GAS LOCKED PUMPS ARE NOT GAS LOCKED

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ABSTRACT

The definition of a Gas Locked Pump is both traveling and standing valves remain closed during the entire stroke. Gas Lock of a sucker rod pump occurs if the tubing pressure on top of the plunger is always greater than the pressure inside the pump chamber, and if the pump chamber pressure is always greater than the wellbore pressure on the outside at the pump intake. The traveling and standing valve open if pressure below the valve is greater than the pressure above the valve.

High compression pumps, specialty pumps, tagging, and slippage through pump clearances cause the traveling valve to open on the downstroke and discharge oil, water and gas from inside the pump chamber into the tubing. Operators stating "my pump is gas locked" usually have pumped too much gas into the tubing, resulting in unloading all tubing fluids. Pump action has ceased and the classic dynamometer card "Gas Lock" shape of a gas locked pump is not observed.

Introduction

The term "Gas Lock" as defined by Gilbert[1] is the condition where the swept volume of the pump is filled with gas and "the compression ratio of the pump is too small, with the result that neither valve opens until the clearance space fills by leakage past the plunger, or the liquid level rises so that a smaller compression ratio is required to force gas from the pump into the tubing." Slippage past the plunger occurs with each stroke to eventually fill the pump chamber with incompressible liquid where the traveling valve will open on the down stroke due to the plunger coming in contact with liquid, no matter how much gas had previously filled the pump. A sucker rod pump can have Gas Lock for a few strokes until slippage fills the unswept space in the pump then gas in the pump chamber is discharged into the tubing. As pump clearance increases then slippage increases, so slippage filling the unswept volume means gas lock is temporary. In a gas locked pump the standing valve on the up stroke remains on seat because pressure inside the pump chamber is higher than the pressure at the pump intake. With the standing valve closed no liquid is being produced and the pressure at the pump intake increases as the liquid level rises in the wellbore. Once the intake pressure exceeds the chamber pressure the standing valve opens on the up stroke. Gilbert's paper discusses that gas lock is cleared due to a rising fluid level or slippage. Gas lock is a transitional condition and the gas that fills the pump chamber after a few strokes is eventually discharged into the tubing. According to Gilbert, Gas Locked pumps discharge liquid and gas into the tubing and the pump does not remain Gas Locked.

On the down stroke before the traveling valve, TV, can open to discharge the fluids from inside the pump chamber into the tubing; the pump must increase the pressure inside the chamber from the intake pressure to slightly greater than the discharge pressure. The valve opens when the pressure below the valve is slightly higher than the pressure above the valve. A sucker rod pump compresses gas inside the pump chamber and the primary reason stated to justify running a high compression pump is to avoid gas lock.

Pump gas into the tubing, then the tubing fluid gradient will become less, tubing pressure will be less, and more gas will become free. If enough gas is pumped into the tubing then the tubing can unload; and a back pressure valve may be required to control the light tubing fluid gradient and maintain pump action. Pump cards seen when gas lock is thought to occur usually show flat pump card having no pump action. The tubing is often blown dry and the classic shape of a gas compression curve of a gas locked pump is typically not observed.

Gas Lock

What is the definition of a Gas Locked Pump? In a Gas Locked pump both the standing valve and the traveling valve remain closed during the entire stroke; the valves are "locked" closed by pressure. During the upstroke the expanding pump chamber pressure, ($P_{chamber}$), is always greater than the outside wellbore pressure at the pump intake, P_{int}. During the down stroke the pressure inside the tubing on top of the plunger at the pump discharge (P_d), is always greater than the compressed pressure inside pump chamber, ($P_{chamber}$). Both the traveling valve, TV, and standing valve, SV, remain on the seat due to the following pressure relationships:

At Top of Stroke:	$\mathbf{P_{chamber} > P_{int}}$.	**(1)**
At Bottom of Stroke:	$\mathbf{P_d > P_{chamber}}$	**(2)**
Over Entire Stroke:	$\mathbf{P_d > P_{chamber} > P_{int}}$	**(3)**

The traveling and standing valves open if pressure below the valve is greater than the pressure above the valve. **Eq. 3** shows for a gas locked pump that during the entire stroke that the magnitude of the pressure inside the pump chamber results in neither the traveling valve nor the standing valve opening.

Reference Loads Lines for Diagnosing the Pump Card

The fluid load, Fo, the pump plunger applies to the bottom of the rod string fluid is directly related to difference in pressure above minus the pressure below the plunger multiplied by the plunger area. Zero load line, Fo from the Fluid Level, and Fo Max are three reference load lines that aid in the diagnostic analysis of pump card shapes. These reference load lines can be calculated independently from the pump card shape calculated using the wave equation[2] from the measured surface dynamometer card's load and position.

During the upstroke if the standing valve were open and the traveling valve were closed, then a reference load line, Fo from the Fluid Level, can be determined. The reference load, Fo from the Fluid Level, that the pump plunger would apply to the rod string during the up stroke when the TV is closed and the SV is open is the result of the pump discharge (P_d) applied to the top of the closed TV across the area of the plunger, Ap, minus the pump intake pressure, P_{int} determined from a fluid level measurement. The assumption in the calculation of Fo from the Fluid level is there is very little pressure drop through the open SV, so that $P_{chamber}$ can be considered equal to P_{int} determined from the fluid level. Also assumed is that the fluid level is acquired at the time of the dynamometer test and corresponding calculated pump intake pressure results from an accurate analysis of the fluid level shot. **Eq. 4** is used to calculate the pump card reference load line, Fo from the Fluid Level, representing the load the pump plunger would apply to the bottom of the rod string during the upstroke when SV is open and TV is closed:

$$\textbf{Fo from Fluid Level} = (Pd - Pint)*Ap \qquad (4)$$

Fo Max from **Eq. 5** is used to calculate the pump card reference load line, Fo Max, and represents the load the pump plunger would apply to the bottom of the rod string during the upstroke when SV is open and TV is closed and the pump intake pressure is zero:

$$\textbf{Fo Max} = (Pd - 0)*Ap = Pd*Ap \qquad (5)$$

During the down stroke if the standing valve were closed and the traveling valve were open, then a reference load line of zero would be determined. The Zero Load reference line represents that the pump plunger would apply no load (Zero) to the rod string during the down stroke when the TV is open and the SV is closed. The assumption in the calculation of the Zero Load Line is that very little pressure drop occurs through the open TV, so that $P_{chamber}$ can be considered equal to P_d.

The diagnostic pump card shape of a gas locked pump card is shown in **Fig 1**. During the entire time of a stroke for the gas lock to occur the pump card loads cannot be greater than Fo from Fluid Level or the pump cards cannot be less the Zero Load Line. If the pump card loads are equal to or greater than Fo from the Fluid Level during the up stroke , then the SV opened because the pressure inside the pump chamber has expanded to become less that the intake pressure on the outside of the pump in the wellbore. If the pump card loads are equal or less than the Zero Load Line during the down stroke, then the TV opened because the pressure inside the pump chamber has been compressed to become greater than the discharge pressure inside the tubing on the top of the plunger.

Compression Ratio

During one stroke the pumping cycle consist of fluids entering the pump chamber volume, Vi, on the upstroke then discharging fluids from the pump chamber volume, V_D, into the tubing on the down stroke. The intake portion of the pumping cycle occurs during the upstroke when expansion of the pump chamber opens the SV and the pump chamber fills with gas and liquid. The discharge portion of the pumping cycle occurs during the down stroke when compression of the pump chamber opens the TV and the liquid and gas in the pump chamber discharge through the TV into the tubing. The sucker rod pump acts as a compressor during the down stroke. **Fig. 2** displays the ideal gas law adjusted for hydrocarbon gas compressibility, Z, to shows the relationship, **Eq. 6**, between the intake and discharge volume when the pump is completely filled with gas. This relationship assumes constant temperature during the pumping cycle and the free gas filling the pump chamber does not condense or dissolve into any liquid.

$$Pint \times Vint/Zint = P_D \times V_D/Z_D \qquad (6)$$

Compression ratio, **Eq. 7**, for a sucker rod pump is equal to the pump chamber intake volume, Vi, when the pump plunger is at the top of the stroke divided by the discharge volume, V_D, inside the pump chamber when the plunger is at the bottom of the stroke. The compression ratio of the sucker rod pump assumes that the unswept volume of the pump, V_D, is completely filled with gas.

$$\textbf{Compression Ratio (CR)} = V_D/Vint \qquad (7)$$

A high compression ratio pump can open the TV on the down stroke for a sucker rod pump having the pump chamber completely filled with gas, if intake pressure times the compression ratio is greater than the discharge pressure (**Pint x CR > P_D**). Pumps having sufficiently high compression ratios can discharge the gas volume completely filling the pump into the tubing. If the compression ratio is not sufficiently high to increase the pressure of the gas filling the pump chamber to a pressure greater than the pump discharge pressure, then usually liquid slippage through the pump clearances will fill the pump above the unswept level in the pump chamber and the TV will open. When liquid slippage fills a portion of the pump volume making the free gas volume inside the unswept chamber volume approaches 0, then TV always opens because the compression ratio of the pump approaches infinity as the plunger approaches the liquid level in the pump chamber. If the plunger is set high in the barrel, then several strokes may be required before slippage fills the unswept volume. Pump clearances and proper spacing are important when considering high compression ratio pumps. Usually high compression pumps are recommended when a well produces high gas rates and the pump may be partially filled with gas.

Pump Slippage

Pump slippage[4,5] through the pump clearances occurs when the TV is on the seat and the pressure above the plunger is greater than the pressure inside the pump chamber (**P_d > $P_{chamber}$**). Pump slippage can fill a portion of the pump chamber with tubing liquid (usually water) that leaks/slips back into the pump chamber through the clearances between the plunger and the barrel. The Patterson pump slippage calculations[6,7] have been added to QRod[8] as a design tool to predict the pump slippage for a specific set of pumping conditions and artificial lift system configuration. For the purposes of lubrication, 2 to 5 percent slippage of the pump's down hole displacement is considered to be sufficient. Pump slippage is calculated in **Tab. 1** using QRod for a 4 foot plunger with various plunger diameters and pump clearances for a surface stroke of 145 at a pumping speed of 9.52 SPM and a pump depth of 7156 feet. For **Tab. 1**slippage may be considered excessive when greater than 20% of pump displacement is lost where pump clearances are 0.007 inches or greater. For what is considered a fairly tight fit between the plunger and barrel of 0.003 inch clearance, **Tab. 1** shows approximately 5% of the pump is filled with slippage during each stroke. If the pump were completely filled with gas and the unswept volume in the pump chamber was 10% of the stroke, then for 0.003 inch clearance the TV would open during the 2nd consecutive stroke, because of slippage filling the unswept volume of the pump. Gas lock cannot occur for the design conditions specified if pump clearance is equal to or greater than 0.005 inch, then slippage would fill the unswept portion of the pump chamber and the TV would open on every stroke. In general the gas lock condition is temporary because slippage quickly fills the unswept portion of the pump stroke during one or two strokes and the gas in the pump is discharged into the tubing. When estimating the percentage of the pump stroke filled with slippage, use QRod to calculate pump displacement, assume 100% liquid pump fillage and examine the "Pump Slippage Plot" to determine amount of slippage based on the pump clearance installed in the well.

Specialty Pump

There are various specialty pumps available on the market that open the pump discharge and allow any gas inside the pump chamber to be released into the tubing. One such pump is the Harbison-Fisher Variable Slippage Pump®, VSP, where the top of the barrel tapers outward to quickly increase pump clearances. Once the pump plunger enters the tapered portion of the barrel on the upstroke near the top of the stroke, then the plunger/barrel seal rapidly decreases. Any gas inside the pump chamber is discharged into the tubing as the tubing liquids full back through the open clearances over the tapered portion of the barrel thereby completely filling the pump chamber with liquid. Proper pump spacing for the VSP pump is critical because the plunger must enter the tapered portion of the barrel at the top of the stroke. **Fig.3** shows the pump card where the plunger is properly spaced out in the barrel where all the gas inside the pump chamber is discharged into the tubing and the pump is not required to act as a compressor on the down stroke.

Tag the Pump

"Tag the Pump" is a frequently employed tactic to maintain pump action by hitting the pump with a sudden large impact force at the bottom of the stroke. The tag shakes the pump and forces the traveling valve to open on the down stroke. Improperly spacing the pump at the bottom of the down stroke to intentionally tag can result in damage to the pump, rods, tubing and sometimes results in damage to surface equipment. **Fig. 4** shows the pump is being tagged hard with a 1200 pound force at the bottom of the down stroke. The pump card shown in **Fig. 4** is almost filled with gas and the pump is spaced out to tag at the bottom of the stroke. This pump needs to be re-spaced to remove the tag and to prevent damage to the artificial lift equipment. On this well on every stroke the severe tag is reducing the life of all downhole and surface equipment. Tagging the pump opens the traveling valve and discharges the gas inside the pump chamber into the tubing.

Gas Locked Pump

The operational problem of producing a well where the pump is filled with gas is not normally due to the pump being Gas Locked, because the TV usually opens to discharge the gas filling the pump into the tubing. Actions taken by the operator, such as high compression pump, slippage through the pump clearances, tagging at the bottom of the stroke, and use of specialty pumps result in gas in the pump chamber being discharged into the tubing. The problem of producing the well usually occurs when too much gas is pumped into the tubing and the liquid in the tubing flows off/unloads.

New vertical and horizontal wells being drilled typically produce a lot of gas and dynamometer data acquired on the wells often show pump cards having pump fillage lost to gas interference. The real problem often called gas lock by the operator is loss of pump action due to tubing liquids being unloading out of the tubing by too much gas pumped up the tubing. When too much gas enters the tubing a light gradient and gas lift effect can result in the liquids flowing out of the tubing, then the pump TV and SV will not function due to loss of differential pressure across the plunger. When tubing liquids unload the pressures ($\mathbf{P_d}$, $\mathbf{P_{chamber}}$, and $\mathbf{P_{int}}$) at the pump are approximately equal and with little or no differential pressure acting across the TV or SV then no load transfer occurs and pump action stops. When the operator states his well has a gas locked pump, then the pump card almost always shows a flat pump card setting on the zero load line **Fig. 5**. If a horse shoe load cell is used to weigh the rod string, then the flat pump card is usually shifted above the zero load line by the missing buoyancy force **Fig. 6**. The horse shoe load cell weighs the rods in the well in "air" and not in fluid when excessive gas pumped into the tubing results in the unloading of the liquid out of the tubing. If there is gas in the pump, then a high compression pump with slippage can increase the pressure of the gas inside the pump chamber and discharge the gas into the tubing. If sufficient gas rate is pumped into the tubing, then the tubing fluid gradient will become less, pump discharge pressure will drop and more gas will become free in the tubing. If enough gas is pumped into the tubing then the tubing can unload; and a back pressure valve may be required to control the light tubing fluid gradient and maintain pressure differential across the TV and SV so that the pump will function. Pumping gas up the tubing and unloading the tubing frequently occurs in gassy wells. Dynamometer data collected on a gas locked pump, usually shows the tubing liquids have been unloaded and the pump card is a flat load line showing no gas compression.

Pumping too much gas up the tubing can create unstable conditions in the tubing. Stable conditions can usually be achieved by keeping the gas from entering the tubing or adding additional back-pressure to the tubing at the surface. Once flow is stabilized by using backpressure on tubing, then the well can likely be produced without intervention. When the tubing unloads the operator frequently must fill the tubing with water to cause the pump to initially operate correctly. Frequent intervention by the operator is required to maintain pump action when too much gas is being pumped up the tubing.

Use Backpressure Regulating Valve on the Tubing

A test to determine if a backpressure valve will help is to close the tubing flow line valve to determine if the well's pump can increase the well head pressure up to approximately 500 psi. If the tubing is dry then then several hours of time may be required to pump up the well head pressure. Once the well pressure reaches 500 psi, then slightly crack the valve and determine if pumping continues for a few hours. Do not leave the well is this configuration, because the cracked surface valve can become fluid cut if operated for an extended time period. If the well continues to pump, then the tubing can most likely be controlled through use of a backpressure valve.

Usually the only way to prevent tubing liquids from flowing off up the tubing is through use of a back-pressure valve (regulator) on the tubing. The added tubing back pressure puts more pressure on the pump discharge and requires more horsepower to produce the well. In addition to no pump action, flowing off up the tubing can result in damage to the sucker rod equipment and results in reduced run life due to rod-on-tubing wear.

Increasing the tubing discharge pressure using a backpressure valve can prevent liquids flowing off up the tubing and can result in more consistent pump action. Increased tubing pressure 1) reduces the size of the gas bubbles in the tubing, 2) increases the tubing fluid gradient, 3) increases the tubing discharge pressure, and 4) keeps some gas in solution in the produced oil. The down hole sucker rod pump maintains pump action because increased tubing pressure prevents gassy fluid from blowing the tubing "dry" and maintains a reasonably constant discharge pressure on the pump discharge. Increases in operating cost due to increased back pressure are primarily due to lower efficiency from: 1) Increased fluid load applied by the pump to the rods, 2) Increased polished rod horsepower, 3) Increased rod loading with higher stress range, 4) Increased load on the prime mover, 5) Reduced plunger effective stroke length due to increased static stretch, 6) Reduced pumping speed, due to motor slip, 7) Reduced effective pump displacement, and 8) Increased frictional forces the stuffing box applies to the polished rod.

Use of a tubing back pressure regulating valve can maintain pump action and prevent unloading of tubing liquids. Excessive gas entering (pumped into) the tubing reduces differential pressure across plunger and lightens tubing fluid. Surface tubing discharge pressure is higher when compared to the surface pressure if no back pressure regulating valve were present. Back pressure increases differential pressure across the plunger and increases the tubing fluid gradient, which allows pump action to be maintained. Increasing the tubing back pressure potentially increases operating cost, but maintains pump action and reduces frequent well intervention by the operator. Use back pressure ONLY IF a well is flowing off due to TOO much gas produced up the tubing. If the tubing unloads and pump action stops, then try 200-300 psi of back pressure on the tubing BUT use more if required by well.

Keep Gas Out of the Pump

If the high gas rate produced up the tubing is blowing all of the liquids out of the tubing, then the recommended action is to prevent the gas from entering the pump. A recommended operating practice is to prevent gas from entering the pump by setting the pump intake below the perforations (set the pump in the rat hole). If a rat hole exists, then be sure to clean out any debris in the wellbore before placing the pump below the perforations. If no rat hole exists, then use a properly sized downhole gas separator to prevent gas from entering the pump. The most commonly used gas separator is the conventional or "poor boy" separator. The poor boy gas separator is typically built from standard oilfield tubing and perforated sub. The downward fluid velocity between the outer barrel and the dip tube should be less than 6 inches per second or the net pump capacity should not exceed 50 barrels per day per square inch of area between the dip tube OD and the inner diameter of the outer barrel of the downhole gas separator. Gas flow velocities in excess of approximately ten feet per second will lift the liquid creating a mist where gas carries liquid and is difficult to separate. The annular area must be sufficient to allow liquid to enter the separator by maintaining a gas velocity below the critical rate and preventing the creation of mist flow.

If a down hole gas separator is used then the casing must be open to the flow line and the casing gas must be vented at the surface through a check back into the flow line. If the casing valve is closed, then all gas is produced through the pump and any type of gas separation will not be effective. If a dead space below the bottom perforations is not available, then the pump should be set as deep in the casing as possible and an improved[9] offset high capacity gas separator should be run. Downhole gas separators do not separate gas in solution; they only separate the free gas at the pump intake.

Improved downhole gas separators are manufactured using thin wall pipe instead of conventional oilfield tubing to manufacture the outer barrel. The outer barrel should also have the same OD as the tubing collar to maximize internal area. The use of collar–sized thin wall pipe results in a greater area between the dip tube and the outer barrel. This increases liquid capacity by reducing the downward liquid velocity in the separator. The use of large fluid entry ports instead of a perforated sub improves the efficiency of the gas separator. The large ports result in little or no pressure drop as liquid flows into the gas separator. Installation of a properly size down hole gas separator in the well can keep the gas out of the pump and can result in little or no gas produced up the tubing. When gas is prevented from entering the pump, pump action can be maintained.

Conclusions

The pressure inside the pump chamber is a function of plunger travel and compressibility of fluid in the pump. Sucker rod pumps intake well fluids through the SV and discharge fluids into the tubing through the TV. Gas pumped into the tubing can be detrimental to the operation of the sucker rod pumping system. No pump action can occur when too much gas is pumped into the tubing. Use of back pressure and/or gas separation may be required in order to maintain pump action.

A recommended practice is to keep the gas out of the tubing by setting the pump intake below the perforations. This is not possible in horizontal wells, so when a rat hole is not available; then the recommended practice is to use a properly sized downhole gas separator. Using a specialty pump such as a VSP® pump will discharge gas into tubing, but prevent downhole rod-on-tubing wear problems created by compressing gas on the down stroke. Using a long stroke length typically increases the pumps compression ratio, but gas in the pump is discharged into the tubing. Proper spacing of the pump to minimize dead space at bottom of stroke increases the compression ratio, but gas in the pump is discharged into the tubing. Slippage through the pump clearances partially fills liquid into a pump chamber full of gas increasing the compression ratio, but gas in the pump is discharged into the tubing. If the pump has clearance between the plunger and the barrel, then it is impossible to gas lock the pump. Sufficient back pressure can prevent tubing fluids from unloading. Unloading tubing fluids is usually caused by poor downhole gas separation, because the gas in the pump is discharged into the tubing. Pump action stops when too much gas is pumped into the tubing, because excessive gas discharged into the tubing lightens the tubing liquids causing the tubing liquids to unload from the tubing. The real problem is loss of pump action, Not Gas Lock. When operators state their pump is gas locked, then the typical problem is the pump has no differential pressure across the valves and the pump will not pump.

References

1. Gilbert, W.E.: "An Oil Well Pump Dynagraph," API Drilling and Production Practices, 1936, pp.94-115.
2. Gibbs, S. G. and Neely, A. B.: "Computer Diagnosis of Down-Hole Conditions in Sucker Rod Pumping Wells,"JPT (Jan. 1966) 91-98
3. Echometer Company Web Site, http://www.echometer.com/support/technotes/pumpcards.html "Diagnostic Pump Card Shapes"
4. John Patterson, Kyle Chambliss, Lynn Rowlan, Jim Curfew: "Progress Report #4 on "Fluid Slippage in Down-Hole Rod-Drawn Oil Well Pumps" ", SWPSC, Lubbock, Texas (2007)
5. Chambliss, R. Kyle: "Developing Plunger Slippage Equation for Rod-Drawn Oil Well Pumps," Dissertation, Texas Tech U., Lubbock, Texas (2005)
6. Chambliss, R. Kyle, James Christian Cox and James F. Lea: "Plunger Slippage for Rod-Drawn Plunger Pumps," Trans. of the American Society of Mechanical Engineers – J. of Energy Resources Technology (September 2004) vol. 126, 208-214.
7. O. Lynn Rowlan, James N. McCoy and J F Lea:" Use of the Pump Slippage Equation to Design Pump Clearances", SWPSC, Lubbock, Texas (2012)
8. O. Lynn Rowlan, James N. McCoy, Dieter Becker, Ken Skinner, Carrieanne Taylor: "Sucker Rod Pumping System Design Tools for QRod", SWPSC, Lubbock, Texas (2013)
9. McCoy, J.N. and Podio, A.L.: "Improved Down hole Gas Separators," presented at the Southwestern Petroleum Short Course, Lubbock, TX, Apr. 7-8, 1998

Table 1 – QRod Calculated Slippage for Stroke = 145" SPM=9.52 Pump Depth= 7156' 4' plunger

Patterson Equation Pump Slippage % vs Clearance @ SPM = 9.52						
	Plunger Diameter - Inches					
Clearance	1.25	1.50	1.75	2.00	2.25	2.75
0.003	6.6	5.6	4.9	4.7	4.7	6.5
0.004	10.2	8.6	7.7	7.2	7.2	10.1
0.005	14.3	12.1	10.8	10.2	10.2	14.2
0.006	18.8	16.0	14.2	13.4	13.4	18.7
0.007	23.8	20.2	17.9	16.9	17.0	23.6
0.008	29.1	24.8	22.0	20.8	20.8	28.9
0.009	34.8	29.6	26.3	24.8	24.9	34.6
0.010	40.9	34.8	30.8	29.1	29.2	40.6
0.011	47.3	40.2	35.6	33.7	33.7	46.9
0.012	53.9	45.8	40.7	38.4	38.5	53.6
BPD =>	258.2	364.5	479.3	579.7	651.0	572.1

Figure 1 – Diagnostic Gas Locked Pump Card Shape

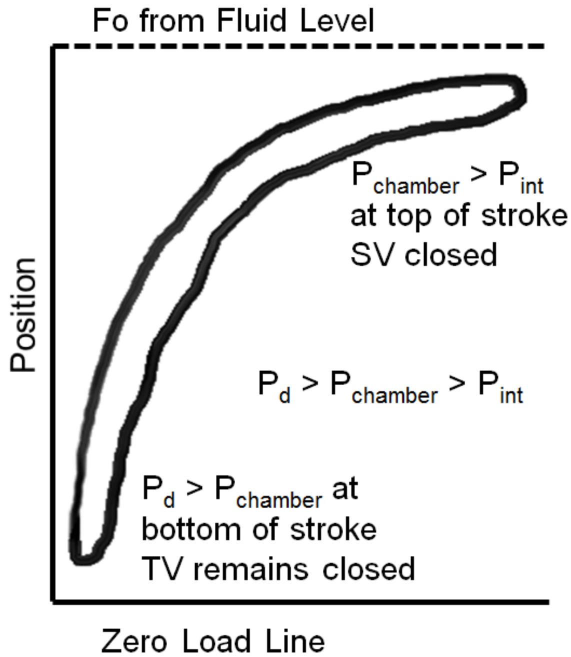

Figure 2 – Pressure Relationship for Gas Filled Pump Chamber from Intake to Discharge Volume

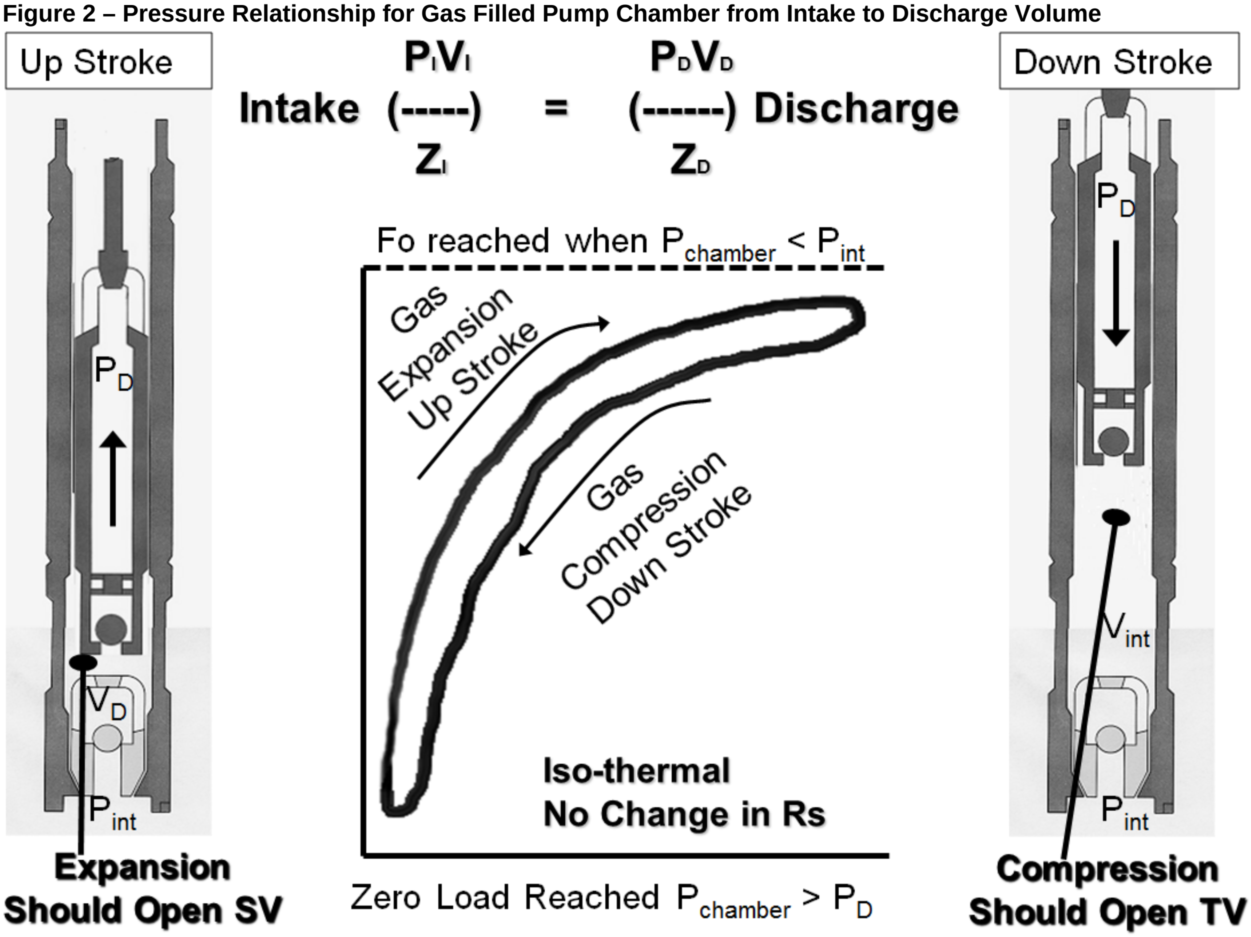

Figure 3 – Variable Slippage Pump Filled with Liquid as Free Gas Discharged at top of Up Stroke

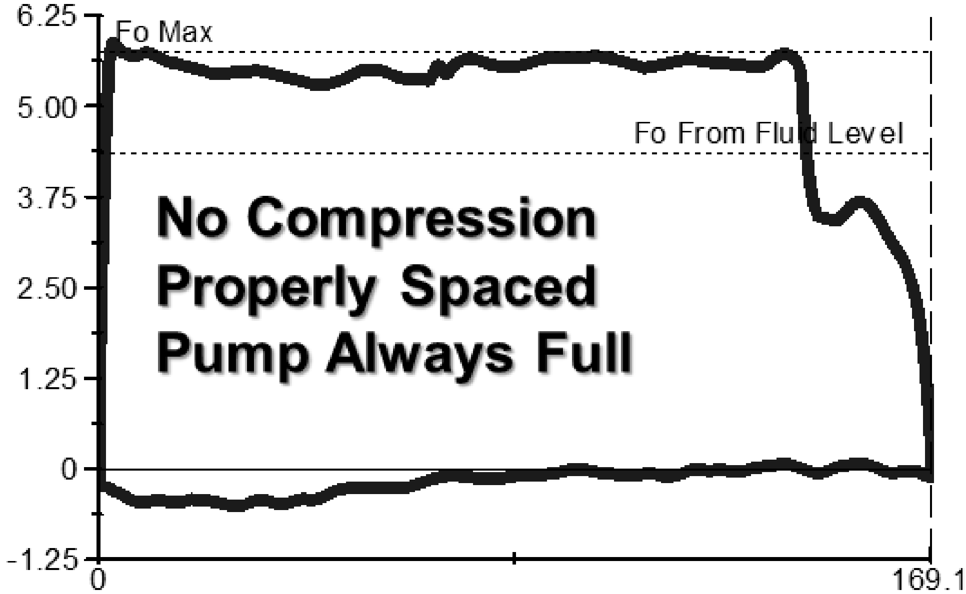

Figure 4 – Tag the Pump to Open TV at Bottom of Stroke

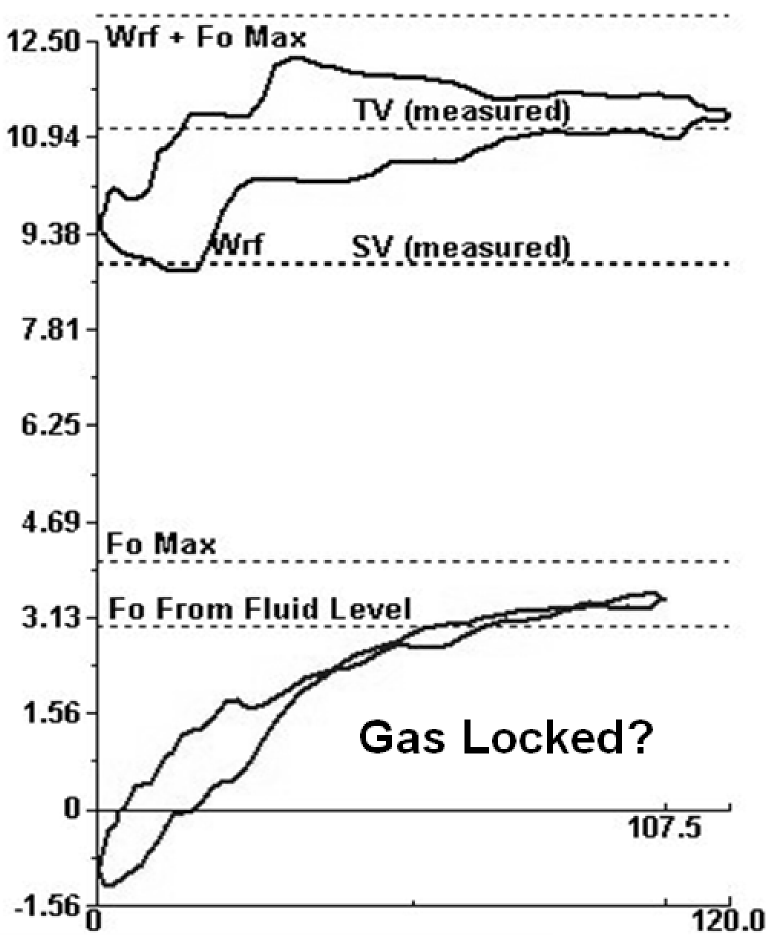

Figure 5 – TV Open Pump Card Showing No Pump Action

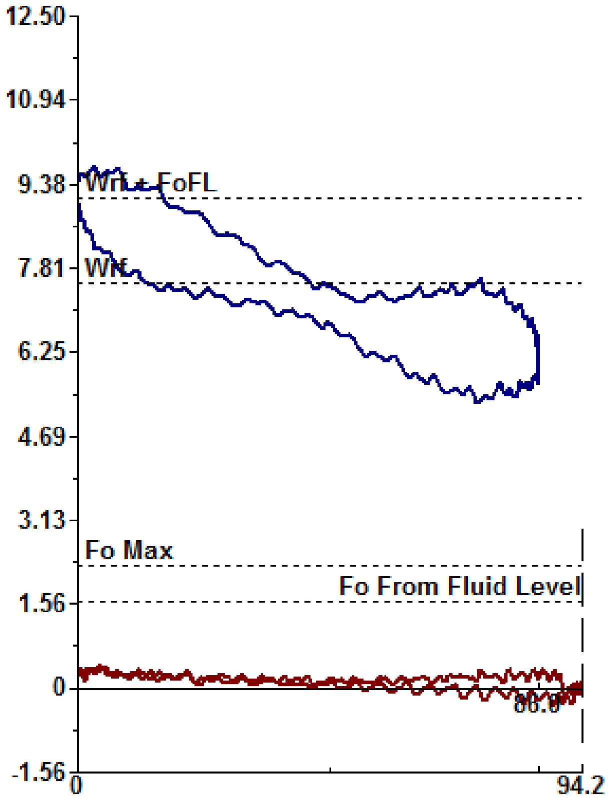

Figure 6 – Tubing Liquids Unloaded by Gas