May 4, 1943. G. L. THOMPSON ET AL 2,318,029

INTERMITTENT GAS LIFT PUMP

Filed Jan. 24, 1940 3 Sheets-Sheet 1

Fig. 1.

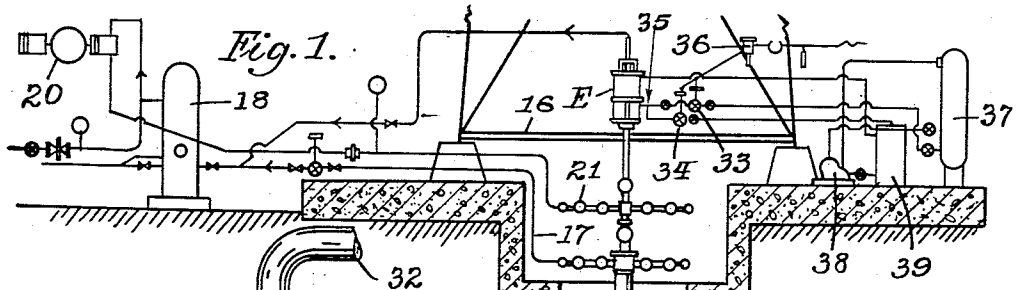
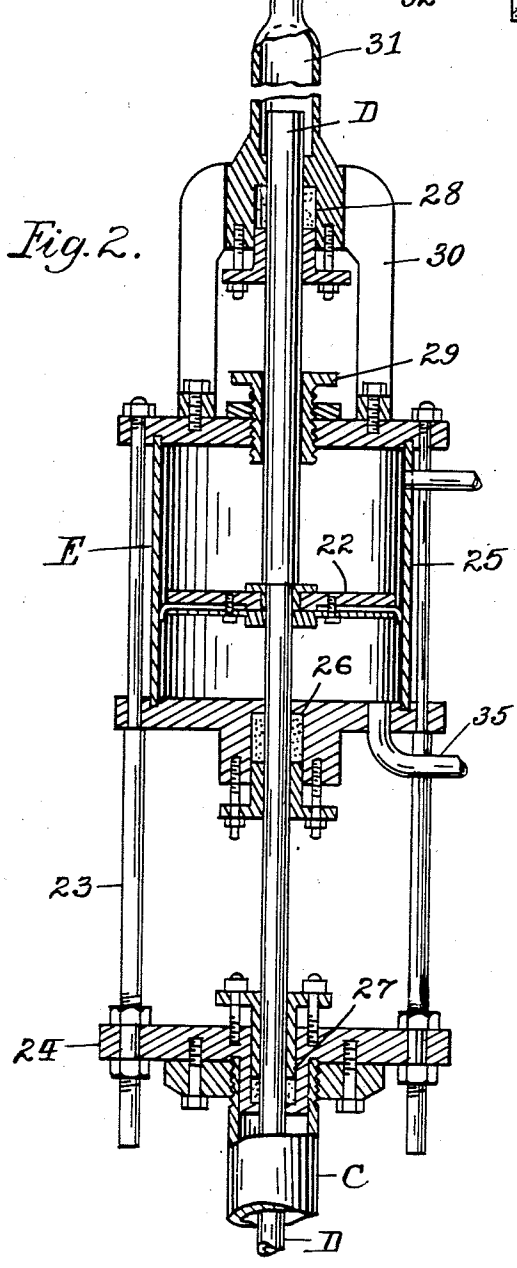


Fig. 2.



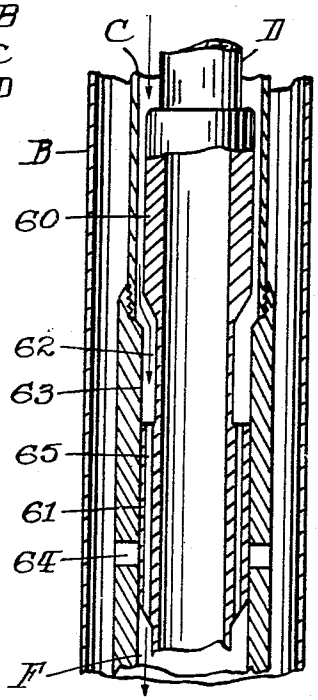


Fig. 13.

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INTERMITTENT GAS LIFT PUMP

Filed Jan. 24, 1940 3 Sheets-Sheet 2

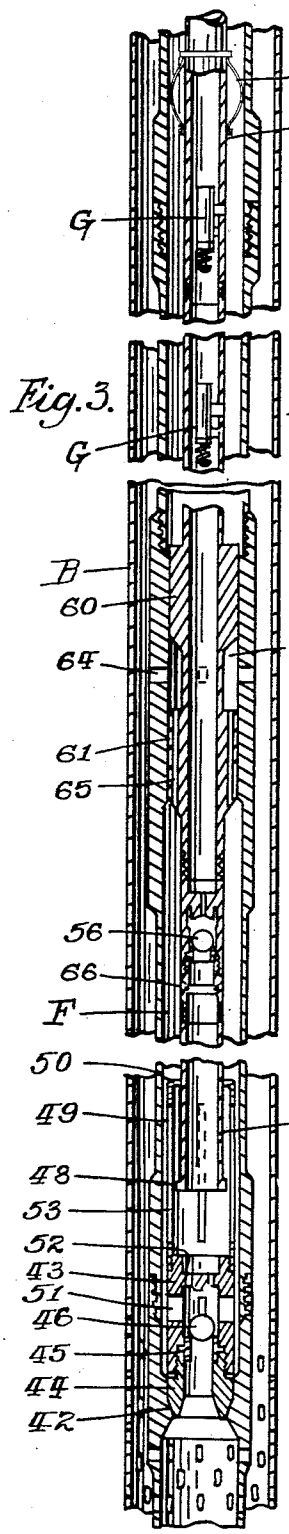


Fig. 3.

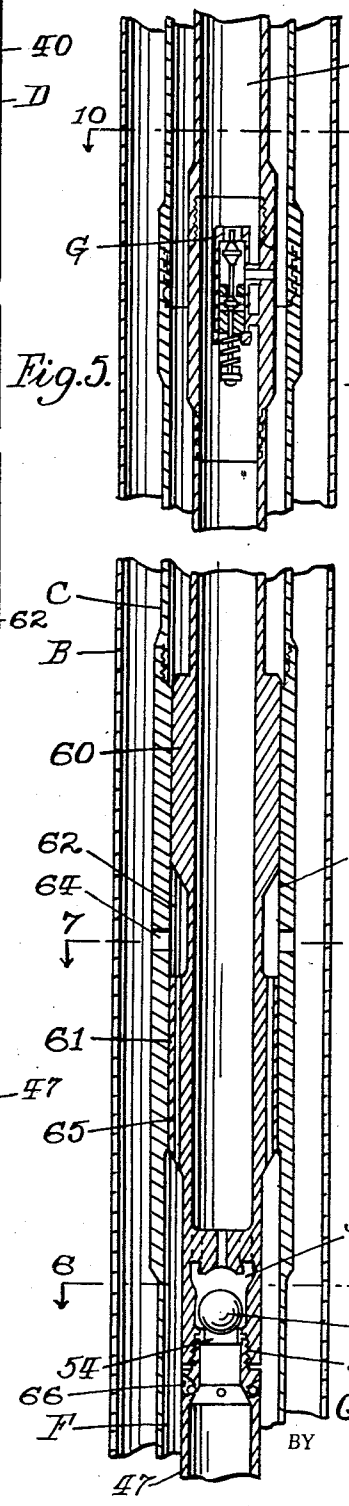


Fig. 5.

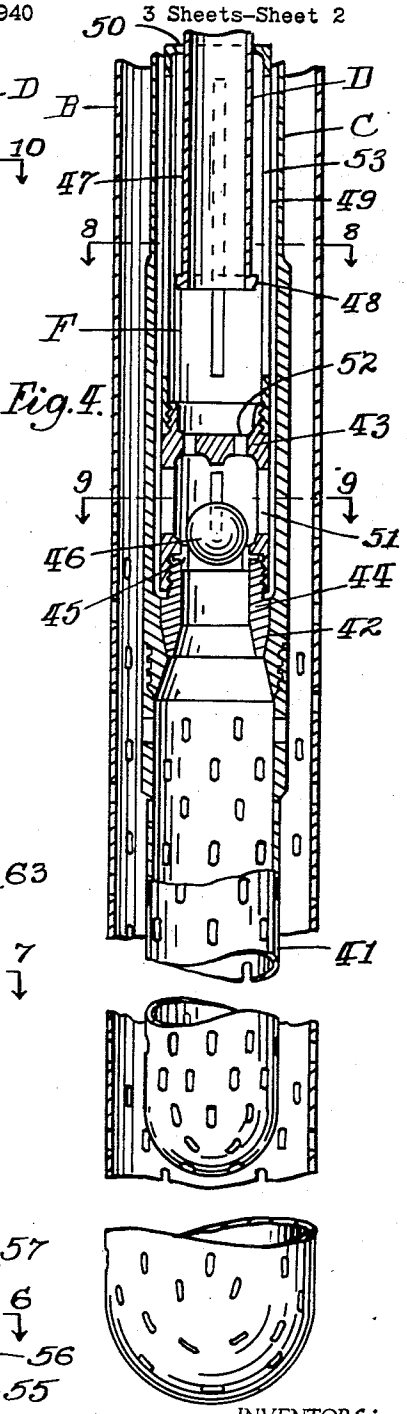


Fig. 4.

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INTERMITTENT GAS LIFT PUMP

Filed Jan. 24, 1940 3 Sheets-Sheet 3

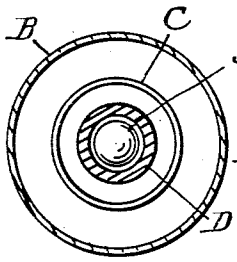


Fig. 6.

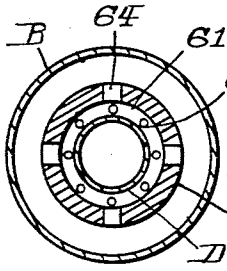


Fig. 7.

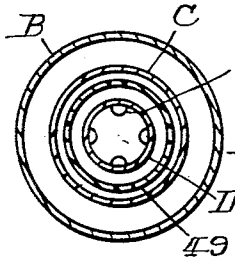


Fig. 8.

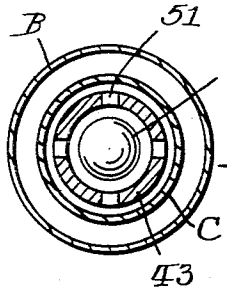


Fig. 9.

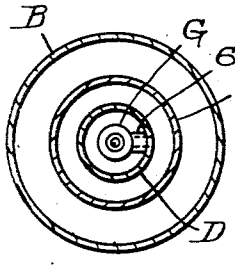


Fig. 10.

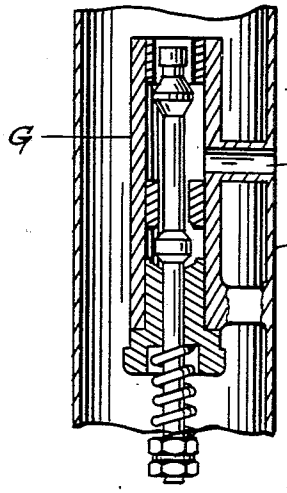


Fig. 12.

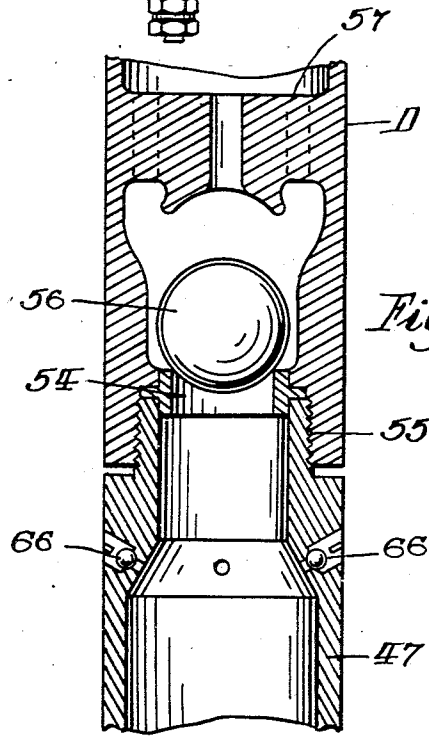


Fig. 11.

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2,318,029

UNITED STATES PATENT OFFICE

2,318,029

INTERMITTENT GAS LIFT PUMP

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Application January 24, 1940, Serial No. 315,410

9 Claims. (Cl. 103—231)

Our invention relates to a surface controlled intermittent gas lift pump, this application being a continuation in part of our co-pending application Serial Number 266,926, filed April 10, 1939. That application issued on September 2, 1941, as Patent No. 2,254,554. In that patent the ingress of impelling or lifting fluid is described as passing downwardly into the well through an innermost duct, usually termed the "macaroni tubing," and the egress of liquid which is pumped from the well is upwardly through an outer annular duct. This "macaroni tubing" which reciprocates valve means in the pump chamber in the lower portion of the well is employed to control the conduct of high pressure lifting fluid such as compressed gas against the liquid in the pump chamber to be lifted and the outer tubular member is employed as a flow line to conduct a series of slugs of liquid to the surface above the well. In this structure a liquid controlling valve means is attached to the flow line and it is necessary to remove the flow line as well as the "macaroni tubing" and pump chamber from the well in order to service said valve means, which operation is laborious and expensive. The present improvement employs inner "macaroni tubing" as a flow line for the liquid pumped from the well and the liquid admission valve means and pump chamber are attached to the "macaroni tubing" so that the admission valve means and pump chamber can be removed from the well and serviced by simply removing the "macaroni tubing" and without disturbing the remaining tubing, or what is known as "stripping the tubing," thus saving time, labor and expense.

In said companion application the liquid load above the pump chamber tends to reduce the effectiveness of the propelling fluid from lifting the static load in the flow line, and when running the pump in a liquid locked well or pool, tends to prevent the pump from starting to function. Our present improvement provides simple and effective means by which this load is automatically reduced to a minimum so that these objections are entirely overcome and the efficiency of the pump is materially improved.

Our invention employs compressed gas or any other suitable impelling fluid as a motivating medium by which the liquid in the well is pumped to the surface, a suitable pump chamber or displacement chamber being provided below or near the normal level of liquid in or near the bottom of the well with suitable valve means for operating the pump which is positively controlled from the surface above the well and mechanically actuated by what is usually termed "macaroni tubing." The impelling fluid is delivered to the bottom portion of the well adjacent to the work to be performed where it is intermittently applied with substantially no loss either in volume or pressure. A continuous series of short slugs of liquid from the well with the impelling fluid is projected upwardly through the macaroni tubing to the surface above the well, the load of the column of liquid in said tubing being automatically reduced so as to augment the flow of liquid from the well and functioning of the pump under any and all conditions to which the well and pumping apparatus are subject. This improved method of operation by which the flow of liquid upwardly through the flow line is augmented, forms part of the invention included in the present application. The objects and advantages set forth in our companion application are embodied in the present invention and in addition this invention provides several distinct advantages which will be set forth in the following description.

A further object of the invention is to provide pumping apparatus of this type in which the operating fluid exhausts from the pump chamber into the outer casing that is in communication through the perforations of the screens with the liquid-bearing formation of the well, but at the same time to provide the apparatus with means whereby the quantity of operating fluid and the pressure of the same exhausted into the formation will be greatly reduced, thereby preventing any incidental retarding effect to the flow of the oil inwardly through the screens and the oil-bearing sands.

To these ends our invention comprises the improved method of operation, features of construction and combination of parts hereinafter described and claimed.

In the accompanying drawings, forming part of this specification, Fig. 1 is a diagrammatic elevation showing a preferred embodiment of our invention applied to an oil well; Fig. 2 is a vertical central section of the reciprocating power ram which is shown in Fig. 1, used above the surface of the well for reciprocating the valve means in the well, it being understood that any type of valve actuating means may be used within the spirit of the invention; Fig. 3 is a vertical central section of a fragment of our improved pumping apparatus showing the various valves and ports and their relative positions in the well; Fig. 4 is a vertical central section, in part, on a slightly enlarged scale of a portion of our improved ap-

paratus which is used in the bottom of the well; Fig. 5 is a vertical central section on a scale similar to that shown in Fig. 4, of a fragment of our improved apparatus showing the positively actuated control valve means and one of the automatic flow valves used for reducing the static load in the flow line; Fig. 6 is a cross section taken on line 6—6 of Fig. 5; Fig. 7 is a cross section taken on line 7—7 of Fig. 5; Fig. 8 is a cross section taken on line 8—8 of Fig. 4; Fig. 9 is a cross section taken on line 9—9 of Fig. 4; Fig. 10 is a cross section taken on line 10—10 of Fig. 5; Fig. 11 is a vertical central section, on an enlarged scale, of a detail, showing the check valve means which is associated with the pump chamber; Fig. 12 is a vertical section of a detail, on an enlarged scale, showing one of the automatic flow valves employed in the marcaroni tubing for reducing the static load above the pump chamber, and Fig. 13 is an enlarged vertical section of a detail showing the control valve in the upper or emptying position in the large tubing.

In Fig. 1 of the drawings, we have shown diagrammatically an equipment embracing our invention applied to an oil well although it is to be understood that the invention is equally applicable for pumping water or any other liquid. In this equipment, A is the usual surface string of casing which is set in the drill hole and cemented into the customary cellar 15, the latter being excavated in the surface of the ground below the derrick 16. B is a string of casing commonly referred to as the oil string, spaced freely from the inner surface of the outer casing, sealed at its upper end therefrom and extending downwardly into and held stationary in the bottom of the well. The upper end of the oil string is closed and connected by the flow line or valved duct 17 of what is generally termed the "Christmas tree," to the trap 18 for separating wet casing head gas and oil that is pumped from the well. C is an impelling fluid line of tubing which extends downwardly in and is spaced inwardly from the oil string. This fluid line is also held stationary in the well from the "Christmas tree," and consists of a string of sectional pipe extending downwardly and terminating near the bottom of the well and is controlled by suitable valve means for pumping oil or other liquid intermittently from the well. The upper end of the impelling fluid line is connected with a compressor 20 or any suitable source of gas or other motivating fluid. In actual practice gas under as high as 2000 pounds pressure can be effectively used by our improved apparatus for pumping oil or other liquid from a depth of 8000 feet, more or less. The admission of compressed fluid from a compressor into the impelling fluid line C can be shut off in case of an emergency by valves 21 of the "Christmas tree," but normally is compressed and transported under full compressor discharge pressure down to the control valve 60. D is a string of reciprocable macaroni tubing, which forms a liquid flow line. This tubing is spaced from and extends downwardly in the impelling fluid line C to the lower portion of the well. The upper end of the macaroni tubing D is supported by the power piston 22 of a ram E, which is incorporated into a frame by reach studs 23 (see Fig. 2), said frame being mounted upon the cap 24 on the upper end of the impelling fluid line C. This ram has a vertical cylinder 25 and said piston 22, the latter serving to support and reciprocate the macaroni tubing D. Suitable glands 26, 27 and 28 produce tight joints for the liquid flow line tubing to slide through. The upper end of the cylinder 25 carries the upright yoke 30 which has a stationary vertical tubular chamber 31, from which the liquid pumped from the well egresses by the duct 32. The chamber 31 allows the macaroni tubing to reciprocate freely therein and said gland 28 provides a leak proof sliding connection in the yoke. The upper end of the macaroni tubing or liquid flow line D opens freely into the terminal chamber 31, thus making a free movable connection.

The reciprocable ram is located above the "Christmas tree" and its piston 22 can be motivated by any suitable means. In this plan we have employed brown neutral oil at substantially 125 pounds pressure. If the weight of the macaroni tubing is counter-balanced the pressure required is reduced and need be only 15 or 20 pounds. This oil is admitted to and bled from the cylinder by two small diaphragm regulators 33 and 34 through duct 35 and is controlled by the variable intermitter 36 which is of usual construction. When desired other means for controlling the operating fluid to cause the reciprocation of the piston can be employed. The brown neutral oil is shown supplied from the reservoir 37 which resembles a gas trap half full of oil and half full of gas and is replenished and kept up to pressure by a small automatic pressure controlled pump 38. This pump receives negative pressure from a small open tank 39 into which the oil is returned from the power cylinder 25. However, any operating means can be used to reciprocate the macaroni line if of sufficient pressure, such as water from a main line having a constant pressure, high pressure gas from the injection gas compressor or main line, or mechanical means such as a walking beam or pumping jack. These devices for operating the control valve or valves in the top and bottom of the pump chamber may be changed if desired.

Gas when used as a motivating fluid in the well may be supplied at a desired pressure, or compressed on the surface to whatever pressure is necessary to meet the depth and productivity conditions and is forced or otherwise supplied into the string of pressure line tubing C. The flow line tubing as shown is coaxially arranged and reciprocable vertically in the impelling fluid line C, suitable spring guides 40 (see Fig. 3) being secured to the macaroni tubing immediately above the pump chamber at any desired intervals, thus centralizing the tubing for a short distance above the control valves.

The lower perforated end of the string of casing B is set in the fluid bearing strata in the usual manner and is immersed in, and receives, liquid such as oil thereinto, the level assumed by the oil varying according to the productiveness or bottom hole pressure of the well and the back pressure exerted against the oil bearing formation by facilities at the surface. The lower end of the impelling fluid line or tubing C has threaded thereto a suction screen 41 (see Fig. 4), which is lowered into the oil in the perforated casing B. Immediately above the junction of the screen with the pump chamber or the lower part of tubing C, the latter is formed internally with a downwardly and inwardly tapering seat 42. A suitable standing valve cage 43 has secured therein, by an upwardly passaged plug 44, a standing valve seat 45. The ball check 46 within the cage lifts off of the seat to permit upward flow of oil or other liquid into the pump chamber F and automatically seats to prevent return flow downwardly.

The standing valve cage is tapered downwardly externally at its lower extremity and seats snugly in the tapered seat 42 to prevent oil from escaping out of the pump chamber once trapped and from entering the pump chamber except through the valved passage in the cage. A tubular section 47 joined to the lower extremity of the macaroni tubing D has an annular outer shoulder 48 immediately above the valve cage 43 and said valve cage is joined to the macaroni tubing by a longitudinally slotted cylindrical shell 49, the upper end of which slips freely over the outer surface of the macaroni tubing and has an annular inwardly directed shoulder 50 on its apper end. This shoulder is adapted to engage the shoulder 48 and lift the valve cage 43 and standing valve with the macaroni tubing when the latter is raised and removed from the well. Thus the operating valves can be serviced by simply removing the macaroni tubing from the well. The slip joint between the cylinder connection 49 and macaroni tubing provides ample space for the reciprocating action of the macaroni tubing without lifting valve cage 43 and 44 out of seat 42. The cylindrical connecting shell 49 is spaced inwardly from the inner wall of the impelling gas line C and passages 51, 52 and 53 in the valve cage 43 and cylindrical connection 49 permit free movement of liquid from below the check valve 46 upwardly into the pump chamber F.

Immediately above the pump chamber F and the lower tubular section or extension 47 of the macaroni tubing D is a check valve or standing valve which functions to permit liquid from below being forced upwardly into the column above, provided by the macaroni tubing and prevent any return movement. This valve has an annular valve seat 54 (see Fig. 11), secured between the abutting ends of two sections of the macaroni tubing by the threaded connections 55, one of said sections as shown constituting the lowermost section 47. It also has the ball check 56 which cooperates with said seat. A suitable grill retainer 57 limits more than adequate movement of the ball check.

Arranged above check valve 56 and its retainer is the control valve, in this case composed of two connected sleeves 60 and 61, which are formed integral on one of the sections of the macaroni tubing and are spaced vertically apart to produce an annular channel 62. These sleeves reciprocate in and are closely fitted in the bore 63 which projects inwardly from the inner surface of the large tubing. While in lowermost position, known as the pump chamber filling position as shown in Fig. 5, the annular channel registers with ports 64 through the wall of the large tubing, thus forming a connection with the passage between the pump chamber F and the outer oil string B or the oil bearing formation. This connection is completed downwardly through a plurality of longitudinal ducts 65 in the lower sleeve valve 61, with the pump chamber F. In this way the pump chamber will become filled through the bottom standing valve 46 with liquid from the liquid bearing formation up to the ports 64 and check valves 66 or at least to a point equal to the liquid level in the oil string B. A plurality of small automatic check valves 66 (see Fig. 11) are placed near the upper end of the lower section 47 of the macaroni tubing below the check valve 56 and between the space within said section and the upper outer portion of the pump chamber to vent or displace vapors caught within tube 47 outwardly through ports 64. When the pressure of the operating gas in the pump chamber has fallen sufficiently to become equalized with the oil bearing formation pressure the bottom standing valve 46 automatically closes.

When the pair of positively actuated controlling sleeve valves 60 and 61 assume uppermost or emptying position the lowermost sleeve 61 slides over and closes the ports 64 and the upper sleeve 60 assumes a position above and out of the bore 63 in the impelling fluid line (see Fig. 13), thus allowing the high pressure or injection fluid, such as gas from the impelling fluid line to pass through the ducts 65 downwardly into the pump chamber F and forcing substantially all the liquid from the pump chamber, upwardly through the tube 47 and check valve 56 and into the inner liquid flow line D and on its way outwardly above the well. The length of each of the sleeves 60 and 61 and the width of the channel 62 and the length of the stroke of the macaroni tubing are proportioned so that the parts will function in synchronism to intermittently pump slugs of oil or other liquid upwardly through the inner macaroni tubing or liquid flow line above the surface of the well.

To lighten the liquid or static load in the flow line above standing valve 56, and reduce the necessary operating pressure for the pump chamber by reducing this static head which the pump chamber must empty against we have provided one or more differential type flow valves such as G at various intervals upwardly in and supported by the macaroni tubing. Each of these valves as shown in Fig. 12 is connected by a duct 69 through the wall of a section of the macaroni tubing with the impelling fluid line C and is regulated to admit the impelling fluid directly into the flow line at any predetermined difference of pressures of the column of liquid in the flow line and the impelling fluid line. These valves may be set to never allow the static pressure to build up in the flow line closer than whatever they are set for in relation to the pressure of the impelling fluid without opening and allowing the high pressure gas or fluid to enter and lighten the load. Due to this means the pump can be run in a well full of oil or liquid up to the derrick floor and the instant the impelling gas or fluid is forced down the tubing C while the sleeve valves 60 and 61 are in the lower or filling position, oil or other liquid from both strings of tubing C and D will start flowing upwardly out of the tubing D and continue until both strings of tubing are empty down to the pump chamber. These flow valves are of ordinary construction.

Operation

Fig. 5 shows the valves 60 and 61 at the top of their up-stroke. Gas or other operating fluid under suitable pressure fills the inside of the pressure line C to a point just above valve 60, at which point this valve 60 controls the admission of the operating fluid to pump chamber F (see Fig. 5). When the valves 60 and 61 are in their lowermost position (see Fig. 3), the pump chamber F would have been filled with the production oil or other liquid that would flow freely through the lower standing valve 46 upwardly into the pump chamber, rising to the level of the pool or higher if a partial vacuum existed in the tubing B. While the pump chamber is filling, vapors or gas trapped inside the lower extension or section 47 of the macaroni tubing are vented or displaced from the upper end of section 47 out through the check valves 66 into the upper end of the pump cham-

ber and this vapor plus any vapor in the lower portion of the pump chamber on the outside of the tube **47** is forced up through ducts **65** and thence out into the space within the outer tubing B through ports **64**. (See Fig. 3.) When the pressure of liquid in the pump chamber has become equalized with the pressure of the liquid in the well, the bottom standing valve **46** will close automatically. As the macaroni tubing is reciprocated by the ram E or any other prime mover used and the control valves are raised into uppermost or emptying position the lower valve **61** closes the ports **64** and the upper valve **60** opens and allows the impelling fluid to pass downwardly through the ducts **65** into the pump chamber thus forcing the liquid trapped within upwardly through tube section **47**, the upper check valve **56** and into the macaroni tubing or liquid flow line on its way out of the well.

The intermitter **36** is set to cause the reciprocation of the macaroni tubing at proper intervals for the efficient functioning of the positively actuating control valves, it being understood that as the macaroni tubing is lowered upon its return stroke the valve **60** enters the bore **63** shutting off the supply of impelling fluid flowing into the pump chamber, which fluid then expels the oil up the flow pipe from the pump chamber, following which the ported valve **61** opens the ports **64** allowing that portion of the spent impelling fluid that remains in the pump chamber to escape and equalize the pressure within the pump chamber with that of the liquid in the oil string B, thus permitting the liquid in the oil string to open the bottom standing valve **46** and freely fill the pump chamber preparatory to repeating the operation. Thus slugs of oil or other liquid are intermittently forced at regular intervals up into the macaroni tubing on its way out of the well.

During the operation of our improved well pump the automatic differential valve or valves G in the flow line cut in and lighten the load of the column of liquid therein to always maintain a predetermined differential pressure between the interior of the flow line or macaroni tubing and the space between the impelling fluid line and flow line in which the high pressure impelling fluid or injection gas is stored above control valve **60**, immediately adjacent to the point of consumption. One or any number of these differential flow valves may be employed and they may be varied in adjustment to function so as to cut in at different reduced pressures according to their elevation or they may be set to release and function all at the same pressure, whereby the static load of the liquid in the flow line is most effectively reduced to increase the impelling effect of the compressed impelling fluid at the point of application in the pump chamber. It is a fact that the local pressure in the vicinity of the screens where the oil is admitted, is of importance as affecting the flow of the oil, and it is desirable to maintain this local pressure as low as possible. Hence it is not ordinarily feasible to discharge a large quantity of operating fluid or gas into the well formation, because such a discharge would tend to raise the local pressure and reduce the flow of the oil into the pump chamber. However, by employing means at an elevated point above the pump chamber, in the flow line, for reducing the static head against which the pump operates, we are enabled to operate the pump with a smaller quantity of gas and at a lower pressure. In this way we reduce the danger of building up local pressure in the well near the screens, which would tend to reduce the capacity of the well, to fill the pump chamber. These booster valves guarantee no wastage of gas in lifting whatever liquid is pumped into the small tubing D, because if the static head in the flow tubing does not approach the pressure of the impelling fluid line very close they will not open and in case it does approach it too close they will only let in enough impelling gas to lighten it the minimum amount required but without waste.

The height at which the pump chamber unit and cooperating valves are placed in the well can be varied from well to well to suit the height and quantity of the liquid in the productive zone in the well. The stroke of the pump and the uppermost stopping point is controlled by adjustments against stretch and the bottom stopping point is controlled by the long threaded reach studs **23**.

When it is desired to service the working parts of our improved pump the macaroni tubing can be removed, carrying with it all of the valves including the standing valves **46** and **56**, the plug **44** permitting this complete operation without disturbing the remaining tubing. This is a distinct advantage due to saving of time, labor and expense.

Among the advantages attained by our invention are the following:

1. The full discharge pressure from the power compressor is available substantially without loss on the outside of the flowing tubing at each one of the flow valves and in the pump chamber where the initial work is to be performed.

2. The static load in the liquid flow line is reduced automatically and continuously controlled at a lower pressure than the lifting effort required in the pump chamber thus making the pump more reliable, efficient and particularly serviceable for deep well pumping and enabling the pump to start and continue functioning under substantially all conditions.

3. The working valves are all incorporated into the inner flow line tubing as a single unit, whereby they may be serviced from time to time by the removal of only a single string of tubing and without disturbing any of the remaining tubing and requiring what is termed a stripping job.

4. The operation of the pump is controlled completely from the surface above the well.

5. The pump will effectively and efficiently lift all of the liquid out of the well up to the capacity of the pump as fast as it accumulates, irrespective of the back pressure held on the casing or bottom hole pressures in the well.

6. All of the formation gas produced from the well is produced through the casing formation without interfering with the functioning of the pump.

7. The use of the pump is not limited as to depth.

8. The injection or lifting fluid is transported to the bottom of the well under full compressor discharge pressure where it is positively controlled, which increases efficiency and whereby the pump chamber is emptied in a positive and reliable manner.

9. The apparatus employed is extremely simple and inexpensive to manufacture, has comparatively few working parts and requires a minimum of machine work in producing.

10. By giving the macaroni tubing a long or excessive length of stroke and having the port openings in the sleeve valves so arranged that if the tubing fails to lower to the same position each stroke, the functioning of the valves and oper-

ation of the pump is substantially unaffected due to friction or stretch.

11. It is possible to take all of the pressure off the oil bearing formation or even pull a vacuum on same without impairing the operation of the pump because the pump chamber fills by gravity or by difference in liquid level inside to outside the pump chamber thus allowing the well to produce gas and oil or liquid at its utmost.

12. Due to the arrangement of the valves, each slug does not have to be followed any further than out of the pump chamber and after the slug has been driven out of the pump chamber the injection fluid is shut off and that trapped within is mechanically bled off and equalized with the formation pressure, thus greatly reducing the quantity of repressuring gas needed per barrel of liquid and speeding up the number of slugs per hour and the capacity much greater than is possible with single slug intermitting gas pumps.

13. Although this pump embodies distinct operating advantages in emitting or discharging small solid slugs of liquid upward into the flowing tubing consecutively without large slugs of gas following them, the functioning of the flow valves smooth out these slugs to such a degree that at the surface the discharge from the small flowing tubing emulates the stream from a flowing well, greatly reducing handling facilities, such as oil and gas separators, compressor plants and pipe lines to handle peak conditions necessary on all other gas lift pumps.

In connection with the valve 56, it should be understood that this valve could be located at any desired point in the flow line leading out of the pump chamber. It, of course, performs the function of a discharge valve, but it would operate even if located at the lower end of the tube 47. However, we prefer to have this valve at a high elevation with reference to the location of the pump chamber, because in an elevated position it increases the capacity of the pump chamber by a quantity equal to the displacement of the tube 47 below it. When elevated in this way, the tendency of this valve to become clogged is greatly reduced as it is above the level where the amount of sand in the oil or other liquid being pumped, would be greatest.

In accordance with the patent statutes, we have described the principles of operation of our invention together with the apparatus which we now consider to represent the best embodiment thereof but we desire to have it understood that the construction shown is only illustrative and that the invention can be carried out by other means and applied to uses other than those above set forth within the scope of the following claims.

We claim:

1. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube-string within the pressure line, with a check-valve for passing the liquid discharged from the pump-chamber, means for reciprocating the flow tube, a valve-chest of restricted diameter in the pressure line, an upper valve head carried on the flow tube and capable of filling the bore of the valve-chest, and a lower valve-head carried on the flow pipe, filling the bore of the valve chest, the lower valve-head having ducts extending completely through the same from end to end, said pressure line having outlet ports through the wall thereof, all located at a level between the said valve-heads when the flow tube is near the lower end of the stroke, said valve-heads and outlet ports cooperating alternately to vent the pump-chamber to the exterior of the well through the ducts and said outlet ports, and to admit the operating fluid down through the said ducts to the pump-chamber.

2. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube-string within the pressure line, with a check-valve for passing the liquid discharged from the pump-chamber, means for reciprocating the flow tube, a valve-chest of restricted diameter in the pressure line, an upper valve-head carried by the flow pipe and capable of filling the bore of the valve-chest, and a lower valve-head carried on the flow pipe, filling the bore of the valve-chest, the lower valve-head having ducts extending completely through the same from end to end, said pressure line having outlet ports through the wall thereof, all located at a level between the said valve-heads when the flow tube is near the bottom end of its stroke, said ducts operating to vent the interior of the pump-chamber through said ports while near the lower end of the stroke of the flow tube to permit the pump-chamber to fill, and said upper head cooperating with the valve-chest in the upper portion of the stroke to pass the operating fluid down through the valve-chest and through said ducts into the pump chamber to displace the liquid in the pump-chamber and force its contents into the flow-pipe to produce an ascending column of the liquid therein, and a plurality of booster nozzles spaced apart from each other up the flow-pipe, each with a differential pressure-controlled valve for admitting the operating fluid from said pressure line to the interior of the flow-line to accelerate the upward flow of the liquid column thereby reducing the discharge pressure from the pump-chamber to the said flow tube valve, and reducing the quantity and pressure of the operating fluid required to empty the pump-chamber.

3. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve at which the pump-chamber fills from the pool being pumped, a flow-line tube string within the pressure line, with a check-valve for passing the liquid flowing upwardly from the pump-chamber, means for reciprocating the flow tube, a valve-chest of restricted diameter in the pressure line, an upper valve-head carried by the flow pipe and capable of filling the bore of the valve-chest and a lower valve-head carried on the flow-pipe filling the bore of the valve-chest, the lower valve-head having ducts extending completely through the same from end to end, said pressure line having outlet ports through the wall thereof all located at a level between the said valve-heads when the flow tube is near the bottom end of its stroke, said ducts operating to vent the interior of the pump-chamber through said ports during the lower portion of the stroke of the flow tube, to permit the pump-chamber to fill, and said upper head cooperating with the valve-chest during the upper portion of the stroke to pass the operating fluid down through the valve-chest and through said

ducts into the pump-chamber to displace the liquid in the pump-chamber and force slugs of liquid into the flow-pipe, thereby producing an ascending column of the liquid therein, and a plurality of booster nozzles spaced from each other up the flow-pipe, each with a pressure-controlled valve for admitting the operating fluid from said pressure line, each of said pressure-controlled booster valves being a differential pressure-controlled valve, and each of said pressure-controlled valves having means for setting the same to open at any desired differential pressure.

4. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube-string within the pressure line, including an extension projecting down into the interior of the pump-chamber, with a check-valve located adjacent the upper end of said extension for passing the liquid discharged from the pump-chamber, means for reciprocating the flow-tube, a valve-chest in the pressure line, valve means therein carried on the flow-pipe, said valve-chest having an outlet port extending through the wall thereof, said valve-means and said outlet port cooperating toward the ends of the strokes to alternately vent the pump-chamber to the exterior of the well through the valve-means and through the outlet port, and to admit the operating fluid down through the valve-means to the pump-chamber; and check-valve means at the upper end of said extension operating to open at a lower pressure than the pressure exerted by the column on the pump outlet valve, to vent any portion of the operating fluid located in the said extension while the pump-chamber is filling with the liquid.

5. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube-string within the pressure line, with a check-valve for passing the liquid discharged upwardly from the pump-chamber, means for reciprocating the flow-tube, a valve-chest of restricted diameter in the pressure line, an upper valve-head carried on the flow-pipe and capable of filling the bore of the valve-chest, and a lower valve head in the valve-chest carried on the flow-pipe filling the bore of the valve-chest, the lower valve head having ducts extending completely through the same from end to end, said pressure line having outlet ports through the wall thereof all located at a level between the said valve-heads when the flow tube is at about the bottom of the stroke, the lower end of said upper valve-head having an inclined shoulder, said flow line tube string operating in the upper portion of its stroke to raise said inclined shoulder sufficiently to enable the operating fluid to descend past the inclined shoulder and through said ducts, to admit the operating fluid into the pump-chamber and displace the liquid therein and impel the same upwardly through the check-valve, and said heads cooperating with the said ports during the lower portion of the stroke to vent the operating fluid left in the pump-chamber, up through the said ducts and through the said ports into the well.

6. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube string within the pressure line, with a check valve for passing the liquid discharged from the pump-chamber, means for reciprocating the flow tube, valve means including spaced valve heads carried by the flow tube, said pressure line having a plurality of outlet ports passing through the wall thereof at a level between the said valve heads when the valve means is in its mid-stroke position, said valve means and said outlet ports cooperating to vent the pump-chamber into the well in one position of the valve means, and to admit the operating fluid in another position of the valve means, into the pump-chamber to discharge the liquid therein through the said check-valve against the static pressure of the column of liquid in the flow tube, and a plurality of booster nozzles spaced from each other up the flow pipe, each with a pressure-controlled valve for admitting the operating fluid from said pressure line, each of said pressure-controlled booster valves being a differential pressure-controlled valve, and having means for setting the same to open at any desired differential pressure, said booster nozzles and their valves operating to accelerate the upward flow of the ascending column of liquid in the flow pipe and reduce the static pressure on the said check valve.

7. In well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface, for carrying operating fluid under pressure, and having a pump-chamber therein, with a foot-valve through which the pump-chamber fills from the pool being pumped, a flow-line tube-string within the pressure line, with a check-valve for passing the liquid discharged from the pump-chamber, means for reciprocating the flow tube, valve means including spaced valve heads carried by the flow tube, said pressure line having a plurality of outlet ports passing through the wall thereof at a level between the said valve heads when the valve means is in its lower stroke position, said valve means and said outlet ports cooperating to vent the pump chamber into the well in one position of the valve means, and to admit the operating fluid in another position of the valve means, into the pump chamber to discharge the liquid therein through the said check-valve against the static pressure of the column of liquid in the flow tube, and a plurality of booster nozzles spaced from each other up the flow pipe, each with a pressure-controlled valve for admitting the operating fluid from said pressure line, each of said pressure-controlled booster valves being a differential pressure-controlled valve, and having means for setting the same to open and close at any predetermined desired differential pressure, said booster nozzles and their valves operating to automatically admit impelling fluid directly from the impelling fluid line into the flow line to reduce the pressure when the static load of liquid in the flow line approaches too closely to the pressure available in the impelling fluid line.

8. In a deep well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface for carrying operating fluid under pressure to the liquid-bearing formation, a pump-chamber, a flow line extending down to a low level in the pump-chamber, a check-valve therein above the pump chamber,

a control-valve with means for venting the upper end of the pump-chamber into the formation to discharge the spent operating fluid and permit the pump-chamber to fill with the liquid to be pumped, said control-valve having means operating thereafter to effect the admission of the operating fluid under pressure from the tubular pressure line into the upper portion of the pump-chamber to displace the liquid being pumped, and force the same up the flow line, said control-valve being devoid of means for admitting the operating fluid directly into the flow line above the pump; means for operating the control valve, and differential pressure operated valve means independent of the control-valve located at a plurality of points up the flow line above the pump for admitting the said operating fluid under pressure into the flow line to reduce the static head against which the liquid is delivered from the pump-chamber into the flow line, thereby enabling the pump-chamber to operate with a reduced quantity and pressure of operating fluid relative to that necessary to overcome the normal static head that would otherwise exist at the pump-chamber.

9. In a deep well pumping apparatus, the combination of a tubular pressure line extending down from the earth's surface for carrying operating fluid under pressure to the liquid bearing formation, a pump-chamber, a flow line extending down to a low level in the pump-chamber, a check-valve in the flow line above the pump-chamber, a control-valve with means for venting the spent operating fluid from the pump-chamber into the formation to permit the pump-chamber to fill with the liquid to be pumped while the pump-chamber is vented, said control-valve having means for thereafter effecting the admission of the operating fluid under pressure from the tubular pressure line into the upper portion of the pump-chamber to displace the liquid being pumped and force the same up the flow line, said control-valve being devoid of means for admitting the high-pressure operating fluid directly into the flow line; means for operating the control valve and a plurality of booster nozzles spaced apart from each other up the flow pipe, each having a differential pressure controlled valve with a spring urging the valve to closed position and operating to open only upon the existence of a substantial difference of pressure between the interior of the flow-pipe and the pressure line, for admitting the operating fluid from the pressure line to the interior of the flow line to accelerate the upward flow of the liquid column.

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