IMPROVING THE EFFICIENCY OF SUCKER ROD PUMPING SYSTEMS IN HIGH GAS LIQUID RATIO WELLS

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INTRODUCTION

The production of high gas liquid ratio (GLR) wells has been a problem for oil producers since the first sucker rod pumping systems (SRPS) were installed. This paper examines three key factors in improving SRPS efficiency in high GLR wells. These include pump design, rod string stability and field operations. Although pump design and field operations are well documented, an attempt is made to clarify these areas. Also, new light is shed in the area of rod string design with special consideration of rod buckling and its associated problems.

GAS EFFECTS

An understanding of how large volumes of gas effect the SRPS is important in eliminating gas gas locking and minimizing gas interference. Many factors influence the systems behavior in gaseous pumping situations. These include the producing pump intake pressure (ppip), the free gas available for injestion into the pump, the gas anchor efficiency and the pump's ability to compress the fluid/gas mixture to the hydrostatic pressure above the traveling valve. These factors will determine whether a pump can compress the mixture to hydrostatic (pump), barely compress the mixture to hydrostatic (gas interference) or not achieve adequate compression (gas lock). Figure 1 exhibits the relationship between pump intake pressure and free gas available for injestion into the pump. This example shows that for a 40^0 API crude / 0.9 SG gas mixture a large quantity of free gas exists from a ppip of zero to 200 psi. As the intake pressure increases, gas is driven back into solution and the amount of free gas is far less. Therefore, a means of separating the free gas from the producing stream must be used (i.e. gas anchor). If a gas anchor system is ineffective or not installed, free gas can only be reduced by designing the SRPS to produce with a slightly higher ppip than usual. Furthermore, the gas which is injested into the pump requires compression in order for the travelling valve to open. The amount of compression is dependent upon the gas compressibility and the oil/water compressibility. However, the gas compressibility is of greatest interest because gas is far more compressible than oil or water. In order to produce efficiently and effectively, we will explore pump design, rod string design, and field operations to insure adequate compression and optimized system efficiency.

PUMP DESIGN

Efficient pumping of a high GLR well begins with proper pump design. A thorough understanding of the reservoir fluids' behavior is required to insure the pump installation will function properly. If a well is gaseous, the compression ratio (CR) produced by the pump becomes very important:

$$CR = \frac{V_{swept} + V_{unswept}}{V_{unswept}}$$

Where V_{swept} is the volume swept by the plunger and $V_{unswept}$ is the volume between the standing and traveling valves at the bottom of the downstroke. Figure 2 is an example of the compression ratio required to produce pressures in the pump which exceed the confining hydrostatic pressure. This example shows that for this oil producing well, the gas volume directly defines the amount of compression required to overcome the hydrostatic pressure. The figure shows that with a differential pressure of 1970 psi across the travelling valve, the quantity of gas has little effect on the required pump compression until the gas occupies 90% or more of the pumping volume. At 95% of the pumping volume, the compression ratio required exponentially increases. If the gas volume occupies 100% of the pump, then the gas cannot be pumped with a compression ratio of less than 70. Since we are not only interested in physical production but also efficient production, a high percentage of free gas must be liberated up the annulus with a gas anchor system and the compression ratio must be maximized to achieve the highest volume displacement possible. After all, pump efficiency is based on volume displacement compared to actual production. If the gas volume moved through the pump is considered, then typical pumping efficiencies are fairly high when the pump is in good condition. Since free gas does not require artificial lift for production, energy which is expended through the SRPS for gas production is unnecessary and decreases overall efficiency. For this reason, we must redefine the system efficiency to account for wasted energy through gas production. This definition does not rely only on the classical pump efficiency definition of "fluid in the tank" versus pump displacement volume.

In order to maximize the compression ratio, the pump must be designed with the longest stroke which will accommodate the SRPS. The pump plunger diameter has no bearing on the compression ratio (assuming equal spacing). Figure 4 exhibits the fact that longer stroke lengths achieve higher compression ratios. This example represents a pump with the traveling and standing valves spaced 2" apart on the downstroke. As seen, the increase in pump compression is linear with an increase in pump stroke. For the previous example of Figure 2 and if the pump is injesting a 98% gas to 2% oil mixture, a pump with less than a 62" stroke will most assuredly gas lock. When the stroke length increases above 62", the pump's ability to move fluid also increases.

Pump manufacture must be accomplished with the above design considerations in mind. Pumps should be fitted with pull rods or tubes which allow for very close spacing (2" or less if possible) between traveling and standing valves. This means that pump repair shops should not reuse pull rods or tubes which have been shortened. Although this practice appears to save money on repairs, the pump's ability to compress gas is reduced. Also, loose tolerances (0.005" to 0.015" under) should be employed between plunger and barrel to increase fluid slippage (providing lubrication). This may seem contradictory to high efficiencies, but loose tolerances keep gas locked pumps from becoming damaged from a lack of lubrication and will reduce long term wear. Also, the increased slippage decreases the gas to fluid ratio slightly and reduces the compression necessary to eliminate gas locking.

Finally, in considering pump design and hardware, mechanically actuated travelling (or "smart") valves must be discussed. It is the opinion of the authors that although these valves are effective in preventing gas locking, efficiency is severely hampered by masking of the gas volume effects. In other words, a SRPS may be kept pumping, yet very little fluid is produced. The mechanically opening valves do not lend themselves to better pump designs and practices. Therefore, a more conservative approach of maximizing compression ratio (CR) and optimizing the gas anchor assembly is recommended. If gas locking persists, then the pumping system must be re-evaluated for effectiveness. A different type of artificial lift may be necessary (i.e. plunger lift).

ROD STRING DESIGN

In the last few years, a better understanding of rod string design has come to light. The main reason for this is that research with downhole load cells (DHLC) has allowed the quantification of compressive forces seen by the rod string. Work with the DHLC now gives a means of confirming the accuracy of wave equation predictive programs. Also, theoretical work on rod string buckling is now validated and can be used in stabilizing the rod string. This information can be applied to high GLR wells through better rod string design. Although gaseous wells do not directly cause rod instability, buckling only serves to aggravate the problems immensely.

When designing a rod string for any well, we want the most stable string achievable so that rod failures (ruptures/fatigue) and tubing failures (rod wear) are greatly decreased. However, in a high GLR well, we must also consider the effect of instability (buckling) on the pump's compression ratio. When rods experience buckling, additional friction is added at the bottom of the rod string. This friction causes a decrease in pump stroke as shown in Figure 3. As buckling becomes more severe in the rod string, rod to tubing friction also increases. As the rod string experiences greater frictional loading, the pump stroke begins to decrease. Even if a pump can be respaced to minimize the unswept pump volume while severe buckling is occuring, the compression ratio is still reduced. Figure 5 demonstrates this fact through a typical SRPS setup. The conventional C640 pumping unit is operating at 8 SPM with a 120" surface stroke. At 5480', the pump will stroke at 104" under normal operation. However, if the lower rods experience 550 lbs of frictional loading, the stroke length decreases to 101" and the compression ratio also decreases. If the free gas volume is high, then the pump may gas lock from only this small change in compression ratio. For a shorter pump stroke, this effect is even more pronounced.

Although friction is the primary reason for a loss in pump stroke, the buckled rod string itself also looses overall length due to the helical shape it assumes. Although this loss usually accounts for only 2 to 3 inches (in most of buckling modes) for typical rod strings in 2.875" or smaller tubing strings, the compression ratio will once again be lowered from the reduced pump stroke length. In large diameter tubing strings (3.5" or greater), the length loss may become much greater and will be a major factor.

$$L_{loss} = \frac{12\ L_b}{pitch} \left[\left(pitch^2 + (pi\ (d_t - d_r))^2 \right)^{1/2} - pitch \right]$$

To optimize the rod string stability and design, a wave equation program must be utilized. In addition, a buckling analysis should be performed to insure no buckling will occur. The system should be designed with a long, slow stroke to maximize the pump's CR and to minimize rod string instability. Also, when the rod string is not stable as designed, large diameter sinker bars must be considered. The large diameter will help to prevent buckling of the string.

FIELD OPERATIONS

When a pump has been designed and manufactured properly and the rod string has been stabilized, proper field implementation will insure the success of efficient operation. To properly produce a gaseous well depends on the correct pump spacing at first installation and after the well has stabilized. In most cases, gaseous wells require adjusting the pump spacing several times. When a well is first hung on, the plunger will stroke higher in the barrel because the plunger load is not as high as in the pumped off condition. After the well has pumped and the ppip is lowered, then the plunger will begin to stroke lower in the barrel (creating higher CR's). However, if the spacing of the valves is not within the desired 2" or less, then the pump's CR will not be sufficient. Figure 6 shows the importance of pump spacing. If the travelling valve is spaced 2" from the standing valve on the downstroke (as designed), then high compression ratios are achieved. However, if the pump valves are spaced 6" apart, the CR is reduced by 67%. For this reason, a pumping assembly may need to be respaced after stabilization has occured. Improper spacing is the most prevalent reason for severe gas interference and gas locking.

With the understanding of why gas locking occurs, we can see the reason for many common practices. Two of the most prevalent are "pounding" the pump and increasing back pressure on the tubing with a back pressure valve. Lowering a rod string to break a gas lock is understood because of the higher CR achieved. However, the damaging practice of "pounding" the pump while producing is not necessary when the well is properly designed and spaced out. When a rod string is lowered so that a pump begins "pounding", the top pull rod or pull tube assembly tags the top of the pull rod guide. Once these assemblies tag at the top of the pump, the traveling and standing valve clearance is at a minimum. Although this practice insures that the spacing is as close as possible for the pump, it damages the pump's components. "Pounding" the pump only shortens the life of the installation.

Another technique commonly employed is the back pressure valve. The valve acts to increase the hydrostatic pressure, which in turn, increases plunger loading, rod stretch and slippage. The increased rod stretch compensates for improper spacing. The increased slippage causes a slight decrease in the ratio of gas to fluid in the pump, which decreases the CR necessary to pump the fluid. Although effective in some situations, a back pressure valve must be evaluated in light of reduced efficiency and increased energy requirements.

Lastly, wells can more efficiently be produced when not over-pumped. The advent of the pump-off controller (POC) has helped to reduce over-pumping. In severe cases, over-pumping will cause a gas lock due to extremely high free gas volumes at the pump intake. Even the best of gas separating devices will not work when only gas is available for pumping. POC's should be set-up to optimize production without maintaining a continuous pump off. This can be accomplished through trial and error or through build-up techniques. The reservoir which is being produced will dictate the most efficient manner in dealing with gas problems. For example, high pressure/tight reservoirs can be produced with longer downtimes and higher ppip's. This allows more efficient production with less free gas. Wells in low pressure/high permeability reservoirs will require effective gas anchor assemblies and greater difficulty in setting the POC. However, if the POC shuts down immediately after a pump off is seen, then the well can be produced while seldom gas locking.

CONCLUSION

Three key factors effect an operator's ability to produce a high GLR well efficiently. These include the pump design, rod string design, and field operations.

A pump must be designed for as long a stroke as possible with the SRPS and with valves spaced as closely as possible. The pump should be designed with a loose plunger to barrel fit (0.005 to 0.015" clearance).

The rod string must be designed to eliminate buckling. This is accomplished through the use of a reliable wave equation program and buckling analysis. Sinker bars may be required to stabilize the rod string.

Field personel must space the well properly initially and then after the well has stabilized.

A POC must be employed and set up to pump the well optimally.

Lastly, wells with excessively high free gas volumes at the pump intake are difficult (if not impossible) to produce. In this case, higher ppip's must be considered so that less free gas is available for injestion at the pump intake.

ACKNOWLEDGEMENT

The authors wish to thank the management of Fiberflex Inc. and Texland Petroleum Inc. for permission to publish this work.

NOMENCLATURE

L_b	= Length of buckled rod section - ft
L_{loss}	= Length lost from buckling - inches
V_{swept}	= Volume swept by plunger - ft ^{3}
$V_{unswept}$	= Volume between traveling and standing valves - ft ^{3}
d_r	= Diameter of sucker rod - inches
d_t	= Inner Diameter of tubing - inches
pitch	= Buckling pitch of rod string - inches

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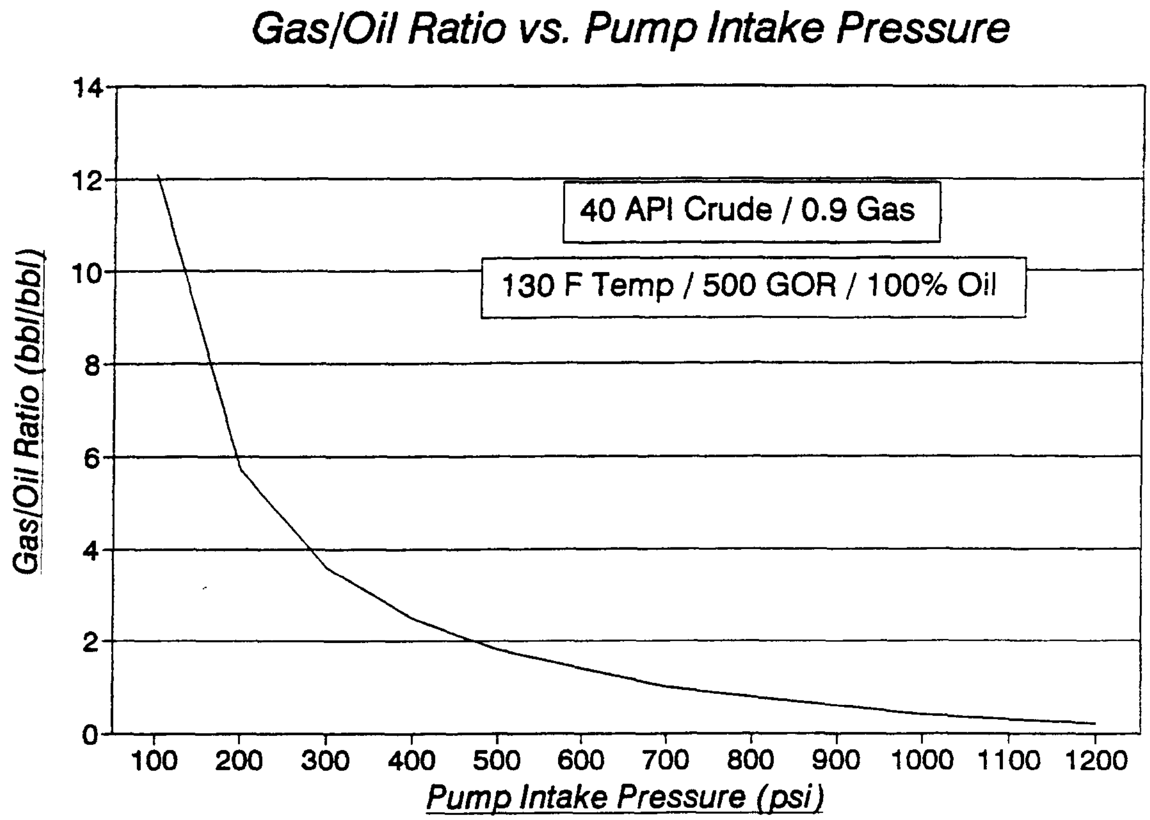

Figure 1 - Free Gas at Pump Intake

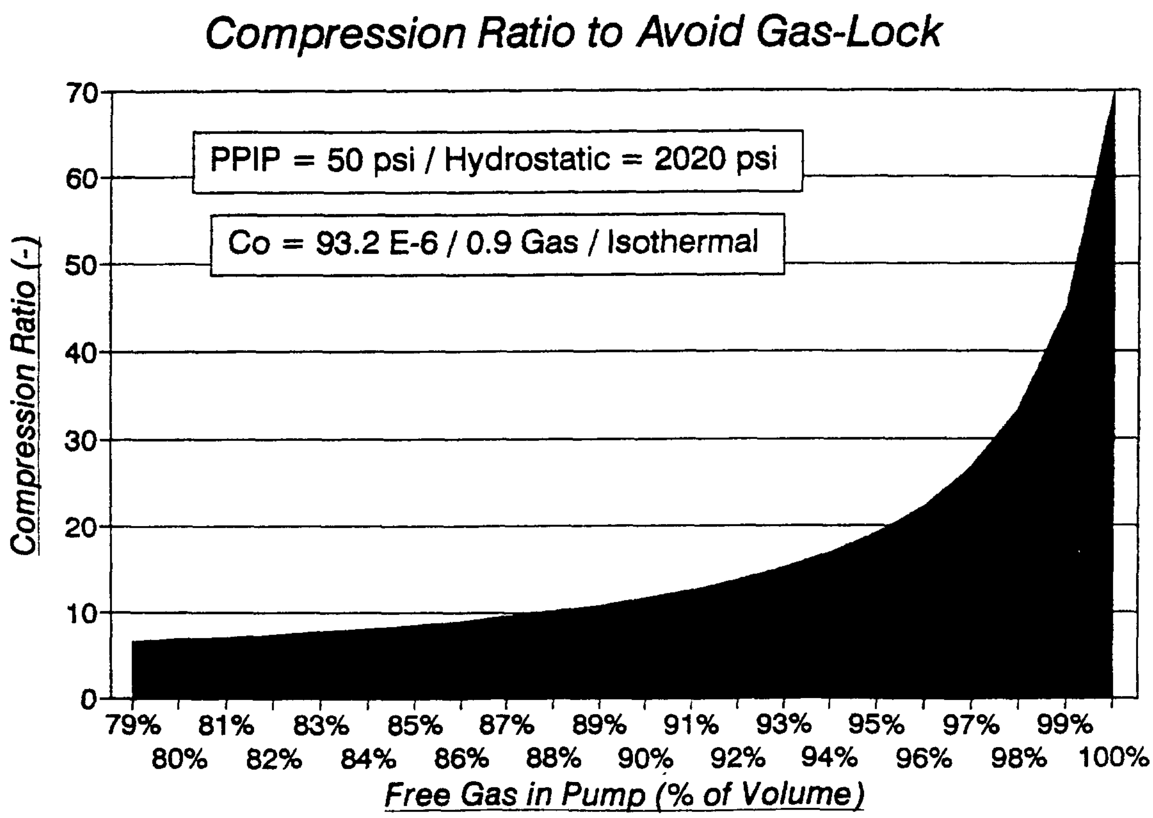

Figure 2 - Compressibility

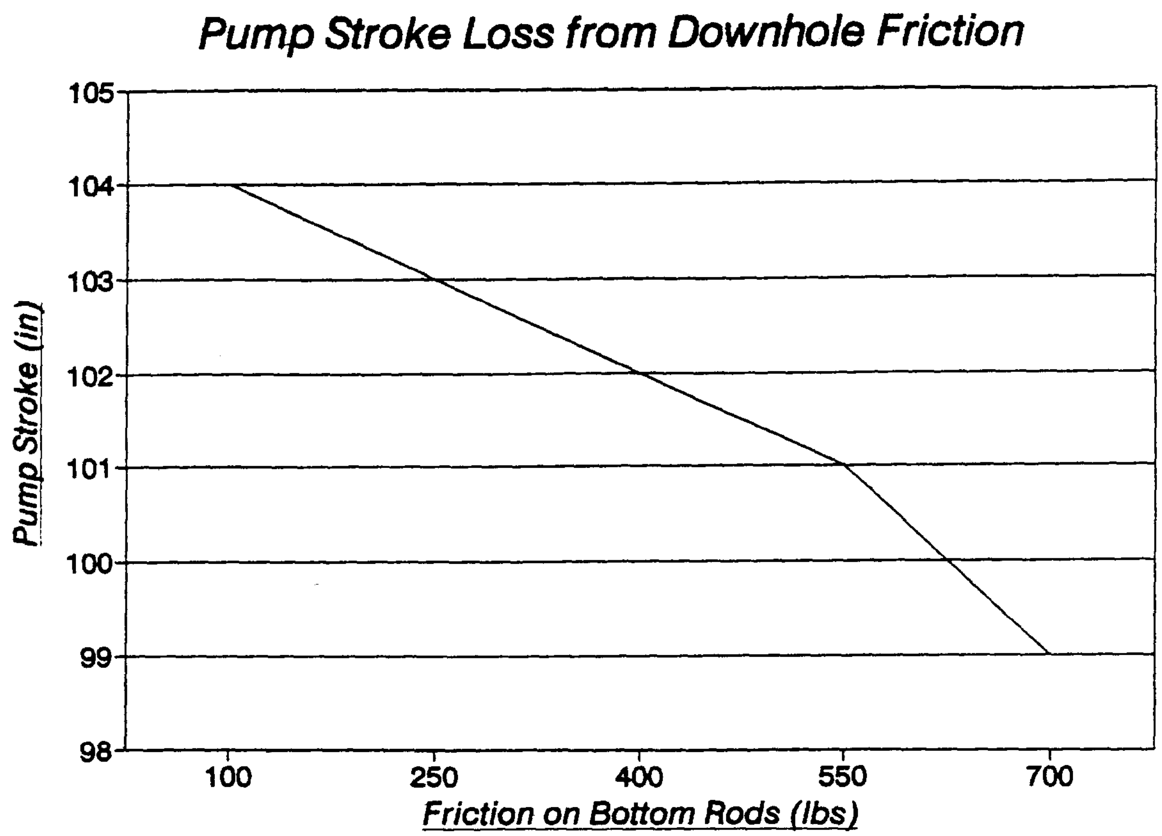

Figure 3 - Friction Effects on Pump Stroke

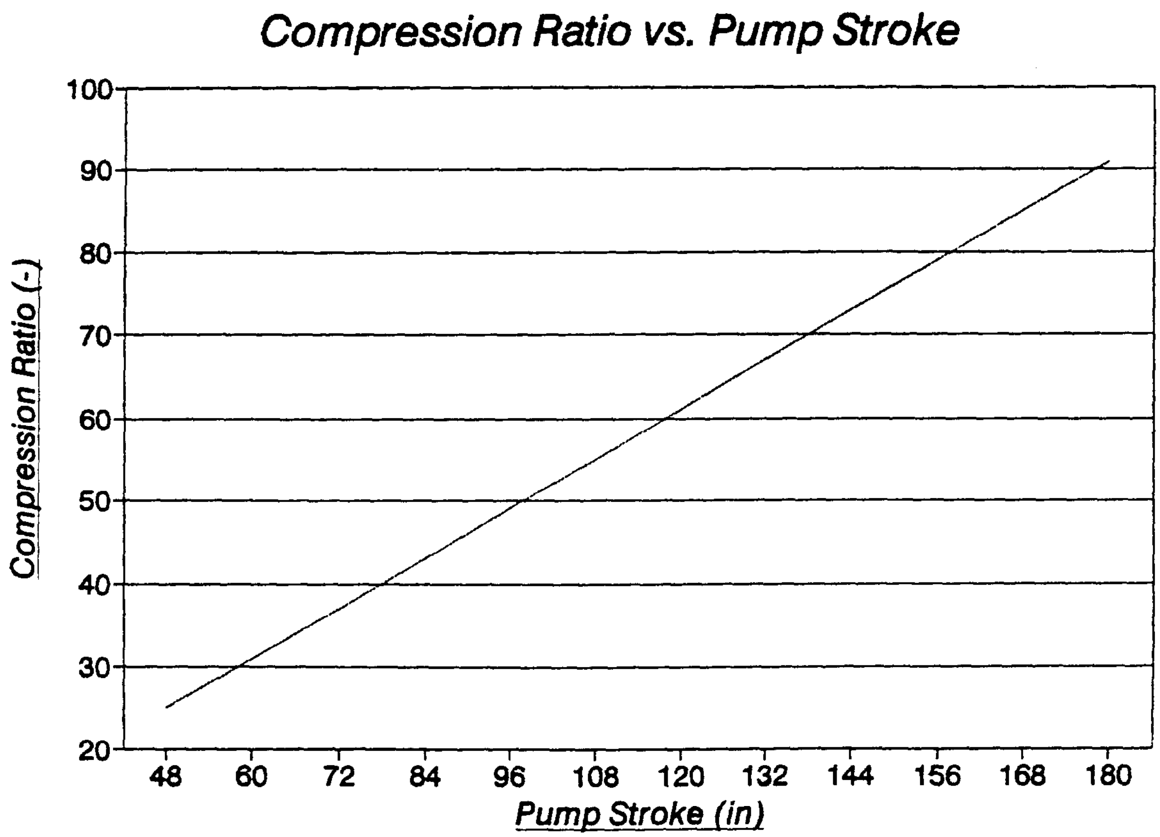

Figure 4 - Pump Compression

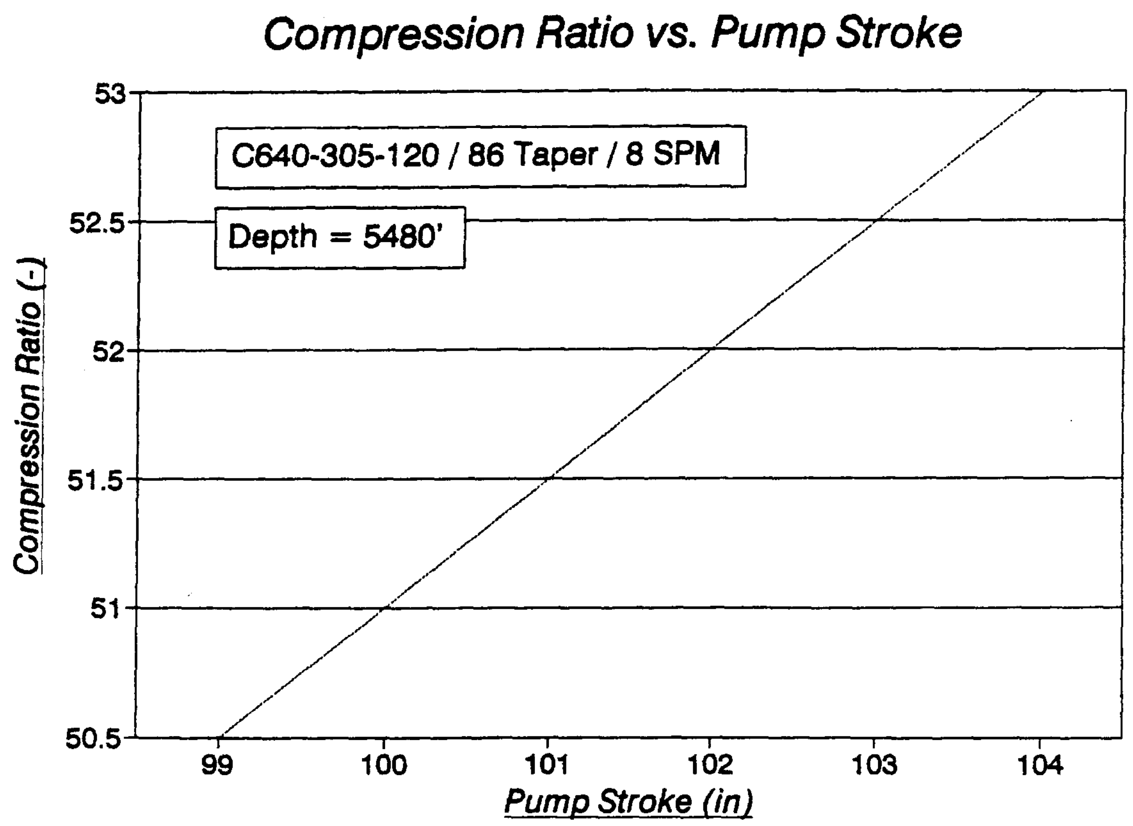

Figure 5 - Pump Compression

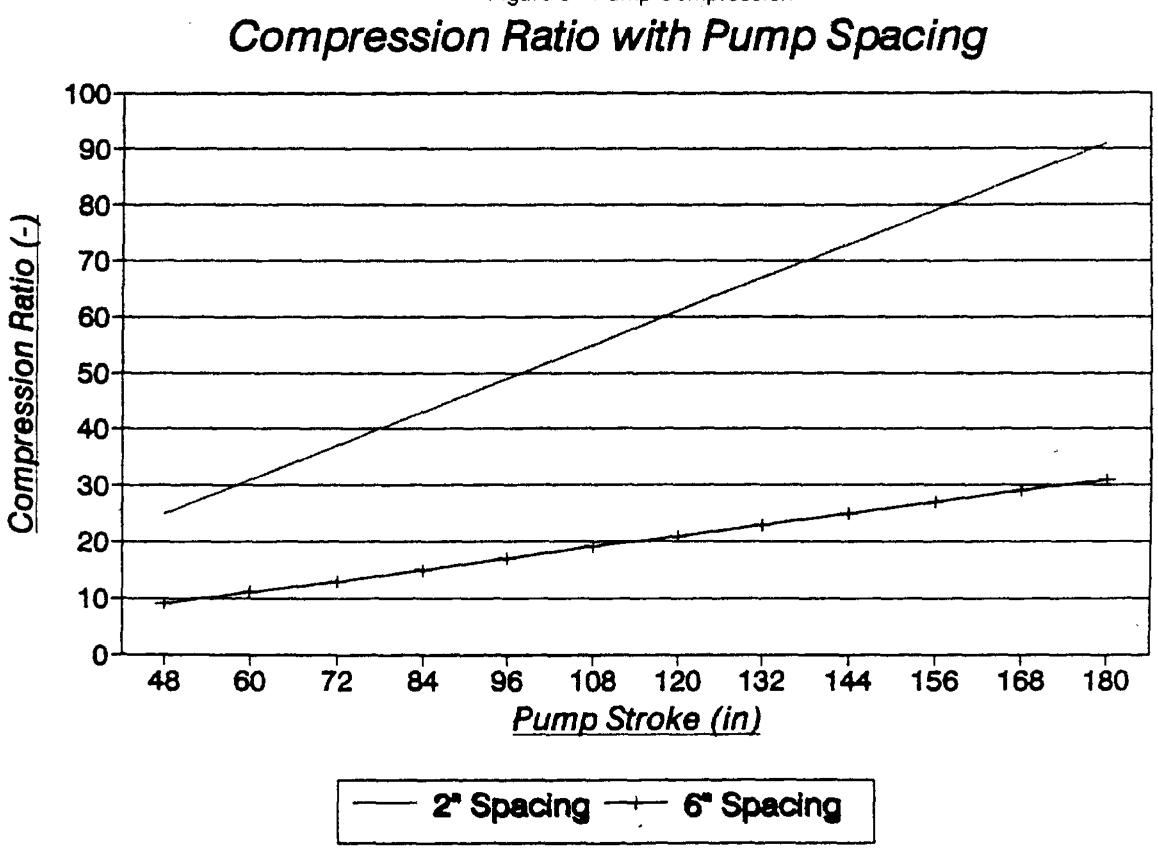

Figure 6 - Pump spacing