MULTI-STAGE LIMITED-ENTRY GAS SEPARATOR – LIMITED-ENTRY EXPLAINED AND TESTS & RESULTS

Brian Ellithorp
BlackJack Production Tools

ABSTRACT

A new gas separation technology was released last year with the goal of creating a substantially increased volume capacity and therefore significantly improved separation quality through application of a process known as limited-entry. This process is more commonly applied to well fracturing and other stimulation procedures wherein the principle is applied to create an equal distribution of fluids to be pumped into an expansive length of producing formation or a variety of formation qualities at once.

The Multi-Stage Limited-Entry (MSLE) separator's design utilizes a reversed method such that the fluids being ingested into the gas separator are purposefully restricted through an intake port or ports located near the bottom of the inner tube inside the uppermost chamber and thus the remaining volume must then be handled by the next chamber stacked in series below with another port limiting total allowable volume throughput. This process continues until the entire volume of fluids designed to be pumped from the well are ingested by the full separator stack, at the designed slow pace, and pumped through the rod pump BHA then to surface.

The most notable benefit of applying this process to gas separation is that it becomes feasible to slow the intake of the gas-laden fluids by an extreme amount; far more than is possible by simply running a much larger OD poor-boy style separator or a much smaller OD packer-style separator. Slowing down the intake of fluids by dividing the work equally into a stacked set of separation chambers allow for a minimum target of 1.0"/second or less fluid drawdown velocity to become possible which is 6 times slower than other separators are designed for and what their claimed capacities are derived from, yet is what will directly drive far greater ability to reach exceptional levels of gas separation quality and, ultimately, far superior rod pumping production and overall operational success.

The MSLE separator manipulates the wellbore and fluid intake path such that the historic and only method of increasing separation capacity, adding more dead-space cross-sectional area, is no longer the primary and also limiting means of improving separation performance. There is only a limited amount of room to work with historic separation options in the typically applied casing sizes of 7" and, more common for much of the Permian Basin, 5.5". Getting too aggressive with design applications in effort to add dead-space ultimately leads to either extreme annular superficial gas velocity (resulting in fluid blow-by and potential for poor intake performance) when applying a large OD poor-boor style separator with tight tolerance to the casing ID or going the other direction, pressure drop inside the flow-through tube (resulting in potential depositions/plugging) when utilizing a small OD packer-style separator.

This paper will explain the process of limited-entry as it applies to gas separation design and how the resultant MSLE separator functions differ in regards to other commonly applied separators. Further, a notable series of MSLE separator tests will be reviewed to illustrate lessons learned, design improvements implemented, and overall performance achieved in a variety of well conditions.

INTRODUCTION

Artificial lift equipment, notably downhole gas separators, have not evolved and improved nearly as quickly or as much as has been needed as wells being drilled and completed have improved in overall quality and strength in recent years. Wells are flowing much harder and longer in nearly all actively targeted production horizons today than they were just a few years back. This is a byproduct of improved completion designs (ever larger frac's and more effective sand placement), extended capabilities of drilling (longer laterals and more time in zone), and more thoughtful flowback methodology and production management.

With may of these wells producing at record high GOR/GLR's and their trends typically increasing those ratios as wells age its no surprise old, over-simplified, and generally antiquated separation designs and practices have not served well in these new-age wells. Further the erratic production behavior of these wells, and especially their downhole fluid dynamic behaviors, are creating an extremely tough and likely insurmountable set of hurdles for those old separation techniques to handle successfully.

Due to this fact it appears time has come where a demand for a major jump in separation process and technology is warranting significant focus and effort be put into the subject to head off inevitable production shortcomings relating to multiple facets of that very lengthy phase of the well's life.

BACKGROUND AND THE SOLUTION PROPOSED

As many completion engineers are aware, fracture stimulation utilizing a process known as "limited-entry" is commonly applied in effort to distribute a more equal % of frac sand into a variety of rock qualities or rock properties that are often witnessed within a certain formation as the lateral traverses thousands and even hundreds of vertical section (VS) feet. (See Figure 1 below for visual and calculable context regarding a limited-entry stimulation technique applied to four distinctly different injection zones being treated withing the same stimulation.)

Using this same technique typically used in fracturing, but applying it to gas separation, the MSLE separator's design utilizes a reversed method such that the fluids being ingested into the gas separator are purposefully restricted through an intake port located near the bottom of the inner tube inside the uppermost chamber and thus the remaining volume must then be handled by the next chamber stacked in series below with another port in this next chamber's innertube limiting total allowable volume throughput. This process continues until the entire volume of fluids designed to be pumped from the well are ingested by the full separator stack, at the designed slow pace (typically targeting <1.0"/second drawdown pace), and pumped through the rod pump BHA then to surface. (See Figure 2 below for example.) It is due to this fact that other separators currently out there would need to cut their claimed separation capacities by 6x in this case assuming they are using the standard 6"/second rather than 1.0"/second.

The size and number of ports, total number of separator chambers, as well as an optimized length per chamber is a bit difficult to predict in some wells since the downhole conditions are going to be changing so rapidly in a rather short period of time with regards to, especially, PIP and total fluid volume to be pumped in both ESP and RP lifted wells. Safe falls and design "cushions" are implemented to ensure these changing bottom-hole conditions do not have an adverse effect on the separator's long-term performance.

The first design queue that may appear overdone from the surface is capacity of these units. Technically each separator chamber would, if following the 6"/second rule, be good for ~230 bfpd, so a 10 chamber stack would then be good for 2300 bfpd. Since we are targeting a drawdown pace inside the separator chambers of 1.0"/second that capacity per chamber becomes ~40 bfpd, thus a 10 unit stack performs optimally at +/-400 bfpd in the toughest of conditions. We'll also consider there will potentially be a significantly higher PIP when earlier in the life of a well and as that well declines it's production in time, or the AL selection's ability to more completely match it's production volume with what the well will give up, the PIP becomes much lower and the dynamics within the MSLE separator change significantly. Thus, it is best to assume some chambers may process as much as 15-20% of the total production volume although that one chamber is likely just be one of ten in the stack. This disproportionate volume of fluid through one chamber is actually not desirable (and precisely what we try to avoid with our designs) as the drawdown pace would obviously then be increased to likely around 1.5x or 2.0x the other chambers and gas would have less opportunity to escape and avoid going into the pump.

It is believed there are two main reason you would see this occur: 1) the uppermost port or ports in the top one or two chambers have too large, or a rather non-restrictive, intake port sizing applied and 2) the over-sized port along with higher initial PIP's will allow the for a more aggressive "push" of the gas-laden wellbore fluids to be run through these uppermost ports at say 800 PSI versus how much will push through the same ports at 300 PSI, for example. This is why it is best to design the chamber lengths to accommodate target conditions for the well that will not only be witnessed upon initial install, but many months or even years down the road.

If a higher volume (+350-450 bbls/d or more on RP or +900 bbls/d on ESP) is intended to be pumped and we're limited to a max of 10 separator chambers per stack for economic reasons (technically you can always run more, it just cost more money to do so), and we know we would initially see rather high PIPs then it's safe to assume it would be best to design the separator chamber lengths to handle at least 20% of the total volume of target fluids. There is another separator on the market which applies a series of stacked chambers, but the main differences being that it utilizes a singular flow path (i.e. one chamber feeds the successive chamber and that continues until pump intake) and also notable it's chamber lengths are exceptionally short and nothing has been made clear about any port sizing or science and physics applied to their intake fluid management and how that is purposefully controlled and/or designed to work for a wide variety of changing downhole conditions. This is vital to success and must be done carefully.

If the separation chambers are very short (e.g. 12", 24", even 36") that means you have absolutely no margin for error in the intake port sizing if it is the intention to apply limited-entry to get a more even distribution across the stack. If you run a very short chamber and there is not really any limit or restriction across the intake port then this is not truly a "limited-entry" process being applied and you would indefinitely intake gas along with the fluids as the target drawdown rate would be far exceeded. If too small a port is run and far too much restriction is applied across the port, then only what can pass that single port would be run through that particular chamber and the remaining volume of the total target volume would need to be produced through the remaining ports. If the combined volume allowed to be passed through all chamber's ports combined is not able to meet or exceed the target total volume target then the overall design is far too restrictive (aka the ports total cross-section is too small), you will be incapable of producing at your target volume, and it is very possible the BHA will need to be pulled and corrected (see Figure 3 for example), thus this is why the design process, having a full understanding of what conditions are today and where they will be in the months and years ahead is exceptionally important and all that goes into the balancing of the design equation for a successful long-term application.

Bottom-hole Assembly Details and Options

The MSLE separator can be easily applied to many forms of AL, but ESP or RP will be the most widely utilized. In a RP application it is to be run on tubing just like an old poor-boy design and a variety of options regarding TAC placement are feasible, yet it is very heavily recommended to run a slimline TAC below the MSLE stack and place a heavy-walled flow-through sub above the TAC and below the blanked off separator stack. (See Figure 4 and Figure 5 below for example.) Users love this design as it does not require them to run a very expensive and sometime unreliable packer as the anchoring mechanism nor are us forced to run some form of backside isolator like a CRP packer which forces additional setting procedure to be following or cup packers which have a very poor history of seal reliability and long-tern successful function. The tool is commonly placed at the kickoff point, but can be run lower and set in the curve or in a tangent as well it that is desired.

The MSLE separator chambers are constructed from all high quality 4130 materials in a 3.50" OD and has a 2.75" ID which results in a very thick 0.4375" wall-thickness. This material is used for several reasons. The thickness of the tubes allow for the API spec thread we desire to us to be cut into the ID of each chamber at both top and bottom. This leads to the ability then to not use a normal coupling to create a way to connect successive units which would drive up the max OD to 4.50" if a standard 3.5" coupling dimension was used, which is undesirable from a fishing perspective in 5.5" wellbores. We are able to keep the OD slim and slick without upsets since we used a heavy-duty cross-over coupling instead that is box-by-pin and screws into the top thread in the ID and the box OD is just over 3.50", thus the MSLE is easily run into very commonly used 5.5" casing and even very heavy-walled 23# options, which can be exceptionally tight for other separators and much strength is typically compromised in other units when wall-thicknesses are minimized and parts are turned down to make fit. The MSLE does not compromise on any element of strength, materials, function and is build for a lifetime of use. On that note the MSLE v4.1 design currently being manufactured is 100% modular so every single piece in the system is fully able to be reconditioned or easily replaced at minimum expense. This is not a cheap design that will be run once and if any small problem arises about its structural integrity, thread conditions, etc arises, then you throw it away, quite the contrary. These units are built to last, but also maintained with absolute minimal service costs.

Also worth noting about the MSLE units is when you have run a large stack of 10 or more into a newer, large volume well and in time it's production declines, when you pull that well for whatever reason and you no longer need to utilize the full capabilities of a 10 stack unit, you can breakdown, clean the internals as needed, reconfigure the port design, and split up the stack for use in two wells with say a stack of 5 and 5 or 4 and 6 chambers per unit depending on each wells volume and conditional needs.

Examples of Successful MSLE Installations

The most functional way to remedy this shortage of capacity problem generated by the other separators out there is to change the biggest driver of their demise: add separation space (aka separation capacity). The way to alter this is made feasible through adding to the total capacity so we can achieve the desired results. This is where the MSLE aides to create a huge strategic advantage over any other separation technique used in unconventional wells.

The first example (Figure 6) to review is of a very high gas rate well coming off of free-flowing. This well was rodded up with a C912-427-168 set in the long hole with a 2" pump set at 8000' with a POC and VSD control. Gas rate starts off ~500 mcfd, dips only when SPM is adjusted from 8.5 to 7.0 SPM for reliability concerns, production then stays rock steady at ~360 bfpd declining only slightly over time and the gas proceeds to increase to ~800 mcfd as the fluid level is pulled down along with the PIP in the next 4 months. Notice the pump fillage trend that goes along with this production. Initially the unit starts off bobbing a bit between 85-96% production during the time the well was sped up and making +400 bfpd (~50/50 cut) then stabilizes and bumps up slightly with the SPM adjustment from ~85 to +90%. The fillage continues to improve slowly and steadily over the next 2 months shown until data stops w/ and average of ~94%. Very interesting to see fillage improve in time as the rate remains almost perfectly stable; it is presumed natural gas separation may be improving over time as the initially higher PIP has been pulled down although the gas rate has concurrently increased by ~60% since start up. This is a very successful test overall and has yielded refinements to the intake design that will put focus on minimizing annular velocity flow patterns focused primarily on providing a higher % liquid concentration immediately at the intakes on future designs.

The next example (Figure 7) is a back-to back comparison of a RP well using another company's centrifugal gas separator/sand separator combo. This is a big Rotaflex unit with a 366" stroke length and a 2" pump at ~10,000'. Note the previous install did pretty well for only a couple days then the fillage dropped never to recover. Also notice the fillage continued to struggle even as SPM was altered through the last couple months before pulling the equipment for this comparison test. With MSLE separator installed notice the pump fillage has been ~97-98% average for the first month online, but also that the SPM has been very steady and they've been increasing it over time with no negative effects. The total fluid volume output on this unit has been averaging very steadily 250-270 bpfd and at the end with the SPM increasing to 3.8 SPM it has reached 300 bpfd. Another 2 months of data is available for this well.

The next example (Figure 8) is an ESP to RP convert. After another short 4 month run on ESP the operator concluded it was best to make the swap to a large 366" Rotaflex instead of paying for another short run ESP. The unit was installed and utilized a MSLE gas separator downhole. The SPM was walked up after being online for about 2.5 months and being limited to max SPM of 3.7 SPM due to surface issues with the PU running any faster. The speed issue was resolved and max SPM was increased to 4.1 and fluid volumes have been producing at very high levels since, ~425-500 bpfd and bobbing between ~75-92% fillage which is recorded as a single point daily, but the avg is calculated to be consistently in the mid-upper 80%'s in this extremely gassy well.

Several refinements and improvements have been made to the MSLE design over the past two years and we've have a consistency in design which has been deployed heavily since early 2020. A significant focus was put into a more final design for mass production that will be create easily repeatable function with non-compromising reliability and be easily and inexpensively redressed and repurposed. Further, some well results have shown the need to add a new design of intake slot(s) that creates a very direct drop in velocity for an extended portion of the annular flow which will create a high % fluid loading to occur directly at, above, and into every chambers so less blow-by occurs and we create an occurrence of intaking a higher quality fluid that is maximized. This design element we refer to as "AVD" or annular velocity disruption and has been in use since early January 2020.

CONCLUSIONS

The MSLE is an extremely simple to assemble and run unit that greatly increases gas separation in common well casing designs often by as much and 6-7x that of other separator options out there.

Considering real-world bubble rise velocities and fluid consistencies in today's most active plays, there is a true need for an increase in separation capacity and this improvement to capacity is easily delivered on a broad scale, reliably, and cost-effectively with the application of MSLE gas separator technology.

The overall size and shaper of the MSLE units are slim, sleek, and continuous, thus very safe to run in casing IDs that may be otherwise too tight for safe running and retrieval with other units, but also maintains max annular gas volume and velocity handling as well as fluid volume capacity. All other separators suffer in trading some good qualities for other bad one's; the MSLE does not sacrifice anywhere, it is the best of all worlds combined and in a simple package.

MSLE separators are easily torn down, cleaned, redressed, and repurposed. They are intended to be the most flexible and their port designs easily altered for well-after-well application and very long life.

Without the MSLE utilized these separation capacities are completely and 100% not feasible and this opens the door for a substantial improvement in AL operations in any well, but especially in 7.0" and 5.5" wells that has never been capable to this point.

The MSLE design has proven to be successful in the first several dozen test wells and the design continues to received refinements that are capturing more and more outstanding performance in extreme conditions - +500 bfpd at ultra-high separation efficiency and pump fillage in RP wells on a consistent basis as well as ultra-high GLR's over 2500:1 in wells making in excess of 1.0MM/d and 400 bfpd.

REFERENCES

1. http://frackoptima.com/userguide/theory/limited-entry-tech.html
2. Ellithorp, B. and Snyder, D., "A Simple Method to Double Separation Capacity in New Wells," presented at Southwest Petroleum Short Course, Lubbock, TX, May 24-25, 2017
3. Ellithorp, B. and Snyder, D., "Evolution of Rod Pump Systems in Unconventional Wells Leading to Today's Best Practice and Beyond," presented at ALRDC Artificial Lift Strategies for Unconventional Wells Workshop, OKC, OK, February 7, 2018.
4. Ellithorp, B. and Snyder, D., "Casing Gas Separator – Initial Installation Learnings and Design Progressions," presented at Southwest Petroleum Short Course, Lubbock, TX, April 17-18, 2019
5. https://www.aogr.com/magazine/cover-story/advanced-technologies-optimize-artificial-lift-production-operations

Nomenclature:
AL= Artificial Lift
VS = Vertical Section
RP = Rod Pump
ESP = Electric Submersible Pump
TAC = Tubing Anchor Catcher
BFPD = Barrels of Fluid Per Day
ID = Inner diameter
OD = Outer diameter
MA = Mud Anchor
BHA = Bottom hole assembly
EOT = End of tubing
PBHP = Pumping bottom hole pressure

Figure 1 – Schematic view of simultaneous treatment with four injection locations

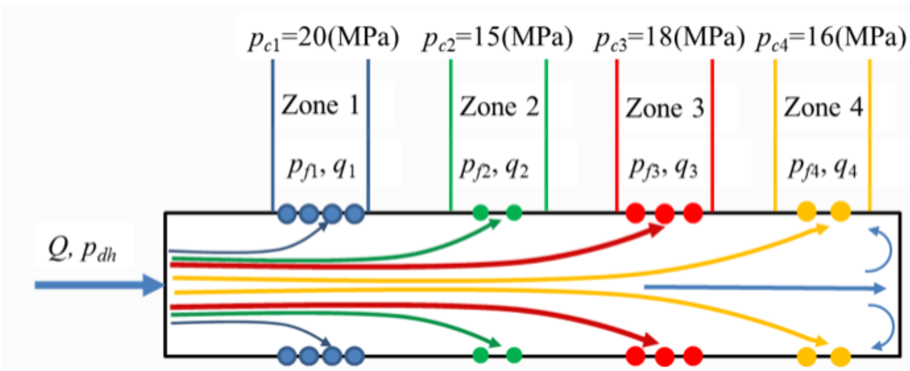


Figure 2 – MSLE separator chambers and flowpath

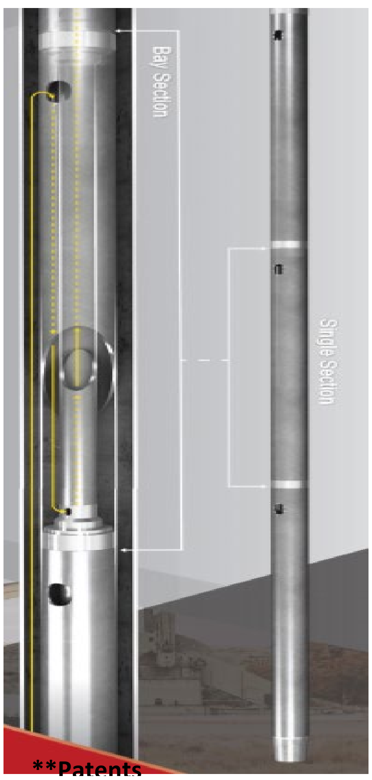
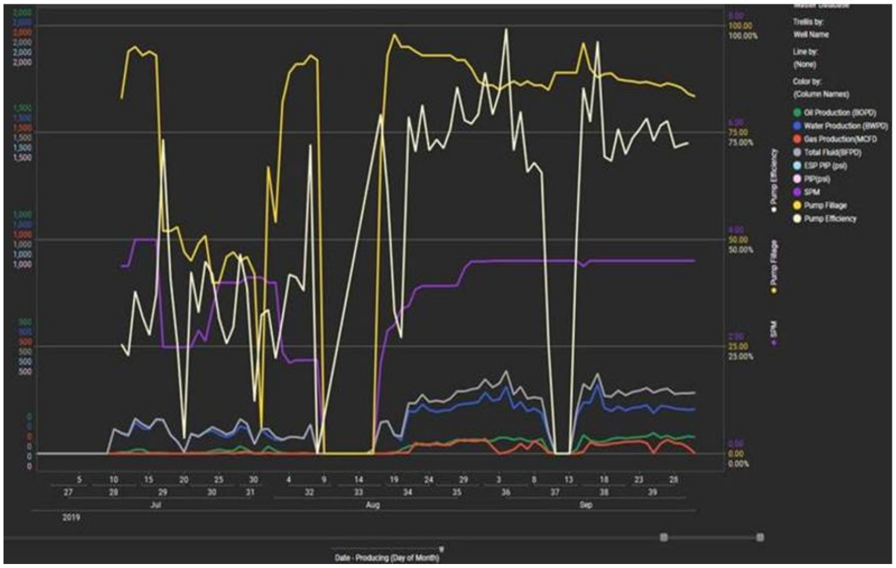


Figure 3 – MSLE separator with too much restriction, BHA pulled, redesigned, and re-run



Run #1

- **1st trial ever**
- **Fillage hit a wall hard and quick; +90%>>>50% or less**
- **SPM alteration tests**
- **Fluid volumes struggle; ~160 bfpd max potential**
- **Learning: FAR too restrictive**

Run #2

- **~1.5mths shown here**
- **Walk-up then steady SPM**
- **~88% avg fillage during this period**
- **Total Port area increase: 127%**
- **Port Count increase: 2x**

Figure 4 – MSLE bottom separator chamber and BHA w/ slimline TAC set low

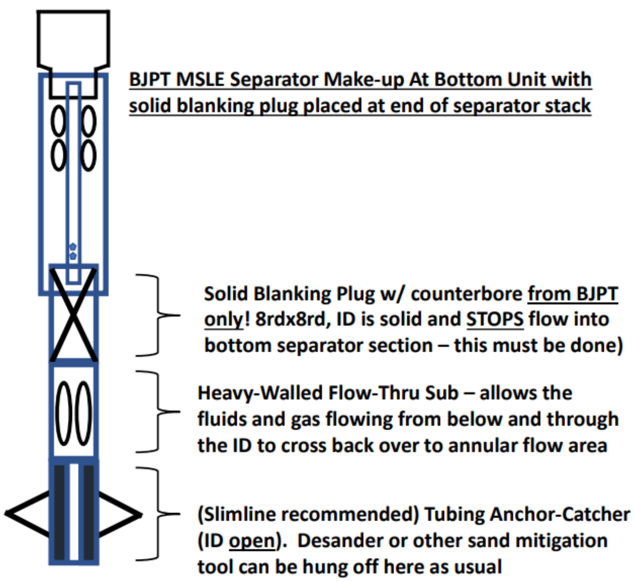
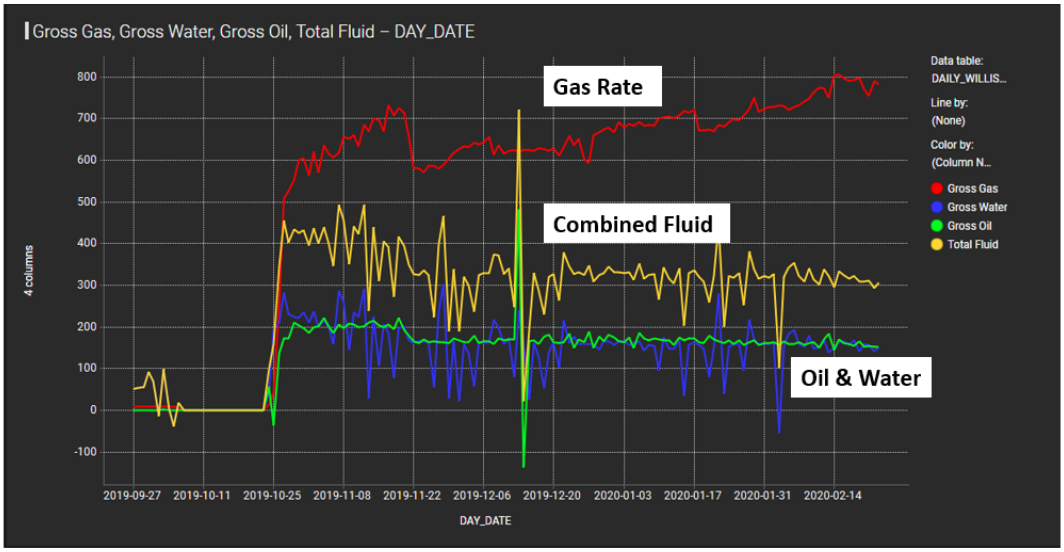


Figure 5 – MSLE anchoring options compared

TAC set low TAC set high

Figure 6 – MSLE example well – High volume with very high GLR/GOR



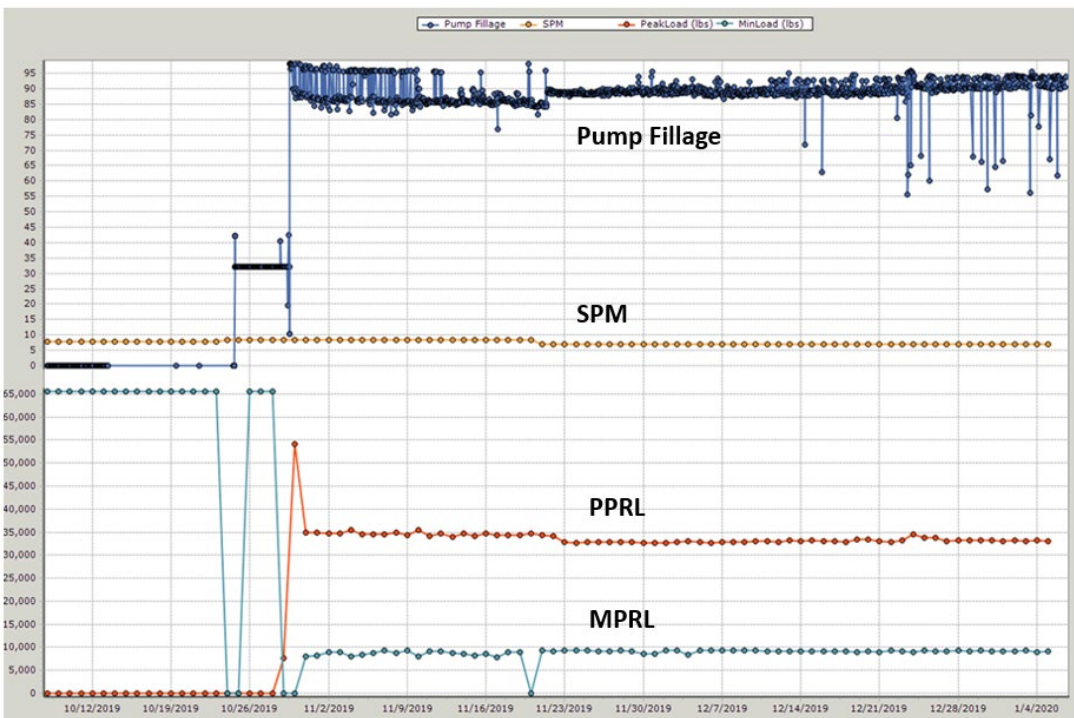


Figure 7 – MSLE example well - centrifugal/sand combo unit swapped for MSLE

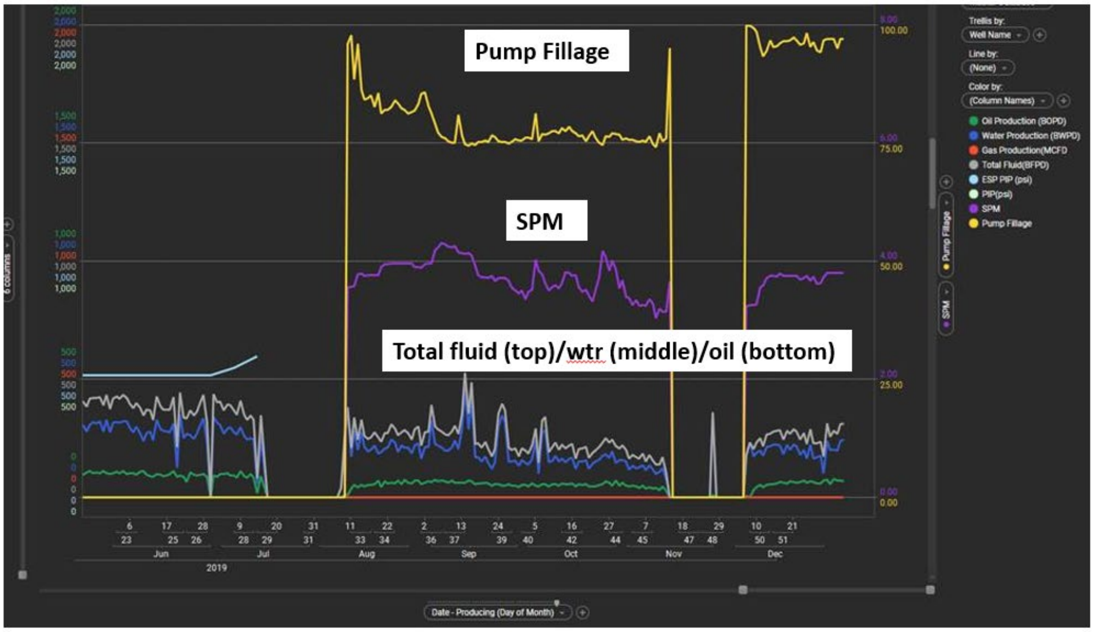


Figure 8 – MSLE example well