ROD PUMPING IN THE CURVE WITH VORTEX BARBELL TRAVELING AND STANDING VALVES

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INTRODUCTION:

Downhole sucker rod pumps are typically installed after a horizontal oil well has been drilled, fractured, flowed, and initially produced with electric submersible pumps (ESP) for high-rate wells.

Although sucker rod pumps are broadly used across the globe in a multitude of formations and production scenarios, these pumps have limitations. Most wells drilled today are horizontal, with wellbores inclinations up to 90°. In conventional applications, traveling and standing valves are limited to inclinations of approximately 42°. The typical sucker rod pump ball and seat valves are inefficient at higher angles of inclination, constraining production potential in the curve.

When pumping with a low fluid level in the annulus (fluid level between the tubing and casing above the pump intake) where the pump is landed, the pump can cavitate, causing the standing and traveling valves to be inefficient or inoperable. Ideally, setting the pump further down the wellbore increases its hydrostatic head, reducing the effect of the low fluid level, which provides a more constant head on the downhole pump assembly. However, the propensity of conventional valves to be inefficient at inclinations beyond 42° leaves many operators landing pumps higher in the well and struggling with gas interference and limited pump efficiency.

A horizontal valve system (HVS) has been developed, incorporating a vortex barbell style design in the standing and travelling valves. The HVS has been tested extensively in over 4,000 wells across North America to address the challenge of pumping in the curve in valve sealing inclinations beyond 42°. With informed installation and established best practices, HVS performance enables pump deployment at depths of 5,000–8,000 feet and angles up to 90°, improving efficiency and productivity.

This paper provides an overview of the HVS design, summarizes laboratory testing and field study, and outlines essential installation considerations and operational best practices for operators to optimize HVS.

THE HORIZONTAL VALVE SYSTEM

The Horizontal Valve System (HVS) is an innovative valve technology that uses vortex valve design and barbell technology (Figure 1). To accommodate the barbell design, two patented vortex insert guides are rotationally aligned and secured inside a 1-piece cage body. The HVS application allows rod pumps to be landed in the curve of the well up to a horizontal inclination.

Conventional ball and seat valves placed in the curve allow the ball to fall to the lower side of the cage, leaving the potential for inefficiency due to late seating and the risk of leaking around the ball if the ball is not seated quickly. The unique ball and seat design of the HVS engages and holds the ball's position relative to the seat's center line. With an aligned barbell-type ball, the valve closes consistently and quickly while maintaining a sealed and engaged position, even when the pump is set in the curve.

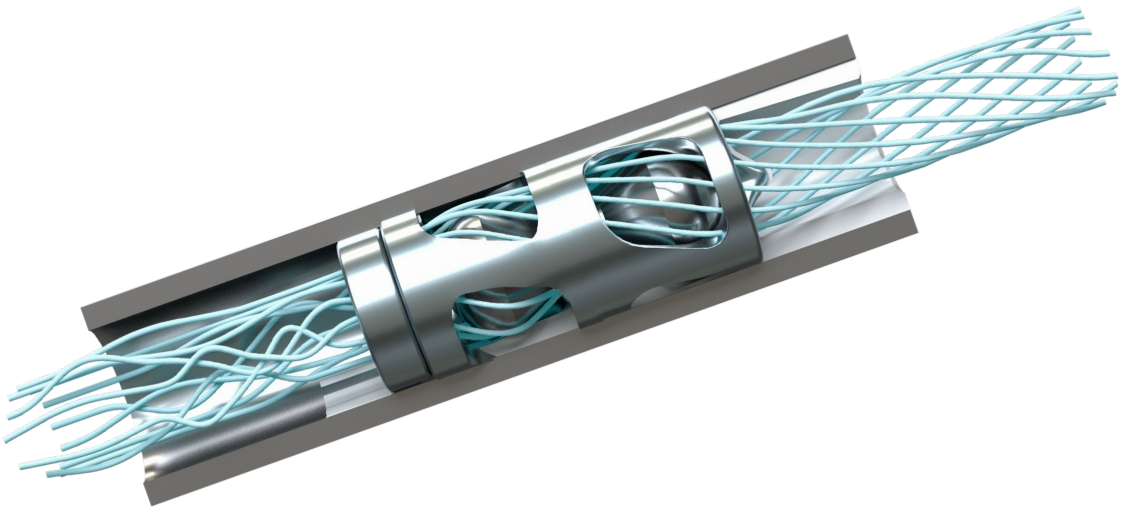

Figure 1 - HVS Vortex Barbell Design

The HVS operates similarly to conventional standing and traveling valves with a comparable reciprocating function. Figure 2 shows the pump upstroke (toward the right in the figure) where the HVS traveling valve closes as the standing valve opens, filling the pump barrel chamber. Conversely, Figure 3 shows the downstroke where the traveling valve opens and the standing valve closes, moving the liquid above the traveling valve into the fluid column being pumped to the surface.

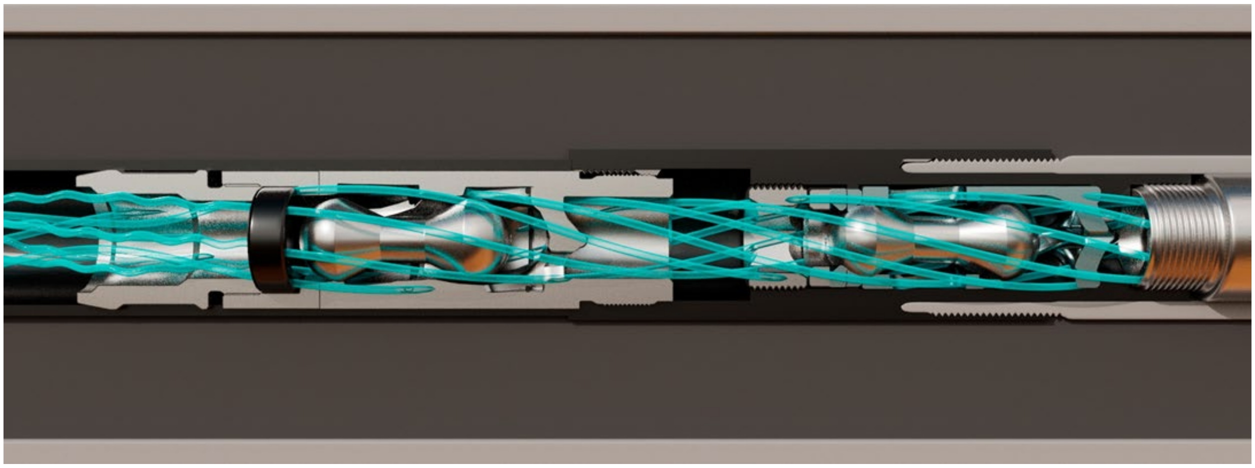

Figure 2 – Upstroke - standing valve open traveling valve closed – fluid into pump barrel chamber.

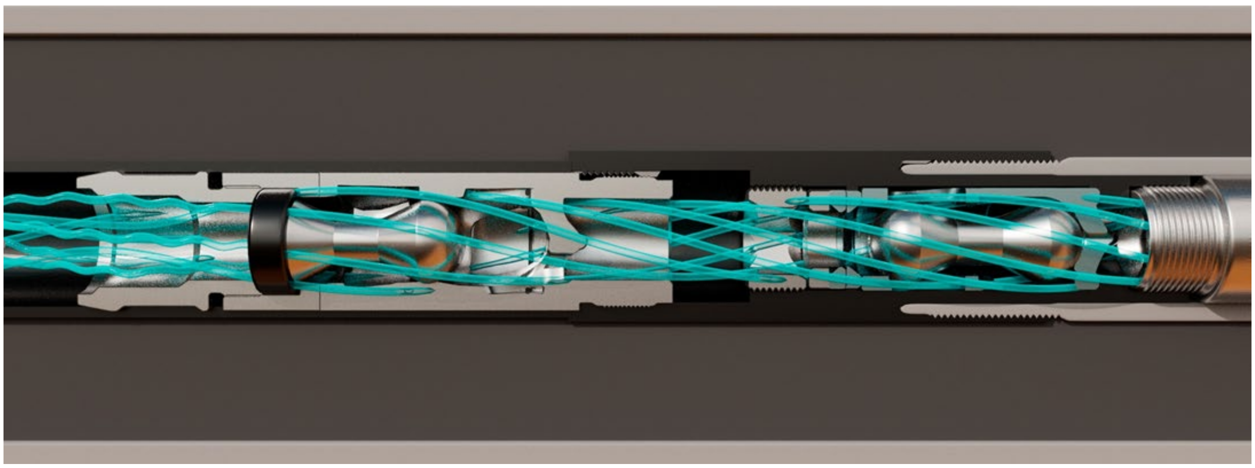

Figure 3 – Downstroke – standing valve closed, traveling valve – fluid into hydrostatic fluid column.

DESIGN FEATURES

The HVS design features optimize pumping in the curve. It enables deeper fluid column access, enhancing gas-liquid separation, increasing pump pressures, and boosting overall efficiency. The specialized vortex valve design and tailored configurations manage abrasive conditions and high inclinations.

The entire HVS is built with a **robust composition.** Tungsten carbide (with optional DLC coating) barbell metallurgy and the valve cage composed of Stellite guides with an Alloy, Stainless, or Monel cage body ensure durability under 2,500 psi pressure and thousands of cycles per day. The valve vortex cage guides are cast from a hard cobalt alloy rather than machined to accommodate tight tolerances, corrosion resistance and long wear life.

Vortex-style traveling and standing valves with barbell tapered seats reduce pressure drop and help transport solids through the pump, keeping solids suspended in a vortex flow. The HVS lifts the solids from the barrel's low side and suspends them, transporting solids uniformly through the valve system.

Vortex-style **seating plugs** distribute and accelerate fluid into the valve body's outside diameter, reducing pressure drop where scale and paraffin could otherwise break out of the solution.

The vortex cage design includes a **unique cross-sectional area** that acts as a shuttle valve, providing a high-pressure to low-pressure sealing surface with an unbalanced hydrostatic pressure that closes and seals the valve system (Figure 4).

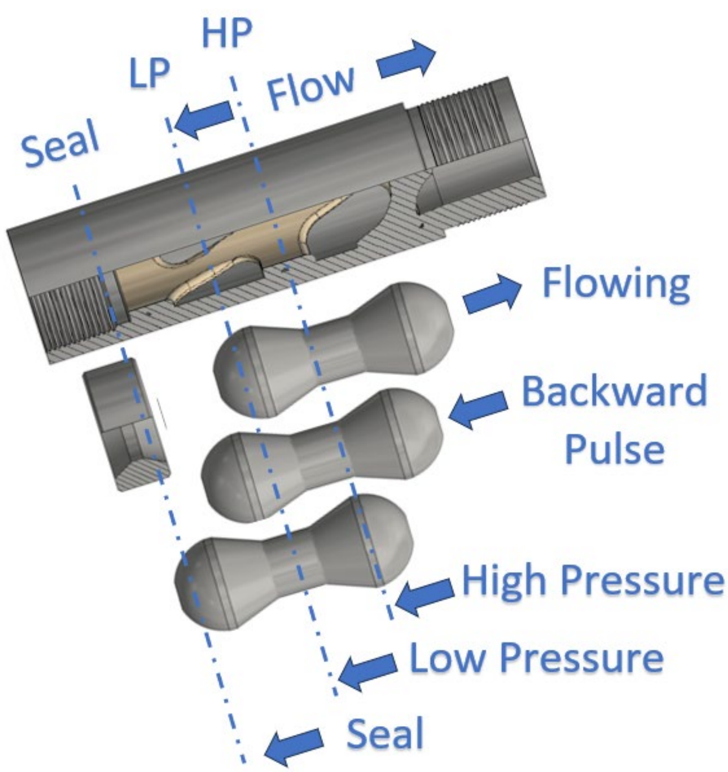

Figure 4 - Cross-sectional area differential between vortex cage and barbell.

Conventional valves have a lap or ledge, which can lead to leaking. The HVS **contour of the tapered seat** sweeps particles at 45° and a 10-micron finish, effectively moving solids through the valve and diminishing solids buildup.

A **maximized sealing surface** is 100 times greater than typical ball and seat configurations, which provides a more consistent and distributed force, spreading the forces to the seat and corresponding cage body.

The **unique geometry** of the barbell and vortex cage generates uniformly distributed forces. Figure 5 illustrates how conventional API/ALT balls and seats have random, varied and narrow force distribution while the barbell has cross-sectional area force distribution. It depicts high-pressure to low-pressure shuttle-type valve actuation. The ball impacts the cage rib and seat at high force, striking at varying angles, possibly making multiple contacts with the double-lapped seat before ultimately settling into position. The HVS barbell has predictable, consistent and evenly distributed forces. It is seamlessly guided into the tapered seat, minimizing repeated impacts and forming a precise, efficient seal through uniform and instantaneous circumferential force distribution. The vortex cage design facilitates rotation of the HVS barbell with each stroke, ensuring even wear on both the inner diameter of the seat and the outer diameter of the HVS barbell's sealing surface.

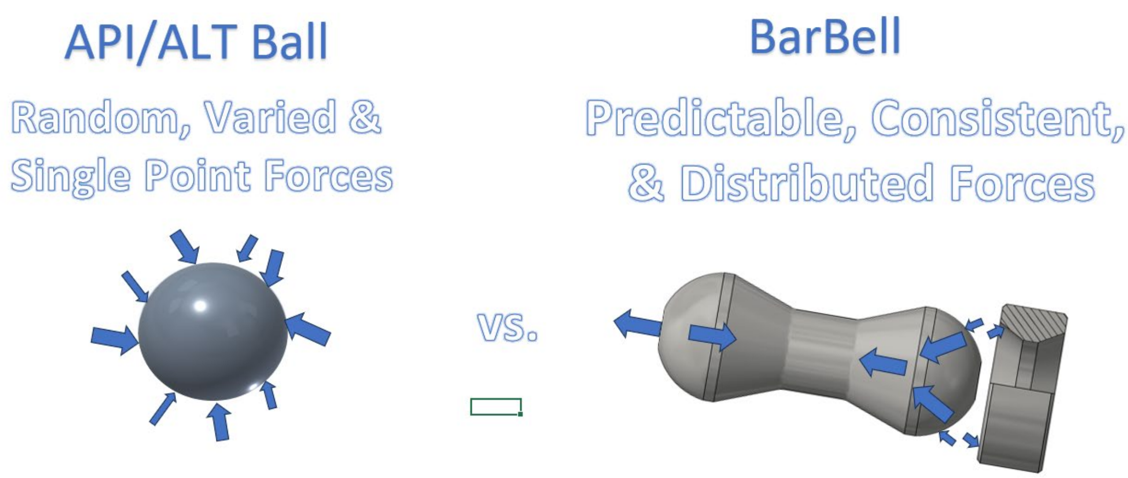

Figure 5 - Conventional vs Barbell

LABORATORY RESULTS

Coyes et al. (2024) completed laboratory testing on the HVS under simulated downhole conditions to learn about the nature of vortex fluid flow through the HVS. Figure 6 below shows the HVS experiment in the laboratory. It provides an example of fluid approaching the HVS (1), in the HVS (2) and the steady state flow after the HVS (3). When reciprocation was introduced on a 60° incline, the differential pressures remained consistent to maximum stroke pressure before and after HVS actuation. At the end of the reciprocation cycle during laboratory testing, the HVS appeared to be a “self-sealing valve”. It was concluded that a backpressure pulse of the barbell inside the HVS cage in the open position overcomes inertia to seat and seal the HVS with no hydrostatic pressure.

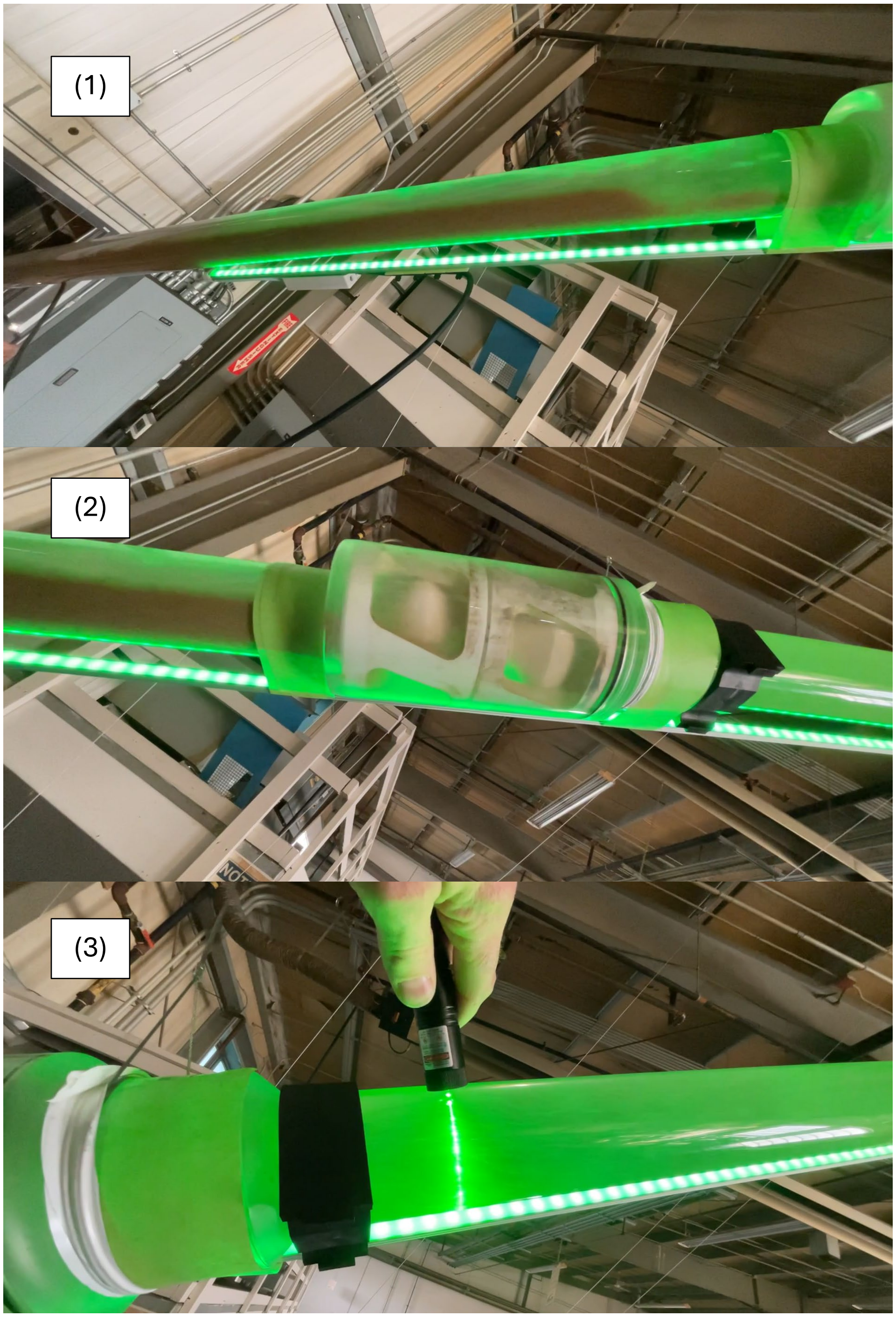

Figure 6 – Flow test with 60° inclination, (1) Sand slug approaching HVS, (2) Sand slug entering HVS, (3) Sand thoroughly mixed with flow stream

<u>FIELD DATA</u>

Below is a comparison of publicly available production data collected over six months, analyzing three months before and three months after HVS system installation. Initial results indicated an 18% increase in well production for 120 U.S. wells and a 10% increase for 300 Canadian wells following HVS installations.

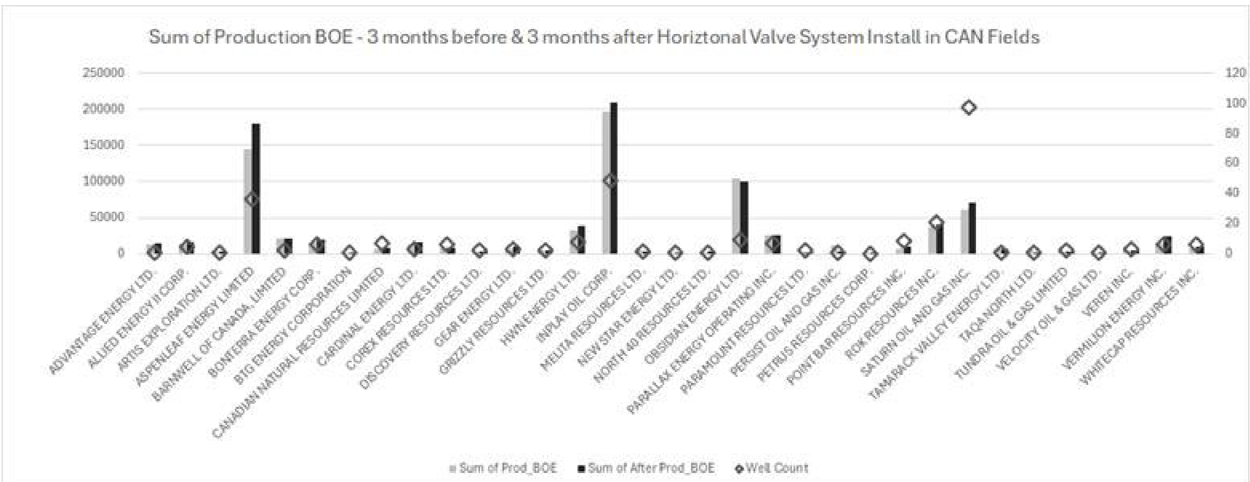

Figure 7 - HVS production data in Canadian fields over 6 months

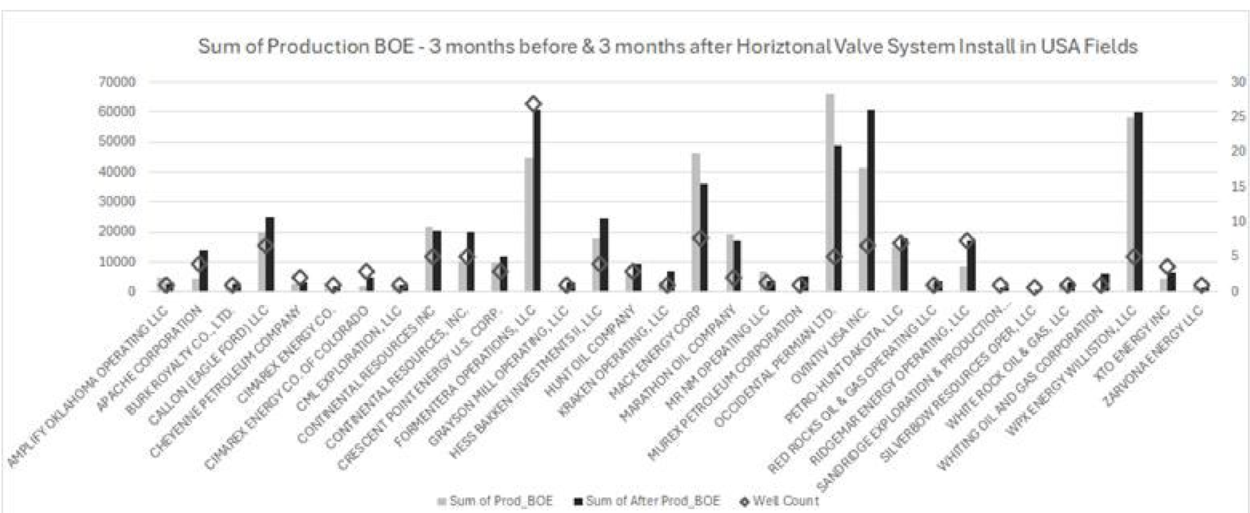

Figure 8 - HVS production data in U.S. fields over 6 months

INSTALLATION

Analyzing and comparing laboratory results, field data, and multiple installations revealed valuable installation considerations for optimal HVS efficiency. These installation considerations optimize flow efficiency while handling the operational stresses associated with high-pressure environments.

Pump placement: Thoroughly review the driller's directional survey before landing the pump. Avoid landing the pump in areas with sliding, rotating, and/or more than 15° dog leg severity (minimize side loading). If the pump is landed in doglegs over 15°, the bottom hole assembly must be redesigned to last under high side-load cyclic fatigue conditions.

Surface Equipment: A rod rotator is recommended to reduce wear for deviated wells on one portion of the string.

Rod Selection: Guided steel sucker rods with 6 to 8 guides per rod will help keep the rod string off the tubing wall at high angles of deviation and minimize bowing of the rod string on the downstroke. These keep the rod guided at large angles of inclination to distribute the forces evenly on the tubing string.

Valve Rod Guides: Hardened or carbide-inserted valve rod guides are recommended as side loading and friction can wear the pump parts at higher angles of inclination where the effects are amplified by dogleg severity. Stellite-lined or Diamond-Like coating rod guides can help with continuous and abrasive wear, extending the run life at highly deviated pump landing zones. Sprayed metal coated and ground valve rods are recommended to reduce friction between the valve rod and valve rod guide.

Plunger Minus Sizes and Tools for Solids Management: There are specific considerations for plunger sizes and solids management for shallow and deep wells, with considerations for tolerances noted below:

- **For shallow wells**, Polypac Viton Ring Tight Fit plungers effectively prevent solids, such as frac sand, from entering the space between the plunger and the barrel. This is particularly important in wells where solids flowing from the reservoir are a primary concern.
- **For deeper wells**, tools like Vortex Sand Twisters, Sand Brushes, and other devices are recommended to block solids from entering the plunger and barrel chamber. These tools help extend pump life, especially at higher inclinations.
- **Plunger minus sizes** usually range from -3 thousandths to -12 thousandths of an inch below the base plunger diameter, with a common minus size of -8 thousandths.

Most wells utilize hard, grooved spray-weld coated plungers. These looser minus sizes are designed to provide a clearance space for solids between the plunger and barrel, minimizing damage to the pump's plunger and barrel and reducing downstroke friction.

Strainer nipples should be engineered to minimize pressure loss before fluid enters the standing valve. This requires using longer nipples with more frequent and larger openings to reduce restrictions.

OPERATIONAL PARAMETERS

The HVS is designed to create a consistent cross-sectional sand load by creating a vortex that evenly distributes sand across the pump's inside diameter. However, it is less effective with large slugs of sand, which can exceed its handling capacity and lead to operational inefficiencies. Proper gas and sand separators and back pressure may be necessary in wells with large solids issues. When starting the system after a large amount of downhole pressure has built up, it is critical to maintain consistent back pressure to minimize a surge of solids into the horizontal pump valve system.

The horizontal well sand avalanche angle has been observed to range between 40 and 65° (Intermezzo, n.d.). At these critical angles, sand deposits in the angled wellbore can become unstable, cascading downward and causing plugging. This typically occurs when the liquid velocity or suspension capacity is insufficient to support the solids bed. Vortex components and continuous operation help to mitigate the avalanche effects of sucker rod pumps reciprocating at these high angles of inclination.

Due to its higher instantaneous velocities, gas moves sand more efficiently than liquid. Large surges of gas in the system can increase the velocity of sand particles, often leading to solids accumulation in build sections of lateral wells. When significant gas slugs are present, deploying an effective downhole gas separator is essential. This ensures that gas is removed before reaching the horizontal pump system, preventing issues caused by gas interference.

There are a few optional operational parameters that may be beneficial:

- Extended dip tubes for optimized fluid intake in high-inclination wells.
- Eccentric gas separator to separate large slugs of gas to the annulus away from the pump and to also provide a man-made reservoir of fluid that can settle out solids into the mud joints and provide gas and solids-free liquid to the system (Saponja et al., 2022).
- An eccentric tubing anchor hanger in the tubing string above the pump reduces pressure drop and allows gas from the separator to move up the tubing casing

annulus, creating a larger cross-section of fluid to act on the pump below. This feeds the reciprocating valve system with an adequate hydrostatic fluid column for optimal pumping parameters (Saponja et al., 2024).

The following **data-gathering practices** are recommended to inform operational modifications during production:

- Downhole Dynamometer data provides direct measurements of load, position, bending forces, and compression along the rod string to assess mechanical friction and validate pump performance.
- Deviation Surveys and detailed well profiles, including inclination angles and dogleg severity, shed light on side loads and optimize rod guide placement.
- Failure Analysis Reports that show historical tubing and rod failure rates (e.g., MTBF) before and after implementing the HVS to evaluate durability improvements. Reports may include pump repair comments, pictures, and analysis of solids types, scale, paraffin, corrosion, and asphaltene precipitation.
- Data on abrasive wear rates on plungers, barrels, and valves under varying sand/solids types and concentrations supports an understanding of sand management efficiency.
- Performance data and field-testing results support the comparison of multiple wells with varying depths (e.g., 5,000–8,000 feet) and inclinations (42°- 90 °) to confirm adaptability across different profiles.

SUMMARY

Pumping in various locations of the curve of horizontal wells over the last few decades has provided sucker rod pump manufacturers with welcome but tough challenges. Many step-wise improvements in run life have been achieved, and the HVS system has significantly advanced production efficiency and increased run life.

The HVS valve system for traveling and standing valves has been lab and field tested since 2022, with positive results in increased production and longer life. This paper covers installation and operational suggestions and parameters to optimize the use of the HVS.

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