The Utilization Of The Free Piston

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Since the start of gas-lift, especially intermittent gas-lift, the need was felt for something to go between the base of a liquid slug and the gas that was pushing it up a pipe.

In the absence of such a solid interface, slippage loss is proportional to the time spent in getting the slug from the bottom to the top of the well; it is proportional to the area of the pipe bore, and is affected to a lesser extent by viscosity.

As the well depth increases, the maintenance of a reasonable degree of efficiency demands longer slugs so that the amount produced at the surface will not be an unreasonably small proportion of the slug that started from bottom, and also demands highest reasonable velocities to minimize the time spent in travelling; both demands are for gas pressure.

The relationship between the velocity achieved and the pressure beneath the slug is illustrated by the graph of Figure 1 in which the horizontal scale is velocity in feet per second and the vertical scale, the percentage pressure excess over the static head of the slug. This graph is derived from a commonly used formula for the flow of oil through horizontal pipe.*

$$Q = 34.5\sqrt{\frac{D^5 \cdot P}{G \cdot L \cdot F}}$$

By substituting pressure excess over slug head in place of the pressure drop "P" for the continuous flow through a pipe of slug length "L" at velocity corresponding to "Q" volume units per hour, we have:

$$P = \left\{\frac{Q}{34.5\sqrt{\frac{D^5}{G \cdot L \cdot F}}}\right\}^2$$

*Meyer, Percy: Journal Institute Petroleum, Englind, Vol. 30, No. 242).

This curve clearly shows the need for compromise between conflicting need and shows why the lifting efficiency of the gas gets less and less and working pressure gets higher and higher as depths increase.

The basic function of the Free Piston is to provide a solid interface between the oil being lifted and the gas that is lifting it and put an end to these difficulties thereby opening the way to better gas lifting techniques.

There are four general groupings of oil well conditions each requiring different Free Piston characteristics which are:

I. Flowing wells that are troubled with paraffin depositing in the tubing.

II. Gas wells that make water which the gas flow cannot lift and which accumulates and restricts production.

III. Oil wells producing on the stop-cocking principle but subject to periodical loading up, especially where there is water or gas/oil ratio too low to maintain production.

IV. Stripper wells.

Figure II—A free piston for the automatic cleaning of the tubing string in a flowing well is shown here diagramatically. It has a packer (1) capable of being reduced in diameter to let the Free Piston fall freely, and of being expanded to the I.D. of the tubing for coming up to surface. The packer is by-passed by the central flow passage (2) which can be opened for going down the well and closed by sliding sleeve valve (3) for coming upwards.

The movement of the inner rod (4) downwards, simultaneously opens the valve (3) and stretches the packer; upwards, it closes the valve and compresses the packer through spring (5). The rod (4) is moved by the piston (6) on which pressure differences act.

If the pressure in the tubing head of a flowing well is 500 psi and at a depth of 2,000 feet it is 1000 psi, a dome pressure of 750 psi above the power piston (6) would make available a downward thrust due to 250 psi differential when the Free Piston was at the top of the well and a similar upward thrust when the Free Piston was at the 2,000 ft. level. This is adequate for the power needed to move the rod (4).

A tubing stop is placed at a depth below any paraffin deposits and the mechanism (7) when it contacts the tubing stop, releases the accumulated force and effects the instantaneous closing of valve (3) and expansion of packer (1) so that the fluid flow can bring the Free Piston to the surface wiping the tubing string as it goes.

The mechanism (8) performs a similar function at the top, releasing a downwardly acting force accumulation when the Free Piston reaches the lubricator.

This type is fully automatic and will go on making round trips indefinitely without interrupting the flow and without any surface controls whatever. The frequency of round trips depends on the fluid flow velocity, the volume of gas present in the fluid column and the depth of the stop. It may vary from one trip per day to perhaps 30.

Where the potential frequency is unnecessarily high, the Free Piston can be retained at the surface each time it arrives and released for another trip at pre-selected times by a clock control mechanism coupled to the catcher (9) pneumatically.

Where one trip per day is sufficient to keep down paraffin, the catcher, of course, could be manually released and immediately re-set to catch again.

This packer, Figure III., contacts the inside surface of the tubing over a wide area to bridge collar gaps. The outward radial pressure set up by the packer spring is enough to ensure a satisfactory seal. The whole circumference of this packer changes inversely as the length is changed. The mean diameter of the 2" unit can be changed from 1-7/8" to 2-1/16" by hand alone while the shape is completely free to maintain a perfect seal in pipe which is out of round.

Figure IV. illustrates the equipment for the de-watering of gas wells. In the lubricator at the top, the Free Piston is held up by the gas flow above the flow outlets. Periodically a controller closes a motor valve on the flow line for a short time, say 20 minutes for a 7,000 foot well, then reopens it. During this time the gas column in the tubing is static and the Free Piston falls through it at about 9 feet per second. At bottom it sinks through an accumulation of water at 1 to 2 feet per second to a bottom stop. When the flow line is re-opened all the water above the Free Piston is produced with the gas flow and the Free Piston remains at the top until the next cycle.

This Free Piston is fitted with a packer (1) similar to the one described, except that there is no mechanism for compressing it, the diameter being less than that of the pipe. A buffer spring (2) at the base of the unit protects both the Free Piston and the bottom stop if it falls in the absence of any liquid accumulation.

If a packer occupies 95 percent of the area in a pipe the remaining annulus around it is too small to allow gas to pass upwards and liquid to pass downwards simultaneously and so there is no liquid "lost" when a perfect shut off is not necessary. In gas wells, the upward flow of gas past the packer is obviously unimportant so long as it is well above the minimum required to lift the Free Piston. The ability of the packer to assume out of round shapes permits its use at a larger mean diameter than the largest solid round body that could travel freely in the same pipe.

In many installations of this type of Free Piston the well no longer requires to be taken off production and blown to atmosphere or "purged" at regular intervals. The water level is maintained much lower and the liquid production, now collected in a separator instead of being blown away, very often includes useful quantities of distillate that was previously lost. In almost all such installations the production has been appreciably increased, sometimes over 100 percent increase being recorded. Total installation costs are usually recovered in from 3 to 9 months.

I would like to refer those interested in this type of well to a paper on this subject presented by Lebeaux and Sudduth at the last fall meeting of the A.I.M.E. petroleum branch.

Figure V. For stop cocking oil wells, the Free Piston packer is given a mean diameter nearer to that of the tub-

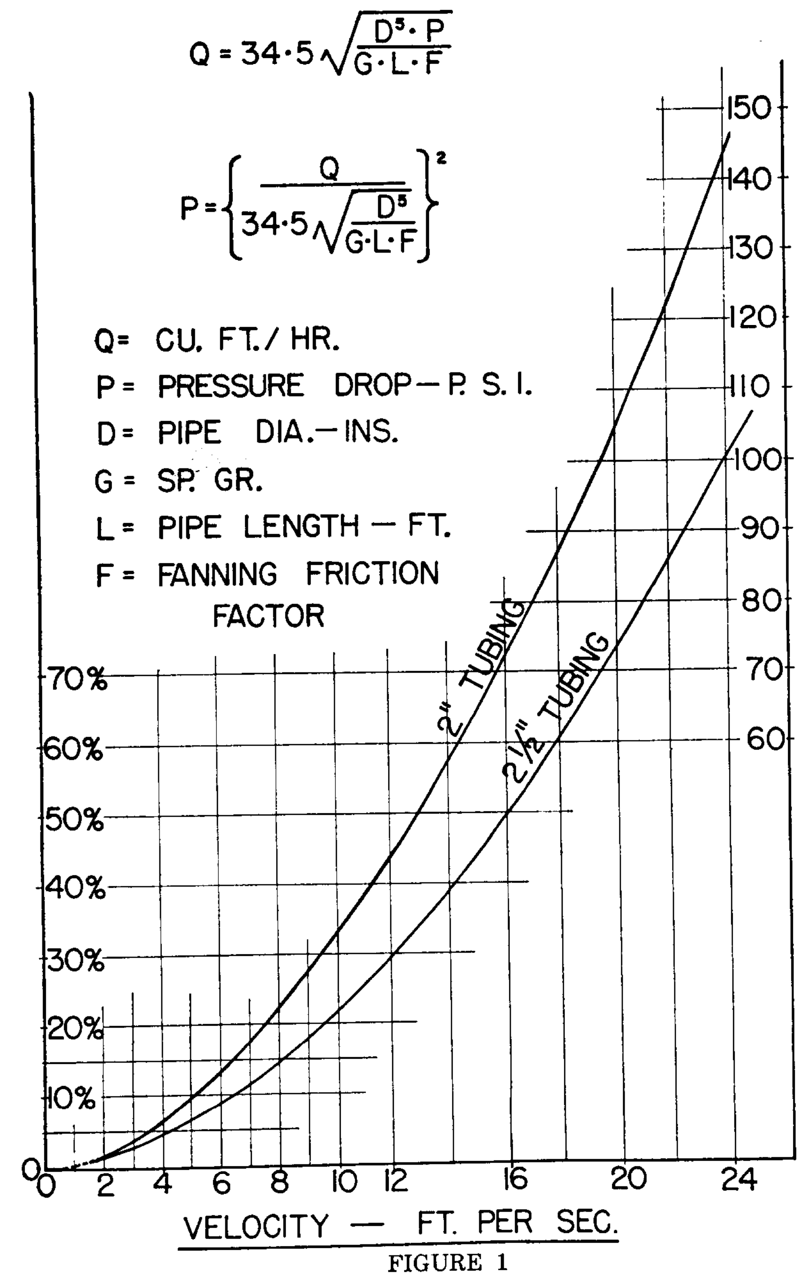

FIGURE 1

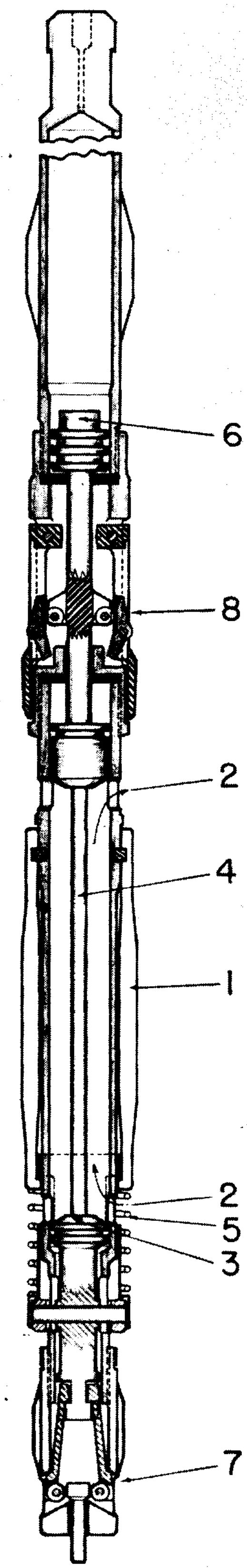

FIGURE 2

ing bore since the upward velocity of gas for lifting it will be less, and since slippage loss is not so negligible as in the one previously described. To enable this unit to make a satisfactorily high number of trips in a day, it is fitted with a valve (1) which is open while falling down the well and it has a packer by-pass passage (2) up through the interior. A tubing stop at bottom is provided and when the Free Piston reaches it, the valve is closed on contact. During the interval between cycles, the fit of the packer in the tubing, while the Free Piston is at rest, is slack enough to let fluids fill up into the tubing but when the Free Piston is falling down the well and when it is being raised up, the pressure difference across it due to the weight of the Free Piston, the same differential in both directions, expands the packer just that little extra that is required to provide a satisfactory seal.

Figure VI. When the Free Piston reaches top of the well, the floating rod (3) contacts the spring buffer (4) and as its mass is much smaller than that of the buffer or of the Free Piston, it is moved relatively to re-open the valve (1) and allow the Free Piston to fall down the well again. The controller (5) mounter on top of the motor valve (6) on the flow line has a clock driven wheel with 180 slots on its periphery and revolves normally at the rate of one revolotion per day The number of pins placed in selected slots evenly spaced determines the cycle frequency as each pin on coming round to a common point, opens a pilot valve which transmits pressure gas to the diaphragm and opens the motor valve. The pilot once opened is maintained open by a latch which can be released in four different ways to effect the re-closure of the motor valve. In stop-cocking wells, the Free Piston on its arrival at the lubricator, moves a feeler (7) which operates a pilot valve (8) which is connected pneumatically to a latch tripping unit (9) in the controller. Thus the motor valve on the flow line is closed when the Free Piston reaches the surface. This ensures perfect timing and maximum efficiency. The tripping of this latch, re-closing the motor valve, can also be performed on the expiry of a pre-determined time interval which can be adjusted accurately to within a second or so. It can also be effected by a fall in casing pressure to preset low, or a rise to a preset high. Thus if the well makes more gas than the lifting of the production requires, the motor valve, after the Free Piston is up, can be kept open until the cas-

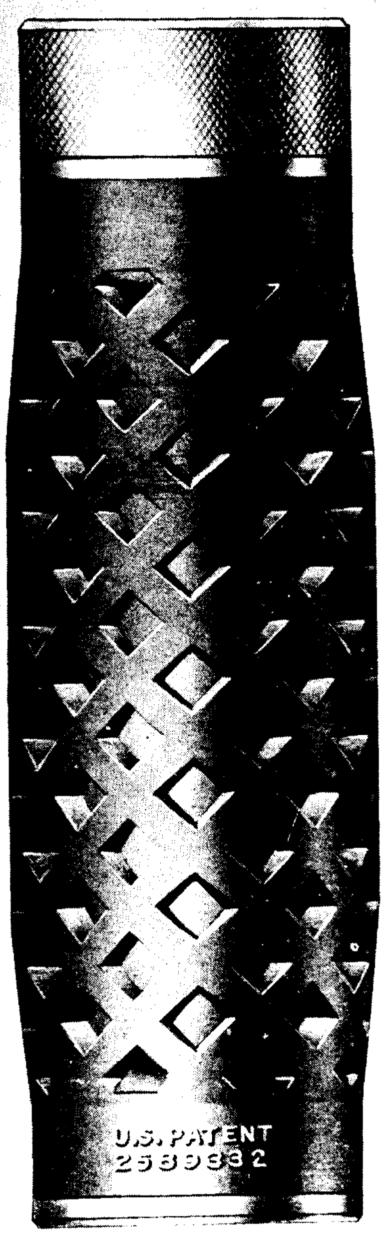

FIGURE 3

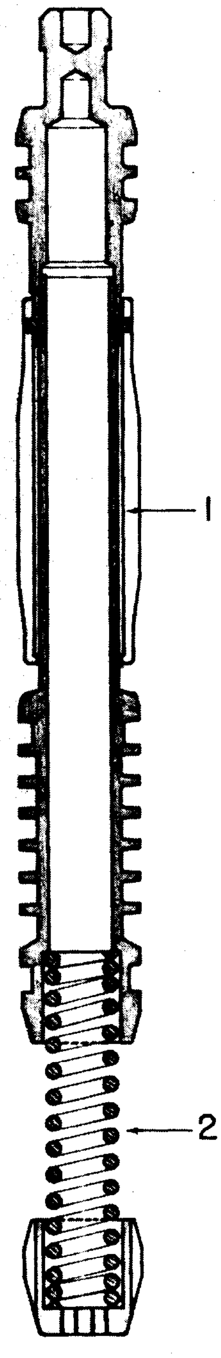

FIGURE 4

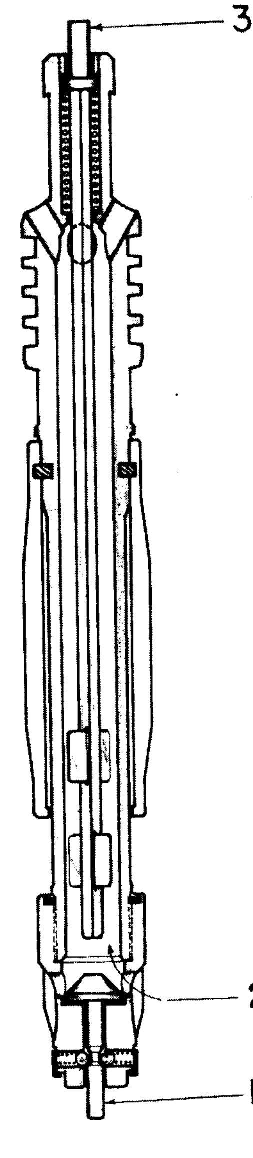

FIGURE 5

ing pressure reaches a selected constant.

When the motor valve on a stop cocking well closes, the casing and tubing, both full of gas, are at nearly the same pressure. If both the casing and tubing remain closed, fluid accumulation raises both fluid height and gas pressure in each. If the tubing is relieved of gas pressure by an amount equivalent to the static head of the anticipated slug length, virtually all the fluid accumulation will be in the tubing and none in the casing when the next cycle starts.

Bleeding of the tubing pressure is occasionally impracticable due to freezing in cold weather but is beneficial whenever it is possible.

Figure VII illustrates the type of Free Piston used in chamber gas lift installations in stripper wells. This Free Piston has a pre-inflated chamber (1) with piston (2) connected by a rod (3) to a valve (4) which opens and closes the bypass parts (5). A crosshead pin (6) links valve (4) with an external sleeve (7) for stretching the packer (8) when it moves downwards and an interposed spring (9) expands the packer when the valve (4) moves upwards and closes the by-pass. A plunger (10) is also carried by the crosshead and cooperates with the spring toggle (11) to provide delayed and "snap" action.

In the well, the tubing string has an insert chamber below the packer or a lower chamber comprising the space between two packers. Above the upper packer a wire line retrievable gas lift valve is situated in a by-pass mandrel. The Free Piston at the bottom of its stroke rests on top of this gas lift valve. For illustrations and further details, I would refer you to standard catalogs.

In operation at the commencement of a cycle, the tubing pressure is low, having exhausted down to the separator or flow line pressure, and the casing annulus is holding the pres-

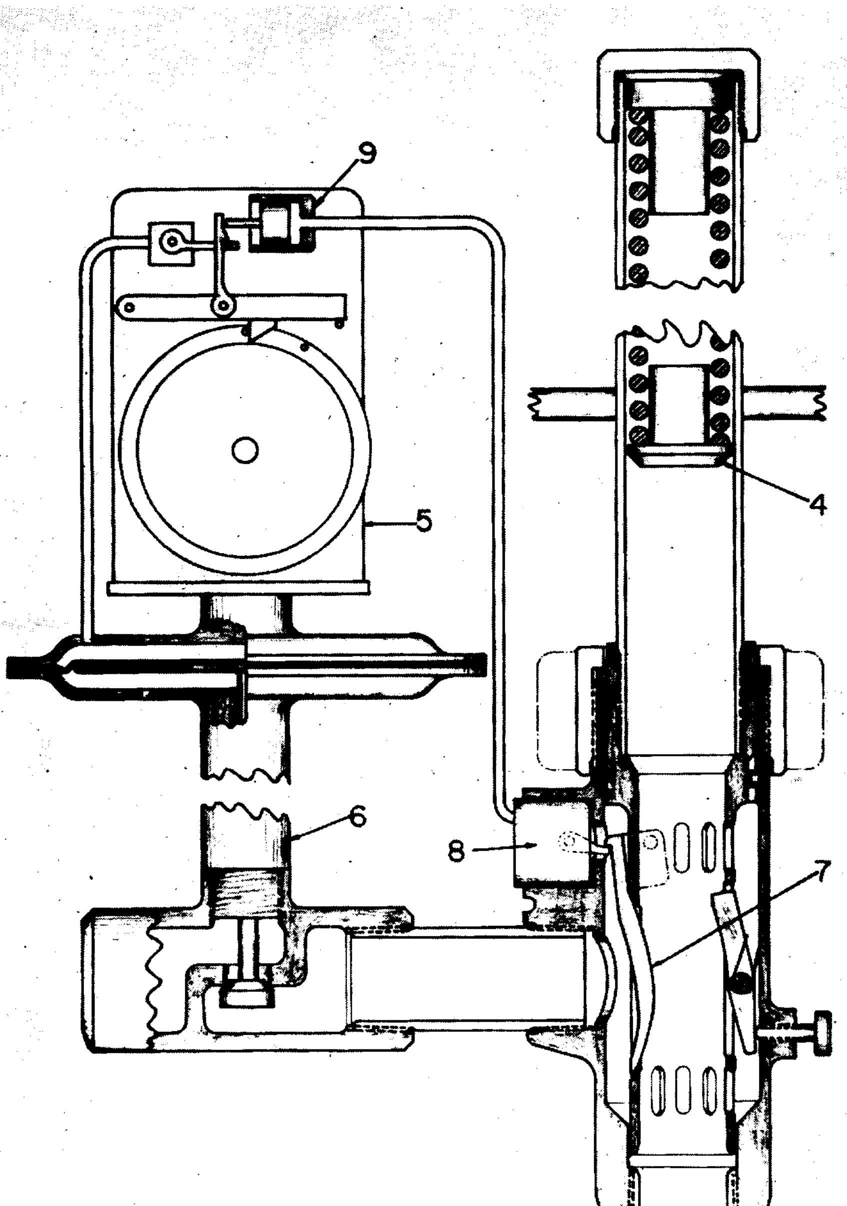

FIGURE 6

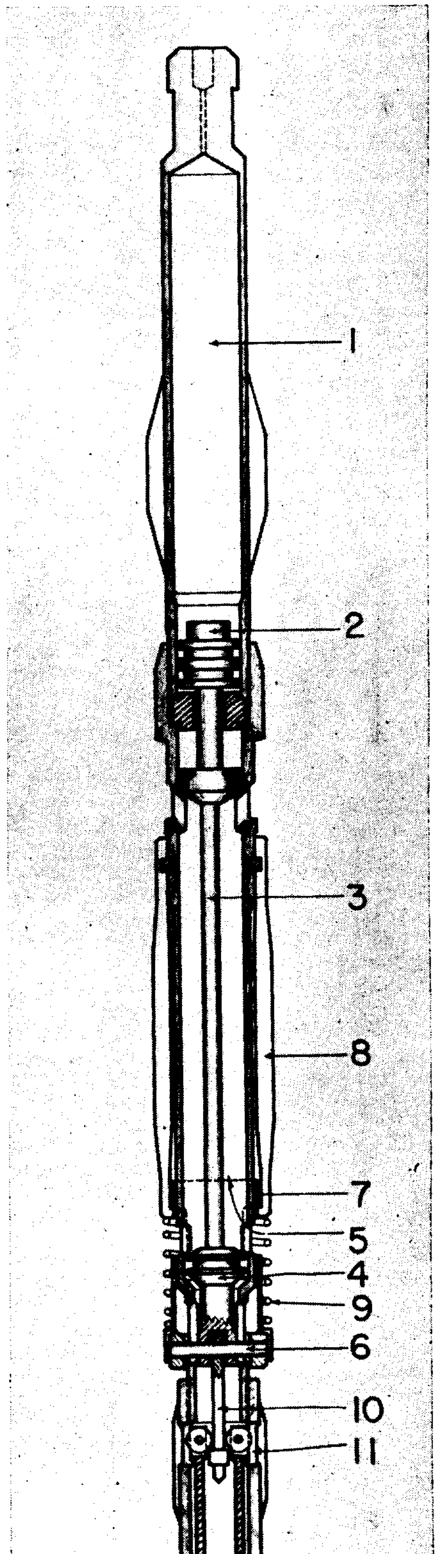

FIGURE 7

sure at which the working valve closed. Fluid from the formation fills the lower chamber through a standing valve while gas is allowed to escape to the tubing through a bleed. When a flow cycle is commenced by the clock controlled motor valve at the surface admitting gas at pressure to the casing, the casing pressure first rises through the range of spread provided by the gas lift valve, then this valve opens.

Gas then passes into the chamber, and displaces the accumulated oil up into the tubing. The by-pass passage up through the Free Piston remain-open until the head of the slug collected in the tubing above it, pressing upwards on the piston (2) overcomes both the pre-inflated dome pressure and the resistance of the spring toggle. The inner piston rod assembly then moves up rapidly closing the by-pass at the sleeve valve (6) and expanding the packer.

It is satisfactory to arrange the dome pressure primarily, considering bottom hole temperature, so that its thrust on the piston (2) plus the toggle constant together equal the static head of the slug. The slug, of course, is the daily production divided by the number of cycles per day.

The gas pressure used to lift the oil is higher than the static head of the slug by an amount that will give the slug a reasonable and satisfactory velocity as shown in the graph Figure I. As oil is being displaced from the lower chamber, the pressure around the Free Piston in the tubing is virtually the head of the accumulated slug but when all the oil is displaced and gas follows on through, the resistance to the flow of gas thru the valve, the lower chamber, and the macaroni, at the same velocity as the oil ahead of it, is very much smaller than that of the oil. The pressure around the Free Piston thereupon rises to the full gas working pressure providing an ample margin for closing it and accelerating it upwards.

The flow line from the well head is provided with a choke of about 1/2" in 2" line to prevent a high finishing velocity and to ensure the maintenance of gas pressure around the Free Piston to keep it closed until after it reaches the surface and permits bleeding down some of the tubing pressure that raised it.

This type of Free Piston makes possible very efficient stripper pumping in deep wells with comparatively low available gas pressures which would otherwise have been quite insufficient for gas lift alone.

The input of gas to the casing is usually shut off as soon as casing pressure reaches a pre-selected high after which the expansion lifts the slug, the gas valve at bottom closes, the tubing exhausts back down to separator pressure, the Free Piston returns to bottom and the lower chamber refills. It is thus possible to pump a very deep, low pressure stripper well with a very high efficiency, very low operating casts, and an equipment cost of the order of one-twentieth of that of a rod pumping equipment for the same duty.

If 100 percent volumetric efficiency is taken to be the production, by 100 psi gas pressure, of a slug whose static head is 100 psi, a Free Piston of this type has operated at over 90 percent volumetric efficiency.

Conclusions

Wherever fluid is lifted by gas, the lifting power of that gas can be utilized to much better advantage with the Free Piston.

The demand for higher and higher gas pressures with straight gas lift as the depth of the well increases has always had to be reconciled with the cost of the gas which has been steadily increasing. Yet straight gas lift has such advantages over rod pumping that the diminishing of volumetric efficiency with depth has not hindered its general acceptance for wells of all depths.

With the Free Piston, however, the rules for longer slugs, higher velocities and higher pressures no longer apply. The volumetric efficiency of the system can be at once raised to about 70 percent and the reduction due to friction to gas flow as depths increase is insignificant at low velocities and this efficiency can then be maintained at all depths.

More important, the cost of a Free Piston installation for a 12,000 foot well is the same as for a 2,000 foot well, that is, under $1,000.

Lastly, the elimination of paraffin scraping problems due to deposit inside the tubing strings, has been 100 percent up to date and has often eliminated scraping costs of the order of $200 per month.

There is very little doubt, therefore, that the utilization of the Free Piston will continue to increase in a growing variety of well conditions as the four general types here mentioned develop further with field experience and improve in design and performance.