MITIGATING SLUG FLOW AND TRANSITIONING FROM GAS LIFTING TO ROD PUMPING RESULTS IN SIGNIFICANT INCREASE IN MULTIPLE WELL NPVS

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INTRODUCTION

Horizontal wells are characterized by sluggy, inconsistent flow that present as rapidly fluctuating gas and liquid rates. In turn, well production challenges are caused by this intermittent flow behaviour from the horizontal. Complex fluid flow behavior creates an environment for gas interference in the artificial lift system and acts as the mechanism for transporting damaging solids along a horizontal wellbore. (Brito, Pereyra, & Sarica, 2016)

Deep, high gas rate horizontal wells, such as those in the Permian Basin, are notorious for excessive gas interference. Artificial lift systems not capable of handling gas interference or solids results in reduced runtime and reliability, excessive workover costs and limited drawdown. Accommodating extreme depth and excessive gas interference can be complicated. Operators may transition through multiple lift systems requiring a workover with each transition and change in rod depth, all increasing both CAPEX and OPEX (see Figure **1**) (Kimery, Jensen, & Saponja, Create Efficiency by Skipping a Step, 2016).

In response to known limitations caused by slug flow, Production Plus developed the flow conditioning HEAL System™ to mitigate slug flow before fluids enter the downhole separator and pump. Slug flow mitigation makes rod pumping more effective and efficient, offering a solution for low cost OPEX to reliably maximize drawdown.

In the Permian specifically, artificial lift system transition is inevitable, typically from gas lift to rod pumping. Given the present economic environment, support for cost savings across multiple wells is highly desirable. Wells with characteristics typical in the Permian basin are well suited to an environment that supports uniform fluid flow. Even, horizontal flow delivered to the pump improves pump reliability along with the potential to reduce capital and operating costs per barrel. This leads to improved production efficiency and production reliability, and when applied across multiple wells lends to a significant increase in NPVs.

CHALLENGES OF THE PERMIAN

In the Permian field, where deep high gas rate horizontals are common, it is highly desirable and economical to effectively manage gas interference. The Permian Basin is a sedimentary basin in the United States, located in the western part of Texas and southeastern New Mexico (see Figure 3 – Permian Basin). It is comprised of three basins: Midland Basin, Delware Basin and the Marfa Basin.

The Permian is the most prolific producing area in the United States. As of December 2016, the Permian region produced upwards of 2.1 million barrels of crude per day (U.S. Energy Information Administration, 2016).

Operators in the Permian commonly install gas lift prior to rod pumping to address early stages of production on deep, high rate horizontal wells. Gas lift can produce at a high production rate, is solids tolerant, can handle gas interference, and is reliable. Although gas lift behaves like an extension of

natural flow, it is limited by high bottomhole pressures which in turn limits production and requires transition to another artificial lifting system, typically rod pumping. Additionally, gas lift is often several times the operating expense of rod pumping, limiting the economic applicability of the system over the life of the well. Rod pumping is cost-effective and reliable across a broad operating envelope of production rates and depths. (Kimery, Jensen, & Saponja, Create Efficiency by Skipping a Step, 2016).

Although rod pumping should theoretically maximize drawdown and minimize lifting costs, in actual practice the slug flow behaviour of horizontal wells can significantly degrade the performance of the system and result in major reliability issues. As such, gas lift can remain the preferred lift method in actual practice even though it is theoretically less preferable. Finding a method to mitigate slug flow behaviour can unlock significant economic advantage in Permian horizontal wells.

MITIGATING SLUG FLOW

Slug flow mitigation begins with an understanding of the nature of slug flow. There are three causes of slugging in horizontal wells:

1. **Hydrodynamic Based** – strictly based upon the multiphase flow regime behaviour (production rates, Gas Liquid Ratio (GLR), wellbore inclination, flow area, and pressure)
2. **Terrain Based** – wellbore geometry, such as undulations and toe-up trajectory
3. **Operational Based** – rapid changes to withdrawal rate from the wellbore, such as interruptions, stops/starts, pump on timer, and erratic fillage and gas locking

Three key provisions can effectively mitigate the impact of slug flow from a horizontal and maximize artificial lift system efficiency: (1) condition flow to minimize the three slugging mechanisms as much as possible, regardless of well trajectory or operating practice; (2) lift fluids from the horizontal to the vertical; and (3) control solids.

Production Plus Energy Services Inc. developed the Horizontal Enhanced Artificial Lift System, or HEAL System™, a downhole artificial lift technology, that addresses these three provisions in a single system. Flow is conditioned through the application of a flow regime that lowers density and regulates flow by lowering a section of production tubing into the bend and reducing tubing internal diameter. This appropriately sized tubing achieves the multiphase flow regime required to stabilize fluid flow from the horizontal to above the kick-off point for the expected productive life of the well. The design of the System permits higher pump placement, out of the bend, in the vertical where pumps are designed to be most efficient and reliable. Conditioning fluid flow from the horizontal interrupts the intermittent nature of slug flow, thereby disrupting the mechanism for solids transport, leaving most solids out in the horizontal. Higher pump placement leaves a large sump for collection of fines and solids moving through the liquid phase.

The HEAL System is a mechanical system comprised of three main components: a HEAL Seal, a sized regulating string (SRS), and a HEAL Vortex Separator (see Figure **2** – HEAL System Components). The SRS has a sized internal diameter and length specific to the reservoir pressures and anticipated production rates over the well's life cycle. The system is designed to minimize operational risk and maximize reliability, with no moving parts and does not extend into the horizontal.

Figure **2** – HEAL System Components illustrates the fluid flow paths through the HEAL System. Flow from the horizontal is conditioned through the SRS and delivered to the Vortex Separator where the cyclonic effect of the Vortex Separator efficiently separates gas and solids from the liquid while discharging to the well's annulus. Separated gas rises up through the annulus. Separated oil, water and solids exit the top of the Vortex Separator, go back down where fluids turn the corner and are drawn back up the Vortex Separator in the crossover path and delivered to the pump (see inset in **Error! Reference source not found.**2). Solids are intentionally dropped out into the sump. (Kimery, Jensen, & Saponja, 2016)

CASE STUDIES

In this case study, a single operator is producing from the Wolfcamp formation of the Permian Basin, with over 50 horizontal producers and an active development campaign. Typical True Vertical Depth (TVD) on these wells is in the 6000-7000 ft range. The typical Initial Production (IP) rate of the wells is in the 1000 to 4000 bfpd range, with watercuts averaging in the 50%-75% range after initial post-fracturing clean-up. These wells do not usually naturally flow, so gas lift is employed to achieve the very high IPs. After producing the wells into the range of rod pumping, wells transition to rod pump for their remaining productive life.

The operator installed 20 HEAL Systems to date, 14 of which have sufficient production history to analyze at the time of this study. Twelve of these wells transitioned from gas lift to HEAL Systems with rod pumps, and two wells transitioned from rod pumping to HEAL Systems with rod pumps.

Case Study 1 – Gas Lift to HEAL System Transition

As discussed previously, the major limitations of gas lift include high operating expense and high bottomhole pressure. Ideally, the transition to rod pumping should occur as quickly as possible since rod pumping has the lowest monthly fixed OPEX of any system and should theoretically have the lowest bottomhole producing pressures.

Figure 4 shows the average of 12 gas lift to HEAL transitioned subject wells. It illustrates a lower bottomhole producing pressure was indeed achieved, as demonstrated by the average increase in total fluid production rate of 33% over the previous production trend. This higher total fluid production rate, along with the reduced cost of rod pumping versus gas lift should significantly reduce lifting costs, and thus improve netbacks and total well economics.

Case Study 2 – Rod Pumping to HEAL System Transition

Results of the first case study surfaced two curiosities. First, how much of the improved performance transitioning from gas lift to rod pumping with the HEAL System can be attributed to the HEAL System itself. Second, since the economics of transitioning from gas lift to rod pumping are so favourable, it is interesting that the typical horizontal well operator in the Permian basin does not transition earlier.

The operator of the subject wells was diligent at optimizing their horizontal producers that had conventional rod pumping. They employed pump-off controllers, frequently monitored pump dynamometers, and reviewed acoustic fluid level measurements to attempt to maximize the production rate from the wells.

For this operator, slug flow from the horizontal is a significant problem, and pump fillage has typically been poor. This caused well underperformance when transitioning off of gas lift, requiring larger, more expensive artificial lift equipment, resulting in an economic burden of increased OPEX.

In an attempt to understand how to best optimize their artificial lift systems, the operator installed and analyzed several different downhole gas separator types in the 23 neighbouring Wolfcamp Formation wells under the same optimization strategy. Over a period of seven months, 140 readings were taken to evaluate the performance of seven styles of downhole separators. The wells with HEAL System installations had extremely consistent, near complete pump fillage.

Figure 5 shows the results of dynamometer tests to determine average pump fillage for the observed downhole separators. As can be seen, all conventional downhole separators have poor fillage when operated in a manner that maximizes the total fluid production rate. Another item to note is that the conventional separators are markedly wide spread on the fillage measurements, showing the negative impact of the slug flow behaviour. Under the same optimization scheme, the HEAL System achieves a higher, and more consistent, fillage behaviour. Thus, it can be presumed that the HEAL System does indeed improve artificial lift performance through the mitigation of slug flow.

The production history of wells that have transitioned from conventional rod pumping to rod pumping with the HEAL System is shown in Figure 6. In this graph, the production increase is even greater than the gas lift to HEAL System transition; total fluid production rates increase by ~100%. This is a departure from what is the historical experience from this field. Many wells drop in production when transitioning to conventional rod pumping from gas lift.

CONCLUSIONS

There are two major conclusions resulting from the observations and analysis of HEAL System installations with this Permian Basin operator. First, slug flow behaviour has a major impact on production, leading this, and many other Permian Basin operators, to utilize gas lift for an extended period of time, even given the economic burden of a high-cost/high-rate/high-bottomhole producing pressure system imposes. The field experience with rod pumping has been fraught with challenges and underperformance, thus gas lift has conventionally been the counterintuitive economic best choice for longer than would be expected through the production life of the wells.

Second, the mitigation of slug flow and the efficient lifting of the fluids from the horizontal to the pump at, or above, the kick off point in the well, leads to an improvement in production rate, and this improvement in production rate is definitively not only due to the transition in lift type. Instead, rod pumping with the HEAL System lead to a ~33% increase in production rate, rather than the typical drop in production seen when swapping to conventional rod pumping.

The impact of these two points is that the HEAL System can deliver higher production and lower operating expense than gas lift or conventional rod pumping. This leads to lower lifting costs and higher netbacks, improving cash flow, extending production down to a lower economic limiting rate, and ultimately improving reserves recovery and well net present value (NPV).

Continuing its work in the Permian Basin and beyond, Production Plus is improving the HEAL System to achieve these benefits at lower cost while tailoring the system to the operating environment of different wells. Improved components to reduce installation and retrieval risk are available and being installed. A slickline retrievable system provides greater access to the wellbore, easier installation, and simpler integrity testing to streamline and reduce the cost of artificial lift transitions, from natural flow to gas lift, plunger lift, rod pumping, and progressive cavity pumping. In addition, two types of ESP systems have been developed to provide the same benefits to an additional high rate lift system required by many Permian Basin operators.

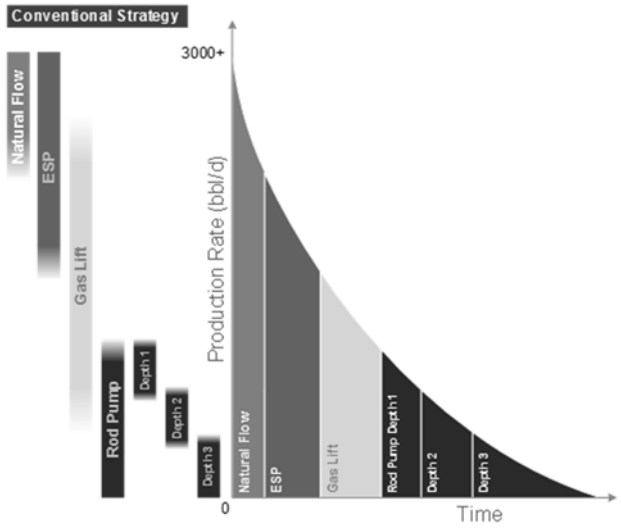

FIGURE 1 – CONVENTIONAL LIFITING STRATEGY IN THE PERMIAN BASIN

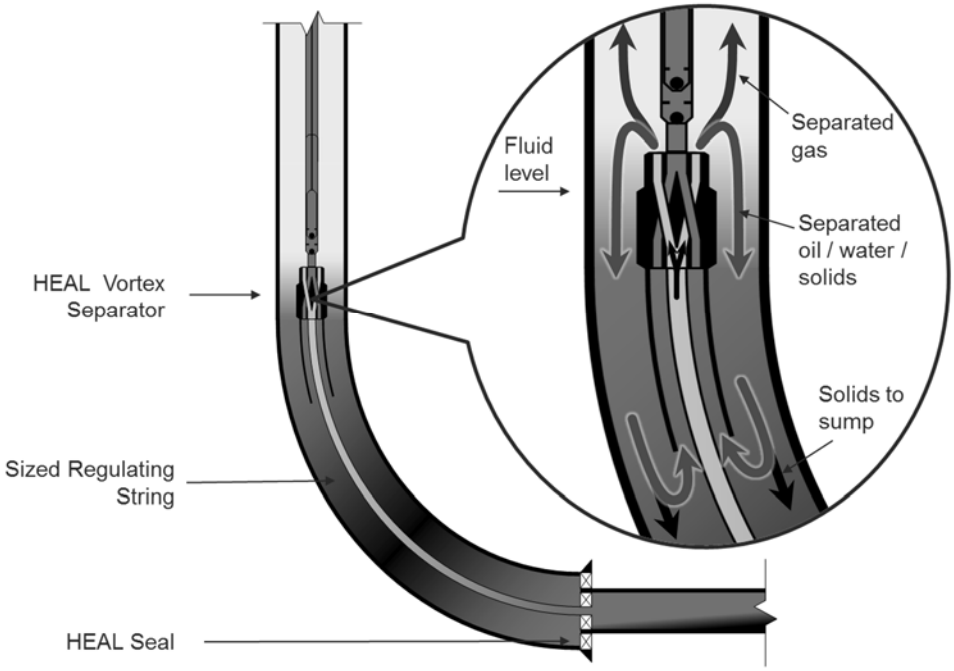

FIGURE 2 – HEAL SYSTEM COMPONENTS

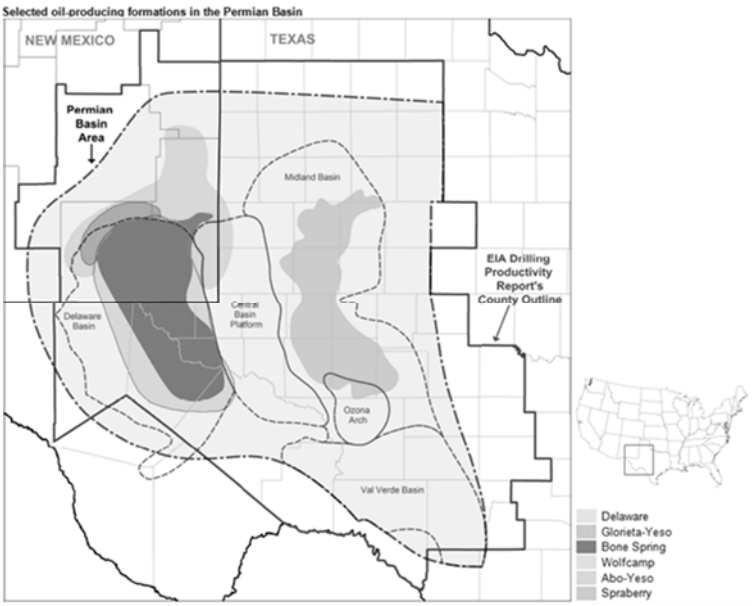

FIGURE 3 – PERMIAN BASIN

Source: U.S. EIA: http://www.eia.gov/todayinenergy/images/2014.07.09/chart2.png

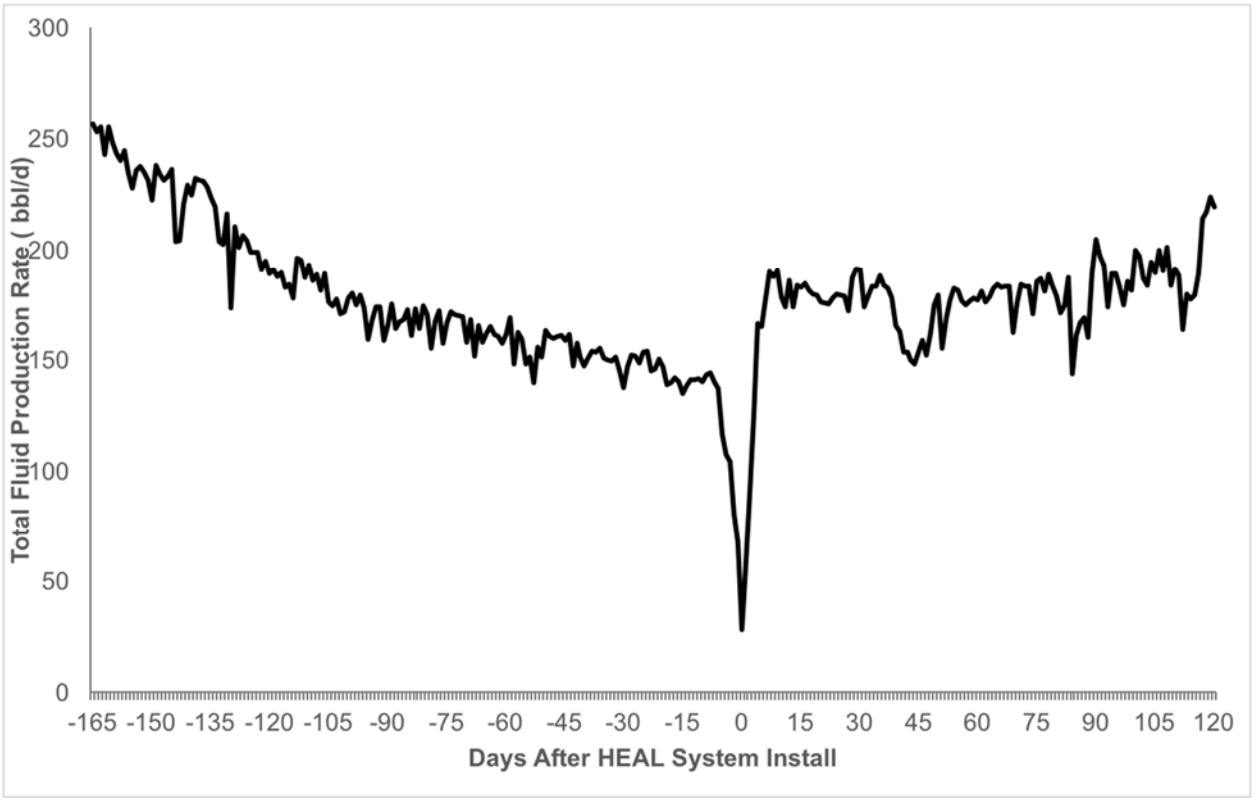

FIGURE 4 - GAS LIFT TO HEAL SYSTEM TRANSITION

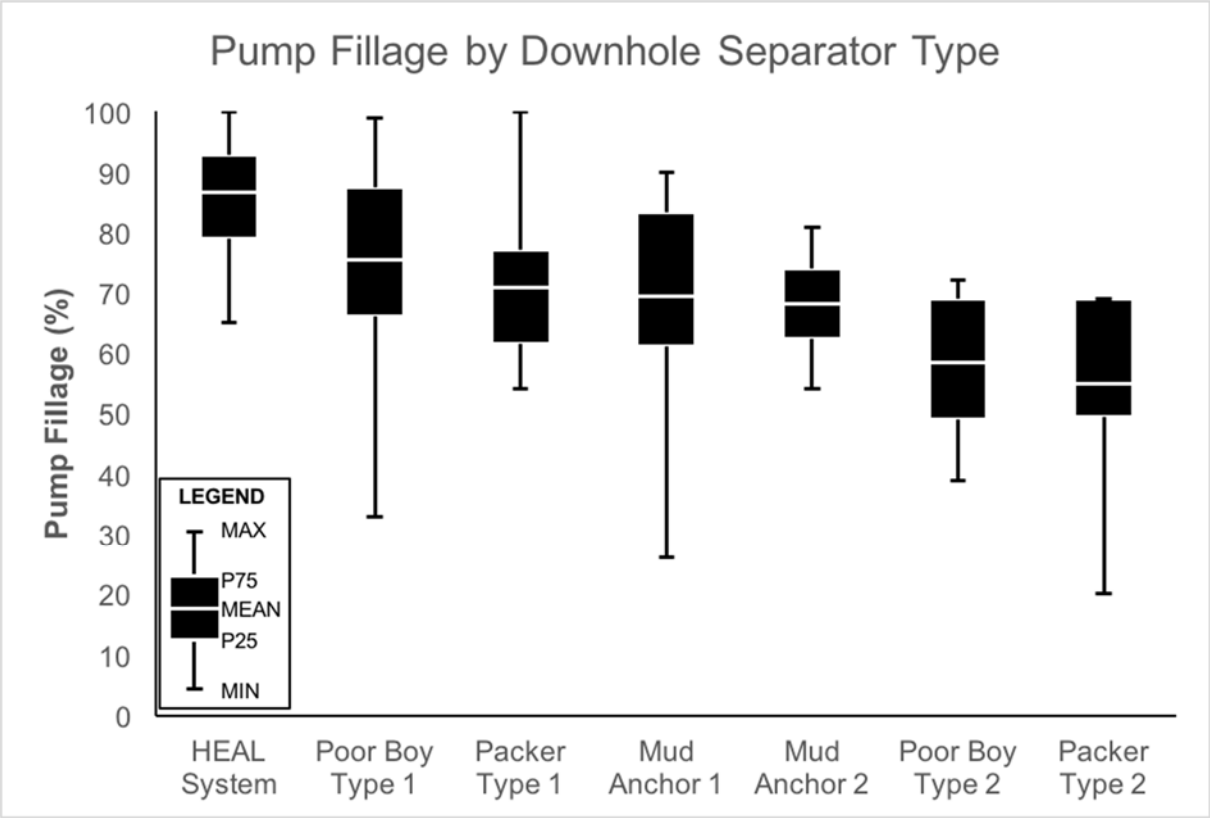

FIGURE 5 - PERFORMANCE OF VARIOUS DOWNHOLE GAS SEPARATORS VS. HEAL SYSTEM

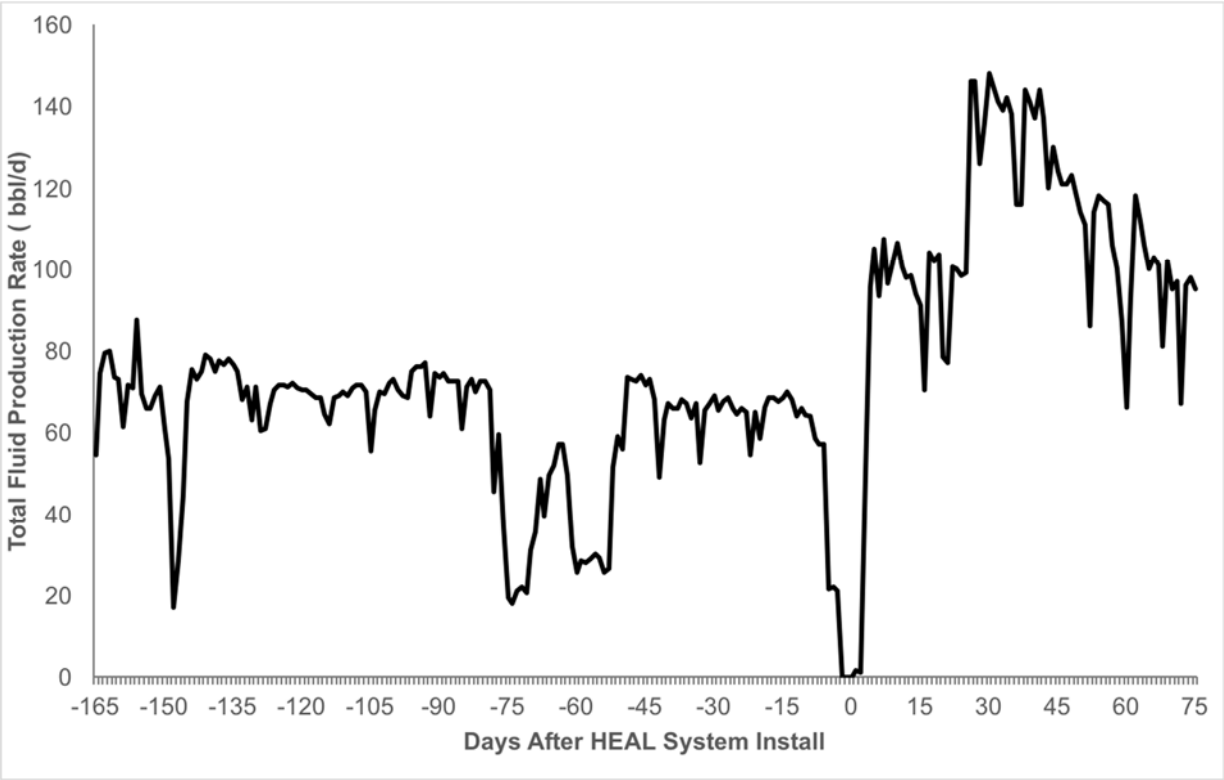

FIGURE 6 - ROD PUMP TO HEAL SYSTEM TRANSITION