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New Era of Oil Well Drilling and Completions—Does It Require An Innovation In Rod Pumping?

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Abstract

A new era of oil well drilling and completions is changing the face of rod pumping forever. Horizontal drilling with multistage hydraulic fracturing often results in very challenging production conditions. Pump placement below the kickoff (i.e. in non-vertical dogleg section), frequent gas slugs, large volumes of flow back frac sand, significant fluctuations in fluid flow rates, and steep decline curves are examples of the common challenges affecting the production of horizontal wells. Even the most sophisticated conventional pump-jack with an AC motor and VFD (variable frequency drive/variable speed drive) does not have the precise rod string control required to help mitigate and resolve many of these complex rod pumping issues frequently associated with horizontal multistage hydraulically fractured wells.

Linear pumping units, and more specifically linear hydraulic pump-jacks, have fundamental differences in geometry and control capabilities. Coupled with the fact that both natural gas and AC drive units support the same functionality, linear hydraulic pump-jacks provide the sophisticated rod string control required by today's demanding wells.

This paper will compare and contrast the different rod pumping methods and their abilities to address these production challenges. The paper will also discuss the additional benefits of combining the unique capabilities of a linear hydraulic pump-jack with sophisticated optimization control and remote access. The combination of these three key features provides an unprecedented solution that has the potential to become the next generation rod pumping technology for cost effectively producing today's challenging wells.

Background

The primary objective of optimizing any artificial lift solution is minimizing the bottom hole pressure to maximize the wellbore inflow at the lowest possible operating cost. Depending on the formation, a newly drilled well could flow on its own for some period of time. Once this initial free-flow production tapers off, an artificial lift system is typically deployed. There are several artificial lift technologies with rod pumping, gas lift, electrical submersible pumps (ESPs), jet pumps, plunger lift, and progressive cavity pumps as examples (Brown, K. E. 1982). Rod pumping is the most common artificial lift method in North America due to cost efficiency reasons (Byrd, J. P. 1977) (Rowlan, O. L. 2007). Bottom-hole rod pumps have few moving parts, and this simplicity translates into reliability and longevity of equipment.

This paper assumes the reader is already familiar with the basic operation of rod pumping, where a rod string connects a surface lift system to a downhole pump (Rowlan, O. L. 2007).

The most common surface equipment used with rod pumping is a pump jack. The pump jack is equipped with a prime mover that is either an AC motor or internal combustion engine. In order to maximize production, a pump jack's stroke speed and stroke length should be adjusted to pump the fluid in the casing down as far as possible while still maintaining a high pump fill. This ideal operating condition minimizes bottom hole pressure, promoting maximum wellbore inflow. However, if the pumping capacity exceeds the production rate of the formation, fluid pound can occur which is one of the most common causes of wear and damage in a rod pumping system. Due to the mechanical nature of stroke speed and stroke length adjustments on a pump jack, finding and maintaining the ideal setting on each well over time can be an expensive proposition.

One pump jack alternative is a hydraulically actuated cylinder which moves the rod string up and down in a similar manner (Mehegan, L. 2013). The simplest version would raise the hydraulic piston until it hits the upper limit of the cylinder then gravity would return it to the lower limit where the cycle would repeat. Position sensors can be added so that the cylinder will turn around when it reaches a specific position along the stroke length. This prevents physical contact between the piston and the inside of the cylinder, extending equipment life. The position sensors can also be manually moved so as to increase or decrease the stroke length up to the length of the cylinder, as well as to change the position offset of the stroke. The linear hydraulic pump-jacks used are typically configured with an on/off style valve and solenoid combination where the cylinder is receiving maximum flow on the upstroke, pressure but no flow to hold a set position, then maximum flow purge on the down stroke. The more advanced linear hydraulic pump-jacks use continuous position measurement and a variable output pump to precisely control the polished rod velocity and position.

The new era of oil wells

One might consider the definition of a new era oil well as either a shale well and/or a well that is horizontally drilled and completed (Zaleski, T. E. 1991). With today's wells, producers are striving to get even more production from their reservoirs. Wells are being drilled horizontally and pumps landed anywhere from the vertical section, above the kickoff point, to severe angles well into the dogleg section, but all are typically above the perforations. This can commonly result in excessive gas problems such as gas locking or gas interference depending on where the pump intake is compared to the perforations. Fracking is being used extensively to promote higher wellbore inflow. This leads to an excess of frack sand and debris which will usually make its way through the downhole pump during production flow-back or pumping.

Once in the pump, it may start clogging the travelling and standing valves or simply accumulate inside the pump leading to a decline of pump efficiency and ultimately loss of production.

Regardless of how a well is completed, rod pumping equipment, like other artificial lift techniques, can encounter an array of issues over its lifetime. These issues range from hardware failures (e.g. surface equipment failures, parted rods, worn tubing, traveling & standing valve issues, etc.) to downhole operational issues (e.g. wax buildup, gas interference, gas locking) (Uren, L.C. 1925). Hardware failures can be partially mitigated with proper rod string design, diligent preventative maintenance, controlled pumping parameters, and regular monitoring but they can never be completely eliminated. Many of the operational issues related to the well bore are harder to avoid because they are unpredictable. Continuous monitoring and timely issue resolution are keys to minimizing the impact of these issues.

These rod pumping issues existed in vertically drilled wells, however, with the introduction of horizontal drilling and multistage fracing the frequency and severity of these issues has increased significantly, especially in the transient phase of a well's life. To maintain optimum pumping conditions and minimize unplanned downtime (i.e. maximize return on investment) it is more critical than ever to have the ability to quickly identify issues as well as the capability to resolve them in a cost effective and timely manner. The most common adjustments required to resolve issues are rod string velocity, rod string position and stroke length. This paper will focus on comparing the capabilities of pump jacks and linear hydraulic pump-jacks to control/modify these parameters and how this can be used to address common issues.

Comparison of Pump Jacks and Linear Hydraulic Pump-Jacks

Pump Jacks

By their nature, pump jacks move in a sinusoidal pattern with the polished rod constantly accelerating or decelerating throughout the stroke. Without installing additional control hardware, operational changes on a pump jack require on site mechanical adjustments. Small short term stroke speed adjustments, typically for testing purposes, are possible by changing engine RPM but generally stroke speed changes require a change to the gear reducer sheaves that connect the motor to the gearbox.

Stroke length changes on a pump jack are also done via on site mechanical changes. Stroke length is determined by the position of the Pitman Arm relative to the crank. To change stroke length the pump jack must be shut down and a small crane used to reposition the Pitman Arm on the crank. The combination of equipment costs, labor costs and production downtime can make these changes very expensive.

Rough calculations, taking into account expected production and average pump fill, can be done to help determine optimum stroke speed and stroke length to match surface production to wellbore inflow. However, this is only an estimate and often there is trial and error required to determine the optimal gear ratio. In addition, wellbore dynamics could result in the need to make relatively frequent changes to maintain optimum production. There are also certain equipment limitations that might not allow for optimal stroke settings so other techniques have been developed over time. An example would be a simple on/off timer used to periodically shut a unit down to prevent poor pumpfill and possible damage to the rod string. (Rowlan, O. L. 2007). This technique also has implications since shutting in a well halts production which is not as efficient as constantly producing a well. There can also be issues with sand and debris settling into the pump, potentially causing it to seize after a period of downtime.

An alternative to a timer would be an AC motor with a VFD. This could eliminate the need for start/stop cycles (which is taxing on the equipment) as well as consume only the required power to keep the well stroking in an automated fashion with the help of a POC (pump off controller). (Bommer, P. M. 2006) AC power availability is the biggest limitation to a VFD based solution. There are a significant percentage of pump jack installations that use an internal combustion engine with no equivalent functionality.

Linear Hydraulic Pump-Jacks

Operation of a linear hydraulic pump-jack is significantly different than a pump jack. With a linear hydraulic pump-jack, the prime mover is mechanically decoupled from the mechanism that strokes the rod string. The prime mover is used to pressure up hydraulic oil which can then be manipulated as necessary to control the movement of the hydraulic cylinder. With basic linear hydraulic pump-jacks, position sensors are used to define the stroke length. A change in stroke length requires an onsite repositioning of the sensors but does not require a crane or other heavy equipment as with a pump jack. Depending on the hydraulic control valves used, the stroke speed may or may not be configurable. On systems that don't have proportional flow control, time between strokes can usually be adjusted as a crude way to change the average strokes per minute. One of the key benefits of linear hydraulic pump-jacks is both AC motor and internal combustion engine driven systems have the same rod string control capabilities

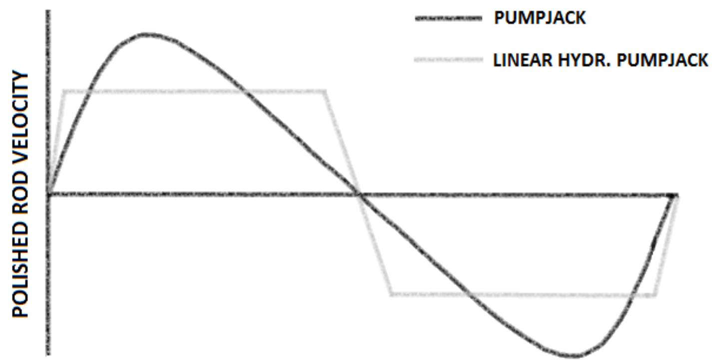

Figure 1, Polished rod velocity profiles of pump-jacks and linear hydraulic pump-jacks

Technology Advancements

Remote Visibility and Two Way Control

In recent years, it has become more common to outfit artificial lift systems with some type of controller that may include a radio system for connection to a remote host. The capabilities of these systems vary widely by technology and vendor and can range from view only to full two way control. Although much of the value remains with the method of operation, remote surveillance/control does provide significant additional value and is very important for fully optimizing challenging wells.

Without remote surveillance / control technology, an oil field operator would typically have a daily route taking him to each well site sequentially to check the status. He would have no indication as to the health of that well until he arrived at site. The introduction of a SCADA (Supervisory Control and Data Acquisition) system allows the operator to remotely monitor and potentially adjust pumping parameters without traveling to site. He or she can also use the technology to help prioritize their daily tasks, allowing them to focus on the key issues (Dunham, C.L. 1987).

A SCADA system would also typically provide some type of alarming functionality, either real time with callout capabilities or time delayed based on a set polling interval. This informs the operator that an error condition has occurred so they can re-prioritize their activities as required. Without this, the operator would travel his set route, discovering the error condition only once they were on site. This method of operation could result in undetected error conditions extending to several hours or even a full day.

The type and complexity of data collected and stored on a SCADA host can vary significantly by technology and vendor. It could be as simple as a run status or as complicated as dynamometer cards. Local controller data storage capabilities are often very limited so adding a remote host also introduces the ability for long term data trending. These long term trends are key to identifying changes in a well's behavior that could be an indication of a current or developing issue.   This makes long term data trending an important part of an effective alarm management strategy.

Remote surveillance/control capabilities become even more valuable for remote sites, sites without year round access or during times of inclement weather when driving is too dangerous or not possible. In addition to the well optimization benefits, remote access has a secondary benefit related to employee safety.   Based on a study done in the US, motor vehicle accidents are the leading cause of work-related fatalities in the oil and gas extraction industry (Retzer KD, 2013).   SCADA systems don't eliminate the need for travel but if simple parameter changes or restarts of stalled engines can be done remotely they can definitely help reduce the number of trips required.

Conventional Pump Jacks

For many years now VFD's have been used on AC motor driven pump jacks. Basic VFDs control only the stroke speed, whereas the more advanced units can control the pump jacks upstroke and downstroke speeds independently.   There are even more advanced models that can support configurable speeds throughout the entire upstroke or down stroke. This allows for custom speed profiles to be developed (Palka, K. 2009).   With these systems the surface stroke can be manipulated in such a way that the polished rod doesn't have to follow the normal sinusoidal velocity associated with the pump jack geometry (as shown in Figure 1). This can be used to precisely tune each system to pump a well as necessary, whether to maximize stretch (like in a fiberglass rod string), or to minimize peak stress throughout the stroke.

The presence of a VFD substantially improves the capabilities to optimize the production from a pump jack. However, because these benefits are only available on AC driven units, fields with a mix of AC and internal combustion engines will not get the full benefit and will need different optimization strategies for different wells.

Linear Hydraulic Pump-Jacks

There have been several significant technology advancements with linear hydraulic pump-jacks over the past several years. One of the more significant is the replacement of the position sensors with continuous position measuring systems such as a linear transducer. This enhancement allows the optimization controller to completely customize both the upstroke and the down stroke resulting in very precise rod string control. Combine this with the transition to a proportional control valve (as opposed to an on/off solenoid style valve) and the surface stroke becomes highly customizable and can be tailored to each well's requirements.

The combination of remote visibility, two way control and adjustable stroking patterns (stroke speed and velocity profile) make the VFD equipped pump jack and linear hydraulic pump-jacks (with position measurement capabilities) the leading contenders for addressing the challenges of today's horizontally drilled, multi-stage fractured wells.

However, the limitations that even the most advanced conventional pump jacks have related to position control means that linear hydraulic pump-jacks have the best overall feature set for addressing these challenging production scenarios.

Precise Rod String Control – A Significant Advantage

One of the key parameters in the optimization of an oil well is control and adjustment of rod string movement. As highlighted earlier, traditional pump jacks are somewhat limited by their geometry because rotational velocity of the prime mover/gear box arrangement is converted to linear velocity of rod string via mechanical connections of the crank, pitman arm and walking beam. Any change to rod string velocity requires a change in prime mover rotational velocity or a mechanical change of the pump; jack components. A variable frequency drive on an AC driven pump jack can provide some variation in prime mover RPM but the variability is still somewhat limited.

Linear rod pumps, such as hydraulic pump-jacks, don't have this geometric limitation. By using hydraulics rather than a mechanical connection between the prime mover and the linear movement of the rod string precise rod string control can be achieved without any adjustment to the output of the prime mover. The hydraulic system can provide *proportional* control during any part of the pumping cycle.

There are several other benefits of eliminating the direct coupling of the prime mover output from the rod string motion. One example is the ability to stop the pumping cycle at any time, move to any position and hold that position without any mechanical intervention (i.e. manual braking or locking mechanisms). This enables the ability for automated travelling and standing valve tests (without any local intervention). This ability extends to easily changing the stroke length by changing the top and/or bottom position limits, often with just a set-point change on the optimization controller. If a remote SCADA communication system is available, this change can be made remotely without the need for a site visit or any production downtime.

Halting the stroking action mid-stroke and holding position is also useful for emergency shut downs due to rod hang-ups, where continued force on the rod string could cause damage to the rods, tubing, downhole pump or surface equipment. Operation with a classic linear hydraulic pump-jack without a continuous position sensor would not see this benefit as the system would rely on low and high pressures or proximity switches to change stroking direction.

A standard pump-jack with a combustible engine would not be able to stop quickly due to the momentum of the counter weights. A VFD assisted pump-jack can slow down very quickly but would be unable to automatically hold its position mid-stroke, due to either rod load or the counterbalance weights (depending on balancing) as there is no automatic brake.

Another example of the benefits of precise rod string control is *temporary*, short term, changes to the way a well pumps. Transient issues are often best addressed with temporary rod string changes. Whether it's setting a pump on tap to clear light debris or shortening stroke length to clear more significant debris, a linear hydraulic pump-jack is capable of quick changes to deal with dynamic well issues. Leaving a pump on tap or with an altered stroke length is not ideal after the condition has cleared so the ability to remotely and easily change the pumping parameters can be a significant advantage.

In horizontal/shale wells higher output of oil and water also brings higher quantities of gas. Despite lower fluid velocities around the wellbore, sand can also be a major issue as it makes its way into the pump (especially if the horizontal section hasn't been sufficiently gravel packed). With all of these potential pumping challenges, there is no one "perfect setting" so having the flexibility to make frequent and remote parameter changes can have a significant impact on a well's production. The following sections will analyze how each rod pumping solution addresses the more prevalent issues in horizontally drilled wells.

Example 1: Rod String Velocity Control - Leaking valves, light sand and debris

Although gravity may help seat the travelling and standing valves in a vertical well, it is not required. Fluid flow and pressure differential should be sufficient to operate the valves. Landing pumps at a steep incline (45-70+ degrees) virtually eliminates any gravitational assistance there may have been with valve seating. (Hein, N. 2007). To improve valve seating spring loaded cages could be used in the downhole pump but these additional parts add more complication because of the potential of getting fouled up with sand or other debris. To improve valve operation, more flow (i.e. higher pressure differential) is required, so increasing the acceleration of the downhole plunger can be very effective.

When the valves in the downhole pump become fouled up with debris or other impediments, the fluid weight in the tubing does not effectively transfer between the standing and traveling valves. Depending on which valve is stuck open, the measured rod string weight may be too low (travelling valve not seating on upstroke) or too high (standing valve not sealing on down stroke). To clear a travelling or standing valve of debris, it has been found that increasing the up-stroke plunger velocity or down-stroke plunger velocity respectively can be very effective.

A possible explanation for this is the increased velocity of the fluid passing through the valve openings (travelling or standing) flushes out the debris which was interfering with the valve operation. Additionally, it is believed that gently tapping the pump can be helpful. This can be explained by the vibrations generated by the tap jarring the ball and potentially dislodging the debris.

Continuous stroking is recommended in wells that are known to produce sand and debris. This is because when pumping is stopped the sand in suspension in the column of fluid in the tubing settles to the bottom plugging up the downhole pump. When the well is restarted, the sand that has settled down between the plunger and the barrel can result in pump damage or a seized pump.

(A) Resolution Options with Pump Jack (with VFD)

An AC powered pump-jack equipped with a VFD could manipulate the upstroke plunger velocity to improve travelling valve seating while maintaining a set stroke per minute. If the well was spaced relatively close to tap, it is often possible to over-speed the downstroke and overstretch the rods to reach tap similar to the linear hydraulic pump-jacks with advanced control, otherwise a manual adjustment to the rod clamp position would need to be made to lower the rod string to enable a physical tap.

(B) Resolution Options with Pump Jack (without VFD)

There is currently no way to manipulate just the acceleration of a polished rod on a pump jack driven by a combustible engine or an AC motor without a VFD. It is also not possible to control the upstroke and downstroke speeds independently. The gearing can be changed to increase overall stroke speed, but that can create other problems such as rod buckling and excessive well bore fluid draw down requiring frequent stops to prevent fluid pound. To put a well on tap the polished rod spacing needs to be adjusted such that tap occurs during regular operation or when pumping speed is increased (as explained above). Otherwise, a manual adjustment to the rod clamp position would need to be made to enable a physical tap (like the conventional pump-jack example above).

(C) Resolution Options with Basic Linear Hydraulic Pump-Jack

Basic linear hydraulic pump-jacks operate with an on/off solenoid style valve control and accelerate to peak polished rod velocity almost immediately on the upstroke. A crude adjustment is possible by setting the valve to open to a different position on the upstroke vs the downstroke, directly affecting upstroke speed vs downstroke speed. Provided the rod-string is spaced properly, tapping can be induced by simply lowering the bottom position sensor. These position changes are manual and would require a site visit.

(D) Resolution Options with Advanced Linear Hydraulic Pump-Jack

As explained earlier, the most significant difference between Advanced and Basic linear hydraulic pump-jacks is the continuous position monitoring as compared to just top/bottom proximity sensors. With continuous position monitoring, the acceleration/deceleration zones can be adjusted independently. The upstroke and downstroke plunger velocities can also be adjusted independently. As a result, it is very simple to make the required plunger velocity changes to address whatever issue is impacting valve seating (See appendix, cases 1A, 1B and 2). Setting a well on tap can also be done simply by lowering the bottom position set point via the local HMI or remotely via a SCADA system (provided the rod string was spaced to tap at its lowest operating position during the initial installation).

Example 2: Position Control – Potential Sand Management

From time to time a larger than normal amount of sand/debris can be drawn into the downhole pump and not immediately produced up the tubing resulting in an accumulation inside the pump. This accumulation can have a very severe impact on pump operation and if left unresolved could restrict or completely block fluid flow into or out of the pump. Sand may accumulate in the bottom of the pump to the point that it interferes with the valves and/or plunger operation. Continued accumulation could result in the pump hitting the sand prior to reaching the bottom of the stroke putting the rod string in compression. This condition appears on a pump card as a tap but is actually happening inside the pump rather than normal tap on top of the pump (Figure 2). The same situation can happen at the top of the pump if sand or debris accumulates above the plunger. This situation can also be seen on the pump card as an increase in rod load, above normal levels, near the top of the stroke. If left unresolved the packing of sand or debris can be significant enough to restrict or completely block off fluid flow from the pump.

Typically a well workover is required to deal with a sanded pump.

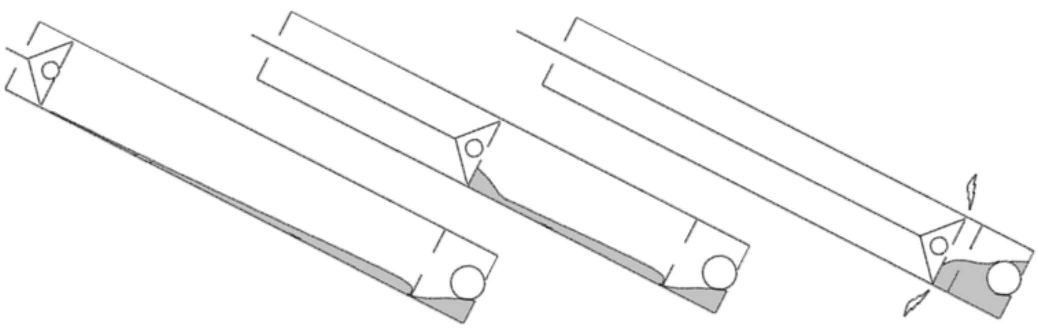

Figure 2, sand/debris accumulations

A shortened stroke length can be used to attempt to clean out a pump that has not yet sand locked (i.e. sand accumulation that blocks plunger movement or blocks the flow of fluid into or out of the pump). For accumulations at the bottom of the pump, the bottom stroke position should be raised so the plunger no longer contacts the sand/debris (refer to the pump card to determine this position). This prevents further sand compression and causes the sand to loosen and mix via agitation with the production fluid. By continuing this action, the pump can be cleaned out fairly quickly depending on the quantity of sand in the pump. If the accumulation is at the top of the pump, the top stroke position should be lowered to the point of no contact. As with accumulations at the bottom, the agitation from continuing to pump (without further packing) can loosen the sand/debris so it can mix with the production fluid and be washed out of the pump. If caught early enough, the probability of successfully cleaning out a sanded pump with this technique is much higher (increasing the odds of avoiding the work-over costs).

(A) Resolution Options with Pump Jack (with VFD)

Changing the stroke length and position offset is possible on a pump-jack; however, it is a time and labor intensive procedure. With a VFD it is possible to get some overstretch at the top and bottom of the stroke, but even with the overstretch feature it is impossible to short-stroke a pump-jack without stopping and manually adjusting the pitman arm or polished rod.

(B) Resolution Options with Pump Jack (without VFD)

On a combustible pump-jack unit, the same limitations apply as the VFD equipped systems. Either the carrier bar clamp would need to be lowered on the polished rod (to raise the stroke region higher) or the full stroke length would need to be shortened.

It may not be possible to simply raise the stroking region depending on the length of the downhole pump. If the surface stroke length exceeds the downhole pump length, changing the stroke top position could inadvertently unseat the pump.

It is possible to install a clamp on the polished rod below the carrier bar to shorten the stroke. This essentially prevents the polished rod from descending once the clamp hits the top of the stuffing box. This technique is not recommended because it introduces a large shock to the wellhead and stuffing-box and completely removes the weight of the rods from the pump-jack on the downstroke. This also leads to the possibility of stalling as there is a sudden lack of rod weight to bring the counterweights to the top position.

(C) Resolution Options with Basic Linear Hydraulic Pump-Jack

A linear hydraulic pump-jack with basic top/bottom position sensors can provide a shortened stroke. The position sensors can be moved manually to either raise the bottom position or lower the top position. If the system does not provide pump cards, a hydraulic pressure gauge can be used to determine where contact with the debris begins. The adjustments on a system like this are manual and require a trip to site. There will also be some trial and error involved to find the correct sensor settings.

Multiple site visits may be required to determine if the debris has cleared and to reset the position sensors back to their original locations.

(D) Resolution Options with Advanced Linear Hydraulic Pump-Jack

A linear hydraulic pump-jack with precise and continuous position sensing can have its top and bottom set-points adjusted either locally with the HMI or remotely with a SCADA system. The pump cards can be used to determine the new set points to avoid contact with the sand/debris.

After a certain period of time the stroke set points can be slowly returned toward the original settings and the pump card can be referenced for instant feedback on whether the sand has been cleaned out. All these adjustments can be made remotely if a SCADA system is installed. (See appendix, cases #3 and #4).

Example 3: Speed Control - Gas interference, Gas Locking and Rod Stress

Today's oil wells seem to have more pronounced issues with gas interference, gas locking and rod stress. This section compares the most common rod pumping solutions relative to their ability to effectively mitigate these issues. First, some general background on gas interference, gas locking and rod stress is required.

Produced gas can cause production issues in varying degrees depending on where and how the downhole pump is set in a horizontal well: vertical (or at an angle just before kickoff) or at an angle post kickoff (Figure 3).

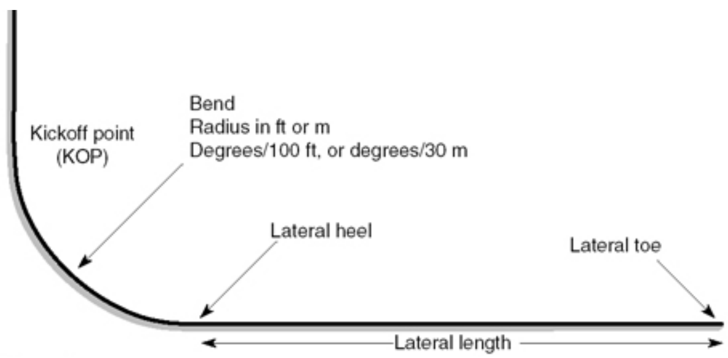

Figure 3, kickoff point where deviation starts after vertical section

If set vertically before the kickoff point, there is no natural sump to use to separate the gas from the fluid since the pump is well above the perforations. To help mitigate issues with excessive gas, a gas anchor or a packer can be installed (Campbell, J. H. 1989).

They perform in a similar manner as a surface gas separator, providing a space for the gas to leave the fluid before the fluid makes its way into the downhole pump. These gas separators have specific flow ratings where they operate most efficiently. If production exceeds the gas separator flow rating, gas starts entering the pump which typically results in a drop in pump efficiency. As a result, to achieve higher pump efficiency during initial production the surface equipment and down-hole separator should be sized for similar production rates.

If the pump is landed after the kickoff, or in general at an angle, then a natural sump is formed. Gas and liquid will separate in non-vertical casing, with gas migrating to the top, above the liquid (Figure 4). The tubing will be resting on the bottom of the casing, and the pump will ideally be fully submerged in liquid to maximize the benefit of the natural separation (Cortines, J. M. 1992). With this pump landing configuration, gas interference and gas locking issues are thought to be less severe because the pump intake is submerged with the separated gas flowing above it.

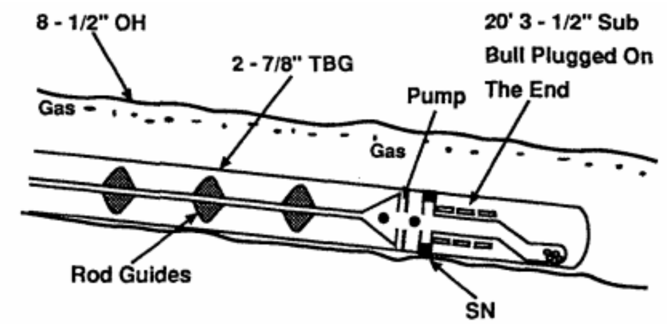

Figure 4, Typical setup for pumping a horizontal well in the deviated portion of the hole (Cortines, J. M. 1992)

A common procedure for addressing a gas locked pump is to lower the polished rod to put the pump “on tap” (physically contacting the top of the downhole pump). The potential theory is that this helps fix a gas locked pump by:

(1) creating enough shock or vibration to cause fluid leakage from the tubing down past the plunger and into the pump to displace some of the gas.
(2) shaking the traveling valve enough to briefly unseat it and allow some of the gas to escape up the tubing

When a pump is on tap, it also guarantees the travelling valve is as close as possible to the standing valve, which is the position that has the highest compression ratio (Parker, R.M. 1992 June). Over time there is also leakage between the barrel and the plunger resulting in additional fluid between the valves leading to a higher compression ratio and increased possibility of opening the travelling valve to allow gas to escape up the tubing.

If the above method is unsuccessful, another strategy is to physically stop the pump-jack at the top most position and manually lock it in place. This gives the fluid a chance to leak between the barrel and plunger to displace some of the gas in the pump. Shutting in the well may also increase formation pressure to help overcome the gas pressure in the pump and open the standing valve to the point that normal pumping can resume. This process typically requires manual intervention to stop and lock the polished rod in the highest position and to restart again hours later.

Finally, another option is to employ a service rig to manually long stroke the polished rod and by extension the downhole pump to maximize compression and break the gas lock.

In addition to gas interference, there are several other factors that need to be considered in the completion and operation of horizontal wells. Rod guides should be carefully selected so as to reduce rod wear from contact with the tubing. Rod buckling is also a much greater concern in horizontal wells. Sinker bars should be installed at the bottom of each vertical section to keep tension on the rods during a down stroke. A faster up stroke and slower down stroke also helps prevent buckling rods as well as reducing slippage in the pump. However, a slower upstroke puts less tension on the rods which is useful for managing stress in medium to large wells with large plungers. The flexibility to make these parameter changes to help address the challenges will be dependent on the type of artificial lift system deployed, as summarized below.

(A) Resolution Options with Pump Jack (with VFD)

By using an AC motor with a VFD on a conventional pump-jack, one can finely tune the pumping speed to not exceed the production rate of the downhole separator. Certain VFD's are also capable of different upstroke vs down stroke speeds so a slower down stoke can be implemented to help keep the rod string in tension while the faster upstroke keeps the overall average strokes per minute at the desired rate. This configuration helps mitigate rod buckling in wells with severe dog legs and pumps landed at steep inclines. VFD features can also be used to address gas interference. For example, increasing the down stroke speed or tapping the pump as mentioned in the speed control section (if spaced properly). The pump-jack can also be locked in the top position to attempt to use fluid leakage to break the gas lock (as explained above).

(B) Resolution Options with Pump Jack (without VFD)

A combustible driven (or AC driven with no VFD) pump-jack can be set so that the production at the surface does not exceed the rating of the downhole separator by changing overall stroke speed. Buckling tendencies will need to be managed with sinker bars or slower overall stroke speed (via manual pump jack adjustments). To break gas lock, the well must be spaced to tap or to leave in top position just like a VFD equipped unit. This would require a site visit to make physical changes to the system setup.

(C) Resolution Options with Basic Linear Hydraulic Pump-Jack

A basic linear hydraulic pump-jack can be set so that the production does not exceed the rating of the downhole separator. This can be done by varying the dwell time between strokes even if the polished rod velocity is not configurable. Alternatively, the output flow rate of the hydraulic pump/valve combination can be reduced via a manual adjustment. The maximum down stroke speed can also be reduced with a manual valve adjustment to help mitigate buckling. To break gas lock, the bottom position sensor could be manually lowered to put the pump on tap (if spaced appropriately). The polished rod can also be raised to the top position, like on the pump-jack, with either a long top dwell setting or manually. The pump can then be restarted either manually or automatically once enough fluid has leaked into the pump to break the gas lock.

(D) Resolution Options with an Advanced Linear Hydraulic Pump-Jack

Advanced linear hydraulic pump-jacks with continuous position sensing can be set so they do not exceed the maximum production rating of the downhole separator. This is done with either dwell times or by directly controlling the polished rod velocity. The hydraulic flow characteristics can be configured to gently drop the polished rod at a prescribed velocity to mitigate buckling and manage rod stress. To break a gas lock, four methodologies have been tested on advanced linear hydraulic pump-jacks:

1. The most frequently used strategy is simply a temporary increase in down stroke speed. It is speculated that this action results in a higher compression ratio to help pop open the traveling valve so the gas can escape. There is also a possibility that the higher stroke rate causes more vibration in the rod string resulting in more fluid leaking past the plunger and into the barrel. This would aid in compression on subsequent strokes forcing the traveling valve open. (See appendix, case 5).
2. The second strategy is to alternate between fast up for ”X” strokes followed by fast down for “Y” strokes. The exact mechanism for breaking gas lock is not well understood but it has been shown to be successful in some situations.
3. The third strategy is to lower the bottom set-point so the pump can be set on tap (as described previously).
4. If none of the first three methods work, a fourth strategy is to enable a feature that sets and holds the polished rod at its highest position and automatically restarts pumping after a preset number of hours. This can be achieved without having to visit the site.

In the research for this paper, the methodologies were only tested by Zedi on the advanced hydraulic pump-jack configuration and not the pump-jack with VFD. However, it is perceived that the first three of these four methodologies, that might address gas locking, would also be applicable on a pump jack with VFD.

It should be noted that “gas lock fixing” methodologies one through four do not always work and we continue to experiment with precise rod string control capabilities to see if gas locking can be more systematically “fixed” in more situations and cases.

Summary

The table below summarizes how the different rod pumping systems solve each issue.

	Pump-Jack c/w VFD	Pump-Jack No VFD	Basic Linear Hydraulic Pump-Jack	Advanced Linear Hydraulic Pump-Jack
Non-Seating Valves Light Sand/Debris	quick upstroke and tapping; possible remotely	increase stroke speed; manual local adjustment	quick upstroke and tapping; manual local adjustment	quick upstroke and tapping; possible remotely
Excess Sand Management	shorten or raise the stroke region higher; manual local adjustment	shorten or raise the stroke region higher; manual local adjustment	shorten or raise the stroke region higher; manual local adjustment	shorten or raise the stroke region higher; possible remotely
Gas Interference Management	match production to the downhole gas separator; possible remotely	match production to the downhole gas separator; manual local adjustment	match production to the downhole gas separator; possible remotely,	match production to the downhole gas separator; possible remotely
Gas Locking Resolution	quick down stroke and tapping, extended stop at top of stroke; tap possible remotely, top stop manual local only	increase the stroke length to tap, extended stop at top of stroke; manual local adjustment	quick down stroke and tapping, extended stop at top of stroke; manual local adjustment	quick down stroke and tapping, extended stop at top of stroke; possible remotely
Rod Stress Management	slow the downstroke to prevent buckling; possible remotely	decrease stroke speed; manual local adjustment	slow the downstroke to prevent buckling; manual local adjustment	slow the downstroke to prevent buckling; possible remotely

Discussion

A pump jack equipped with an AC motor and VFD provides greater flexibility than one without a VFD to assist with effectively pumping today's shale or horizontal wells. The ability to adjust upstroke and down stroke characteristics independently is crucial for maximizing production potential. Going a step further and adding the ability to modify parameters *throughout* the upstroke and downstroke adds further flexibility to control a rod string and by extension the downhole pump.

Linear hydraulic pump-jacks, by their nature, provide the same level of rod string control, regardless of the powerpack type (i.e. AC or combustible). As a result, maximum optimization can be employed regardless of grid (AC) power availability and without the added cost of a generator. As for stroke length adjustments, the linear hydraulic pump jack allows for instantaneous control over stroke length and position whereas a pump jack (with or without a VFD) requires labor intensive local intervention (and downtime). Likewise, stopping and holding a stroke position (other than maximum top) is not possible on a pump jack without a mechanical brake that must be engaged (and disengaged) locally. The ability of the linear hydraulic pump jack to stop and hold any position is very useful for things like performing traveling and standing valve tests. The results of these tests will provide an indication as to the performance of the downhole valves. This in turn provides information useful in determining if some cleanout action is required to restore pump efficiency. Consistently poor results in these tests could indicate that a pump change is required or that long term operational changes must be implemented to improve pumping efficiency

Precisely controlled linear hydraulic pump-jacks are more flexible than their standard 2-sensor or no-sensor counterparts. The addition of a SCADA system with an advanced linear hydraulic pump jack provides even more flexibility for identifying and resolving common rod pumping issues by taking full advantage of the system's capabilities for remote control.

Conclusions

Pump jacks equipped with AC motors/VFDs and linear hydraulic pump-jacks with continuous position sensing are similarly capable of remotely and precisely controlling polished rod velocity and are therefore useful at dealing with light debris and gas interference issues that commonly occur in horizontally drilled wells. Linear hydraulic pump-jacks with real time position and speed control capabilities also have the benefit of precise position control enabling features such as automated valve tests and cleaning out moderate amounts of sand from a downhole pump. As an added benefit, these features are not restricted to sites that have AC power. They can also be exploited on a linear hydraulic pump jack with a combustible powerpack.

New and sophisticated hydraulic solutions deliver unprecedented capability beyond the most sophisticated conventional pump jacks. These features are critical for operating the new breed of horizontally drilled and hydraulically fractured oil wells. Their unique capabilities to deliver truly optimized operation make then the best in class and are the best match to effectively produce today's oil wells.

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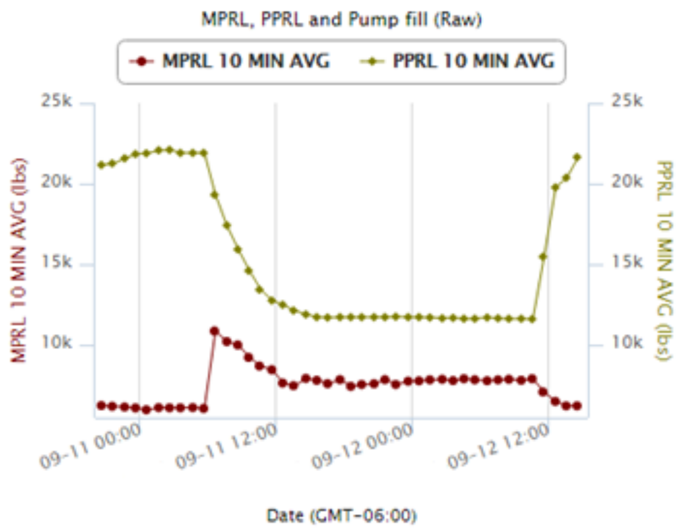
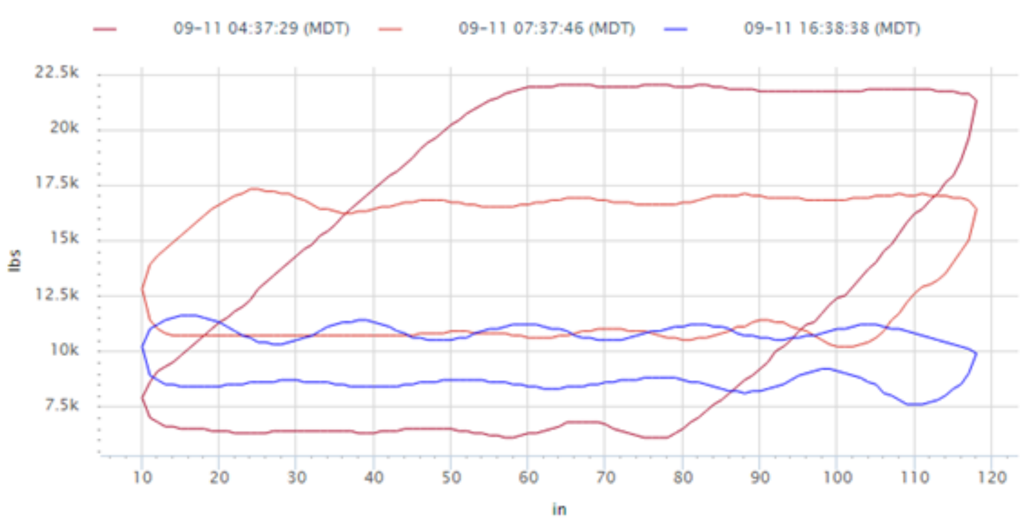
Appendix

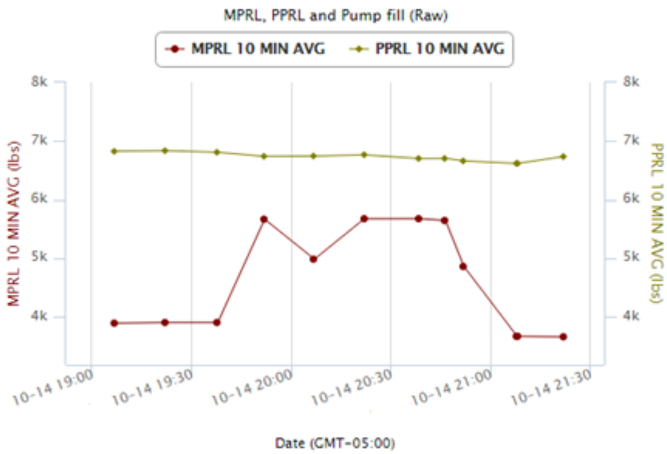
Case 1A: Stuck Open Standing Valve – Remote Intervention after 24 hours

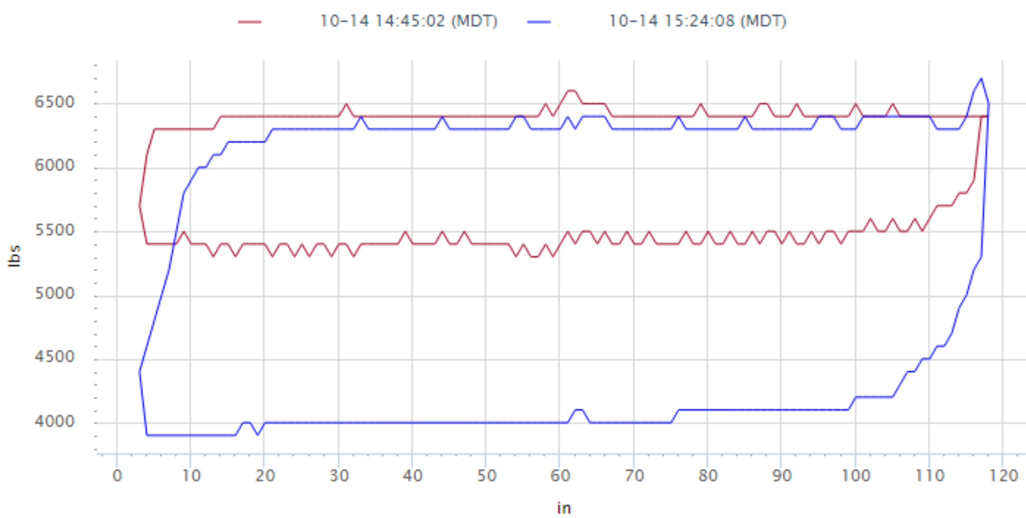




This is a well in northern Oklahoma; the pump is landed at 4780ft (1457m). The initial symptom was a sudden increase in min polish rod load followed by a steady decline in peak polish rod load. This is a classic sign of a stuck open standing valve where the traveling valve isn't opening and fluid is slowly lost due to slippage.

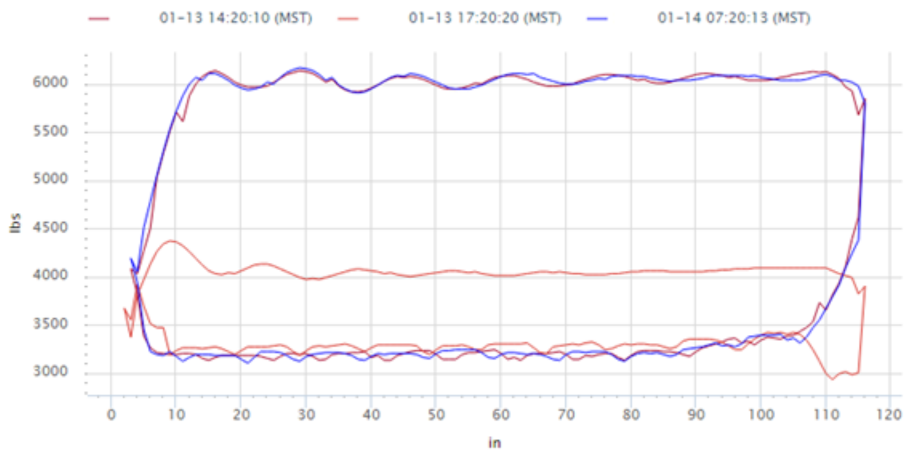
Case 1B: Stuck Open Standing Valve – Remote Intervention after 2 hours





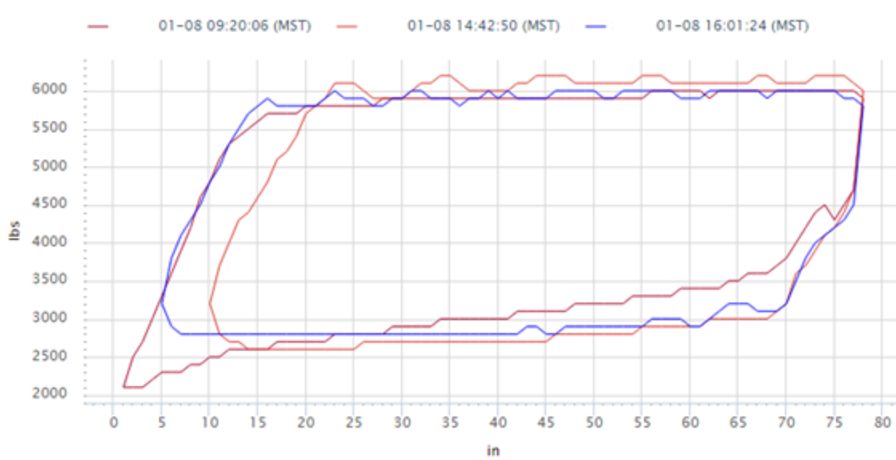
This is a well in northern North Dakota; the pump is landed at 3150ft (960m). Stuck open standing valve resulted in sudden increase in min polish rod load. In both Case 1A and 1B, resolution was a remote change in down stroke velocity (increased by about 1/3) for a period of about 30 minutes. Once cards returned to normal the initial down stroke velocity was restored.

Case 2: Stuck Open Travelling Valve – Remote Resolution:



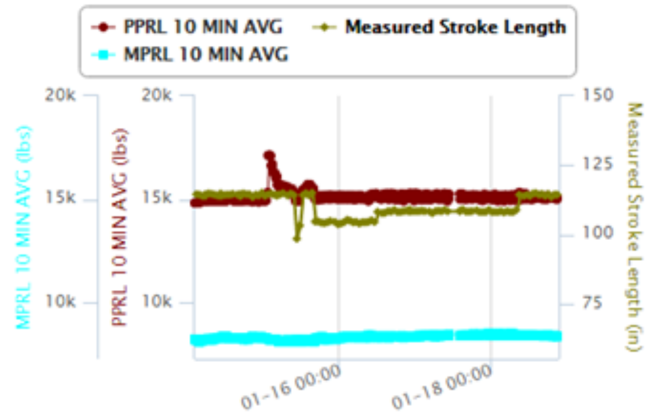
This is a well in south eastern Alberta; the pump is landed at 2560ft (780m). The travelling valve was not seating on the upstroke at 3spm. Increased upstroke speed and valve had proper sealing again. Cards shown: regular operation, non-sealing valve, back to regular operation

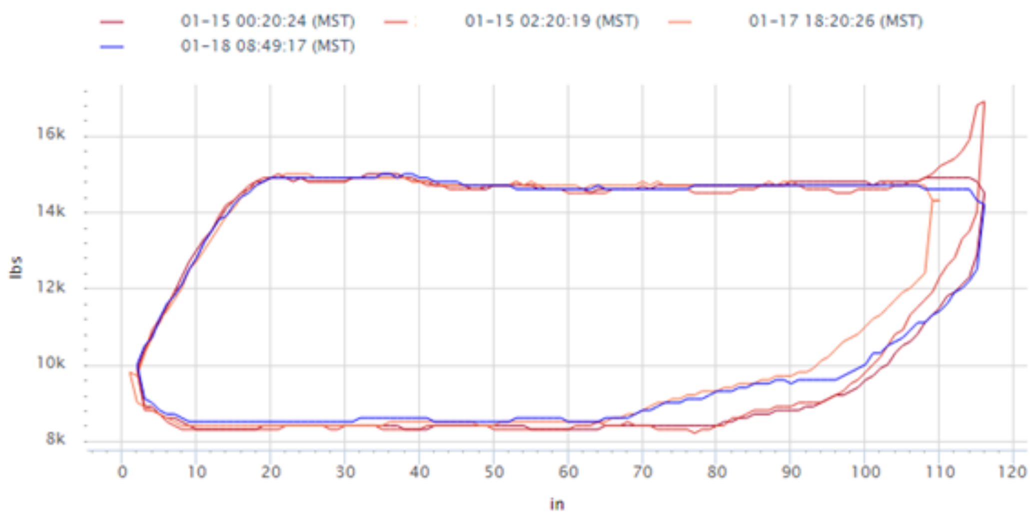
Case 3: Sand Build-up In The Bottom Of Pump – Remote Resolution



This is a well in south eastern Alberta; the pump is landed at 2723ft (830m). Sand entered pump and built up, the stroke was shortened and pump speed increased, then stroke length and rate restored, standing valve and pump now clear

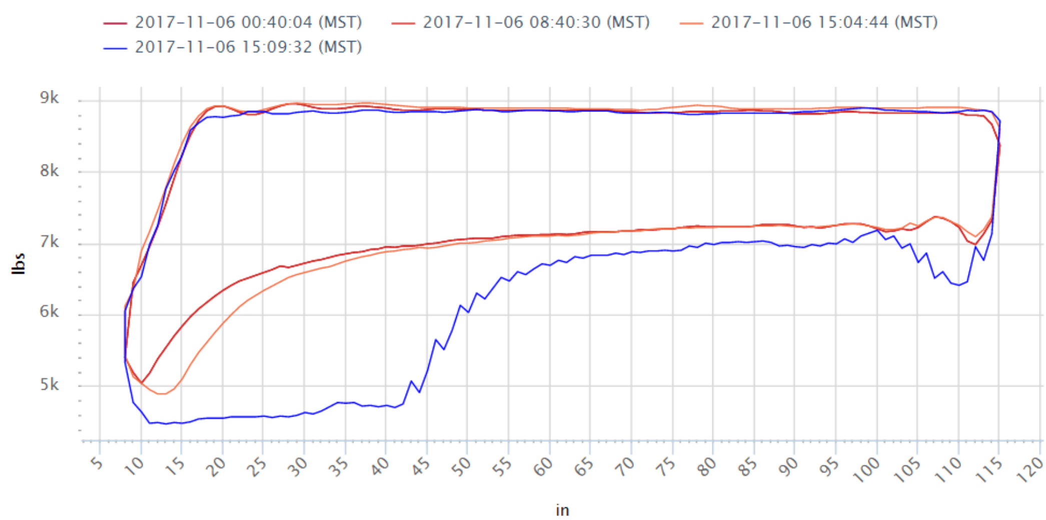
Case 4: Sand Build-up at Top of Pump- Remote Resolution





This is a well in south eastern Saskatchewan; the pump is landed at 4026ft (1227m). Sand accumulated at the top of the pump and caused plunger to have resistance at top of pump. The stroke length was lowered to stop compressing the sand. After a period of time, the sand got produced up the tubing and stroke length was restored.

Case 5: Gas Lock – Remote Resolution



This is a well in southern Alberta; the pump is landed at ~3740ft (1140m). In this example, gas lock was first observed around midnight (red line). After 15 hours of operation (orange line) the pump was still in a gas locked state and field operations confirmed no production at surface. At that time, the down stroke velocity was increased by about one third. Within 5 minutes, regular down stroke rod weight resumed and shortly after that surface production was confirmed by field operations. This type of intervention on gas locked wells is not always successful.