THE SILVER BULLET: OVERCOMING GAS INTERFERENCE IN UNCONVENTIONAL ROD PUMPED WELLS

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ABSTRACT:

With today's highly dynamic unconventional wells, gas separation is essential after the conversion from electric submersible pumps (ESP) to rod lift. Unconventional wells in the Permian Basin have high initial production rates with steep decline rates, which result in a high gas-to-liquid ratio (GLR) early in the life of the well. As the reservoir pressure draws down below bubble point pressure, increasing volumes of free gas begin to break out of solution. Unnecessary downtime can be a result of erroneous well condition data and can cause the well to pump off at a critical period when instead, aggressive fluid extraction is the best course of action. Well optimization is achieved through proper gas separation to maximize production and minimize downtime.

Common solutions to the above problem involve the use of Mother Hubbard or packer-style separators, which are not always adequate and can easily be overrun by gas. Additionally, if the well is pumped too aggressively, the gas separators can actually be overrun by production, resulting in minimum gas separation.

Combining the efficiency of the industry's leading packer-style gas separator, a patented shroud and the new innovative technology of the bypass tubes from the ESP Gas Bypass, the Silver Bullet maximizes gas separation by providing two pathways for separation to occur naturally.

Utilizing the Silver Bullet increases total production by ensuring the pump is full and also by reducing the amount of time the well spends idle. Additionally, decreasing the number of gas interference events helps reduce failure and increase the life of downhole equipment. Less gas interference in the pump leads to longer run times, more consistent pump fillage and ultimately more revenue.

This paper details the technology behind the Silver Bullet and presents case studies that prove efficiency.

I. INTRODUCTION

Unconventional wells in the Permian Basin have high initial rates with steep declines, cf. [5], which creates a significant challenge to rod pumps. Steep decline rates result in a high GLR very early in the life of the well. As the reservoir pressure draws down below bubble point pressure, increasing volumes of free gas begin to break out of solution, see [1,2].

These high GLRs create a significant impediment for rod pump operations. Rod pumps are most effective when pumping only fluid and habitually experience problems when attempting to handle a large amount of free gas, as described in [6, 7]. In these rod pumping applications, high GLRs and excessive gas interference will be mistaken for fluid pound or low pump fillage and cause the pumping unit to erroneously stop. This is costly for the operator in both lost production and downtime, see [5].

Figures 1 and 2 showcase two examples of erratic behavior of casing gas. They also highlight the minute-by-minute output of instantaneous MCF/day casing gas rates from a multivariable transmitter. In Figure 1, the gas rates fluctuate between 8.46 MCF and 135.88 MCF then back down to 2.07 MCF in a period of just 30 minutes. This means a shot of 2418 MCF in that 30-minute window. In Figure 2, the gas rates shoot from 155.39 MCF to 401.76 MCF in the same 30-minute window. This means a sudden increase of 11453.37 MCF. The industry practice when discussing the gas production of a well is to reference a 24-hour value. That value represents the total gas that came from both tubing and casing in the stated 24-hour period. When the casing is isolated and data monitored more frequently, the drastic fluctuations in gas rates moving through the fluid column on the back side (casing) becomes obvious. These dynamic gas rates moving through the back side of wells absolutely influences the fluid level and reservoir. For example, more gas moving through a 5,000-foot fluid column makes the column lighter by decreasing the fluid gradient. A lighter fluid column equals reduced hydrostatic head on the reservoir, allowing for greater inflows. The opposite also holds true. Less gas moving through the same 5,000-foot fluid column equals a heavier, more dense fluid column and more hydrostatic head on the reservoir, reducing inflows, see [4].

The conclusion of this data is that the dynamic casing gas rates seen when rod pumping horizontal wells prove the foundation of the industry's gas interference problems is not as simple as ensuring the well is being produced at a downward fluid velocity below .4 feet per second. The problem is actually much more nuanced and is reservoir/fluid gradient based. Knowing the fluid level numbers change drastically throughout the day proves this problem cannot be solved by simply putting a unique piece of pipe in the hole. The most effective current solution is a practical bottom hole assembly (BHA) that maximizes the separation area within the casing and, additionally, proper optimization practices.

Not only do dynamic casing gas rates decrease overall production, but they also degrade the mechanical integrity of the pump. This leads to higher maintenance costs and, eventually, a costly rod pump failure. Failures ultimately lead to more operator expenses when replacing the pump becomes necessary and overall loss of production. More importantly, shutting down during gas interference conditions only extends this very difficult time in the life of the well. Gassy conditions are temporary and the system needs to achieve 100 percent run time to keep the hydrostatic head from building on top of the reservoir and choking out gas production. Keeping the hydrostatic head off the reservoir allows the well to "breath" and get the excess free gas out of the system.

Some of the industry standards include running gas separators such as Mother Hubbard or packer-style to mitigate the amount of gas that enters the pump, see [4]. Of these two separator styles, the packer-style separator yields superior results. Complete pump fillage, however, is still difficult to achieve in low fluid gradient conditions commonly seen when producing horizontal wells on rod pump.

In order to overcome these operational challenges, the amount of free gas entering the pump must be minimized. This improves runtime, decreases operating expense and increases overall production.

During testing, it was determined a gas/liquid interface accumulates naturally beneath the packer. As gas is released out of solution, a column of gas builds up, works its way down and eventually is pulled into the desander or pump intake. The solution lies in giving this free gas column an isolated path to discharge above the entire BHA and pump intake.

II. WHAT IS THE SILVER BULLET

The Silver Bullet is an innovative system which improves on the traditional packer-style systems. This new technology was first applied to ESP applications and allows the free gas interface below the dual HNBR packer cups to be exhausted out into casing 30 to 90 feet above the BHA system via an isolated path through the packer ID and a three-fourths inch bypass tube. Since this system allows free gas to travel past the packer, the fluid intake of the system can be laid at a 45-degree angle, allowing for an additional natural gas bypass of approximately 25 percent.

Beneath the packer, a two-phase system naturally develops as the gas rises out of the fluid. The gas column is then channeled through the bypass tubing of the Silver Bullet system and discharged above the slots of the Max gas separator and encouraged to flow freely up the annulus.

In addition to free gas being bypassed from below the packer, the original gas separation properties of the packer-style system still apply. The fluid column travels through a desander, where the solids are separated and discharged below the point of fluid intake. Clean fluid moves up through the desander, through the ID of the packer and into the Max gas separator. Fluid and entrained gas then travel 40 feet upwards toward the top of the Max gas separator.

Fluid velocity is slowed as the fluid and gas pour into the casing annulus to allow the remaining gas to be separated out and exited through the slots at the top of the Max gas separator, while fluid flows back down the casing annulus to the patented shroud. Once captured in the shroud, fluid then enters the three-fourths inch dip tube before traveling up 40 feet to the pump intake.

In testing this tool, separation efficiencies were increased by 45 percent compared to other technologies on the market, resulting in improved pump performance in rod pumped wells. This system effectively reduces the amount of free gas entering the pump, which ultimately extends the life of the rod pump system.

1) <u>OBJECTIVES OF THE SILVER BULLET</u>

The best method for gas handling is to leverage natural gas separation as much as possible within every design. During testing, the fluid intake was set at various inclinations throughout the curve to determine the degree that would best utilize natural separation. After extensive testing, it was determined setting the fluid intake point at 45 degrees is the optimal set point. At this inclination, gas rides the high side of casing while the tool intake naturally lands on the low side of casing, buying the end user 25 percent of natural gas bypass. But, as gas accumulates beneath the packer, a column of gas will begin to form, creating a gas/liquid interface.

The primary function of the Silver Bullet is to create a path for the gas accumulation below the packer to travel and discharge above the slots of the Max gas separator and pump intake. After the gas is discharged, it will naturally rise up the casing annulus to the surface. Utilizing the Silver Bullet to reduce the amount of free gas entering the pump will accomplish two main objectives: It will help to stabilize pump performance and will in turn extend the runtime of the downhole equipment. Longer run times result in lower expenses for the operator.

2) <u>DESIGN OF THE SILVER BULLET</u>

The standard design for the patented Silver Bullet system is based on two reference points: Seating nipple set depth and the desander or fluid intake point, which is recommended to be at a 45-degree inclination. Working up from the bottom of the assembly, a typical design starts with a bull plug and mud joints. A bull plug is set at the very bottom of the assembly to create a closed system for separated solids to be stored. The recommended size and number of mud joints varies depending on severity of solids within each well. A picture of the system is displayed in Figure 3.

Above the top mud joint, a desander is set at 45 degrees. If solids are not a major concern, the desander can be replaced with a slotted sub for a fluid intake point. It is crucial to have this point of intake in the assembly to prevent fluid restriction. Above the desander, a tail pipe is used to assist in reaching the recommended set point of the desander. A directional survey should be implemented to help determine the amount of tail pipe needed in order to achieve the proper set point.

Above the tail pipe is the Gas ByPass port. This is a short sub with a built-in bypass channel ran between the tail pipe and the dual cup packer. The purpose of the Gas ByPass port is to create a flow path, allowing the gas accumulation below the packer to be moved through the assembly. Above the Gas ByPass port is the dual cup packer. This dual cup packer has no setting elements and acts only to create a seal, minimizing the risk of a stuck packer. Moving up the assembly, a Gas ByPass Connection sub is then ran. This sub acts as the bottom connection point for the Gas ByPass tube that will be banded to the OD of the Max gas separator assembly.

The Max gas separator assembly sits directly above the Gas ByPass Connection sub, followed by three joints of 2-3/8-inch tubing and then the Gas ByPass Discharge port. Three joints of 2-3/8-inch tubing is recommended with this system to create more distance between the top slots of the Max gas separator and the Gas ByPass discharge port. This discharge port is made with a ball and seat to mitigate any possible debris passing by the channel.

The discharge port is the top connection for the Gas ByPass tubing and is machined to be an offset of the Max gas separator assembly to assist in protecting the top of the Gas ByPass tubing. Production tubing is then ran to surface.

An example of a Silver Bullet BHA design procedure is shown in Figure 4. The total length of the rod pump components and the length of the bypass tube are calculated. The main design considerations to highlight are the added length of the system, overall length of tail pipe required to get the intake at 45 degrees and length/OD of the bypass tube.

Figures 5 and 6 depict clearance diagrams for design considerations based on casing inner diameters of 4.65 inches for 5.5-inch casing scenarios and 6.18 inches ID in 7-inch casing scenarios. Given the 1.9-inch OD of the Max gas separator, there is plenty of clearance in both casings to allow for a single three-fourths inch bypass tube.

III. CASE STUDY RESULTS

A case study was conducted on a well with high GLR as can be seen in Figure 7. According to Figure 7, this well has an average GLR greater than 1,000, making this a difficult well to produce on both ESP and sucker rod applications, see [4].

As part of the case study, a Silver Bullet was installed in November of 2021. As shown in Figure 8, this well was converted from ESP to Rod Pump. The Silver Bullet was installed as part of the BHA to better mitigate gas. Gauge PIP, gas, water and oil production are displayed in Figure 8 and gas, water and oil production show increased stability and a maintained rate after Silver Bullet installation.

In Figure 10, runtime, average speed (avg spm), spm, average pump fillage, pump fillage and yesterday's inferred production are all marked. After Silver Bullet installation, at the beginning of the graphs in Figure 10, average runtime increases and maintains at 24 hours.

Speed is increased and inferred production jumps without affecting the average pump fillage. The pattern or findings from this install and others thus far seems to be a delayed benefit to the tool. The first two weeks of production with this BHA seemed to be incredibly difficult because a running system is imperative. However, as the well was produced harder and longer, the benefits of the BHA were amplified.

These findings are logical because attaching the bypass tube to the side of the Max reduces the separation area early in the life of the well and there may be little or no free gas below the packer. This would explain the early production difficulties encountered.

However, when optimized properly and the gas interference conditions are pumped through, drawdown can be achieved in time, allowing for increased free gas below the pump. The bypass tube then becomes beneficial, allowing the reservoir to breath the free gas out into casing above the entire BHA. At this point, the well settles down, allowing for maintained production.

IV. CONCLUSION

At some point during the life of a well, running an ESP installation becomes too expensive to maintain due to declined production and excessive ESP failure due to gas interference, see [2021 SWPSC GreenShot]. When this occurs, converting to rod pump is a cheaper and more reliable alternative. Pairing

Silver Bullet with rod pumps allows the operator to have all the lower OPEX rod pump advantage while maintaining production and reducing failures.

This technology can play a key role in reducing lost production due to high GLRs and related gas interference, decreasing operating expense, increasing runtimes and production. The case study presented in this paper shows stabilized and maintained production after ESP to rod pump conversion.

Higher efficiencies, optimized production and higher runtimes are all achieved with the Silver Bullet system. Without the utilization of the Silver Bullet system, all free gas that does not naturally bypass the pump has to be produced instead, causing operational issues and lost production. The Silver Bullet is an innovative technology that will allow operators to produce unconventional wells with rod pumps more efficiently and economically, improving rate of return on investments.

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TABLE AND FIGURES:

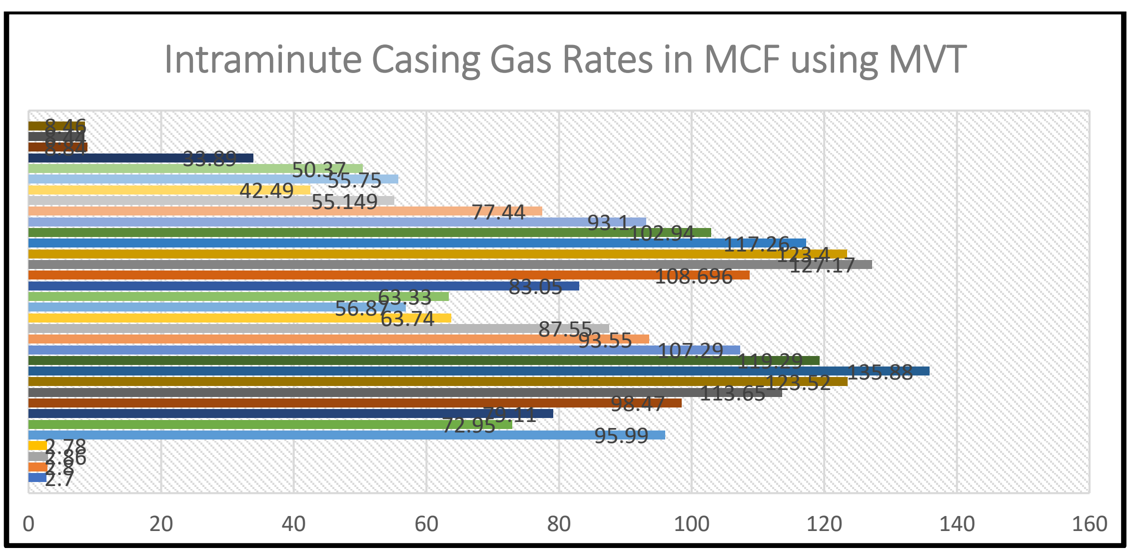

Figure 1: Intra-minute Casing Gas Rates in MCF Using Multivariable Transmitter

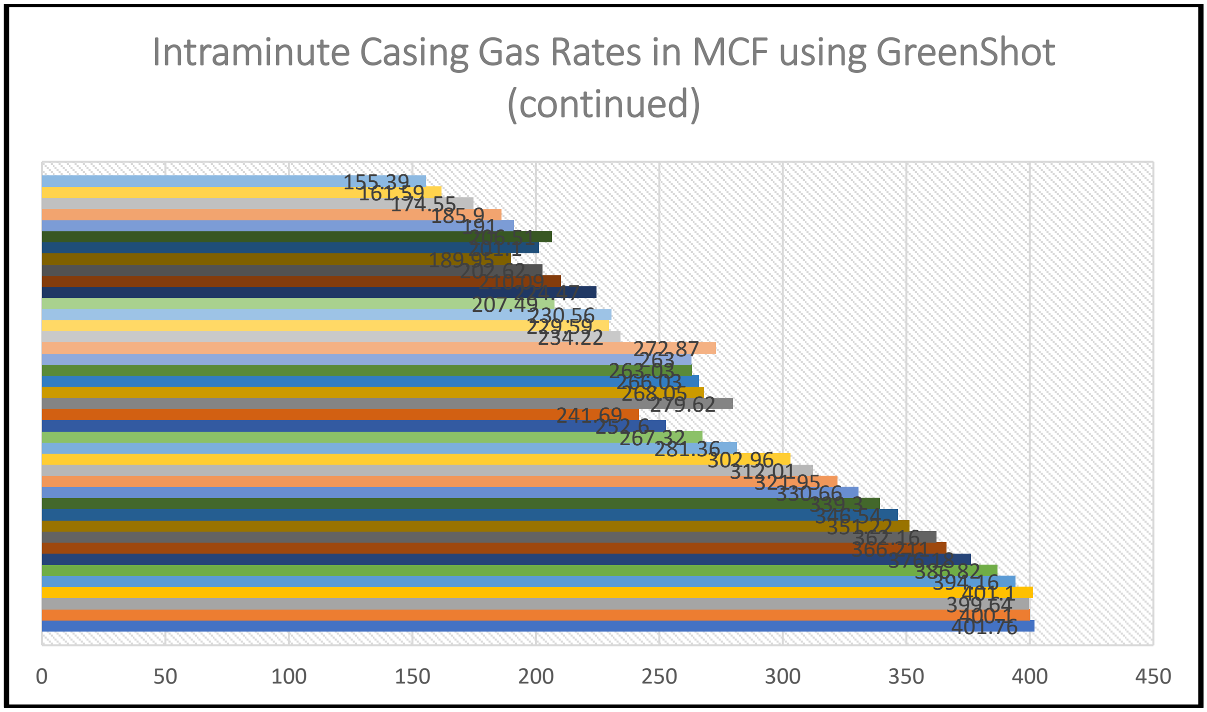

Figure 2: Intra-Minute Casing Gas Rates in MCF Using Multivariable Transmitter

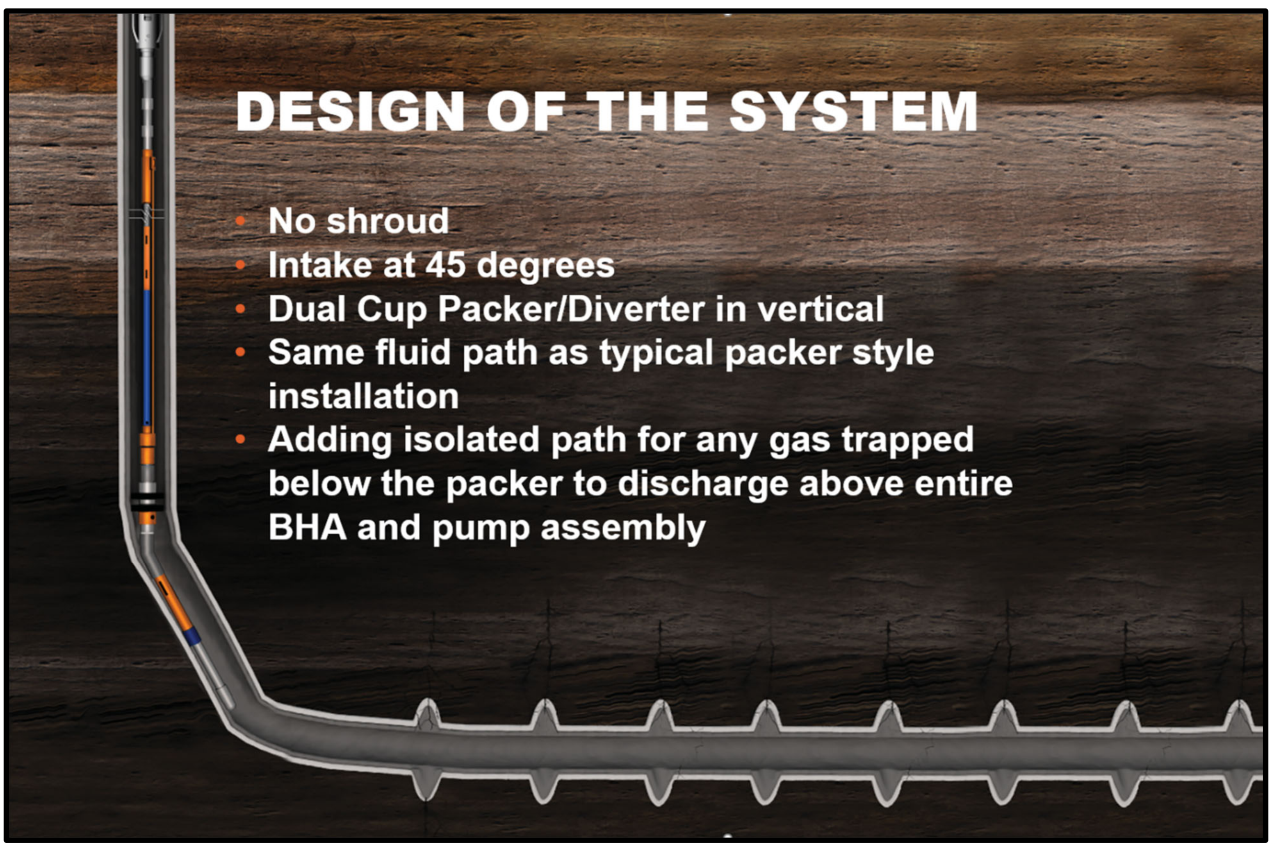

Figure 3: Silver Bullet Tool Diagram

Quantity	Item	Typical OD, in	Item Length (ft)	Total Length (ft)	Bottom Depth (ft)	Top Connection	Bottom Connection
197	2-7/8" Production Tubing*	2.875	32.7	6438.1	6,438.1	2.875	2.875
1	Conventional TAC	5.5	3.25	3.25	6,441.3	2.875	2.875
7	2-7/8" Tubing Joints*	2.875	32.7	228.9	6,670.2	2.875	2.875
1	Enduralloy Blast Joint	2.875	32.7	32.7	6,702.9	2.875	2.875
1	**Seat Nipple**	**2.875**	**1.1**	**1.1**	**6,704.0**	2.875	2.875
1	Gas Discharge Port	4.25	0.67	0.67	6,704.7	2.875	2.375
1	2-3/8" Tubing*	2.375	32.7	32.7	6,737.4	2.375	2.375
1	2-3/8" Lift Sub	2.375	2.0	2.0	6,739.4	2.375	2.375
1	MAX Gas Separator (no shroud)	1.9	40.0	40.0	6,779.4	2.375	2.375
1	2-3/8" Nipple	2.375	1.1	1.1	6,780.5	2.375	2.375
1	Gas Bypass Connection Sub	4.25	0.67	0.67	6,781.1	2.375	2.875
1	NR-1 (HNBR) Dual Cup Type Packer	5.5	2.0	2.0	6,783.1	2.875	2.875
1	Gas Bypass Sub (Gas Intake)	3.625	0.67	0.67	6,783.8	2.875	2.875
15	2-7/8" Tail Pipe*	2.875	32.7	490.5	7,274.3	2.875	2.875
1	2-7/8" Lift Sub	2.875	4.0	4.0	7,278.3	2.875	2.875
1	Helix Desander (Fluid Intake @ 46.15°)	3.75	9.0	9.0	7,287.3	2.875	2.875
4	2-7/8" Mud Joints*	2.875	32.7	130.8	7,418.1	2.875	2.875
1	Bull Plug	2.875	0.65	0.65	7,418.8	2.875	N/A

**estimated lengths, will depend on tubing tally*

Notes: TAC must be set above Gas Discharge Port

Total Length of Rod Pump Components (ft):	79.81
Total Estimated Length of 3/4" Bypass Tube (ft):	104.81

includes additional 25' safety factor

Figure 4: Silver Bullet Detailed BHA Design Procedure Example

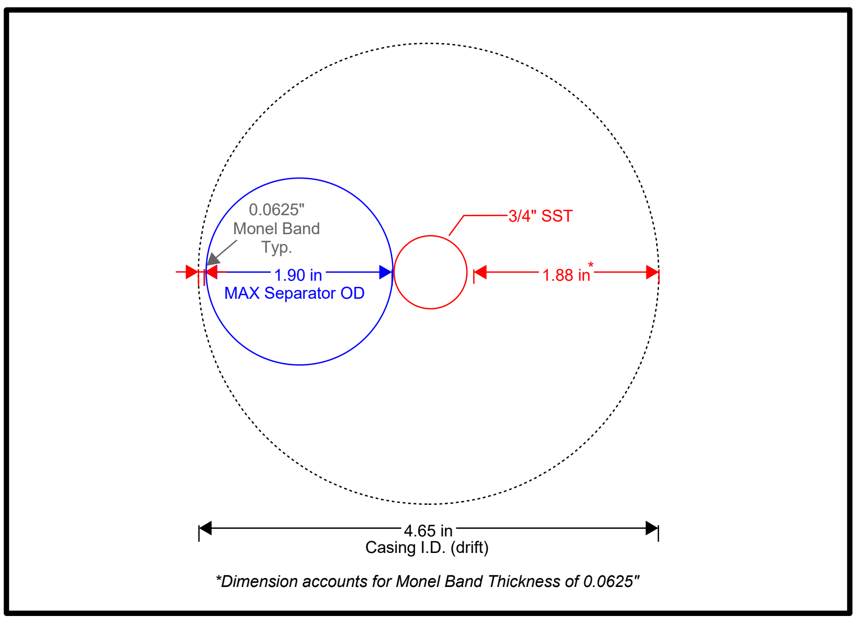

Figure 5: Silver Bullet Design Considerations

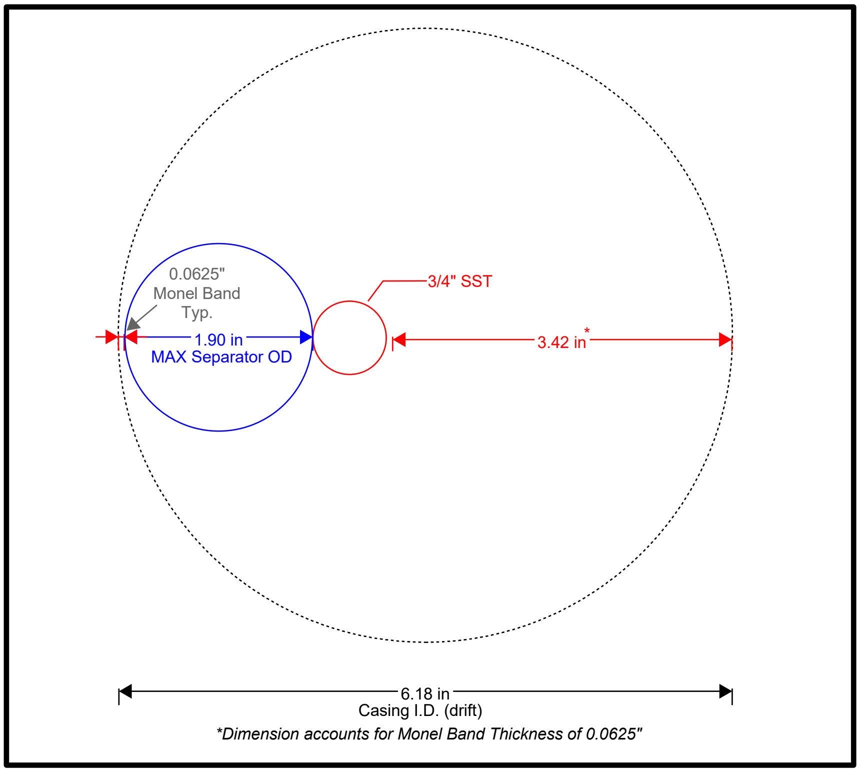

Figure 6: Silver Bullet Design Considerations

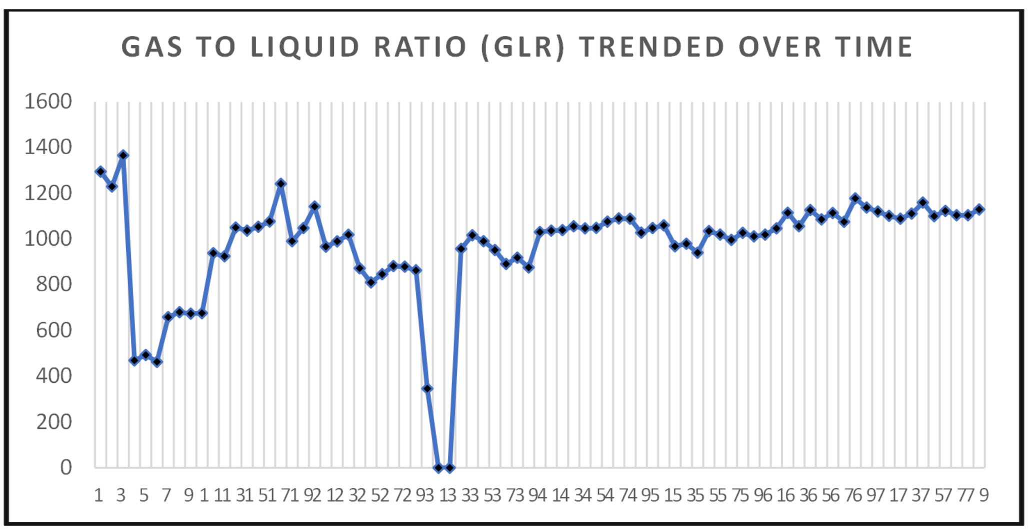

Figure 7: Case Study Gas to Liquid Ratio GLR Curve Over Time

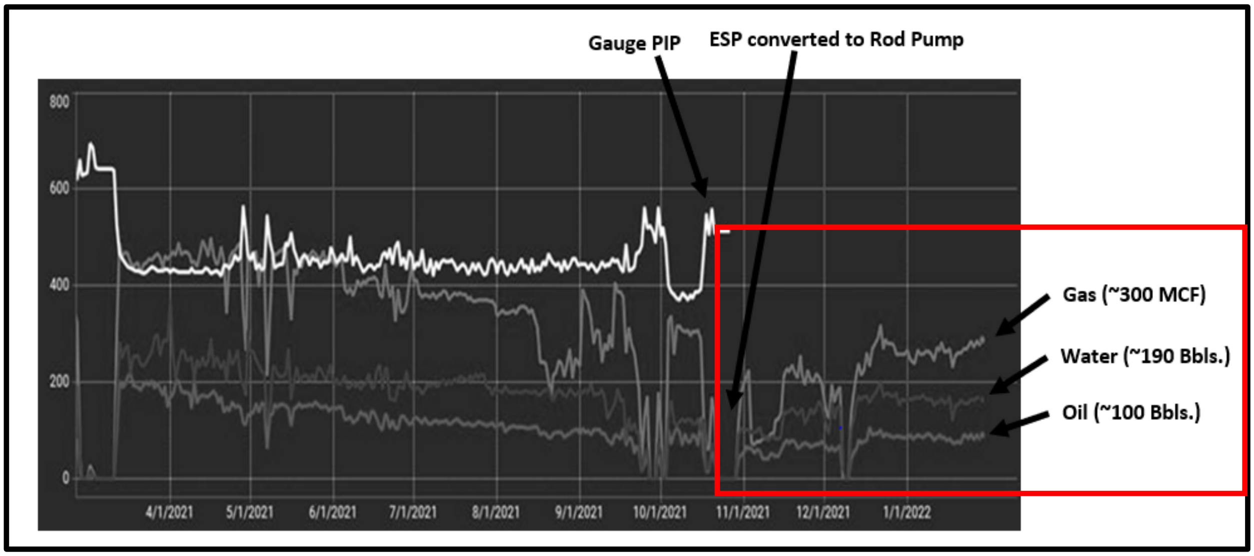

Figure 8: Case Study Production Results

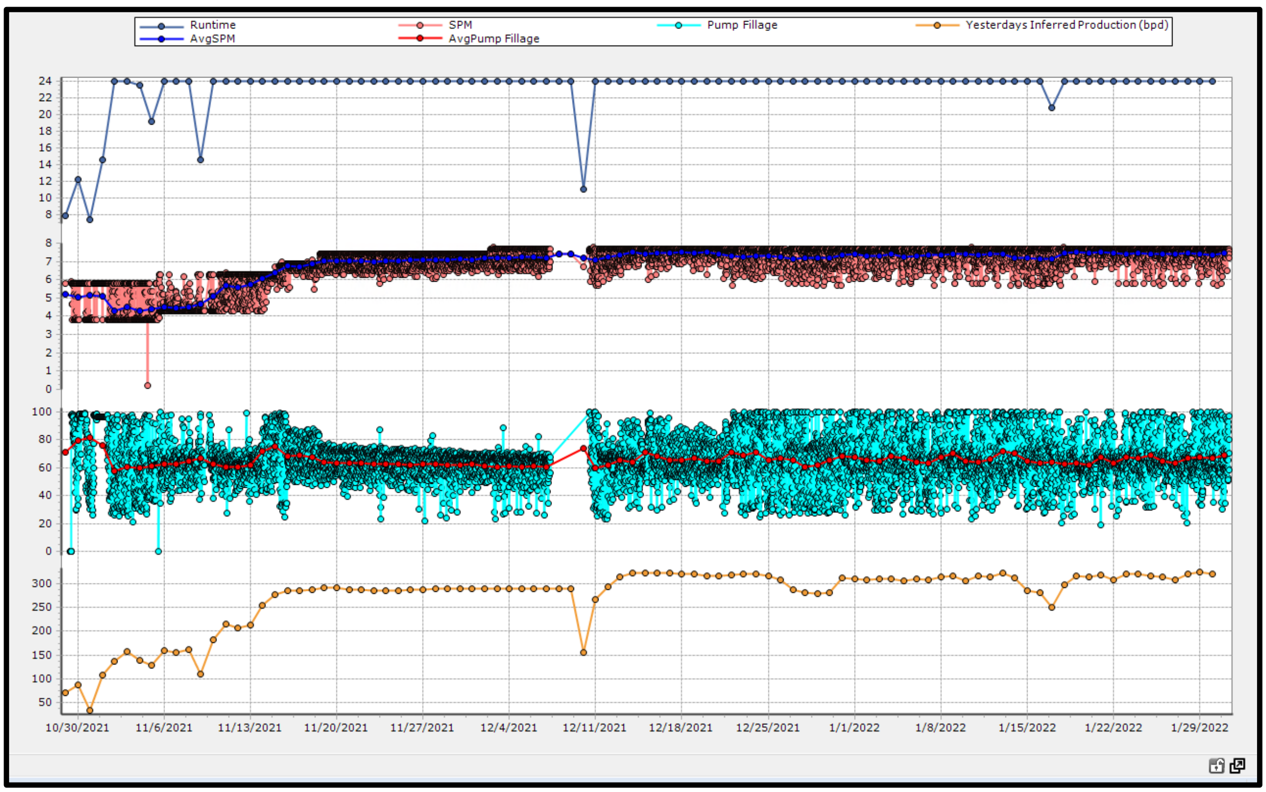

Figure 9: Case Study Key Performance Indicator Results