REAL TIME PLUNGER VELOCITY TO DETECT PUMP OFF VS. GAS INTERFERENCE: FIELD DATA EXAMPLES

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ABSTRACT

This paper proposes an approach to diagnose pump-off condition versus gas interference condition utilizing a patented overlay of real time plunger velocity on top of the real time downhole card via pump-off controller interface. Field results showing the impact of this methodology are presented.

Traditionally, the industry only looks at the surface and downhole card to optimize and achieve better well control. This requires a series of experts, dynagraph interpretation and optimization processes. Even with all of this, scenarios exist where a downhole condition is not identified properly or leaves questions to be answered.

One of the major problems in sucker rod pump (SRP) wells is that the well will shut down or slow down when the pump fillage goes below a certain predetermined (user set) value, which can either be attributed to gas interference or pump off condition. If the first scenario applies, the operator may have the option to pump through this condition and achieve more production and drawdown on the well without damaging the system. If the second, the well should be stopped immediately to avoid equipment damage and failures.

Unfortunately, knowing the difference between these two conditions is not always intuitive or obvious. Moreover, pump-off controllers (POCs) certainly cannot tell the difference. This causes the operator to lose potential production and revenue and leads to today’s condition where too many wells are carrying thousands of feet of fluid over the pump and are not achieving effective drawdown or hitting their production target.

Field results show that gas interference can be distinguished from pump off, reducing unnecessary shut down and improving drawdown in SRP wells.

The options available today for plunger velocity are only available through modeling software and sporadically gathered dynos and are not in real time. This does not afford the operator effective control and live decision-making capabilities. The proposed offering puts the decision and control capabilities back in the operator’s hands.

INTRODUCTION & BACKGROUND

Plunger velocity - also referred to as pump velocity - is defined as the speed in which the plunger is moving through the barrel of the pump. It is plotted with the 'Y' axis representing feet or inches per second and the 'X' axis representing downhole stroke length in inches. Plunger velocity or 'V' is derived by differentiating the equation for pump position developed in the pump-card theory. [1]

Plunger velocity is available when utilizing the two industry-standard rod design programs based on modeled data. It can also be found when reviewing the industry-standard well dynagraph reports that are gathered on location. In each of these scenarios, the plunger velocity is shown separately from the downhole pump card. Unfortunately, rod designs and dyno reports are not frequently collected. This lack of frequency does not allow the intricacies of the live rod pump system to be captured over time and limits what can be learned from monitoring plunger velocity.

From a well optimization perspective, plunger velocity monitoring is rarely utilized and, until recently, has not been offered at the pump off controller or SCADA level. Well optimization practices are typically based on production, surface and downhole cards, fluid level and rod design POC review.

Fortunately, technology has recently improved to allow for cloud-based POCs and integrated variable-frequency drive (VFD) packages. These systems showcase live, stroke-by-stroke well data that is reviewable both remotely and on location.

With downhole card capability in real time, plunger velocity can then be calculated. These two features have allowed for plunger velocity to be plotted for each stroke at the POC level for the first time. This patented feature further enhances current well optimization practices by being plotted over the top of the downhole pump card. To accomplish this, all surface card data points are captured and then run through the wave equation [2]. From here, a downhole card is created and all of the data points making it up are captured. Plunger velocity is simply one downhole position data point subtracted by the previous point [1].

Surface Position 1	Surface Load 1		Downhole Position 1	Downhole Load 1	Plunger Velocity Plot
0	11.02732	0.013128	0.848407398	-5.193541641	-0.133490817
0.013128449	11.03483	0.015776	0.714916581	-5.106296598	-0.133407219
0.028904327	11.04615	0.017406	0.581509362	-5.057894924	-0.132449172
0.046310662	11.06006	0.014092	0.44906019	-5.047090769	-0.127458044
0.060402337	11.07192	0.020468	0.321602146	-5.066235919	-0.116175878
0.080870658	11.08523	0.02129	0.205426267	-5.101723299	-0.097361676
0.102160968	11.09767	0.02304	0.108064591	-5.135495791	-0.070807712
0.125201444	11.10968	0.024953	0.037256879	-5.147426958	-0.037256879
0.150154036	11.12149	0.035045	0	-5.118210034	0.001767561
0.185198949	11.14141	0.043955	0.001767561	-5.03228179	0.044199317
0.229154254	11.16372	0.048967	0.045966878	-4.880281061	0.087706251
0.27812157	11.18643	0.044951	0.133673129	-4.660605214	0.129976565
0.323072355	11.20581	0.057879	0.263649694	-4.379772291	0.168983126
0.380951533	11.23002	0.062834	0.43263282	-4.05149736	0.203198561
0.443786001	11.25493	0.06756	0.635831381	-3.694613219	0.231740383
0.511346338	11.28214	0.072173	0.867571764	-3.330168226	0.254434279

Figure 1: Plunger velocity data set

Plunger velocity is important because it helps operators better understand what is happening downhole which, in turn, helps better optimize production. It’s important to identify the precise point in the stroke that plunger velocity peak is reached. In general, it is assumed peak is reached in the middle of the stroke. The pumping unit changes direction twice each stroke; once at the top of stroke and once at the bottom of stroke. To change direction, velocity has to hit zero at least twice per stroke.

Pumping unit geometry, fiberglass rod strings, pump fillage, speed, and loads can all affect the plunger velocity but, generally speaking, the plunger is moving fastest through the barrel around the middle of the up stroke and the middle of the downstroke.

In a tagging condition such as when a pull rod crashes into the clutch found at the top of the pump during the downstroke of the pumping unit, it would be safe to expect the plunger velocity to rapidly decrease to the zero line on the downstroke as the plunger cannot mechanically move further downward. Furthermore, in a 50 percent pump fillage fluid pound scenario, it could be assumed that the plunger would build speed as it free falls through the empty void within the pump barrel and then dramatically falls to the zero line as the traveling valve crashes into the fluid, instantaneously stopping the plunger and buckling rods.

During a gas interference or gas compression downstroke, it would be reasonable to expect that the plunger velocity is slowly building back to zero while gas is compressed and velocity begins to increase again once the traveling valve opening moment occurs. None of these situations are free of damage to the system but the severity of each case differs.

When the patented plunger velocity measurement feature was introduced by WellWorx Energy in 2023, this was certainly the expectation. Yet once the data was meticulously monitored stroke after stroke over many different conditions, it became clear there were many instances that broke these pre-conceived notions.

The genesis of overlaying plunger velocity on top of the downhole card was an effort to more easily and quickly identify wells that could be pumped more aggressively and/or more easily and quickly identify wells that were being over pumped.

Without a doubt, one of the largest issues encountered when producing today's horizontal wellbores on rod pump is gas interference. In this gas interference scenario, the pump is filling to 100 percent with every stroke and the well is carrying a fluid level of some kind. The problem is the fluid within the pump is so gaseous and must be compressed before the traveling valve can become unseated. This can cost the end user roughly 20 to 60 inches or more of every stroke. At 8,500 strokes per day, per well, the production inefficiencies add up quickly. The question then becomes whether or not the end user can produce through this gas interference condition or if these actions are damaging the system.

Answering this question is quite the process. A fluid level on the well in question must be acquired. Next, the rod design needs to be rerun with this current fluid level so the design can consider the current buoyancy effects [3]. A well carrying thousands of feet of fluid above the pump will often prove to be quite underloaded at the rods, structure and gearbox. From here, the design can be rerun again to match the pump fillage currently seen at the controller. This will give the end user an idea if any rod buckling is taking place based on current conditions. At this point, it is likely proven that the system is underloaded, not buckling and under producing. Next the rod design program can be run yet again at increased speeds until the new threshold can be identified and more production is achieved. This completes the process required to prove the system is not being damaged by over-pumping to achieve the desired production goals.

The end user is expected to complete this process repeatedly over time as additional drawdown is expected and equipment loading changes. It is unrealistic to expect the well to be constantly watched for the moment when gas interference becomes fluid pound, not to mention that these wells are known for being extremely dynamic with daily alterations. Multiply this scenario by thousands of wells. The process and workforce alone required to be on top of this could be considered staggering but the production being left on the table due to these practices not taking place is impossible to ignore.

METHODS AND PROCEDURES

Seeing a plunger velocity plot over the top of the downhole card each stroke of the pumping unit at any given time is meant to circumnavigate the process defined above.

Having access to a series of downhole and surface cards certainly brings clarity but there are still missing factors a current plunger velocity plot can clear up such as:

- Verifying the TVO moment/pump fillage pick.
- Is it a tag or is it just the moment the drive is making an intra-stroke speed change on the downstroke?
- Effects of excessive stuffing box friction on plunger velocity.
- Optimize zone control settings for long stroke pumping unit applications.
    - Ensure the speed increase on the downstroke doesn't take place until after the TVO.
- Quantify the delta between gas interference conditions and pump off conditions on the same well.
- "Tweener" card clarity. The pump card that could be gas interference or pump off is nearly impossible to tell.
- Help the POC identify the difference between a gas interference condition or pump off condition with advanced control algorithms.

In the example shown in Figure 2, the operator must ask themselves if more production is possible despite an unknown fluid level. To the trained eye, it is obvious the below card is from a long stroke pumping unit and experiencing roughly 55 percent pump fillage. The main question here would be if this is a pumped off condition, which would be damaging the system. Alternatively, it could be a gas interference condition that is not doing as much damage and could potentially be pumped through to achieve more production [3].

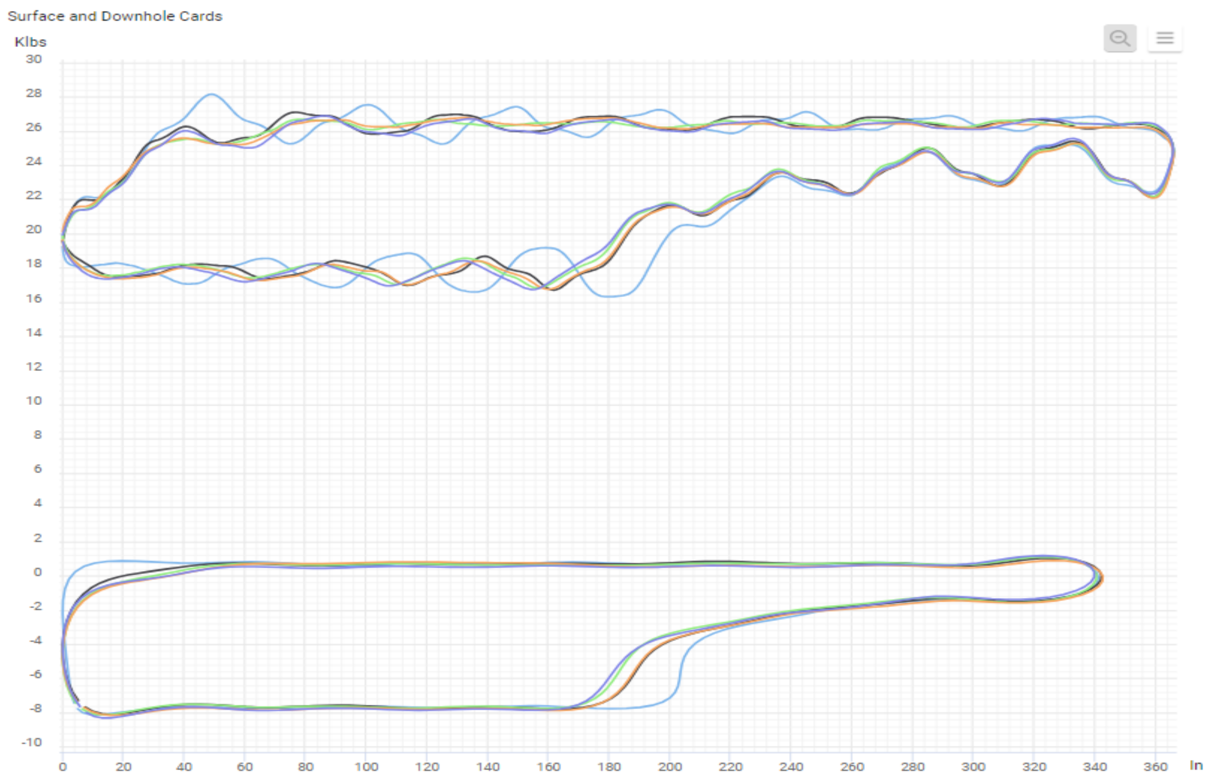

Figure 2: Sample downhole card from long stroke pumping unit.

To try to make a quality recommendation, review the same data set with a plunger velocity plotted over the top of the downhole card shown in Figure 3.

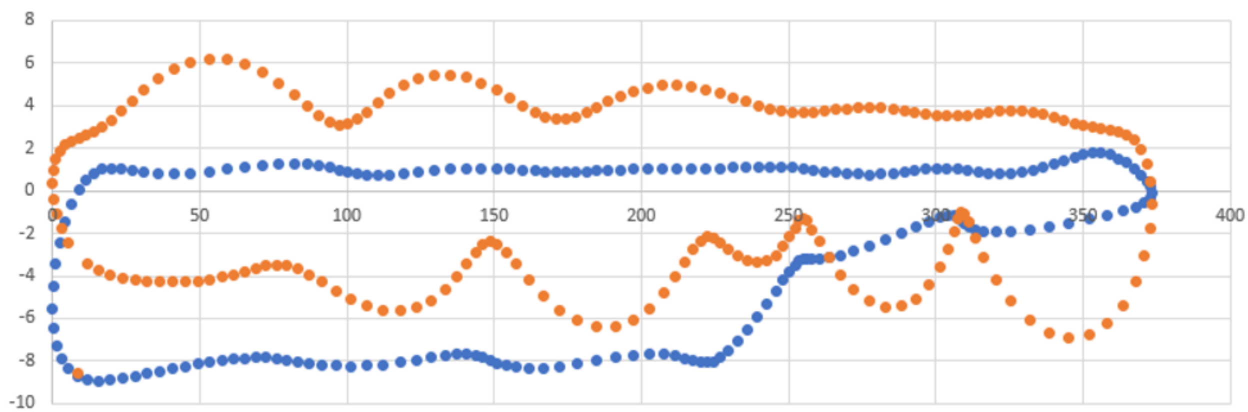

Figure 3: Sample downhole card from long stroke pumping unit with plunger velocity.

Here, the pump card is represented in blue and the plunger velocity is represented in orange. As the pumping unit starts the downstroke at the 366-inch mark on the right side of the plot, the velocity increases. With velocity peaking at the 350-inch mark, velocity begins to slow and work back toward zero.

Two things of note on Figure 3; the velocity is not hitting zero at this point and it is not the traveling valve opening moment. Additionally, the speed of this well was around 2.3 strokes per minute (SPM) and it was running at a minimum speed which bypasses pumping unit zone control. In other words, the pumping unit was moving at a constant speed in this situation. So, what causes this first reduction in plunger velocity? Rod dynamics.

The next velocity reduction event takes place at the 252-inch mark. Again, velocity does not hit zero and this is not the traveling valve opening moment. Rod dynamics again.

Finally at the 225-inch mark, the traveling valve open (TVO) moment can be seen in the pump card and the plunger velocity verifies this. Note that this TVO moment is further from the zero line than the previous two rod dynamic conditions. Lastly, note the rod dynamics taking place at 150-inch mark after the TVO. Note the two rod dynamic moments occurring in the upstroke at 100 inches and 160 inches.

With all of this in mind, it leads the end user to two conclusions: The plunger is never coming to a complete stop at any point during the stroke and the TVO moment actually appears to be one of the most harmless things taking place in this stroke. From here, a recommendation was made to ensure 24 hour run times, increased speed within design limitations and a fluid level verification was requested.

The next day, a fluid level was supplied. The well mimicking pumped off conditions in Figure 2 was actually carrying a fluid level above pump of 6,624 feet.

If the plunger is not coming to a full stop and the slope change in velocity plot is minimal, why should the well be slowed down? Why should the well be allowed to pump off? Perhaps the most important outcome of the plunger velocity plot is that it is shown in real time.

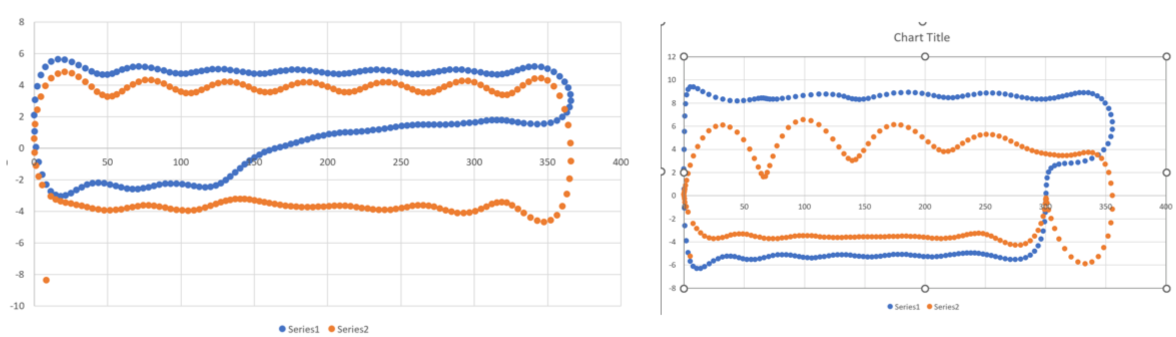

Figure 4: Plunger velocity comparison.

In Figure 4, both card examples are taken from the same well but at different times. In both situations the well was producing at 2.1 SPM on a long stroke pumping unit with a steel rod string. The well was carrying a 7,000 fluid level above pump on the cards shown on the left. At this time, the well is clearly experiencing severe gas interference but note that the plunger velocity is unphased by the compression it is experiencing on the downstroke as it moves past the TVO moment without any change.

The same well is now pumped off as shown in the card on the right. Note how the plunger velocity rises quickly and abruptly comes to a stop at the TVO moment. This proves the theory that producing through the gas interference on this particular well was free of charge. But the pump off situation that occurred later was a much more damaging stroke.

Figure 5 represents a similar situation where the gas interference taking place does not appear to be affecting the system.

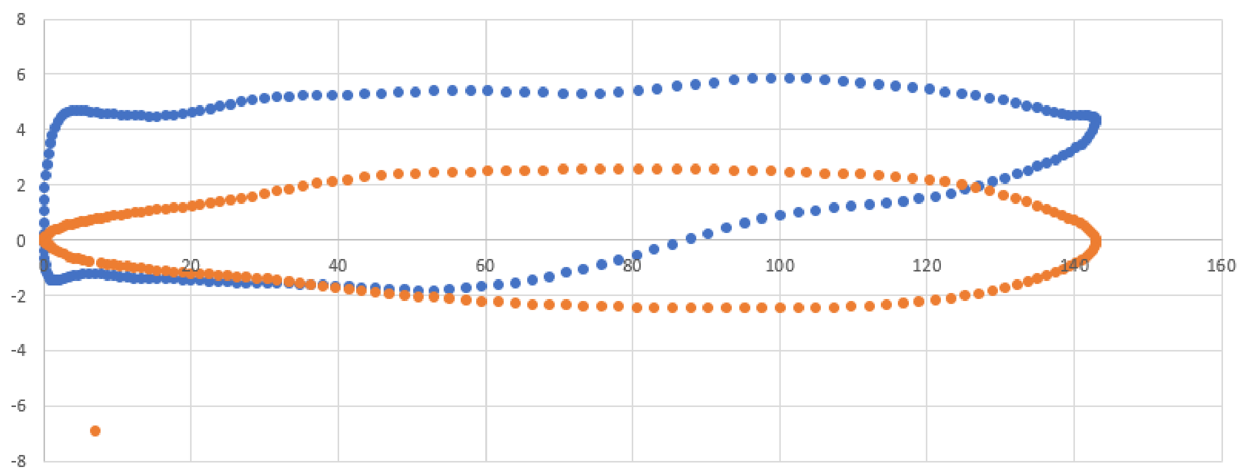

Figure 5: Gas interference

This well has a pump depth of 7,000 feet with fiberglass rods running 11.1 SPM on a 640 pumping unit making quite a bit of oil and water but very little gas. The orange plunger velocity indicates no velocity change through the compression and TVO moment of the down stoke. Upon seeing this information, the operator sped this well up to its current speed of 12 SPM.

Alternatively Figure 6 demonstrates a gas interference condition where the plunger velocity returns to zero at a fairly gradual slope.

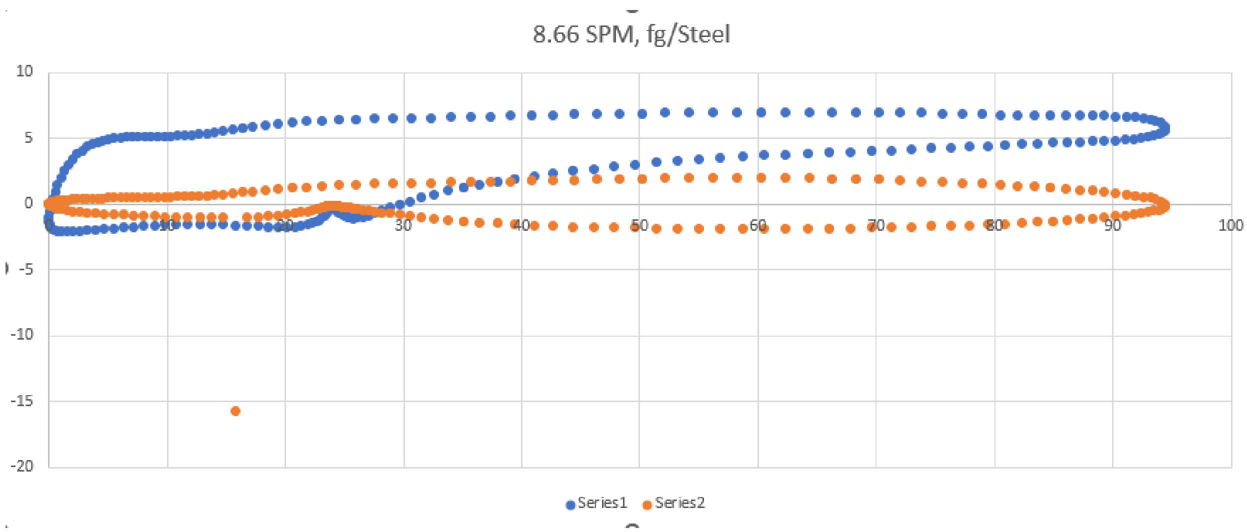

Figure 6

CONCLUSION

While there is still much to be learned from this patented, new POC capability, there are several conclusions that can be drawn from this data. Namely, that not all gas interference scenarios or fluid pound scenarios are the same and that they must be treated individually. The cause of these differences is due to the variables of the rod pumping system such as water cut, pump clearance and fluid properties. While the variables will continue, plunger velocity being monitored in real time can and should be used as a tool to ensure the proper controller settings are being put into place.

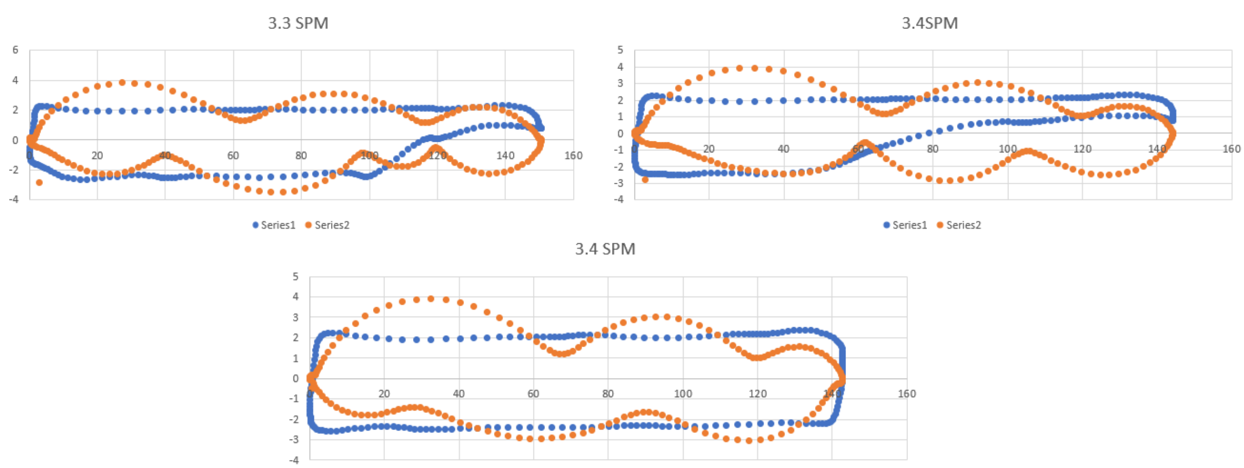

Figure 7: Plunger velocity monitored over time.

The data sets in Figure 7 represents a conventional pumping unit with steel rod string running at 3.3 SPM in all instances. Note the full pump card shown in the bottom card.

While this could be considered a best-case scenario, rod dynamics are still slowing the plunger velocity at 4 points within the stroke. Regardless, no action is taken.

The two top cards in Figure 7 show incomplete fillage due to gas interference with roughly the same plunger velocity consequences. In this case, the POC would normally want to slow down or even pump off. But because the operator was able to read the plunger velocity, they wisely knew to produce through gas interference conditions as there was no harm to the system that wasn't also taking place in full pump conditions.

Figure 8 summarizes the findings in this paper.

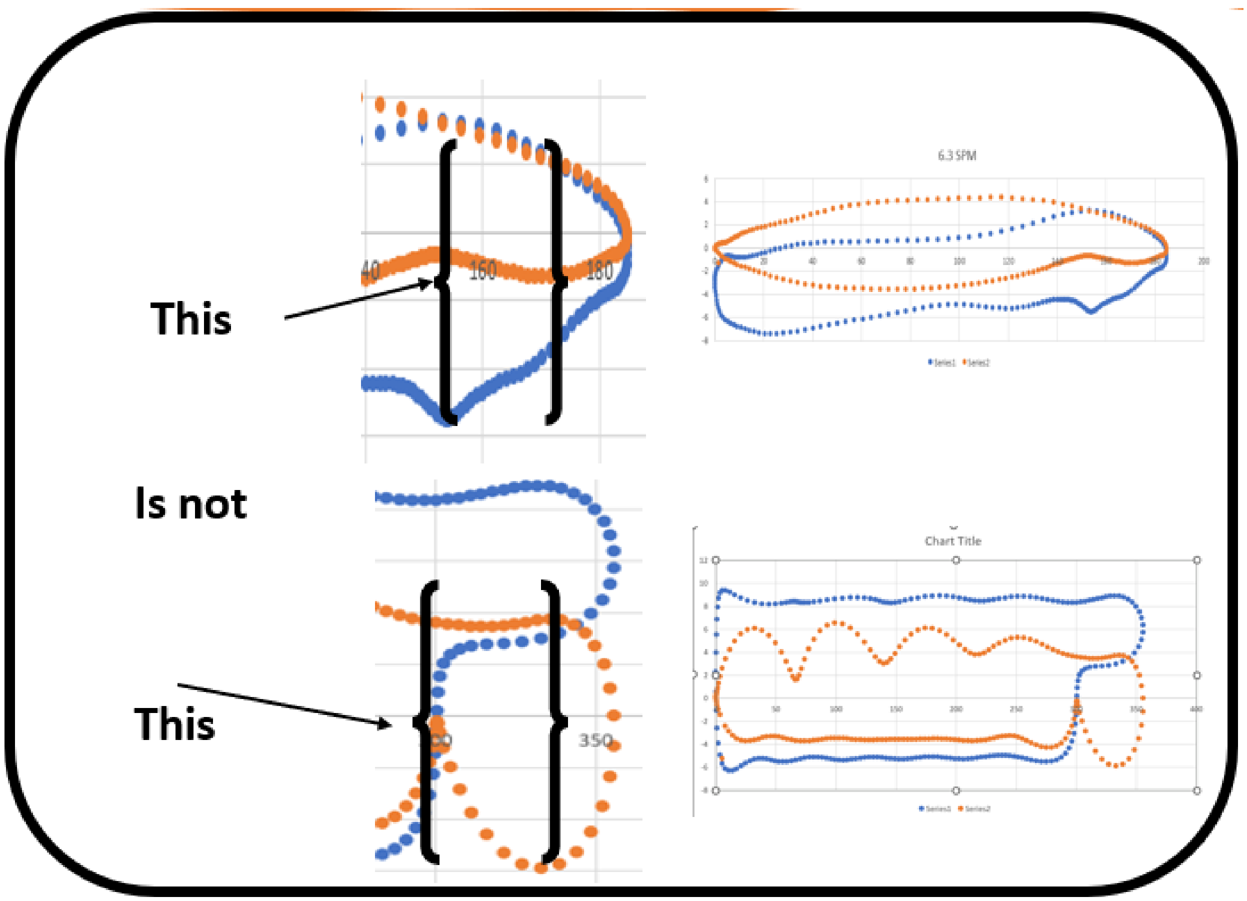

Figure 8

When monitoring plunger velocities in real time, a gradual slope back towards zero is not the same as a rapid slope hitting the zero line or even crossing the zero line in the down stroke. It is imperative that these two conditions should be optimized differently.

This patented technology could be implemented in a number of exciting ways and further development and monitoring is underway. Among the prospects are the following:

- Tie plunger velocity to rod buckling tendencies.
- Advanced control algorithms.
- Help POCs and drives accurately identify a pumped off condition vs. a gas interference condition.
- Tag verification.

REFERENCES

1. Gibbs, Sam and Nolen, Kenneth B.: "Quantitative Determination of Rod-Pump Leakage with Dynamometer Techniques." SPE Paper 18185 (1990).
2. Gibbs S. G., "Rod Pumping: Modern Methods of Design, Diagnosis and Surveillance", 2012
3. Messer, Russell, Pons, Victoria, "Enhanced Optimization of Deviated Wells Utilizing GreenShot: A Permanent, Automated, Fluid Level System", 2021 Southwestern Petroleum Short Course, Lubbock, August.