GAS ISSUES WITH DOWNHOLE SUCKER ROD PUMP OPERATIONS

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INTRODUCTION

Downhole sucker rod pumps are simple, linear, reciprocating compressors of oil well production, and water and condensate production from gas wells. This class of pump is relatively trouble-free and is resistant to fluid-borne particulates, corrosion, high pressure and varying oil/gas ratios, aided as needed by special metallurgies and/or special pump designs.

Free gas in the compression chamber of downhole sucker rod pumps causes problems with the efficient operation of the pump. At the least its hydraulic efficiency, based on fluid production, is reduced, and at the most the pump does not operate at all or operates intermittently.

Unless otherwise stated, this paper will consider the common, standard sucker rod pump assembly of parts.

MISCONCEPTIONS

Everyone has an opinion about various sucker rod pumps, accessories and operating parameters. Here are a few thoughts about what I consider to be misconceptions:

Double Valves

I have heard over the years that double valves are “double trouble,” “suspenders with a belt,” “insurance,” “double expense,” “good for gas locking,” or “good for particulate production.” Some of these reasons are not arguable since they can’t be proven or are obviously true, but “good for gas locking” is definitely worth arguing. Note that when a double valve is added, that additional compression chamber volume is being added in the traveling valve and standing valve, and the compression ratio of the pump is thus reduced.

The additional, double standing valve does not affect the downstroke compression ratio but theoretically delays the opening of the lower standing valve on the upstroke and gives less time for fluid entry.

Thus, the upstroke of a sucker rod pump has a “decompression ratio” and a job of opening the standing valve(s) soon enough to allow adequate time for fluid entry into the compression chamber on the upstroke. Fortunately, at the start of the upstroke there is likely to be almost solid fluid in-between the traveling and standing valves so that the compression chamber pressure is reduced quickly to the annulus pressure and the standing valve opens right away.

However, on the downstroke, there is probably free or entrained gas in the compression chamber and its compressibility delays or prevents the opening of the traveling valve(s). Double valves in the traveling valves add additional compression chamber volume, and therefore can make gas-locking problems worse.

Double valves being “Good for particulate production” in fluids does make sense because particulates can lodge between the normal, single valve ball and seat, and leak high pressure fluid during part of the upstroke/downstroke cycle. This high-pressure leakage, along with fluid-borne particulates can quickly fluid cut a single valve seat and cause an early pump failure. The traveling valve has this possibility during the upstroke because that is when it is subject to the tubing high pressure across the ball and seat, and the standing valve has this possibility during the downstroke when it is closed and holding the high pressure of the tubing. The addition of a second valve gives the pump the opportunity of having one ball and seat to be free of particulates on the seat sealing face, and holds the pressure when the other valve has particulates in this vital sealing area. These particulates will probably be washed away during the next opening of the valve allowing the two valves to repeat the statistical possibilities of sharing sealing duties during the following stroke.

"Smaller diameter pumps have higher compression ratios"

This is actually a true statement, but not because of the smaller diameter. It will be shown later in this paper that the diameter of a pump falls out of the compression ratio calculations during reduction of terms in the derivation of the compression equation. The actual reason for smaller diameter pumps having higher compression ratios was found to be due to the smaller standing valve volume of a smaller diameter pump. The standing valve operational volume is very influential to the compression ratio of a sucker rod pump.

"If it ain't bumping, it ain't pumping"

This is true with regard to some actual field operations, however it is hard on pumps, rods, tubing and pumping units due to the valve rod bushing at the top of the pump impacting the valve rod guide on the top of the barrel of an insert pump, or impacting the puller and standing valve assembly of a tubing pump. For a tubing pump it can also damage the pulling assembly above the standing valve and make it impossible to pull the standing valve with the plunger. So, does "bumping" or tagging the pump help with gas locking? Maybe not, because of the high pressure holding the valves closed, each in their turn. But because the experience in the field shows an improvement in pumping efficiency in some wells, it is worth considering double valves, because the need for tagging may be due to particulates in the valve ball and seat sealing area when it is their turn to hold the high pressure.

"Lower pressure drop in the valves helps with gas problems"

This is true for the standing valve, because a higher-pressure drop in the standing valve can cause more gas breakout in the compression chamber. An increase of free gas in the compression chamber means that more of the downstroke will be needed to increase the compression chamber pressure high enough to open the traveling valve, or it could possibly cause a gas lock if that pressure is not reached by the end of the downstroke. A lower pressure drop through the traveling valve doesn't help with breakout of gas in the compression chamber, since it is above the compression chamber, but it does help reduce the upward force imparted to the sucker rods on the downstroke, thus helping with sucker rod longevity.

"Low pump efficiencies can be helped by eliminating gas locking"

This is only true if the pump is actually gas locking, which can be shown by studying a multitude of successive pump cards. Most of the time the pump is experiencing gas interference and not gas locking. With gas interference, the compression chamber has free gas in it on each stroke, but the plunger assembly still comes into contact with the relatively solid fluid in the compression chamber on each downstroke, and sufficient pressure above tubing pressure is quickly achieved and the traveling valve opens and fluid moves past the traveling valve. Therefore, accessories for gas locking only, when only gas interference is causing sucker rod pump inefficiency, will be a waste of time and resources. Gas interference in the sucker rod pump can be helped with an efficient gas separator to keep some gas out of the pump, and therefore increase the fluid pumping efficiency. Normally what needs to be addressed with gas interference, with respect to the pump, is a fluid pound condition. This is similar to tagging the pump with respect to damaging well components, but not as severe.

USEFUL, SIMPLE VALVES AND FITTINGS

There are several simple changes that can be made to a standard sucker rod pump to help with gas issues. The ones which decrease the compression chamber volume help with gas locking, and the ones which offer less standing valve pressure drop additionally help with gas interference.

Lower pressure drop in the standing valve

There are standing valve designs which, based on their internal design, have less fluid restriction and therefore less gas will break out of solution during fluid entry into the pump through the standing valve, helping with both gas locking and gas interference. Several manufacturers have these designs and should be able to provide flow rate vs. pressure drop data upon request. Note that an oversize standing valve automatically helps with pressure drop and gas interference, but it will have the disadvantage noted in the following paragraph.

Less operational volume in the standing valve

The volume of a standing valve from the seat, including the seated ball, to the top of the cage is the compressible volume of a standing valve. This is also part of the unswept volume in a sucker rod pump. Reduction of this standing cage volume without increasing the pressure drop helps with the compression ratio of a sucker rod pump. There are several designs on the market that accomplish this without great cost or large pump changes.

Zero clearance seat plug

A common, standard seat plug in the bottom of the traveling valve extends below the traveling valve an inch or so, depending on the pump size. There is volume on the outside and inside of this seat plug that contributes to the uncompressible volume of a sucker rod pump. A zero clearance seat plug is an all-thread design, and fits entirely within the threaded part of a traveling valve. This eliminates the entire outside wasted volume and half or more of the inside volume of a standard seat plug. Most of the zero clearance seat plugs on the market have an internal, broached hex shape for tightening of the seat plug.

Seat plug with an oversized outside diameter

A compromise between the common, standard seat plug and the zero clearance seat plug is the seat plug design with an outside diameter that is close to the inside diameter of the barrel. This eliminates the waste volume of the outside of the seat plug, but retains the inside diameter uncompressible volume, and contributes to less compression chamber volume.

RH pump standing valve that connects directly to an RH barrel

All standard design heavy wall insert pumps (RH) have a lower extension below the barrel tube, which connects the barrel to the standing valve. This stroke through feature is helpful in scale conditions to keep the entire length of the barrel stroked during pumping to help eliminate scaling tendencies of the lower, unstroked part of a pump barrel without an extension. RH pumps are heavy wall insert designs that are run into deeper wells. But, the inside diameter of the lower extension is larger than the inside diameter of the barrel, so additional uncompressible volume is added. If an RH pump is needed in a gassy well without scaling tendencies, then a special standing valve cage can be attached directly to the lower end of the barrel tube, eliminating the lower extension and increasing the compression ratio. These cages are otherwise the same dimensions internally as a standard standing valve. Note that this simple design feature is also available for tubing pumps, because they are a similar configuration to RH insert pumps.

RH “zero” length extensions

These extensions are not really without length, but are so short that the standard standing valve cage is almost touching the end of the barrel through the inside of the extension. This is a low-cost solution to provide an increase in compression ratio without using a special cage. Of course, there is not any stroke out advantage below the barrel, so it also should not be used in barrel scaling conditions.

Sliding sleeve valve

This is an ingenious idea and has been is use for many years in the oil fields of the world. Generally speaking, it is a sliding sleeve in a housing around the valve rod at the top of the pump. The sleeve has a relatively close clearance to the outside of the valve rod and additionally seals pressure at the lower end of the housing during part of the downstroke of the pump. Therefore, it holds back the hydrostatic pressure of the tubing momentarily during the start of the downstroke and allows the traveling valve to open with less applied pressure. This is helpful in gas locking conditions, and gives some cushion to a fluid or gas pound, but doesn’t help with gas interference. It is a common pump accessory, and various life-lengthening coatings and/or sleeve modifications are available from several manufacturers of the sliding sleeve valve.

COMPLEX SPECIAL VALVES

There are many special valves for sucker rod pumps which open, or are assisted to open by other than the simple hydraulic pressure developed by the compression chamber of the pump. These fall into the broad category of mechanically assisted opening of the traveling valve on the downstroke. There may be some products for the standing valve, but as mentioned above, due to almost solid fluid in the compression chamber at the start of the upstroke, there is probably not a need for an assisted opening of the standing valve. The exception to this, for the standing valve, is when there is very little or no fluid in the compression chamber, which can happen in very low fluid production wells with high viscosity fluids present. This condition is seen sometimes in stripper wells and a special pump is needed rather than a special standing valve.

These types of assisted traveling valves typically utilize the free inertia of a tethered mass to assist the traveling valve to open, sometimes with a probe, which unseats the ball on the downstroke. Others use a similar looking arrangement but with a closer fitting probe which develops some hydraulic force, or mechanical drag force to assist the probe with unseating the traveling valve.

There are many other devices that operate on a mechanical or hydraulic principle to help open the traveling valve. A review of the literature and an online search will show many interesting ideas to achieve this purpose.

ACCESSORIES OR PUMP PARTS THAT DECREASE THE COMPRESSION RATIO OF THE PUMP

While not intended for gas locking problems in the sucker rod pump, there are some pump parts and accessories that can increase the compression chamber volume and thus decrease the compression ratio of a sucker rod pump.

Bottom Discharge Valve

This valve is intended for particulate production when the particulates tend to settle out of the fluid and accumulate above the hold-down of a bottom hold-down pump and prevent it from being pulled from the seating nipple. This can lead to a stripping job or other remedial action to prevent the pulling of a wet string. The bottom discharge valve works well, and is widely available, but it does add a substantial volume of uncompressible space to the compression chamber volume, and thus can contribute to gas locking problems.

Stroke through insert pumps and tubing pumps

The lower extension in these two types of sucker rod pumps add compression chamber volume equal to the length and annular space between the inside diameter of the lower extension, and the outside diameter of the plunger. A shorter extension helps in this situation, or as mentioned earlier, the elimination of the lower extension by connecting the standing valve directly to the sucker rod pump barrel.

INDUSTRY OPERATIONAL SOLUTIONS

There are ways to operate a sucker rod pumping installation that are beneficial for gas problems. The most obvious is the close spacing of the pump at the well site at the bottom of the pumping stroke, after the well has stabilized. This will maximize the operational compression of the fluid/gas mixture in the compression chamber. Of course, tagging of the pump should be avoided.

Another is matching the pumping rate as close as possible to the production rate of the well to avoid pumping off and pounding fluid. It takes a certain annular depth of fluid above the intake of the sucker rod pump to provide enough pressure to fill the pump on each upstroke. This varies substantially due to the pumping displacement of larger or smaller pumps, pumping speed, and stroke length. A rule of thumb for 1-1/4" to 2-1/4" pumps with reasonable stroke lengths and pumping speeds is that at least 200' of fluid is needed above the pump to fill it on the upstroke.

It seems that industry resources may be under utilized with respect to sucker rod pump education and equipment provider problem solving assistance. Sucker rod pump companies and other ancillary parts/equipment suppliers offer both of these resources, normally free of charge.

COMPRESSION RATIO CALCULATIONS

Theoretical compression ratio calculations are straight-forward and simple. The following is partially the traditional method with a change to standardize the treatment of the standing valve cage incompressible volume.

Note that this is a method to compare various pump arrangements of parts, and is not useful for actual pump operations because this method assumes only compressible gas for the compression chamber. However, it has traditionally been used to calculate this ratio and is useful for pump comparisons.

Boyles Law

$P_1V_1 = P_2V_2$

Where:
$P_1 = Tubing\ Pressure, psi, in\ the\ tubing\ above\ the\ pump$
$V_1 = Total\ Compression\ Chamber\ Volume\ Including\ Standing\ Valve, in^3$
$P_2 = Pump\ Compression\ Chamber\ Pressure, psi$
$V_2 = Pump\ Compression\ Chamber\ Volume, in^3$

The incompressible volume of the standing valve can be written as:
$V_{sv} = SL_{eq} \times A$

and
$SL_{eq} = \frac{V_{sv}}{A}$

Where:
V_{sv} = incompressible volume of the standing valve in cubic inches
SL_{eq} = an equivalent length in inches of the subject pump stroke such that when multiplied by the pump cross-sectional area, equals the standing valve incompressible volume in cubic inches
A = pump cross-sectional area in square inches

Which converts the traditional standing valve incompressible volume calculation into an equivalent length of stroke for further calculations

Rearranging Boyles equation:

$$P_2 = \frac{P_1V_1}{V_2}$$

And substituting for V_1 and V_2

$$P_2 = \frac{P_1(SL_1 + SL_{eq})A}{(SL_2 + SL_{eq})A}$$

And dividing out "A"

$$P_2 = \frac{P_1(SL_1 + SL_{eq})}{(SL_2 + SL_{eq})}$$

Where:
$SL_1 = Pump\ maximum\ stroke\ length\ in\ inches$
$SL_2 = Pump\ stroke\ length, variable\ from\ 0\ to\ maximum\ stroke\ length, inches$

Thus, the theoretical compression chamber pressure, P_2 , can be calculated at any part of the pump stroke, up or down. For any chosen case, SL_2 will be the only variable in the right side of the equation, with the others being constant from the data in the chosen case. Note that SL_2, the variable in the equation representing the position of the plunger during its stroke up or down, is measured from the bottom of the pump, with zero at the bottom of the stroke and maximum stroke length at the top of the stroke.

Also, any other incompressible, compression chamber volume, such as in a bottom discharge valve or RH pump extension, can be converted to an equivalent stroke length and added to SL_2.

This method and these calculations only consider the total compression chamber volume as being compressible, (no liquid), and do not account for various levels of liquid being present in the pump. If the liquid level in the pump compression chamber is known, then its volume can be subtracted from the total compression chamber volume to obtain a more representative pressure calculation.

Example:

Given:
$Plunger\ dia. = 1.25\ in.$
$V_{sv} = 2.36\ in^3$
$P_1 = 200\ psi$
$SL_1 = 144\ in$

Calculations:

$$SL_{eq} = \frac{2.36}{\pi\left(\frac{1.25}{2}\right)^2} = 1.92\ in$$

$$P_2 = \frac{200\ (144 + 1.92)}{SL_2 + 1.92} = \frac{29{,}184}{SL_2 + 1.92}$$

$$P_2 = \frac{29{,}184}{SL_2 + 1.92}$$

Please refer to Figure 1 for a graphical representation of this formula.

SUMMARY

Sucker rod pumps continue to be the most popular form of artificial lift, and although many improvements have been made in sucker rod pump design, metallurgy and accessories, there is still room for improvement, especially as new, applicable technologies are applied to this simple form of artificial lift.

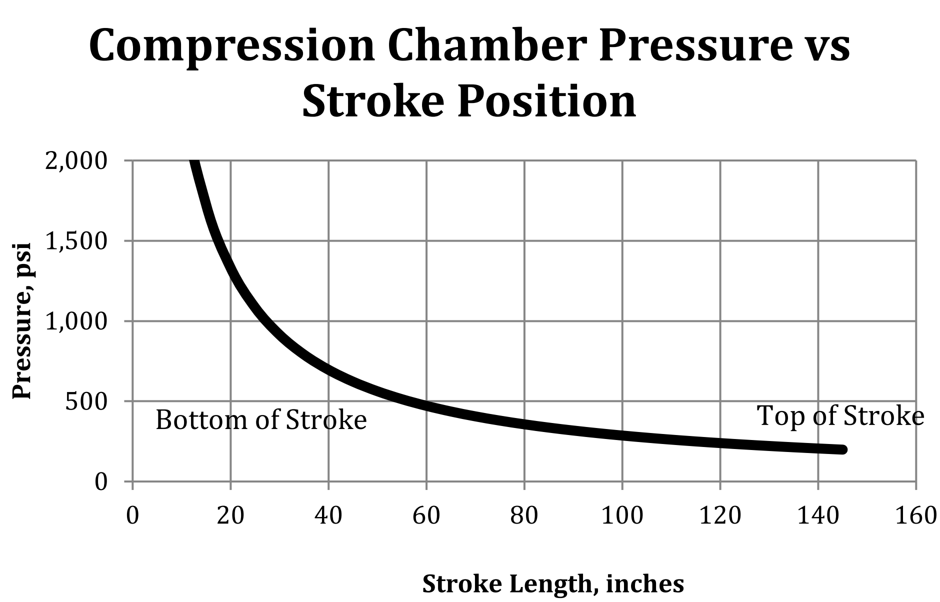

Figure 1