ANALYSIS AND OPTIMIZATION OF SUCKER ROD PUMP DESIGN

Levins Thompson, Brandon Zachry, Zack Smith, Ricky Roderick and Greg Gonzales
Don-Nan Pump & Supply

ABSTRACT

Rod lift design methods remain overwhelmingly unchanged since the mid-20th century. Meanwhile, drilling and completion technology has undergone a dramatic transformation. The innovation gap between the two technologies and low-flow artificial lift has resulted in the need for improved design and workflow methods to more effectively operate an unconventional well throughout its lifecycle.

New designs and processes are established which offer potential to improve common practices through observation of well characteristics and root cause analysis of equipment failure. This analysis outlines the scope of processes necessary to properly optimize a sucker rod pump from the perspective of a sucker rod pump vendor.

PAPER

Under ideal scenarios there are clear steps which should be taken in order to properly manage how a well is assessed, designed to bring to production using a rod lift method, and optimized based on well conditions and variables.

Evaluating if the well under consideration is a proper candidate for sucker rod pumping (SRP) should be the primary task. Economics and feasibility are always reviewed for financial considerations but more applicable reasons will be focused here. Certain well characteristics like oil, water, and gas production rates with details of undesirable conditions and reservoir fluid properties will lead several decisions. The fluid flow rates dictate if a SPR is capable of reaching the desired production. A typical maximum of approximately 1,500 bpd can be used as a guideline. By comparison Progressive Cavity Pumps (PCP) and Gas Lift (GL) are capable to produce approximately 5,000 bpd and Electric Submersible Pumps (ESP) are capable to produce approximately 7,000+ bpd in onshore applications. Undesirables vary in type, severity, frequency, and mixtures. For example, excessive gas influx or an overly deviated well could indicate Gas Lift as a more viable alternative. Total fluid production is a major variable. If the well's natural production remains high then a high volume lift method like an ESP or PCP may be chosen to achieve those higher volumes while the reservoir has a high rate of fluid entry.

The severity level of the well's undesirable variables, like corrosives and solids, can be detrimental to certain downhole working mechanisms that are the basis of artificial lift methods. It is widely known the damaging effects of solids to ESPs, gas to PCPs, and both for SRPs. Additionally, unconventional wells have added another layer of unpredictability from horizontal well effects compared to traditional wells.

It is commonplace for aggressive drilling practices to leave challenging wellbores for certain artificial lift (AL) methods. Therefore the wellbore profile and particularly its deviations will play a major role in the efficiency of each AL method. Specifically for rod pumping deviations create drag when reciprocating sucker rods make contact with bended tubing creating increased loading to lift and wear on rods and tubing. Shallow depth deviations are especially detrimental due to the drastically increased side loading created at the bend.

Once it is determined a SRP is the most practical lift method for the well it should be designed so that it lifts most efficiently. Established software technologies are able to calculate the required designs however based on the quality of information provided can potentially yield sub-accurate results. There are two basic types of methods to take to perform a design; designing equipment around target production or maximizing production from given equipment. In reality it is usually a combination of both where there are certain equipment types and sizes to work from but also should reach a target fluid production. For example, if a user only has a C-912-365-168 pumping unit available and a 2-7/8” tubing string this would limit the weight of the fluid load being displaced to 912,000 in-lbs gearbox torque, 365,000 lbs of structural loading or peak polished rod loading and the length of the stroke to 168 inches. Also, the tubing will restrict the size of an insert pump to a 2” bore. Depending on how much production is needed the SPM to achieve that might not be realistic for a 365 sized pumping unit. In this case either a change to the size of the surface equipment, a change to a tubing pump for a larger bore, or a change in expected production should be expected. In order to achieve a rod pumping system which will operate most efficiently the design program output should be qualified by an experienced user.

After the design of the well has been determined based on the equipment and production constraints the only variables of the pump which have been established are the calculated downhole stroke length and the pump bore size in inches. The downhole pump assembly type and associated metallurgies will be considered next based on the understanding of the downhole well conditions and well specifics to properly optimize the pump for the well. Several aspects of the well will filter which sucker rod pump assembly types fit the application such as the placement in the well geometry and the expected production fluid volume and makeup.

The SRP was originally designed for vertical pumping operations. However, due to the drive for increased production and the popularity of unconventional wells the downhole pumps are increasingly being used beyond their original application. Risk mitigation factors should be evaluated for pump placement based on the well’s inclination, dogleg severity, and proximity to perforations.

Inclination refers to the deviation from vertical, regardless of compass direction or azimuth, expressed in degrees. Simply, in ideal conditions, the higher the pump inclination during operations the faster the assembly will wear and reduce run life. The acceleration of wear is highly variable but anything beyond vertical will introduce forces which contribute more to wear than vertical.

Another wellbore profile characteristic which is capable to decrease efficiency or the run life of the downhole pump is dogleg severity, DLS. DLS is defined as an abrupt turn, bend or change of direction in a survey line, a wellbore, or a piece of equipment. Dog-legs can be described in terms of their length and severity and quantified in degrees or degrees per unit of distance. A particularly deviated place in a wellbore where the trajectory of the wellbore in three-dimensional space changes rapidly, either from inclination, azimuth (compass direction), or both. DLS is usually expressed in degrees per 100 feet (or 30 meters) of wellbore length.

Calculation 1

The following formula provides dogleg severity in degrees/100’ and is based on the Radius of Curvature Method (Laperyrouse, 2002):

$$DLS = \{\cos^{-1}[(\cos\theta_1 * \cos\theta_2) + (\sin\theta_1 * \sin\theta_2) * \cos(A_2 - A_1)]\} * \frac{100}{CL}$$

Where:

DLS = dogleg severity, degrees/100ft

CL =course length, distance between survey points, ft

θ_1, θ_2 =inclination (angle) at upper and lower surveys, ft

A_1, A_2 = direction at upper and lower surveys, degrees

^Azimuth = azimuth change between surveys, degrees

The sucker rod pump is designed to reciprocate linearly. When placed in a curvature it introduces lateral forces on internal parts not designed for bending which contribute to wear and stress that ultimately decrease performance, efficiency, and usage life. As expected, the severity of the DLS will contribute greatly to the amount of internal stress and its effect on fatigue life acceleration. Deviation surveys are frequently recorded at 100 foot intervals. This can be an issue because sucker rod pumps are typically 20 to 30 feet long. Therefore, if the survey's DLS for that 100 foot interval is an average of the instantaneous DLS readings throughout that 100 feet then it may not be a smooth curve transition. The pump could potentially be placed in a portion of the 100 foot interval where the instantaneous DLS over the pump's length exceeds the maximum recommended DLS. The below image is an example wellbore demonstrating how an average DLS over a large interval can look to have a gradual build rate but could include sections which have instantaneous sections of extreme deviations. Section A shows a higher deviation than the average where Section B shows a lesser DLS which and looks more tangential. Section B would be a safer section to land the SRP.

Therefore, when evaluating the directional survey care should be taken which DLS interval to select. To reduce risk it should be considered to place the pump in a smoother transitional DLS series of values rather than one with erratic increasing and decreasing DLS values in order to avoid placing in close proximity to a highly instantaneous DLS transition. For example, a 300 foot section with three 100 foot intervals made up of 4 deg/100 ft DLS each might be a better application than a 300 foot section made up of one 3 deg/100 foot, one 7 deg/100 ft, then one 2 deg/100 ft intervals. As stated by (Hein, 2007), use the wellbore deviation to find an area with the least amount of deflection and least rate of change (unplanned deviation) over an area of at least 1-1/2 to 2 times the pump length. Ideal conditions would have the dogleg severity less than 5 degree per hundred (within the planned build rate).

Well treatments are a critical part of ensuring wells remain free of buildup, control corrosively, and keep the formation stimulated for continued production. Some well treatment chemicals however have adverse effects on pump components. Conversely, if corrosion is not mitigated by well treatment chemicals the well corrosion can have adverse effects on pump components as well. Therefore, a medium must be kept.

A common form of well treatment is known as acidizing. This process involves the pumping of acid into the wellbore to remove near-well formation damage and other damaging substances. This procedure commonly enhances production by increasing the effective well radius. When performed at pressures above the pressure required to fracture the formation, the procedure is often referred to as acid fracturing. In addition, cleanup treatments including hydrochloric acid without entering the formation using smaller volumes of solutions can be used as well which can come in contact with the sucker rod pump.

For chrome plated barrels, hydrochloric acid depending on the concentration, can yield severe corrosion damage through pit formation and flaking of the coating. (Karpuz-Pickell, 2015)

On acid treating jobs where the pump is sent back in the well too soon after the swabbing [before the acid is spent] are known to cause the dissolving and flaking of the coating. One of the key characteristics of chrome plating is that it is easily dissolved in hydrochloric acid. Hydrochloric acid, mixed with other chemicals is used to acidize the wells. The remnant acid from such acid jobs damages the Chrome coating rapidly and results in local degradation of the barrel's inner surface. (Karpuz-Pickell, 2015)

Additionally, corrosive elements in the production fluid will have detrimental effects on steel which is a common base material for many SRP parts. Brass conversely is a naturally corrosive resistant metal and is an option for certain parts. Stainless steel and Monel are also capable options. Therefore, there are material options but a minimum level of protection must be kept for parts of vulnerable materials but with care not to cause harmful effects to the chrome coating. Furthermore, Nickel Carbide plating is a suitable option for SRPs with expected exposure to these chemical treatments. Unlike chrome coating, it has a homogeneous coverage on the base material, and yields a very even coating and an almost perfectly smooth surface. The finished structure does not have any cracks or porosity like the chrome coating. This may be an advantage since cracks can act as open paths for the corrosive media to reach the base material. (Karpuz-Pickell, 2015) Electroless nickel carbide composite plating forms a composite layer on the base material that is formed of microscopic and uniformly sized silicon carbide particles in an electroless nickel-phosphorus matrix. Unlike chrome coating, it has a homogeneous coverage on the base material, and yields a very even coating and an almost perfectly smooth surface. The finished structure does not have any cracks or porosity like the chrome coating. This may be an advantage since cracks can act as open paths for the corrosive media to reach the base material. However, one needs to consider the improved wear resistance of chrome due to the cracks' lubricating behavior during the barrel's relative motion with the plunger, while comparing the efficiencies of the methods. (Karpuz-Pickell, 2015) Additionally, when using Nickel Carbide plating on the barrel solids can increase friction between the plunger and the barrel and in high volume cases can stick the plunger in the barrel. Thus, care should be taken when using in a solids burdened environment.

Pump placement in relation to perforations will determine how much gas and solids to expect entering the pump intake. When placed below perforations solids will tend to settle on the pump while gas bubbles are able to migrate up the casing annulus away from the pump intake. When placed inside the perforations both gas and solids can be expected. Finally, when placed above the perforations rising gas bubbles can interfere and some but less solids can be expected.

With the growth of unconventional wells like in the Permian Basin of Texas it is common for wells to produce a combination of both gas and solids which depending on the severity must be mitigated with BHA tools below the SRP and/or use a SRP assembly capable to handle these hazards. Such specialty assemblies which deviate from those which API controls exist to withstand such production types. Hollow Valve Rod pumps have become widely used across many regions because of its unique differences from a conventional valve rod pump. The 2-stage HVR pump has improved gas and solids handling capabilities compared to most of the standard API pumps due to two key components. Instead of using a solid valve rod, a hollow valve rod, or pull tube, is used. This pull tube allows for solids to flow through, isolated from the barrel of the pump, instead of being released in an area where it can fall down in between the plunger and the barrel. The second key design change to this pump is that there is a three-wing open valve cage located at the top of the pull tube. This three-wing cage acting as an upper travelling valve reduces the hydrostatic load on the lower traveling valve allowing for the ball to unseat more easily, reducing gas interference. The upper traveling valve creates a second compression chamber which compresses on the upstroke further improving gas handling capabilities.

In scenarios where little to no solids are expected and gas interference has affected SRP performance a modified two-stage style pump with a plunger style hollow valve rod and tighter barrel to plunger tolerances design can offer improved gas handling. These are capable to withstand the increased gas influx into the pump intake compared to API pumps and the previously mentioned HVR pump. These style assemblies can be placed below a packer forcing all the fluid to enter the pump intake rather than try and allow the gas to migrate up the casing annulus.

There are several examples of specialty pumps and parts which are capable for moderate to extreme downhole environments, production, and completion methods. Reach out to your sucker rod pumping vendor for more information on such conditions and a recommended assembly for the application.

An explanation of a recommended pump from supplied wellbore information could be described as follows. Production levels are reported to be 500 bpd with moderate gas and previous exposure to frac sand production. The well has some corrosive conditions but is being well treated with no recorded holes or pitting affects to the tubing string or sucker rods. A 2-7/8" tubing will allow for a 2" bore pump to deliver the desired rate. Due to the effective control of corrosion and the presence of moderate gas and frac sand the recommended pump could be described as a 2-stage HVR assembly with steel or brass chrome plated barrel. Chrome would be selected over Nickel Carbide plating because of the solids influx and corrosively being properly managed.

Certain specialty accessories are valuable additions to assemblies and the small changes in their designs can offer dramatic improvements in the SRP capabilities. One such specialty accessory is a modified plunger adapter designed to mitigate the effects of abrasion damage seen with solids on the barrel and plunger clearance. The adapter directs produced solids away from the pump barrel by modifying to a smaller fit against the barrel than the barrel plunger fit. Also creating a beveled leading edge in combination directs solids inside it rather than around it. Solids can be made up of formation sand, frac sand, iron sulfide scale, or any other foreign material. If the fit between the barrel and plunger is scored or worn this will affect the efficiency of the pump by increasing the slippage traditionally only allowed to lubricate the plunger action. Furthermore, a standard barrel to plunger fit is 0.005"-0.006" clearance. Therefore, any excessive solids accumulation has potential to build up and stick the plunger in the barrel halting the pumping action and cause an intervention.

In actuality the design and optimization practices are much different than represented on paper and in process. From the perspective of a sucker rod pump provider the process encompasses pump disassembly, documentation, compiling statistics, and presenting findings to clients.

Post pump pull disassembly and documentation is critical to gather evidence of what is going on downhole, why the pump was pulled, and what changes need to be made so to extend the next run life compared to the previous. During the disassembly foreign material is collected, if any. This shows the type and quantity of material that is passing through and not effectively passing through the pump. Indicating, for example, a possible change to a chemical program if iron sulfide or scale is found or a change to solids control BHA tools if formation sand or frac sand is found. Regardless, the samples should always be gathered and kept.

In order to build statistics of the performance trending categorizing the quality of each part must be conducted. Each part is given applicable categories from which to grade; wear, scoring, pitting, cracked, and stuck to name a few.

Once compiled it tells a story of what contributed to the failure and thus a root cause of the failure can be presumed. A presumption can only be made at this time because from the vendor's perspective we don't necessarily have all of the information to make a diagnosis. Furthermore, once a data set of entries is made a more macro view of an area or field can show the overall performance of the chosen SRP assembly can be tracked.

In order to achieve a definitive diagnosis we must combine our information with the operator's. Our physical evidence combined with the operator's knowledge of what led to the well going offline will identify what sucker rod pump changes, if any, need to be implemented. This emphasizes the importance of joint meetings to determine the root cause of failure. However, there is an unintended flaw in this process because of the delay involved between the reinstallation of the next pump to resume production and the analysis of why the pump failed. Therefore, in some cases, the root cause of failure is not identified and corrected until the following well pull.

To mitigate this lapse it is important to implement and utilize a pump service database which allows for near real time access to disassembly and diagnosis information from the pump repair shop. A user can proactively spot trends and major issues in order to make faster changes if needed. Allowing the user to diagnose remotely greatly improves the opportunity to catch an instance which may negatively affect an operator's failure rate.

Conclusion:

Understanding the processes which are established to enhance optimization includes both actively qualifying well characteristics and properly analyzing equipment failures in combination with the sucker rod pump vendor. When implemented consistently on well by well basis can lead to failure rate improvements for not only localized but on a field or area level too.

References:

Karpuz-Pickell, P., Roderick, R., From Failure to Success: A Metallurgical Story on Sucker Rod Pump Barrels, presented at Southwestern Petroleum Short Course, 2015

Hein, N.W., Long S.W., Mahoney M., Stevens, R., Sucker Rod Pumping Horizontal & Highly Deviated Wells – A Review & RPs, presented at Artificial Lift R&D Council - Sucker Rod Pumping Workshop, 2007

Laperyrouse, Norton J., Formulas and Calculations for Drilling, Production, and Workover, Second Edition, 2002. Page 200-201.

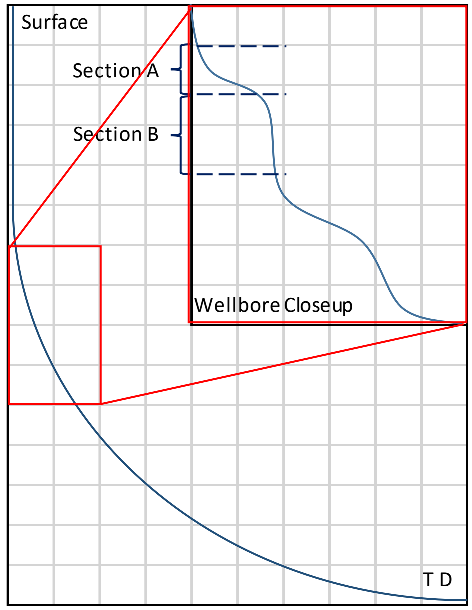

Figure 1: Example wellbore showing DLS profiles.

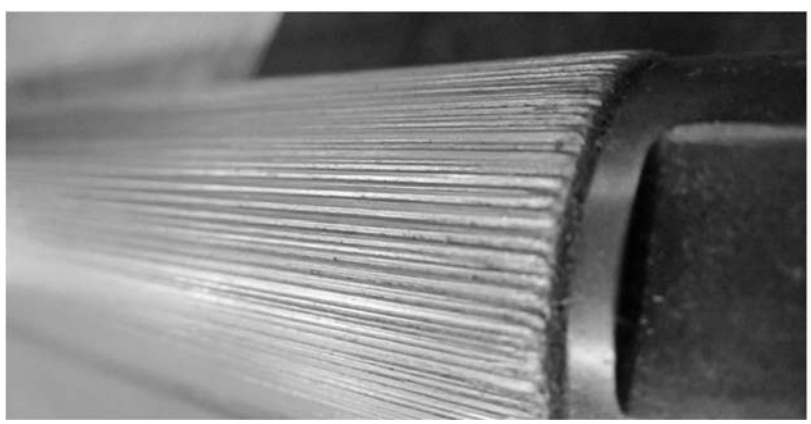

Figure 2: Example of plunger categorized as 'scoring' as recorded in a SRP tracking database.

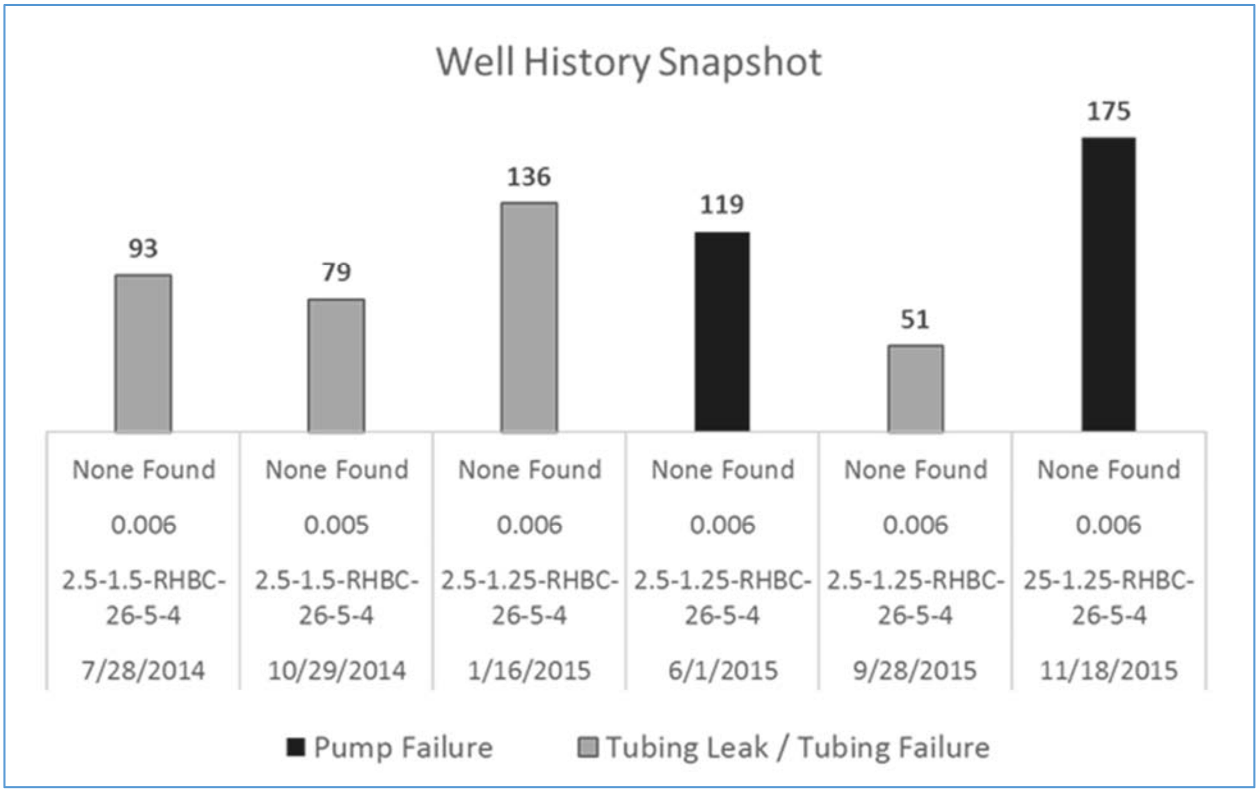

Figure 3: Example of SRP performance in one well.

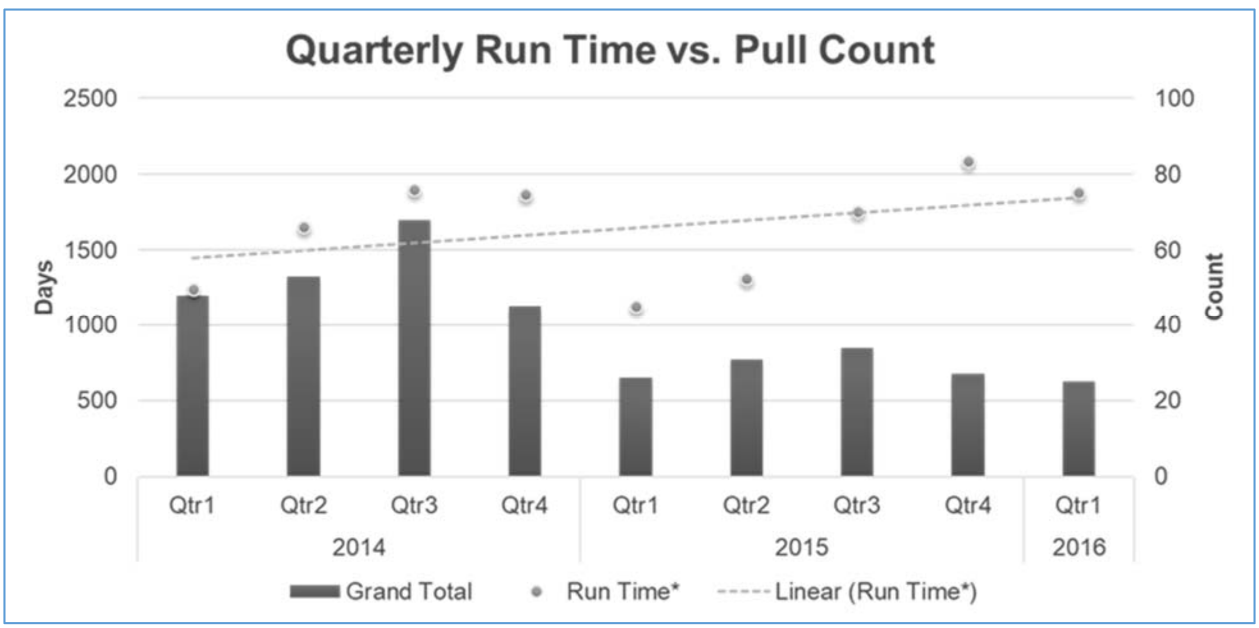

Figure 4: Example of pump runtime data graphed to show trend analysis.