may be connected directly to the gas lift valve in the tubing string **725***e* or to the port **770** for discharge into said tubing string of gas from the pump **730** for aerating the column of liquid therein to lift the same from the upper producing formation. If a gas lift valve is connected in the tubing string **725***d*, similarly to the gas lift valve **570** in FIG. **11**, the elevation or depth of the gas lift valve in the tubing string **725***d* may be selected in accordance with good gas lift operating practices as set forth in connection with the installation of FIG. **11**. The regulator **29** in the lateral flow line **28** between the casing and the surface gathering line **27** maintains proper back pressure or elevated or superatmospheric pressure in the accumulator **765** to provide for proper operation of the device. If desired, a pump or compressor and regulator similar to that illustrated in FIG. **11** may be connected with the accumulator chamber **765** to maintain the pressure in said chamber at the desired superatmospheric level.

A further modified well installation utilizing the pump of the invention is illustrated in FIG. **14**, wherein a single zone well is shown in which the well produces liquids into the casing **820** at an extremely high rate. In such a well, the pump **830** may be located sufficiently deep in the well to function to lift liquids through the tubing string **825** to the surface, while the discharge conduit **860** from the pump may be terminated at the check valve **861** at an elevation or depth in the well determined by good gas lift practices to be proper to permit the exhaust gas from the pump to aerate the column of liquid in the tubing casing annulus above the gas anchor **835** and inlet ports **837** to lift the liquids from the tubing casing annulus through such annular passage to a lateral flow line **828** connected to the upper end of the casing below the well head **824**. The back flow check valve **861** is provided on the open upper end of the discharge conduit **860** from the pump to prevent back flow of liquids into the pump and to eliminate a fluid back pressure head from acting on the pump to prevent actuation thereof. The power gas is supplied through the power gas conduit **845** from a source of gas pressure or compressor **870** connected therewith at the well surface and drawing gas or air from a suitable source of supply, which may be another well producing gas or from the atmosphere.

The length of the discharge conduit **860** will be such that a sufficient gas pressure head is maintained on the control valve of the pump to assure proper operation of the pump. Similarly, the open end outlet and check valve on the discharge conduit will be located at the desired depth in the column of liquid in the annular space to permit proper gas lift operation for lifting the liquids in the annulus to the surface.

From the foregoing, it will be seen that an improved gas-operated pump has been provided for lifting liquids from wells with a maximum efficiency and minimum use of power gas. Also, the pump is adapted for tandem or multiple installations to pump from great depths, and is likewise adapted for use in multiple zone wells for producing more than one zone from a well. The provision of the accumulator chamber for collecting the discharged gas from the pump at a superatmospheric pressure permits recompressing the gas for reuse as a power gas with a minimum use of power and with great economy.

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

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

1. A well system for lifting liquids from a well, comprising: a well bore penetrating a producing earth formation; well casing disposed in said well bore and communicating with said producing earth formation; eduction tubing disposed in said well casing and communicating at the lower end thereof with the bore of said well casing; chamber means connected in flow communication to said eduction tubing for accumulating well liquids therein; valve means having a flow passage connected to said chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said valve means having means operable for selectively alternately connecting said part means in flow communication with said flow passage; valve-actuating means associated with said valve means and responsive to fluid pressure for actuating said valve means to alternately communicate said chamber means with said source of power gas pressure and with said region of lower pressure to sequentially fill said chamber means with and empty said chamber means of well liquids, whereby well liquids accumulated in such chamber means will be displaced by gas pressure into the eduction tubing connected thereto; and backflow control means preventing backflow of liquids from said eduction tubing to said chamber means and from said chamber means to said producing formation, whereby the well liquids emptied from said chamber means to said eduction tubing are displaced to the surface.

2. A well system for lifting liquids from a well, comprising: a well bore penetrating a producing earth formation; well casing disposed in said well bore and communicating with said producing earth formation; eduction tubing disposed in said well casing and communicating at the lower end thereof with the bore of said well casing; chamber means connected in flow communication to said eduction tubing for accumulating well liquids therein; valve means having a flow passage connected to said chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said valve means having means operable for selectively alternately connecting said port means in flow communication with said flow passage; valve-actuating means associated with said valve means and responsive to fluid pressure for actuating said valve means to alternately communicate said chamber means with said source of power gas pressure and with said region of lower pressure to sequentially fill said chamber means with and empty said chamber means of well liquids, whereby well liquids accumulated in such chamber means will be displaced by gas pressure into the eduction tubing connected thereto; and backflow control means preventing backflow of liquids from said eduction tubing to said chamber means and from said chamber means to said producing formation, whereby the well liquids emptied from said chamber means to said eduction tubing are displaced to the surface; said valve means, said valve-actuating means, and said backflow control means being removable through said eduction tubing.

3. A well system for lifting liquid from a well, comprising: a well bore penetrating a producing earth formation; well casing disposed in said well bore and communicating with said producing earth formation; eduction tubing disposed in said well casing and communicating at the lower end thereof with the bore of said well casing; chamber means connected in flow communication to said eduction tubing for accumulating well liquids therein; valve means having a flow passage connected to said chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with an accumulator region of superatmospheric lower pressure, said accumulator region comprising the annular space between said eduction tubing and said well casing above the upper level of the liquid therein, said valve means having means operable for selectively alternately connecting said port means in flow communication with said flow passage; valve-actuating means associated with said valve means and responsive to fluid pressure for actuating said valve means and responsive to fluid pressure for actuating said valve means to alternately communicate said chamber means with said source of power gas pressure and with said accumulator

region of lower pressure to sequentially fill said chamber means with and empty said chamber means of well liquids, whereby well liquids accumulated in such chamber means will be displaced by gas pressure into the eduction tubing connected thereto; backflow control means preventing backflow of liquids from said eduction tubing to said chamber means and from said chamber means to said producing formation, whereby the well liquids emptied from said chamber means to said eduction tubing are displaced to the surface; and means for repressuring the gas collected in said accumulator region for reintroduction through said valve means into said chamber means.

4. Apparatus for lifting liquids in a well having a well casing penetrating a producing earth formation and having a lower portion thereof communicating therewith and a tubing string disposed in said well, said apparatus including: pump chamber means for accumulating well liquids therein, said pump chamber means having means for connecting it to said tubing string; means for communicating a source of power gas with said pump chamber means; exhaust means from said pump chamber means communicating with a second chamber for collecting therein power gas discharged from said pump chamber means at super atmospheric lower pressure; valve means having port means connected to said pump chamber means and having other port means connected to said means communicating said source of power gas to said pump chamber means and having further port means connected to said exhaust means from said pump chamber means; valve-actuating means in said pump chamber means associated with said valve means exposed to and separating the liquid and the power gas in said pump chamber and responsive to power gas in said pump chamber means and to the movement of liquids in said pump chamber means to actuate said valve means to alternately communicate said source of power gas with said pump chamber means and to exhaust said power gas from said pump chamber means through said exhaust means, whereby said pump chamber means is sequentially filled with and emptied of well liquids, said liquids being displaced from said pump chamber means upwardly through said tubing by said power gas, said actuating means separating and closing off power gas from liquid in said pump chamber means for preventing power gas from escaping therepast form said pump chamber means to said tubing.

5. Apparatus for lifting liquids in a well having a well casing penetrating a producing earth formation and having a lower portion thereof communicating therewith and a tubing string disposed in said well, said apparatus including: pump chamber means for accumulating well liquids therein, said pump chamber means having means for connecting it to said tubing string; means for communicating a source of power gas with said pump chamber means; exhaust means from said pump chamber means; valve means having port means connected to said pump chamber means and having other port means connected to said means communicating said source of power gas to said pump chamber means and having further port means connected to said exhaust means from said pump chamber means; valve-actuating means in said pump chamber means associated with said valve means and responsive to power gas in said pump chamber means and to the movement of liquids in said pump chamber means to actuate said valve means to alternately communicate said source of power gas with said pump chamber means and to exhaust said power gas from said pump chamber means through said exhaust means, whereby said pump chamber means is sequentially filled with and emptied of well liquids, said liquids being displaced from said pump chamber means upwardly through said tubing by said power gas, said actuating means closing off power gas from liquid in said pump chamber means for preventing power gas from escaping therepast from said pump chamber means to said tubing; said exhaust means including a second chamber for collecting therein power gas discharged from said pump chamber means at superatmospheric lower pressure.

6. The apparatus of claim 5, wherein said second chamber is the tubing-casing annulus of the well below the well head and above the liquid level in said casing.

7. The apparatus of claim 4, wherein said exhaust means includes an exhaust tube connected with said pump chamber means and extending upwardly therefrom in the tubing-casing annulus to an outlet at a location therein above the liquid level in said annulus.

8. The apparatus of claim 4, wherein said source of gas pressure includes: a compressor having suction means connected to the upper portion of said tubing-casing annulus and discharge conduit means for compressed gas connected to said means communicating said source of power gas with said pump chamber means through said valve means.

9. The apparatus of claim 6, wherein said exhaust means includes: vent means connected to said tubing-casing annulus, and back pressure valve means connected in said vent means for maintaining the gas in said annulus at a predetermined superatmospheric pressure.

10. The apparatus of claim 9, wherein said back pressure valve means is adjustable to maintain the pressure in the well bore opposite the producing formation at a predetermined value to regulate the productivity of the well.

11. The apparatus of claim 4, including check valve means connected with said exhaust means from said pump chamber means to prevent backflow of liquids into or from said pump chamber means.

12. The apparatus of claim 8, wherein said compressor discharge conduit means includes a check valve to exclude well liquids from said conduit.

13. The apparatus of claim 5, wherein the second chamber means includes a relief conduit connected to said second chamber; and a back pressure valve in said relief conduit for releasing excess gas from said chamber automatically.

14. The apparatus of claim 4, including: first check valve means operatively connected with said pump chamber means upstream thereof to prevent backflow of well fluids from said pump chamber means to said producing formation; and second check valve means operatively connected with said pump chamber means downstream thereof to prevent backflow of well fluids form said tubing string into said pump chamber means.

15. The apparatus of claim 4, wherein said valve means includes: a three-way valve having a housing with a closure member shiftable therein between a first position wherein said exhaust port means communicates with said pump chamber means while said port means communicating with said source of power gas is closed off, and a second position wherein said pump chamber means communicates with said port means communicating with said source of power gas while said exhaust port means is closed; and said valve-actuating means comprises: an elongate operator rod attached to said valve closure member and axially disposed in said pump chamber means; a plunger disposed in said pump chamber means and slidable longitudinally with respect to said valve operator rod; and limit stop means on said operator rod engageable by said plunger whereby filling of the chamber with well liquids moves said plunger in said pump chamber means to engaged said stop means and move said operator rod to shift said valve closure member to said first position to cause emptying of said pump chamber means and moves said plunger to shift the valve operator rod to shift said valve closure member to said second position to cause refilling of the chamber automatically.

16. The apparatus of claim 4, wherein said exhaust means vents gas from said pump chamber means into the column of well liquids in the tubing-casing annulus to aid in lifting said well liquids to the surface through said tubing-casing annulus.

17. A pump for lifting liquids from a well bore penetrating a producing earth formation and having well casing disposed therein and communicating with said formation and eduction tubing disposed in said casing and communicating at its lower end thereof with the bore of said casing, said pump including: an elongate housing connected in flow communication to said

eduction tubing and with said casing below the working liquid level therein and having a pump chamber therein for accumulating well liquids therein; valve means having a flow passage connected to said pump chamber and having inlet port means communicating with a source of power gas and outlet port means communicating with an accumulator chamber in the annular space between the tubing and casing above the upper level of the liquid therein, said valve means having means operable for selectively alternately connecting said inlet port means and said outlet port means in flow communication with said flow passage of said valve means; valve-actuating means in said housing coacting with said valve means and responsive to fluid pressure in said pump chamber for actuating said valve means to alternately communicate said pump chamber with said source of power gas and with said accumulator chamber in said annular space to sequentially fill said pump chamber with and empty said pump chamber of well liquids, whereby well liquids accumulated in such pump chamber are displaced by power gas into the eduction tubing connected thereto and power gas is exhausted from said pump chamber to said accumulator chamber; backflow control means preventing backflow of liquids from said eduction tubing to said pump chamber and from said pump chamber to said producing formation, whereby the well liquids emptied from said pump chamber to said eduction tubing are displaced to the surface; pressure regulator means connected with said accumulator chamber in said annular space in said well casing for maintaining a predetermined superatmospheric lower pressure on the exhausted power gas in said accumulator chamber; and means for repressuring the power gas collected in said accumulator chamber for delivery to said source of power gas for reintroduction through said valve means into said pump chamber.

18. The pump of claim 17, wherein said backflow control means comprises: check valve means in said eduction tubing upstream from said pump chamber for preventing backflow of fluid from said pump chamber to said producing formation; and check valve means in said eduction tubing downstream from said pump chamber for preventing backflow of fluids from said eduction tubing to said pump chamber.

19. The pump of claim 17 wherein said pressure regulator means includes: a relief conduit having one end connected in flow communication with the accumulator chamber in said annular space and having its other end connected in flow communication with a disposal pipeline; and back-pressure-regulating valve means in said relief line openable when the pressure in the accumulator chamber in the annular space exceeds a predetermined set valve, whereby excess gas accumulated in said accumulator 17, will escape through said relief conduit and the pressure in said accumulator chamber will be regulated to a predetermined value.

20. The pump of claim 17, including: exhaust tube means having one end connected to the outlet port means of said valve means, said exhaust tube means extending upwardly in the annular space from said valve means and having its upper end located at an elevation above the upper level of the liquid in the annular space, whereby the hydrostatic head of the liquid above the pump means in the annulus will not be exerted in the chamber means when the chamber means is in direct communication with said outlet port means of said valve means.

21. The pump of claim 20, wherein said exhaust tube is provided at its upper end with check valve means for preventing the flow of fluids from the annular space into the exhaust tube.

22. The pump of claim 17, including: passage means communicating said inlet and outlet port means of said valve means; and pressure-responsive valve means in said passage means between said inlet and outlet port means of said valve means openable in response to fluid pressure to permit flow of power gas from said inlet port means through said outlet port means and through said exhaust tube into the annular space between the tubing and the casing to expel any liquid in said exhaust tube.

23. The pump of claim 17, wherein said valve means comprises a valve body having a closure member movable longitudinally therein from a first position wherein it communicates said valve inlet port means with said valve flow passage connected to said pump chamber means and a second position wherein it communicates said flow passage with said outlet port means; and wherein said valve actuator means includes means in said pump chamber movable in response to the movement of fluids in said chamber, and comprising interface separator means between the liquid and the gas therein, and means cooperable with said separator means for actuating said valve closure member in response to the movement of said separator means by the fluid pressure in said pump chamber to admit power gas to said pump chamber to displace liquid therefrom and to exhaust power gas from said pump chamber to admit liquid thereto.

24. The pump of claim 23, wherein said interface separator means in said pump chamber is provided with a central opening and said means cooperable with separator means for actuating said valve closure member includes an elongate central member slidably disposed in the central opening of said interface separator means and having one end thereof operatively connected to said valve closure means, said elongate central member having spaced limit stops thereon engageable by said separator means for limiting the relative longitudinal movement between said elongate central means and said separator means, whereby movement of said interface separator means in said chamber in response to the pressure of fluids therein causes said separator means to engage said stop means of said elongate central member to move said valve closure member between said first and second positions to cause said pump chamber to be alternately filled with and emptied of well liquids, said well liquids being displaced through said eduction tubing to the surface.

25. The pump of claim 23, including: detent means connected with said valve closure member for restraining said closure member in said first and said second operating positions, for producing snap-action movement of said valve closure member from one to the other of said operating positions.

26. The pump of claim 25, wherein said detent means comprises: a head member connected with said valve closure member and slidable in said valve body; recess means on one and spring-biased plunger means on the other of said head member and said valve body coengageable when said valve closure member is in either of said first or said second positions, said closure member being movable from one operating position to the other operating position upon being subjected to a longitudinally acting force sufficient to overcome the restraining force of said detent means.

27. The pump of claim 17, wherein: said valve means, said valve-actuating means and said backflow control means are insertable into and removable from said elongate housing through said eduction tubing without moving said eduction tubing.

28. A well system for lifting liquids in a well, comprising: a well bore penetrating a plurality of producing earth formations; a string of well casing in said well bore, the bore of said well casing communicating with each of said plurality of producing formations; a plurality of tubing strings in said well casing forming an annulus between said casing and said tubing strings, the bore of each tubing string communicating with a separate one of said producing formations; lateral port means in one of said tubing strings communicating the bore of said one of said tubing strings with said annulus; chamber means connected to at least another one of said plurality of tubing strings for accumulating well liquids from at least one of said producing formations therein; valve means connected to said chamber means, said valve means having an exhaust passage and a power gas passage, said exhaust passage communicating with said annulus, said valve means including a valve member movable between a first position wherein said chamber means communicates with said exhaust passage while said power gas passage is closed and a second position wherein said chamber

communicates with said power gas passage while said exhaust passage is closed; a source of gas pressure connected to the power gas passage of said valve means; valve actuator means in said chamber means associated with said valve means and responsive to the movement of well liquids in said chamber means for moving said valve member between first and second positions alternately communicating said power gas conduit and said exhaust conduit with said chamber means to sequentially fill said chamber means with and empty it of well liquids, said well liquids being displaced from said chamber means to the surface through said another tubing string by said power gas, means conducting used power gas from said chamber means into said one string of tubing to aid in lifting well fluids therein to the surface.

29. The apparatus of claim 28, including: check valve means upstream and downstream of said chamber means to prevent backflow of well liquids into and from said chamber means.

30. The well system of claim 28, wherein said lateral port means in said one tubing string includes a gas lift valve for controlling the admission of gas from said annulus into the bore of said one tubing string.

31. The well system of claim 28, including: an exhaust conduit connected to said exhaust passage of said valve means extending upwardly in said annulus to a location above the liquid level in said annulus; and an intake conduit connected to said lateral port means of said one tubing string and extending upwardly in said annulus to a location above said liquid level in said annulus for conducting gas from said space above said annulus to said one tubing string to lift liquids therein.

32. The well system of claim 28, including: a gas conduit having one end connected to the exhaust passage of said valve means and the other end connected to said lateral port means.

33. The well system of claim 28, including: relief conduit means connected to the upper portion of said annulus and having back pressure valve means therein adjusted to maintain the pressure in the upper portion of said annulus at a desired superatmospheric value.

34. The well system of claim 28, including: compressor means having a suction conduit connected to said annulus and a discharge conduit connected to said valve means for compressing gases collected in said annulus to a higher pressure for delivery to said pump chamber means to displace well liquids collected therein to the surface, said gas subsequently being vented from said chamber means into the annulus and collected therein for recompression and reuse.

35. The well system of claim 34, including: second compressor means having a suction conduit connected to a pipe line carrying gas and a discharge line connected to said annulus, said compressor means including control means responsive to the pressure in the annulus for activating and deactivating said compressor, whereby excess gas is vented from the annulus to the pipe line and shortage of gas in the annulus is made up from the pipeline, said gas from said pipe line being compressed by said second compressor means to a pressure in excess of the pressure in the annulus.

36. The well system of claim 34, including a check valve in said discharge conduit near the lower end thereof to exclude well liquids from said discharge conduit.

37. Apparatus for lifting liquids in a well bore penetrating a plurality of producing earth formations, one of which produces principally liquids and a second of which produces principally gas, and having well casing therein communicating with each of said plurality of producing formations, and a plurality of tubing strings in said well casing each communicating with a separate one of said producing formations, said tubing strings providing an annular space between said tubing strings and said well casing, and barrier means sealing between the tubing and casing in the annulus between adjacent formations, said apparatus including: gas pump means connected to the one of said plurality of tubing string communicating with the liquid-producing formation, said gas pump means having a fluid passage with an inlet from said liquid-producing formation and a fluid outlet to said one tubing string; valve means in said pump means having a gas inlet passage and a gas exhaust passage; means in said gas pump means responsive to movement of liquid and fluid pressures in said gas pump means for operating said valve means to alternately admit and exhaust gas from said pump means to admit liquid into said pump means and displace liquid from said pump means to said one tubing string; gas conduit means having one end communicating with the bore of said second of said tubing strings and having its other end connected to said gas inlet passage of said valve means, whereby said gas from said second tubing string is conducted as power gas to said gas pump means to operate said gas pump means.

38. The apparatus of claim 37, wherein the upper end of the casing is closed around the tubing strings to form an accumulator chamber in the casing above the liquid level therein, and gas discharged from the exhaust passage of said gas pump is accumulated in said accumulator chamber at a superatmospheric pressure lower than the pressure of the power gas.

39. The apparatus of claim 38, including: an exhaust tube connected to said exhaust passage of said gas pump and extending upwardly in said annulus to the accumulator chamber above the liquid level in said annulus.

40. The apparatus of claim 39, including: a sleeve valve disposed in said another one of said tubing strings at the lateral port therein movable for controlling the flow of fluids through said lateral port.

41. The apparatus of claim 36, including: inlet port means opening through the wall of a third one of said tubing strings and communicating the bore of said third tubing string with said accumulator chamber, whereby gas from said accumulator chamber entering said third tubing string through said inlet port means aids in lifting well liquids in said third tubing string.

42. The apparatus of claim 41, including: a vent line connected to said accumulator chamber; and a back pressure valve in said vent line adjusted to hold a predetermined superatmospheric pressure in said accumulator chamber and permitting excess gas to escape from said accumulator chamber.

43. The apparatus of claim 37, wherein gas discharged from said exhaust passage from said gas pump aids in lifting well liquids through said annulus.

44. The apparatus of claim 37, including: inlet port means opening through the wall of a third one of said tubing strings; and a gas conduit having one end connected to said inlet port means and the other end connected to the exhaust passage of said gas pump.

45. A well system for lifting liquids from a well, comprising: a well bore penetrating a producing earth formation; well casing disposed in said well bore and communicating with said producing earth formation; eduction tubing disposed in said well casing and communicating at the lower end thereof with the bore of said well casing; first chamber means connected in flow communication to said eduction tubing from accumulating well liquids from said producing earth formation therein; first valve means having a flow passage connected to said first chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said first valve means having means operable for selectively alternately connecting said ports of said first valve means in flow communication with said flow passage thereof; first valve actuating means associated with said first valve means and responsive to fluid movement in said first chamber means for actuating said first valve means to alternately communicate said first chamber means with said source of power gas pressure and with said region of lower pressure connected with said first valve means to sequentially fill said first chamber means with and empty said first chamber means of well liquids, whereby well liquids from said producing formation accumulated in such first chamber means will be displaced by gas pressure into the eduction tubing connected thereto; first backflow control means preventing backflow of

liquids from said eduction tubing to said first chamber means and from said first chamber means to said producing formation, whereby the well liquids emptied form said first chamber means to said eduction tubing are displaced upwardly in said eduction tubing; second chamber means connected in flow communication to said eduction tubing and in flow receiving communication with said first chamber means for accumulating therein well liquids displaced form said first chamber means upwardly in said eduction tubing to said second chamber means; second valve means having a flow passage connected to said second chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said second valve means having means operable for selectively alternately connecting said ports of said second valve means in flow communication with said flow passage thereof; second valve-actuating means associated with said second valve means and responsive to fluid movement in said second chamber means for actuating said second valve means to alternately communicate said second chamber means with said source of power gas pressure and with said region of lower pressure connected with said second valve means to sequentially fill said second chamber means with and empty said second chamber means of well liquids accumulated in said second chamber means, whereby well liquids accumulated in such second chamber means will be displaced by gas pressure into the eduction tubing connected thereto thereabove; and second backflow control means preventing backflow of liquids from said eduction tubing to said second chamber means, whereby the well liquids emptied from said first chamber means are displaced through said eduction tubing to said second chamber means and are then displaced from said second chamber means to the surface.

46. A well system for lifting liquids from a well, of the character set forth in claim 45, wherein said inlet port means of said first valve means and the inlet port means of said second valve means communicate with a common source of power gas pressure; and said outlet port means of said first valve means and said outlet port means of said second valve means communicate with a common region of superatmospheric lower pressure.

47. A well system for lifting liquids from a well, comprising: a well bore penetrating a producing earth formation; well casing disposed in said well bore and communicating with said producing earth formations; eduction tubing disposed in said well casing and communication at the lower end thereof with the bore of said well casing; first chamber means connected in flow communication to said eduction tubing for accumulating well liquids from said producing earth formation therein; first valve means having a flow passage connected to said first chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said first valve means having means operable for selectively alternately connecting said ports of said first valve means in flow communication with said flow passage thereof; first valve actuating means associated with said first valve means and responsive to fluid movement in said first chamber means for actuating said first valve means to alternately communicate said first chamber means with said source of power gas pressure and with said region of lower pressure connected with said first valve means to sequentially fill said first chamber means with and empty said first chamber means of well liquids, whereby well liquids from said producing formation accumulated in such first chamber means will be displaced by gas pressure into the eduction tubing connected thereto; first backflow control means preventing backflow of liquids from said eduction tubing to said first chamber means and from said first chamber means to said producing formation, whereby the well liquids emptied from said first chamber means to said eduction tubing are displaced upwardly in said eduction tubing; barrier means sealing between said eduction tubing and said well casing above said first chamber means; port means communicating said eduction tubing with the annular space between said eduction tubing and said well casing above said barrier means, whereby well fluids displaced from said first chamber upwardly in said eduction tubing enter said annular space above said barrier means; second chamber means connected in flow communication to said eduction tubing above said barrier means and in flow-receiving communication with said annular space above said barrier means and with said first chamber means for accumulating therein well liquids displaced from said first chamber means upwardly in said eduction tubing to said annular space and said second chamber means; second valve means having a flow passage connected to said second chamber means and having inlet port means communicating with a source of power gas pressure and outlet port means communicating with a region of superatmospheric lower pressure, said second valve means having means operable for selectively alternately connecting said ports of said second valve means in flow communication with said flow passage thereof; second valve-actuating means associated with said second valve means and responsive to fluid movement in said second chamber means for actuating said second valve means to alternately communicate said second chamber means with said source of power gas pressure and with said region of lower pressure connected with said second valve means to sequentially fill said second chamber means with and empty said second chamber means of well liquids accumulated in such second chamber means, whereby well liquids accumulated in such second chamber means will be displaced by gas pressure into the eduction tubing connected thereto thereabove; and second backflow control means preventing backflow of liquids from said eduction tubing to said second chamber means and from said second chamber means to said annular space above said barrier means, whereby the well liquids emptied from said first chamber means are displaced through said eduction tubing to said annular space above said barrier means and to said second chamber means and are then displaced from said second chamber means to the surface.

48. A well system for lifting liquids from a well, of the character set forth in claim 47 wherein: third backflow check means is provided in said eduction tubing adjacent said barrier means and below said port means from said eduction tubing to said annular space above said barrier means.

49. A well system for lifting liquids from a well, of the character set forth in claim 47, wherein said inlet port means of said first valve means and the inlet port means of said second valve means communicate with a common source of power gas pressure; and said outlet port means of said first valve means and said outlet port means of said second valve means communicate with a common region of superatmospheric lower pressure.

50. A method of lifting liquids to the surface in a well having a well casing therein penetrating a producing formation and communicating therewith, comprising the steps of: installing an eduction tubing in said well; providing a pump chamber communicating with said eduction tubing below the working liquid level in said well casing; venting said pump chamber to a region of superatmospheric lower pressure; collecting well liquids in said pump chamber; closing the pump chamber vent; and introducing power gas from a source of superatmospheric higher pressure into said pump chamber to displace the well liquids collected therein from said pump chamber through said eduction tubing to the surface of the well.

51. The method of claim 50, with the additional steps of: venting the power gas from said pump chamber after the well liquids have been displaced therefrom; accumulating the vented power gas from said pump chamber in the region of superatmospheric lower pressure; recompressing the accumulated vented gas from said lower pressure to a desired higher operating pressure for reuse as power gas; and introducing the recompressed power gas into said pump chamber.

52. The method of lifting well liquids to the surface in a well having a well casing therein penetrating a producing forma-

tion and communicating therewith, comprising the steps of: installing in said well an eduction tubing having a pump housing with a pump chamber therein connected in flow communication with said eduction tubing and communicating with the well casing below the working liquid level in said well casing; lowering fluid flow-controlling means through said eduction tubing and installing the same in said pump housing; venting said pump chamber to a region of superatmospheric lower pressure in said well casing above the working liquid level therein; collecting well liquids in said pump chamber to fill said chamber; closing the chamber vent and introducing power gas from a region of superatmospheric higher pressure into said pump chamber to displace well liquids collected therein from said chamber to be conducted to the surface of the well through said eduction tubing; venting the power gas from said pump chamber to said region of superatmospheric lower pressure in said well casing after the well liquids have been displaced from said pump chamber; admitting additional well liquids from said casing to said pump chamber to fill said chamber; closing the vent and again introducing power gas into said pump chamber to displace said additional well liquids from said chamber to be conducted to the surface through said eduction tubing; and repeating the steps of collecting and displacing well liquids.

53. The method of claim 52, with the additional steps of: accumulating the power gas vented from said pump chamber in said region of superatmospheric lower pressure in said well casing above the liquid level therein; compressing the accumulated vented gas from said lower pressure to a desired higher operating pressure fore reuse as power gas in said region of superatmospheric higher pressure; and reintroducing the recompressed power gas from said region of higher pressure into said pump chamber to displace well liquids therefrom.

54. A method of lifting liquids to the surface in a well having a well casing therein penetrating a production formation and communicating therewith, comprising the steps of: installing an eduction tubing in said well; providing a first pump chamber communicating with said eduction tubing below the working liquid level in said well casing and with the well producing formation; providing a second pump chamber communicating with said first pump chamber and with said eduction tubing to the surface; venting said first and second pump chambers to a region of superatmospheric lower pressure; collecting well liquids in said first pump chamber; closing the first pump chamber vent; introducing power gas from a source of superatmospheric higher pressure into said first pump chamber to displace the well liquids collected therein from said first pump chamber through said eduction tubing to said second pump chamber; closing said second pump chamber vent; and introducing power gas from a source of superatmospheric higher pressure into said second pump chamber to displace the well liquids therein from said second pump chamber through said eduction tubing to the surface of the well.

55. A method of lifting liquids to the surface in a well having a well casing therein penetrating a producing formation and communicating therewith, comprising the steps of: installing an eduction tubing in said well, providing a first pump chamber communicating with said eduction tubing below the working liquid level in said well casing and communicating with the well producing formation; providing a barrier seal between said eduction tubing and said casing above the working liquid level in said well casing; providing a second pump chamber communicating with said annular space between the eduction tubing and casing above said barrier seal and with said first pump chamber and communicating with said eduction tubing to the surface; venting said first pump chamber to a region of superatmospheric lower pressure; venting said second pump chamber to a region of superatmospheric lower pressure; collecting well liquids into said first pump chamber; closing said first pump chamber vent; introducing power gas from a source of superatmospheric higher pressure introducing said first pump chamber to displace the well liquids collected therein from said first pump chamber through said eduction tubing to said annular space above said barrier seal and into said second pump chamber; closing said second pump chamber vent; introducing power gas from a source of superatmospheric higher pressure into said second pump chamber to displace the well liquids therein from said second pump chamber through said eduction tubing communicating therewith to the surface of the well.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,617,152 Dated November 2, 1971

Inventor(s) Leslie L. Cummings

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 29, for "well casing" read --wherein the--

Column 1, line 30, for "disposed" insert--lifting--

Column 1, line 31, for "in to backflow" read --to the--

Column 4, line 54, for "sanding" read --standing--

Column 9, line 9, for "inner" read --and--

Column 10, line 13, for "movement of" read --movement or--

Column 14, line 71, for "te" read --the--

Column 16, line 9, for "part" read --port--

Column 16, line 73, delete the line

Column 19, line 50, for "17" read --chamber--

Column 22, line 55, for "from" read --for--

Column 23, line 3, for "form" read --from--

Column 23, line 8, for "form" read --from--

Column 25, line 30, for "fore" read --for--

Signed and sealed this 2nd day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents