STATE OF THE ART SOFTWARE FOR SUCKER ROD PUMP SYSTEM DESIGN, ANALYSIS, OPTIMIZATION AND TRAINING

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INTRODUCTION

In this paper, we discuss the industry's need for a state of the art software program that can model the variety of conditions that a sucker rod pump system can experience. The importance of this is multifaceted. First, the ability to design a rod pump system with the knowledge of how it will respond to different pump conditions is of vital importance to ensure longevity of the system. Second, the capacity to use a predictive program to analyze and optimize an existing well by mimicking current conditions, and then creating different scenarios to learn and measure how the system might respond, or even fail, is highly valuable. Third, and of potentially of the highest significance, is the virtually infinite number of cases that can be created to teach production personnel about the fundamentals, the nuances, and the sensitivities of a rod pump system. Image the ability to create an entire course on sucker rod pumping and dynagraph interpretation using just one well!

There are two main predictive programs that are used in the industry to design rod pumped wells. These programs have the capability to model all the components of the rod pump system: the motor, the pumping unit structure and gearbox, the sucker rod string axial and side loading, as well as the downhole pump. However, the downhole pump conditions that can be modeled are limited to a full pump, incomplete fillage from fluid pound and incomplete fillage from gas interference. These few downhole conditions can also be altered by modeling tubing movement.

The challenge that arises is in determining how the pump unit system would responds to the multitude of other individual surface and pump conditions as well as combinations of these conditions.

PREDICTION AND DESIGN

It is well known that the current software packages can predict and design the behavior of both vertical and deviated rod pumped wells with basic pump conditions. However, when the operator wishes to have a knowledge of how the system will perform under other potential real conditions that are not uncommon, none of the existing industry software that can accomplish this feat.

Suppose that an operator wishes to implement a rod pump system in an area where there is extremely high gas interference and gas expansion at the pump. It would be useful to see how the rod pump system behaves in these conditions.

The first pump condition that was designed was with 5% pump fillage, no gas expansion due to 0" of unswept clearance between the traveling valve and standing valve, 0 BPD of

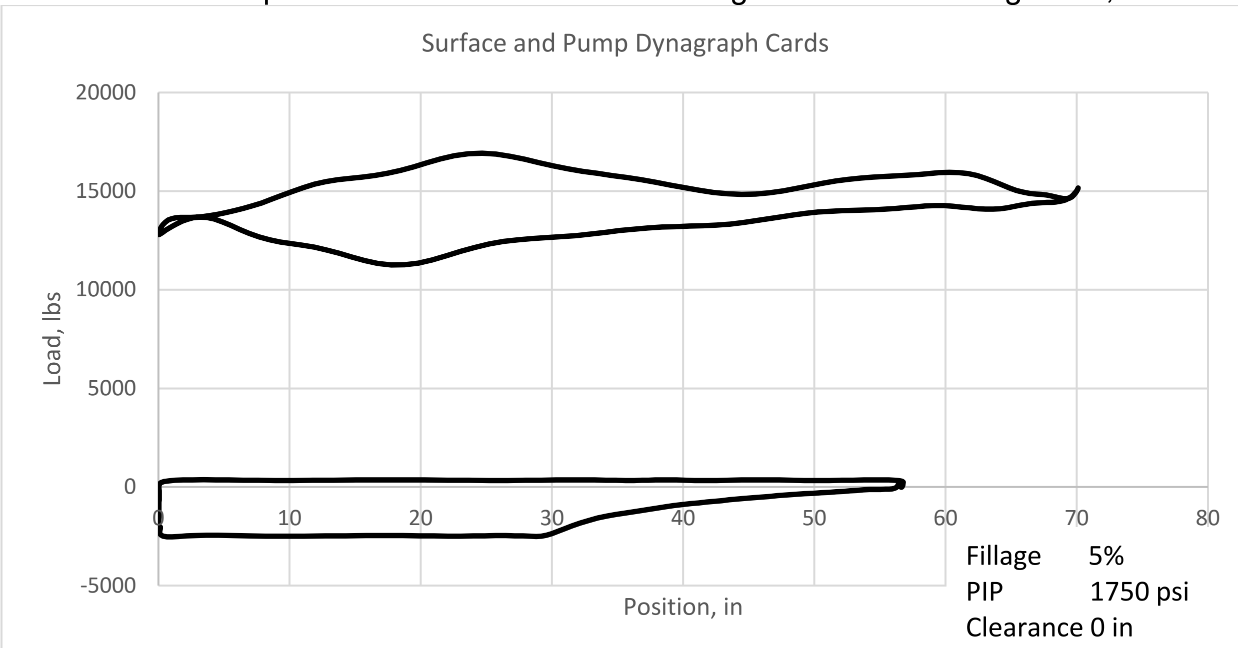

Figure 1.

pump leakage (traveling valve/plunger nor standing valve), with pressure above the pump of approximately 3700 psi and a pump intake pressure of 1750 psi. The downhole pump card that the author initially expected was one with a very short net stroke due to severe gas interference, but not quite the "Loch Ness monster" of rod pumping (gas lock). As seen in Figure 1, this is not the card that was expected with only 5% pump fillage.

Notice that the gross and net strokes of the pump are approximately 56" and 30", respectively. This results in a perceived fillage of 30"/56" = 54%, which is materially different than the 5% liquid fillage that was programmed. Why the difference? In this case, 5% fillage is equivalent to 2.8" of pump stroke, so the remaining 30" – 2.8" = 27.2" of net stroke is due to the high pressure free gas that entered the pump at pump intake pressure and was then compressed to 27.2" at pump discharge pressure.

In Figure 2 we introduce a significant unswept clearance of 24" between the standing valve and traveling valve, while keeping all other conditions the same. Notice that the gross stroke length increased slightly to 58" and the net stroke decreased from 30" to 20". However, 20"/58" = 34% fillage is still much more than the programmed amount of 5% liquid fillage. This is again due to the gas compressing in the pump barrel during the downstroke. The most significant difference is the delay in standing valve opening at 20" into the upstroke.

In Figure 3 the only change from the case in Figure 2 is that we decrease the pump intake pressure from 1750 psi to 1300 psi. In this example the gross pump stroke decreases to 53", but the most substantial differences are first, the net stroke decreasing to 12" so that the perceived fillage is now 12"/53" = 23%, and second, standing valve opening is delayed until approximately 35" into the upstroke.

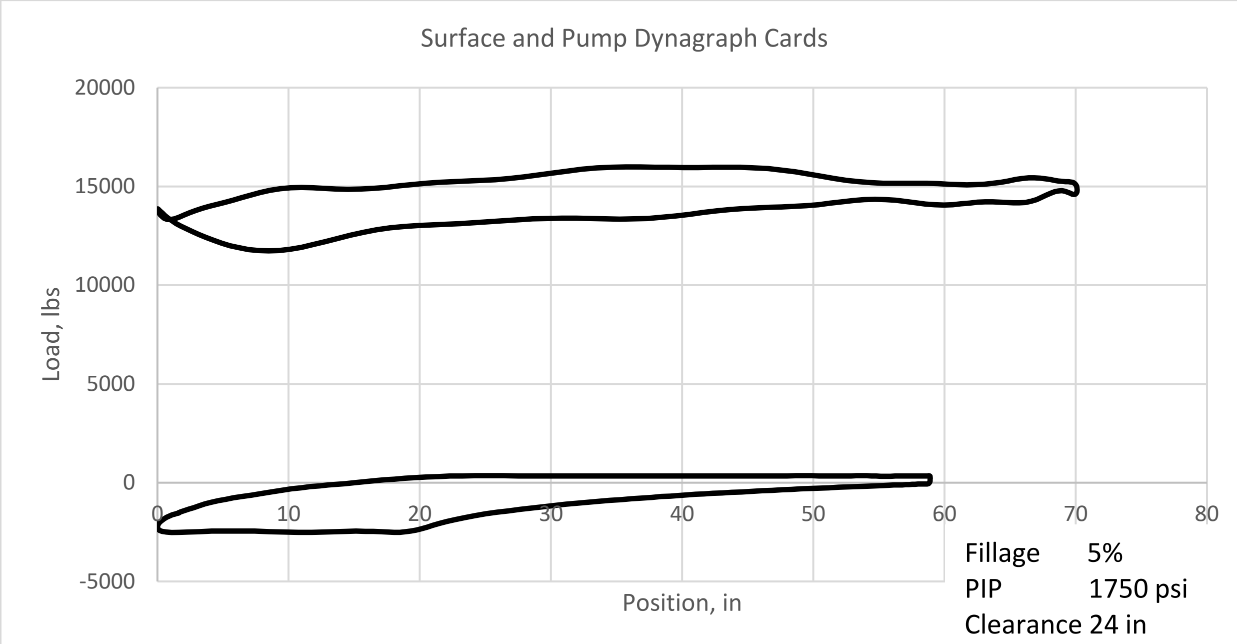

Figure 2.

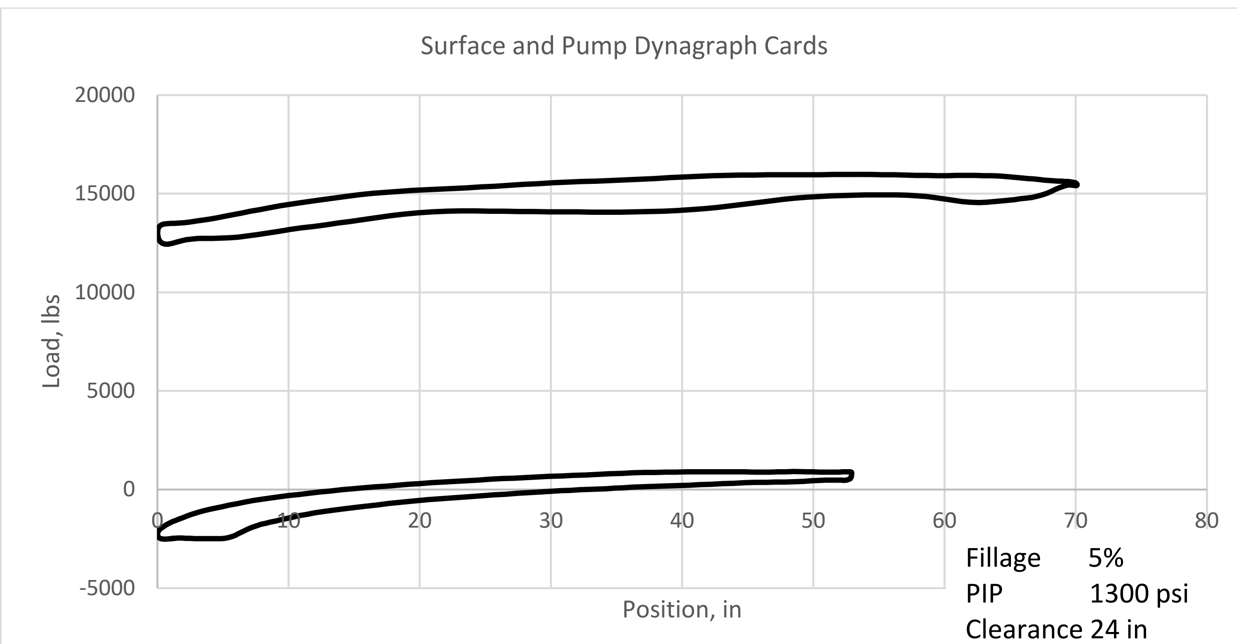

Figure 3.

However, in Figure 4, when we reduce the pump intake pressure to 850 psi, the downhole card shows no fillage! Is this the Loch Ness monster? Have we predicted a potential gas lock situation? It turns out that the fillage of 5% at 850 psi is not a sufficient volume to cause either valve to open during the stroke with the current pump conditions. It turns out that gas lock is a function of pressure, fillage, and pump design, and what is gleaned is that gas lock is more likely to occur at lower pump intake pressures rather than at higher pump intake pressures, with all other parameters remaining unchanged.

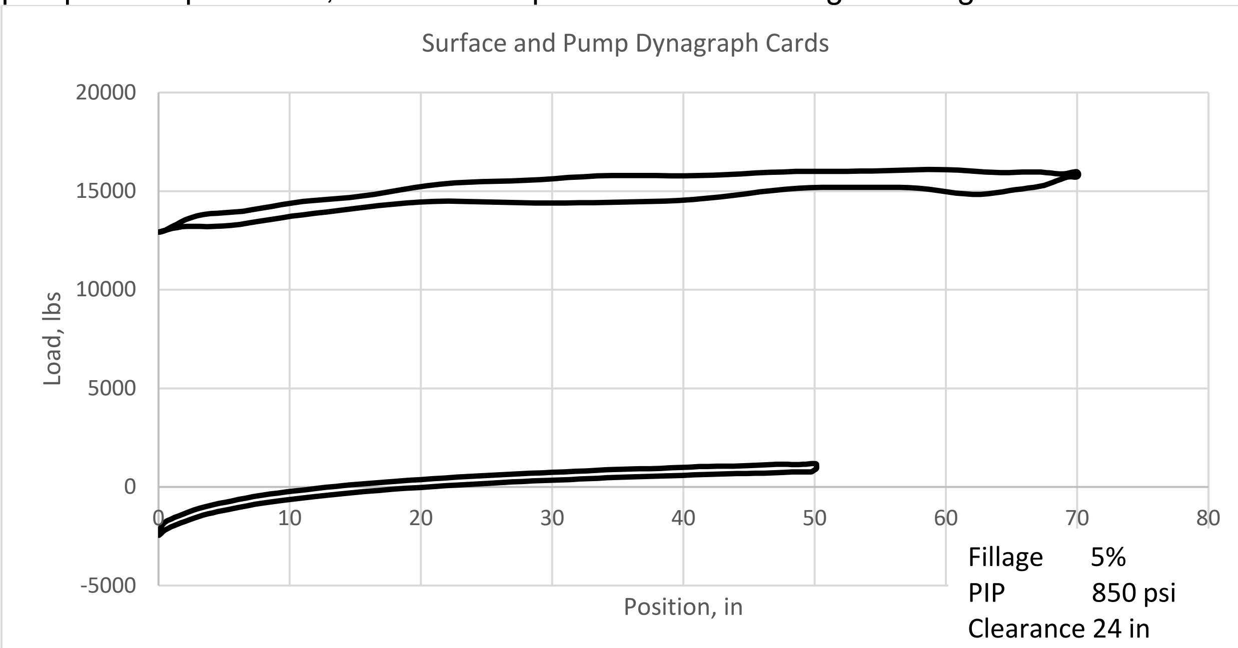

Figure 4.

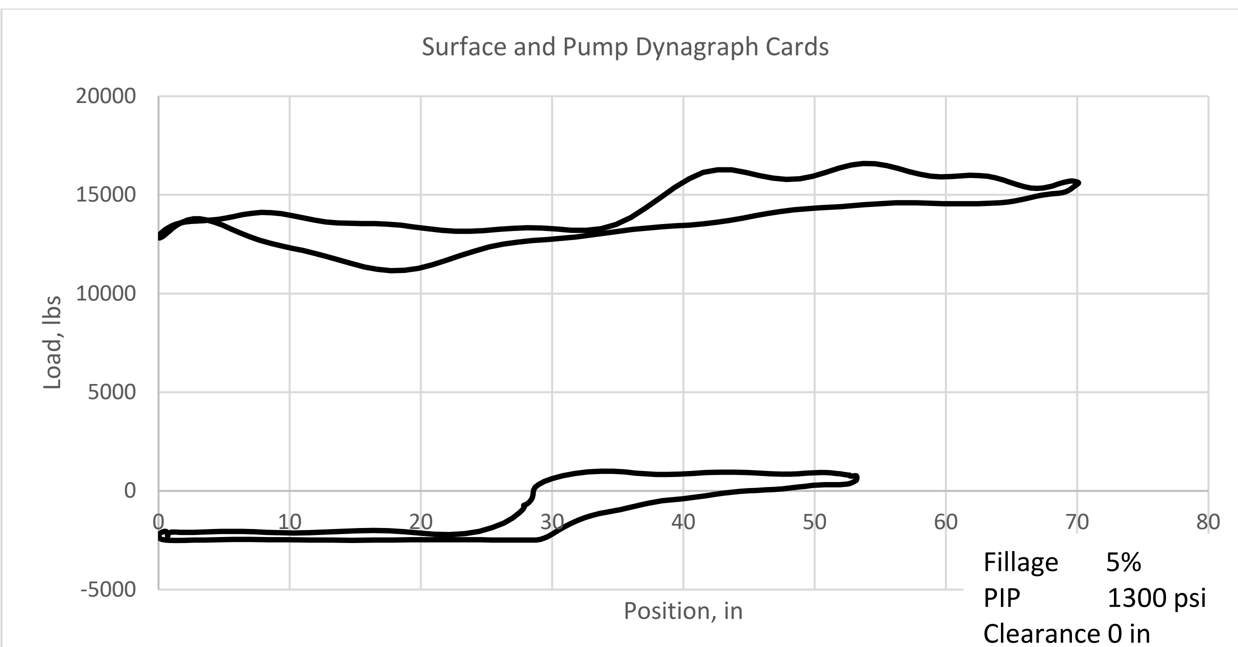

Figure 5.

An interesting fact about this predictive analysis that we are about to implement is that the author learned something (yet again!) about the behavior of rod pumping systems, this time about gas interference. This lesson for the author was made by repeated runs using the software to identify the factors involved in creating a gas lock situation. And just for fun, the author wanted to see what would happen with perfect pump clearance, 5%

fillage with 1300 psi of pump intake pressure,17 BPD of traveling valve leakage and a delay traveling valve closure. The possibilities are endless! See Figure 5.

ANALYSIS AND OPTIMIZATION

The software can be used to analyze and optimize the performance of sucker rod pump systems. For example, in order to analyze and optimize an existing system, it is necessary to have an accurate model of the existing conditions. To accomplish this task, the software program must be able to closely mimic virtually any pump condition that is observed in the field. Only once an accurate model is obtained can the operator be confident that changes made in the program will accurately predict changes in the field.

In Figures 6 and 7, we overlay the two industry predictive software packages system and the subject rod pump software packages with an existing rod pump system. It is easy to see that unless the rod pump system has only vanilla conditions occurring in the rod pump system, the ability of the industry programs to properly model the conditions in the field is nonexistent.

In this case, notice in Figures 6-8 that the field measured surface and downhole cards (black) show drag friction and traveling valve leakage, among other conditions. Figures 6 and 7 demonstrate the inability of the two industry programs (red) to properly mimic the surface and downhole cards. Thus, any changes made using these programs will not provide as accurate a representation as using the subject software program in Figure 8, which has the built-in utility to properly mimics the conditions mentioned, and many more, which results in a very close match in both the surface and downhole cards.

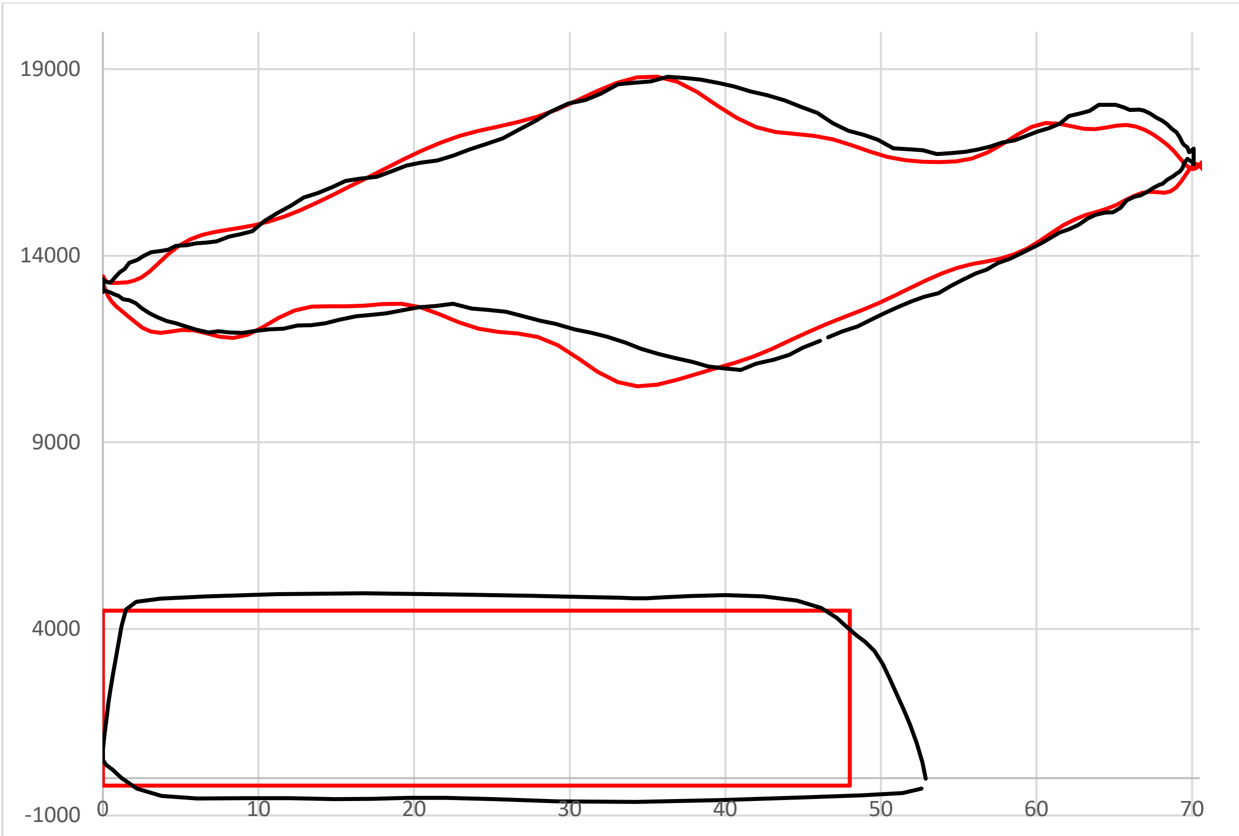

Figure 6. Industry program[5] unable to properly mimic field measured data.

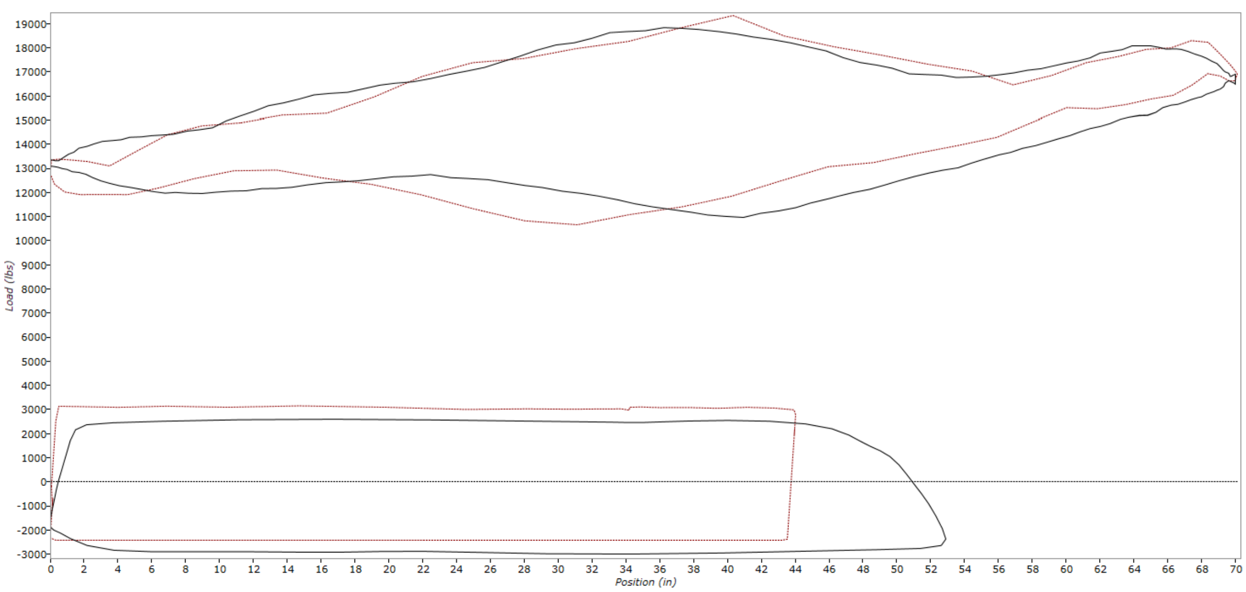

Figure 7: Industry program[4] unable to properly mimic field measured data.

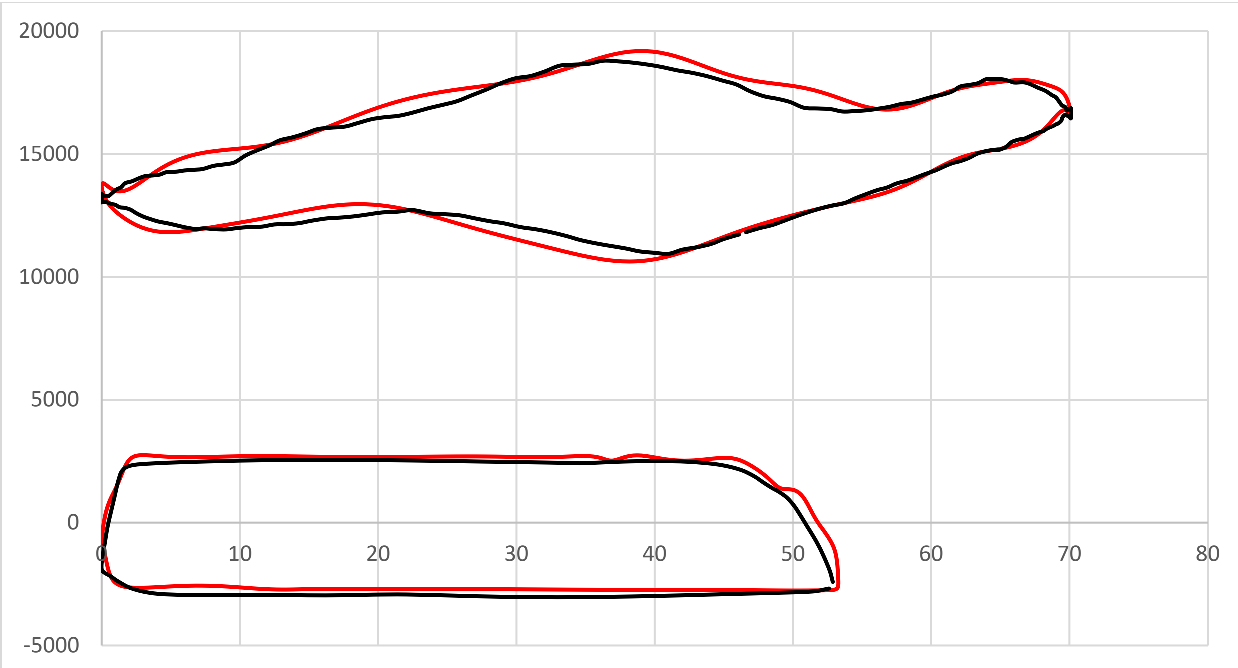

Figure 8. The software program[3] that is the subject of this paper demonstrating it functionality in properly mimic field measured data due to the multitude of surface, rod, and pump conditions that can be modeled.

<u>TRAINING</u>

We now provide explanation of how the software can be used for educating and training production personnel on the fundamentals of rod pumping and dynagraph interpretation. Dynagraph interpretation is one of the most sought after training for those working with sucker rod pumping systems. The reason for this is simple, the way a rod pump system

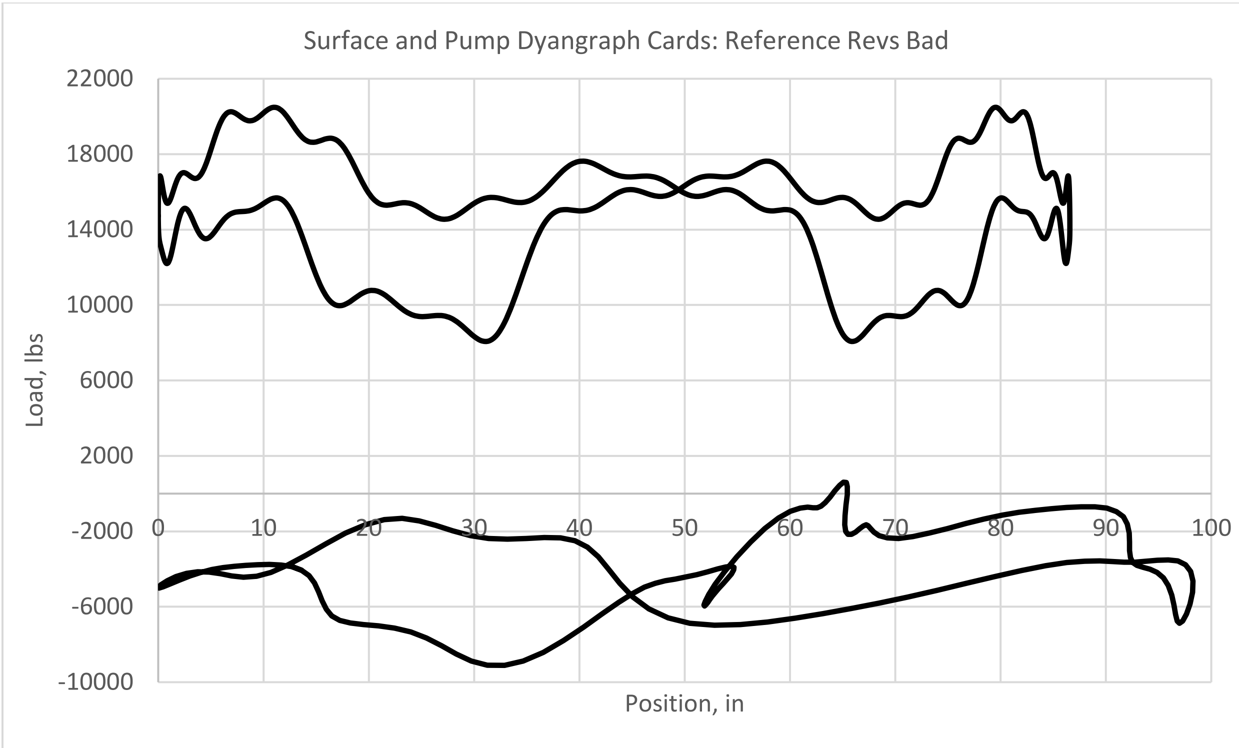

Figure 9.

communicates the condition of its components quantitatively is through accurate measurements of polished rod loads and positions and a properly computed downhole pump card. In other words, the surface and pump dynagraph cards are essential for an operator to properly analyze and troubleshoot a rod pumped well. Of course, we all know that nothing trumps being out in the field accurately gathering data from the well using a portable dynamometer![2]

We are all familiar with the twelve basic shapes of the downhole pump cards. But what the industry does not have that this software provides is a virtually limitless library of the twelve basic downhole pump cards and their associated surface cards as they relate to the specific system being studied, which includes pumping unit geometry and rotation, SPM, rod string design, pump plunger size and of course, different downhole conditions. Furthermore, combinations of the different downhole conditions can also be made to create even more examples of specific surface and downhole cards to reference for a given well. Moving this to a classroom setting has significantly improved dynagraph interpretation training for operators by creating dozens of different examples of different well conditions for a particular well design.

For example, suppose that there is a desire to understand what a split pump barrel would look like with a batman/butterfly/mirrored/symmetric surface card, which is really a reference revolutions malfunction in the rod pump controller. This can be accomplished easily by indicating that the downhole condition is a split pump barrel and the reference revolutions have doubled from the correct value. The split pump barrel with problematic

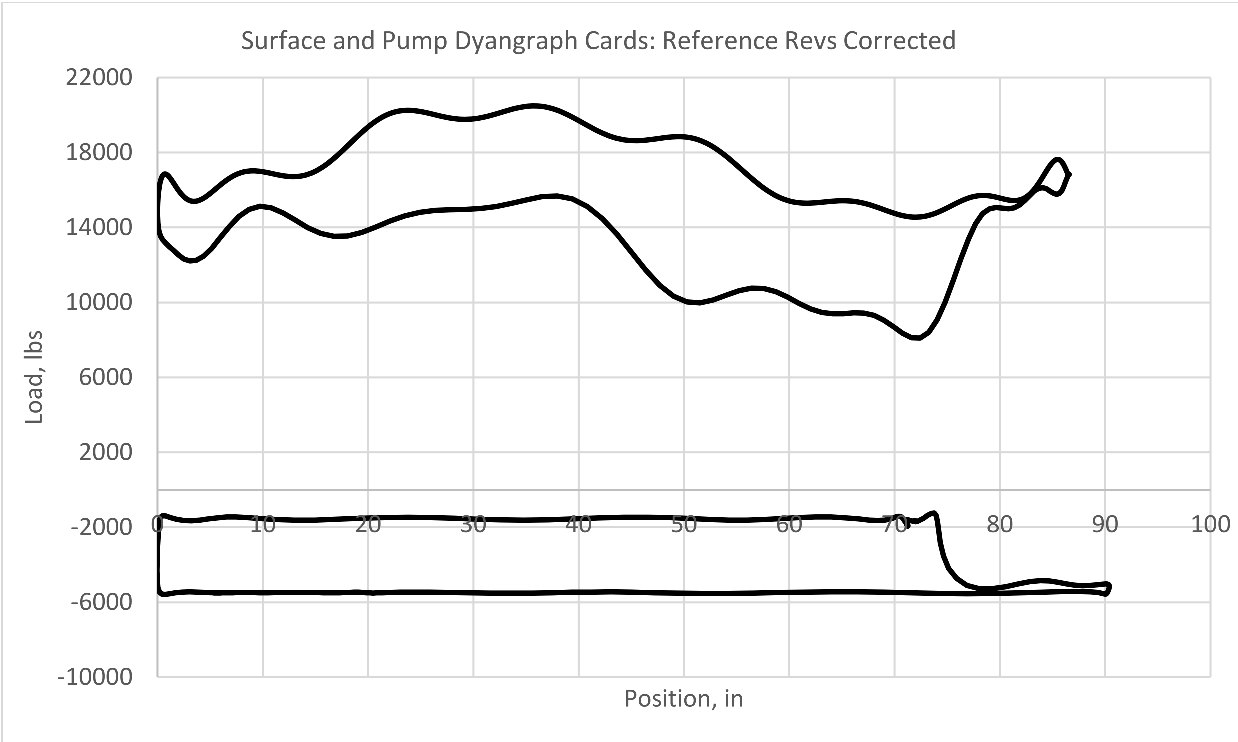

Figure 10.

reference revolutions is given in Figure 9 and the split pump barrel with corrected reference revolutions is given in Figure 10.

CASE STUDIES

The following case studies will serve as a presentation of illustrative of real-world examples demonstrating the effectiveness of the software in improving the design, analysis, optimization, and training of sucker rod pumps.

TRAVELING VALVE LEAKAGE/SLIPPAGE

For each of the following cards in Figures 11-14, the pump fillage that results from fluids entering the pump barrel through the standing valve is 60% and the leakage rates are those that are measured during a traveling valve check. It is well known that for incomplete fillage in many cases, the pump will leak more than the rate that is measured during the traveling valve check.

For concreteness, notice in Figure 11, which shows no leakage, the net stroke, which is the length of the plunger stroke where the traveling valve is open, is approximately 39” long versus the gross stroke, which is the entire length of the plunger stroke, is approximately 65”, and 39”/65” = 60%.

Figure 12 shows that with 40 BPD of leakage, the gross pump stroke decreased to 57”, but the net stroke increased to 48”, which is 84% fillage. But since the software was programmed to fill the pump with 60% fillage, the additional 24% fillage comes from the leakage past the traveling valve ball and seat and/or the slippage around the plunger.

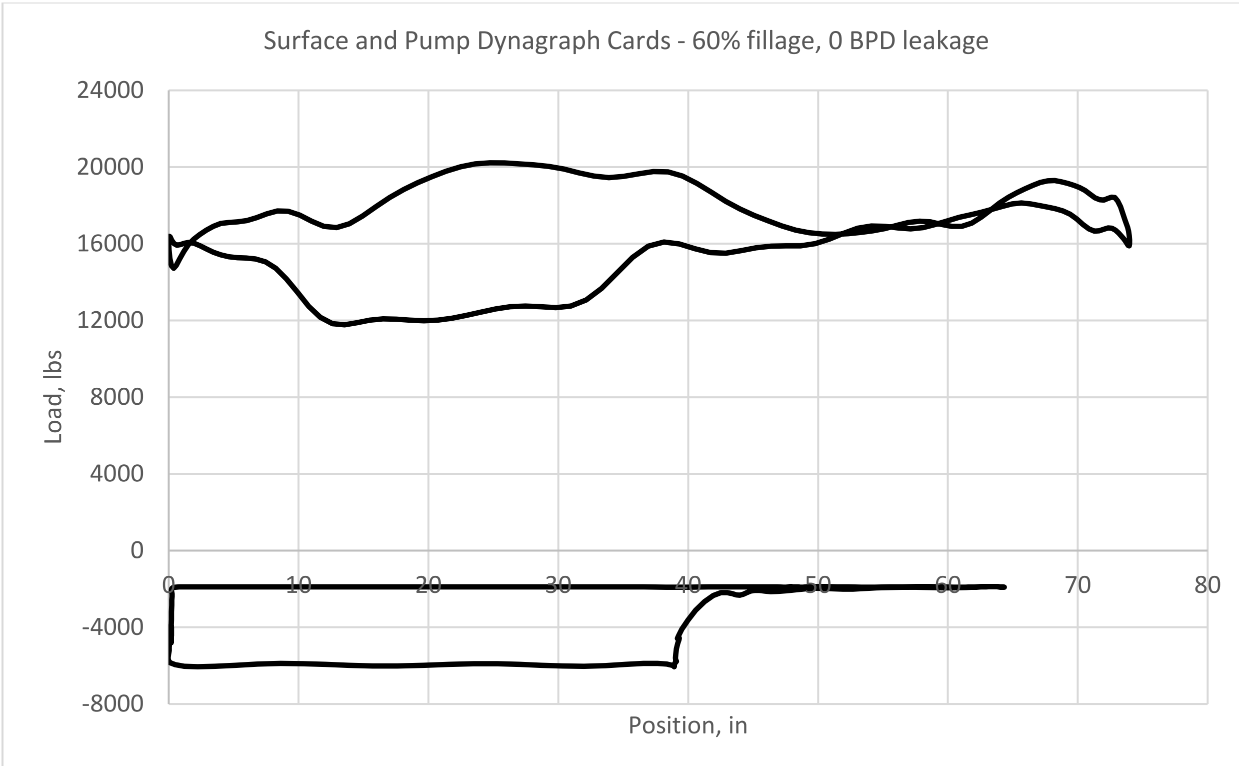

Figure 11: Pump card showing 39/65=60% pump fillage, no traveling valve leakage.[1]

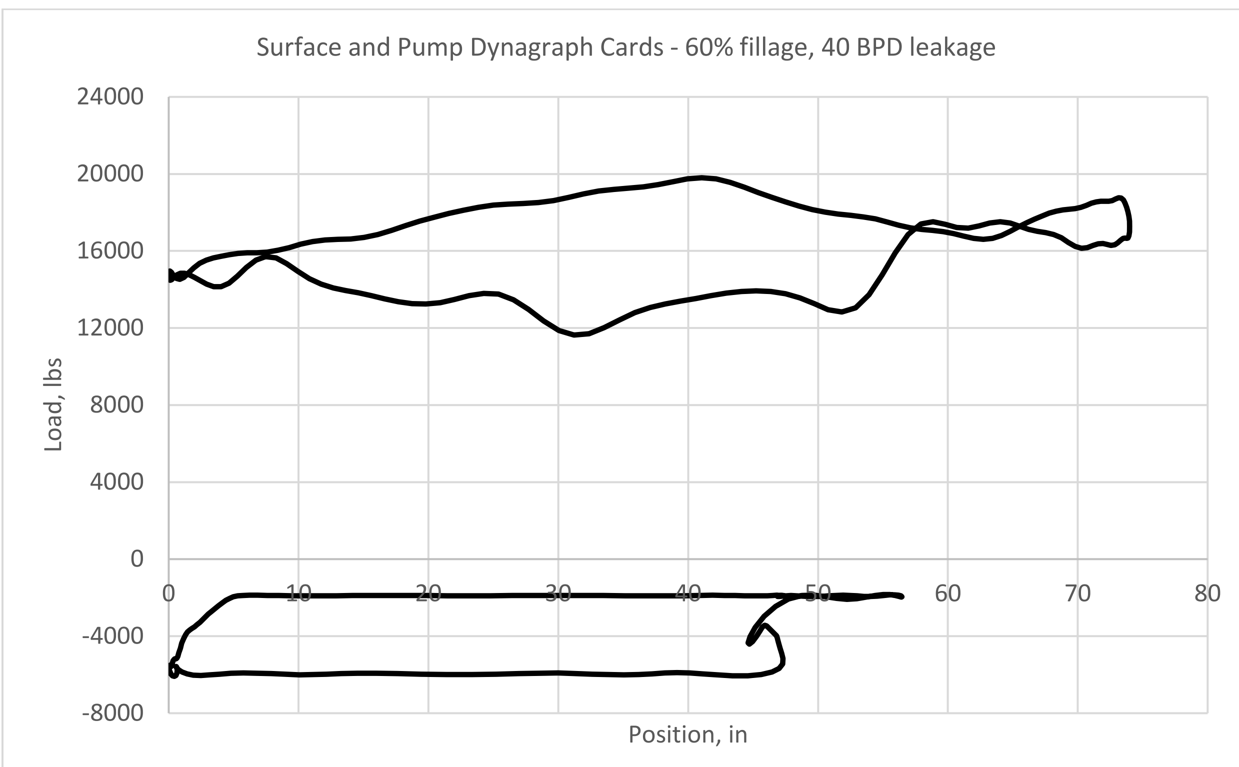

Figure 12: Pump card showing 48/57=84% perceived pump fillage.[1]

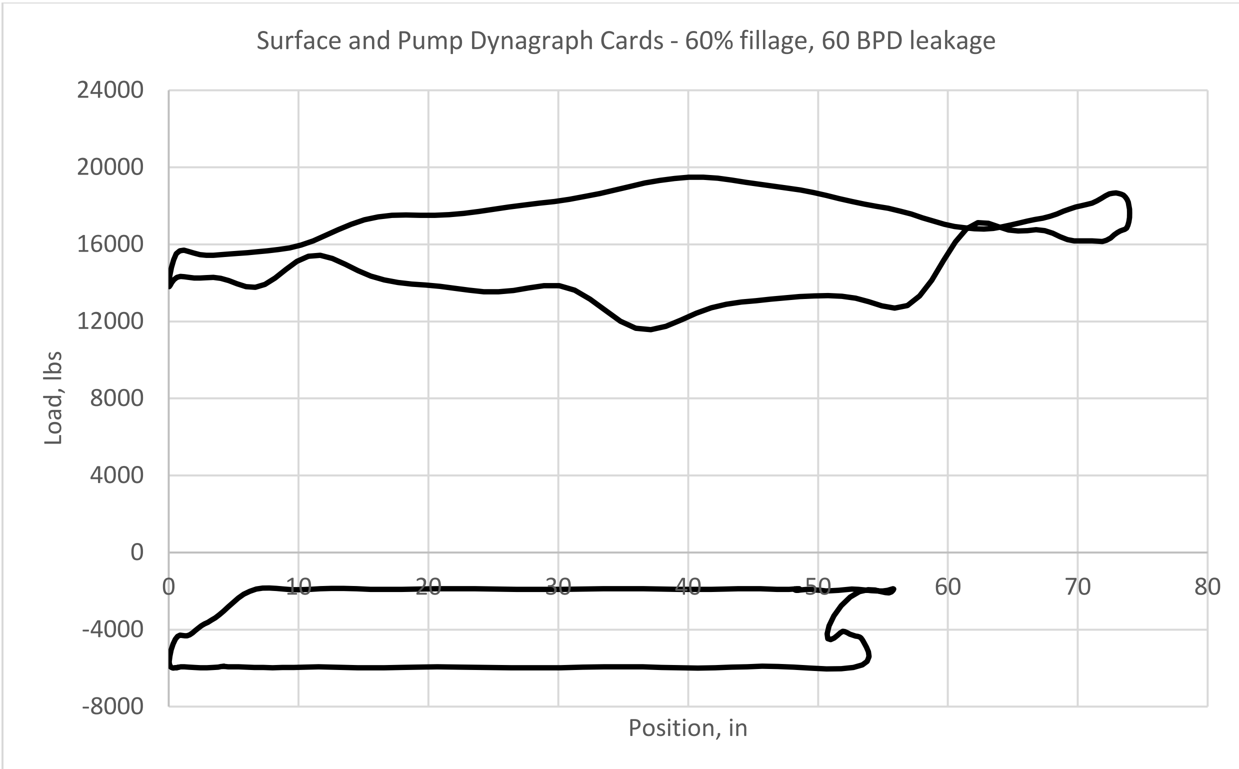

Figure 13: Pump card showing 54/56=96% perceived pump fillage. [1]

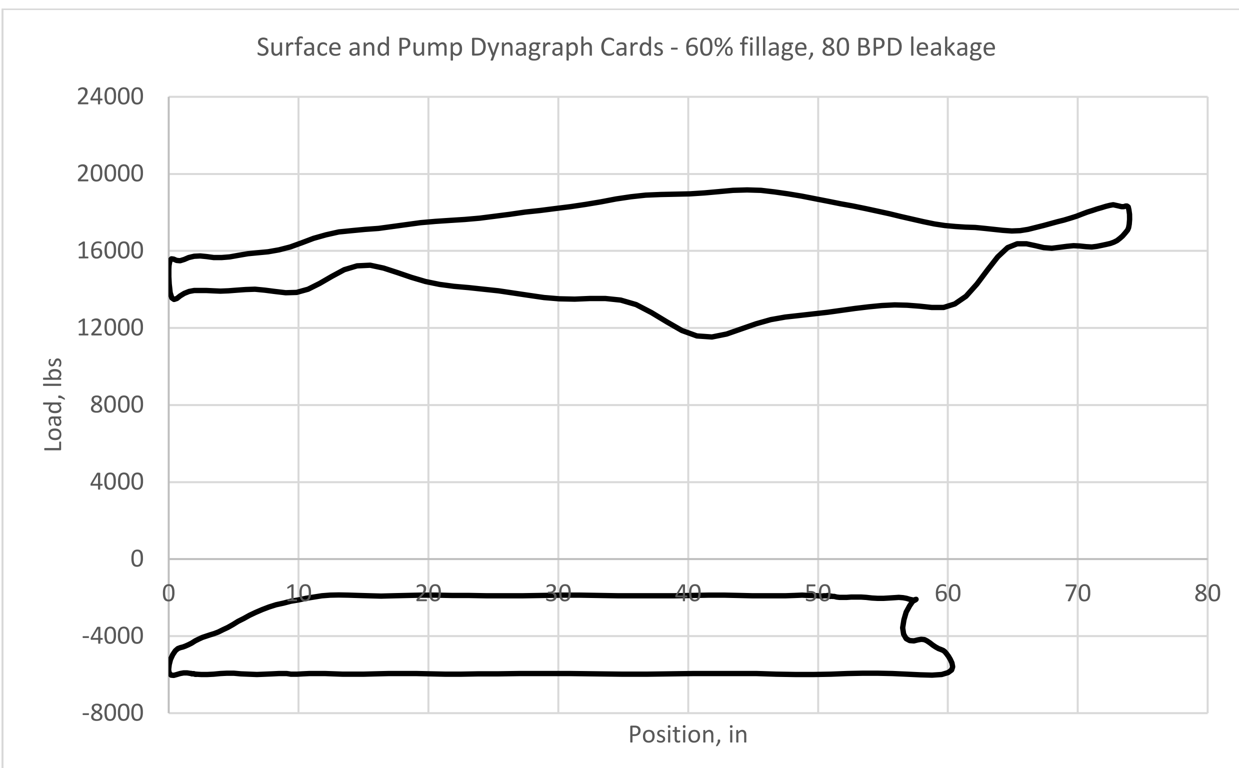

Figure 14: Pump card showing 60/60=100% perceived pump fillage. [1]

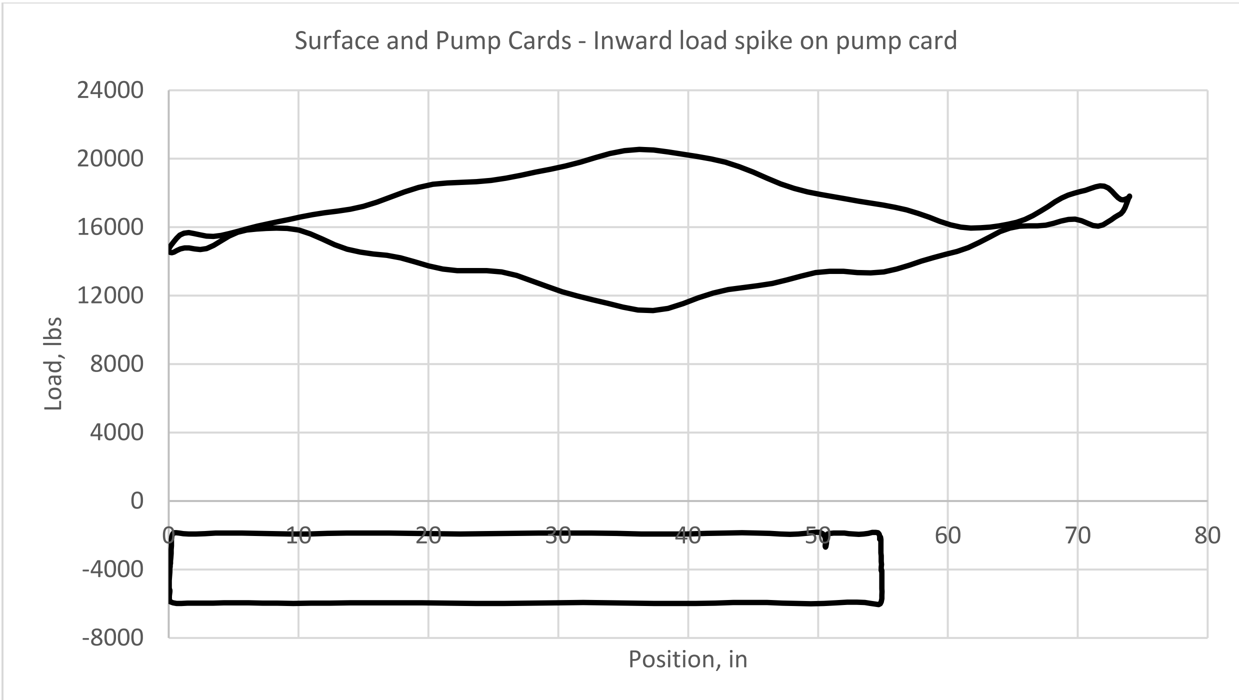

Figure 15. [1]

Similarly, Figure 13 shows that with 60 BPD of leakage, the gross pump stroke decreased to 56”, but the net stroke increased to 54”, which is 96% fillage. Given that the software was programmed to fill the pump with 60% fillage, the additional 36% fillage comes from the leakage past the traveling valve ball and seat and/or the slippage around the plunger.

Finally, Figure 14 shows that with 80 BPD of leakage, the gross pump stroke is 60”, but the net stroke increased to 60”, which is 100% fillage. Recall that the software was programmed to fill the pump with 60% fillage, so the additional 40% fillage comes from the leakage past the traveling valve ball and seat and/or the slippage around the plunger. In this case, the pump has leaked itself full.

<u>INWARD LOAD SPIKES AND HORNS ON PUMP CARDS WITH TRAVELING VALVE LEAKAGE</u>

Inward load spikes, as shown in Figure 15 on the top right hand side of the pump card, are not an uncommon occurrence. These inward load spikes do not cause damage to the rods or downhole equipment. They show up at the pump from waves that travel along the rod string during the stroke. They can sometimes occur during the load transfers from the standing valve to the traveling valve or vice versa, which occur on the left hand side of the pump card and the right hand side of the pump card, respectively. Typically, it is difficult to see these load spikes/changes because without any pump leakage, the load and positions of the card trace over themselves. Thus, the only evidence is a thicker part of the left or right side of the downhole pump card trace.

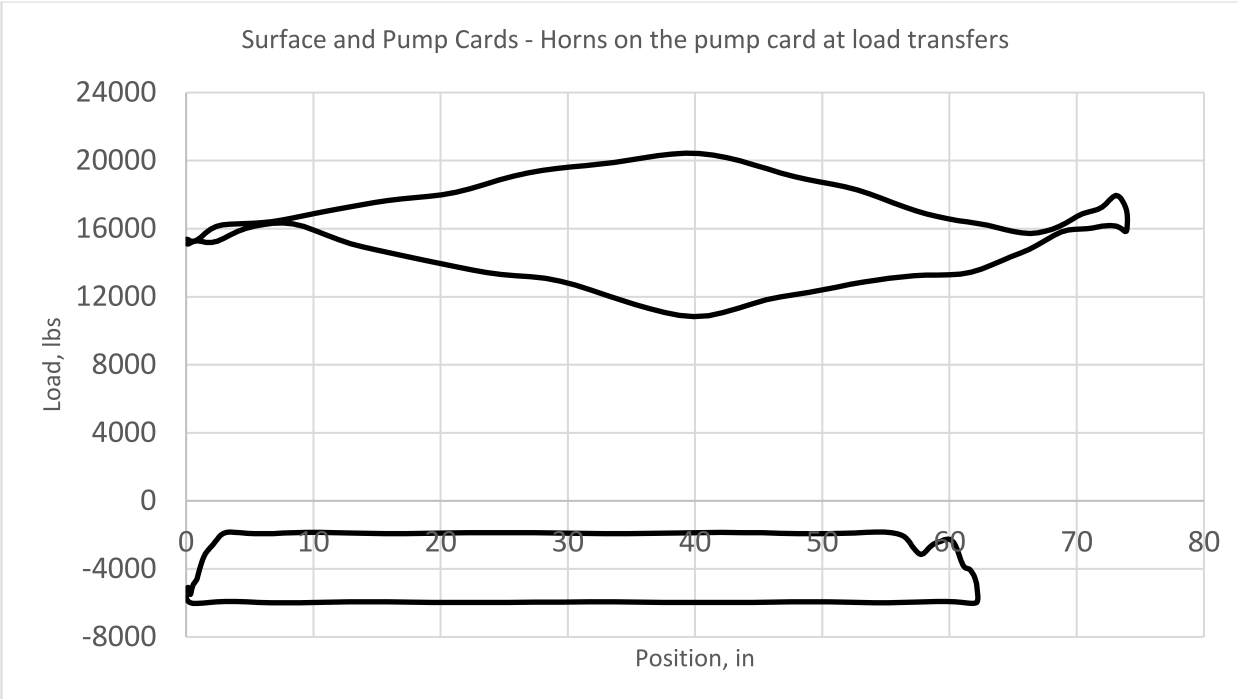

Figure 16.[1]

These inward load spikes become more pronounced and take the appearance of horns when there is leakage at the pump. In Figure 16, we have the same well as in Figure 15, but now with 27 BPD of traveling valve leakage/slippage as measured by a valve check.

UNDERSTANDING PUMP LEAKAGE AS A FUNCTION OF PUMPING SPEED

To begin this section, we ask the reader to inspect the four pump cards in Figures 17-20 and determine which pump is leaking the most. Visual inspection would easily point to the pump card in Figure 17, but would we be correct? In Figure 17, the pump displacement is 21.3 BPD, the leakage rate is 19.3 BPD, and so the pump is producing 2 BPD to the surface, without considering oil shrinkage from gas liberation. Progressing through the remaining pump cards in Figures 18-20, the respective leakage rates are 22.1, 22.6, and 22.7 BPD, respectively, while the corresponding pump displacements are 39.5 BPD, 79.9 BPD, and 158.2 BPD, respectively. How is this possible? See Table 1.

Table 1.

FIGURE	PUMPING SPEED, SPM	PUMP CAPACITY, BPD	PUMP LEAKAGE, BPD
17	2	21.3	19.3
18	4	39.5	22.1
19	8	79.9	22.6
20	12	158.2	22.7

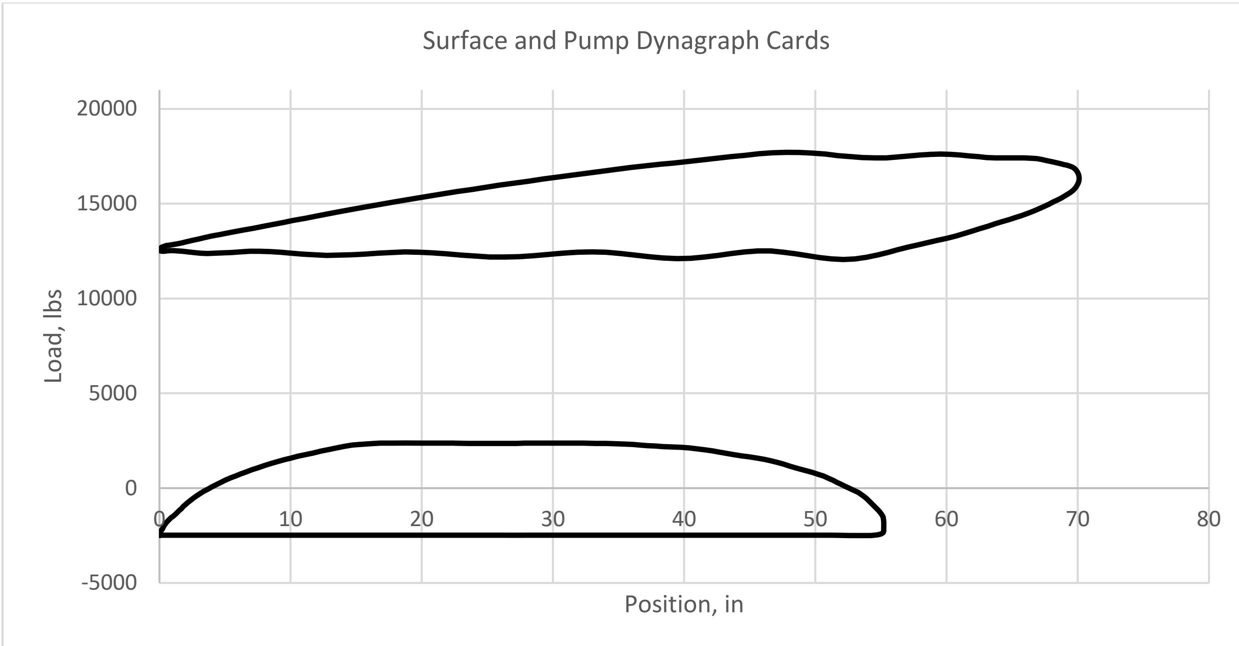

Figure 17. Pumping speed=2 SPM, pump capacity=21.3 BPD, and leakage=19.3 BPD.

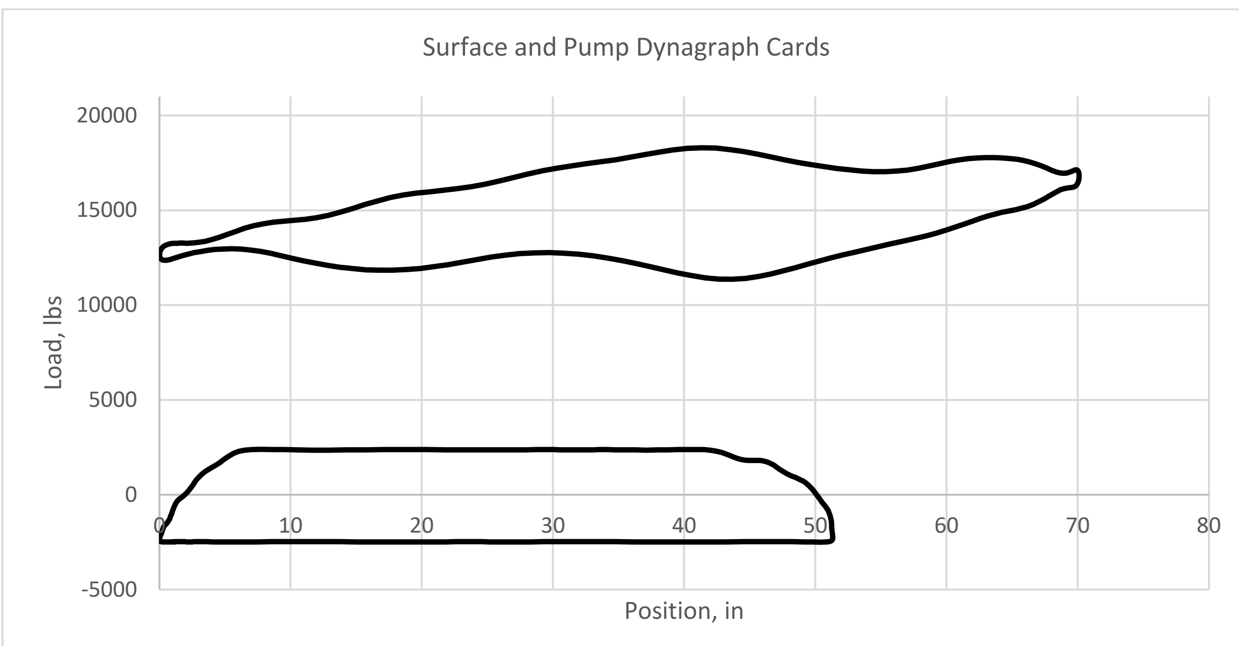

Figure 18. Pumping speed=4 SPM, pump capacity=39.5 BPD, and leakage=22.1 BPD.

In each of the Figures 17-20, the rod pump system is the same, with each pump programmed to have 25 BPD of leakage measured by a traveling valve check. The slower the pump is moving, the worse the leakage rate appears to be. However, if one is being highly meticulous, then technically, the slower pumping rate yields slightly less leakage since the maximum pressure difference across the traveling valve is present for a shorter time during the upstroke of the pump. However, for application purposes, the leakage rates for realistic pumping speeds (between 4 to 12 SPM in this case) are relatively

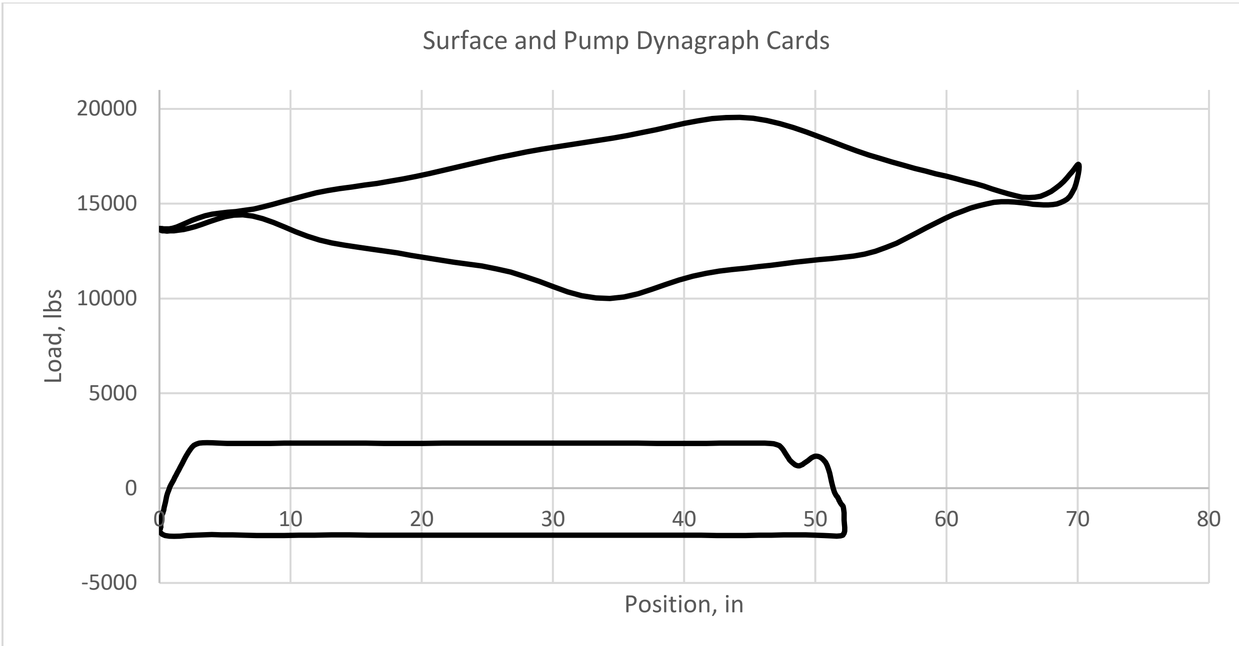

Figure 19. Pumping speed=8 SPM, pump capacity=79.9 BPD, and leakage=22.6 BPD.

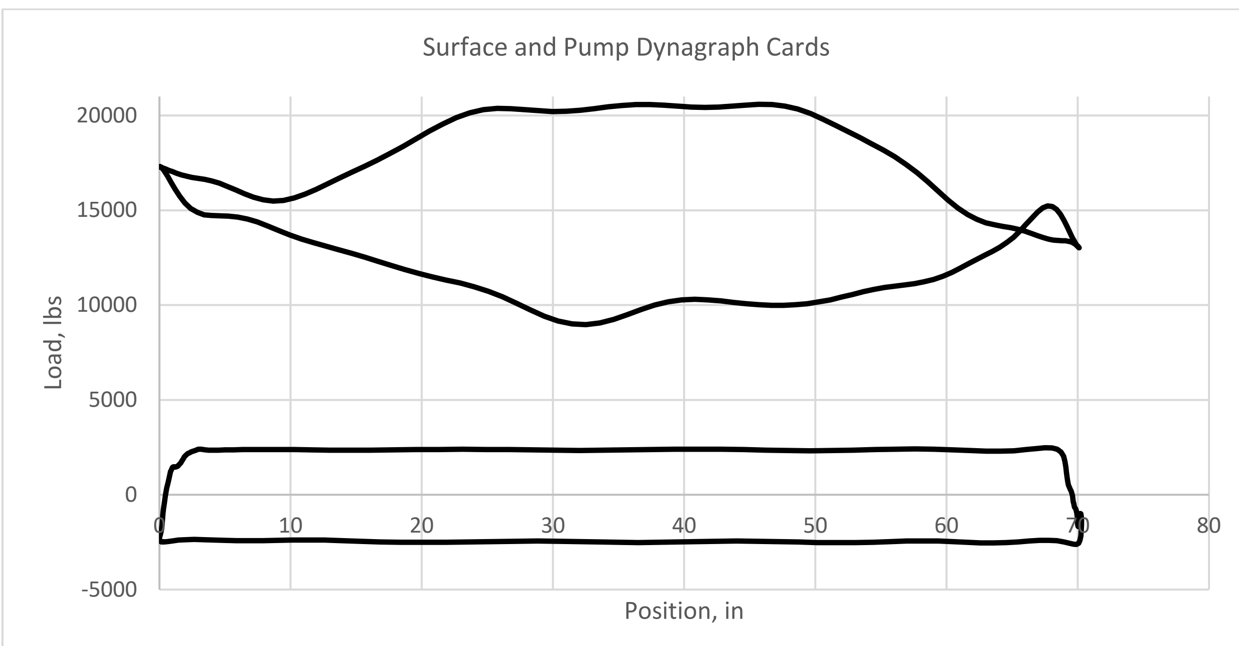

Figure 20. Pumping speed=12 SPM, pump capacity=158.2 BPD, and leakage=22.7 BPD.

constant. Thus, the answer to the age old question of “does leakage rate depend on pumping speed” is “yes, but not really by a substantial enough amount to matter.”

This is the reason that speeding up a pump with a high leakage rate can put off a workover for a little while, since the increase in speed increases the pump’s capacity, while keeping the leakage rate relatively constant.

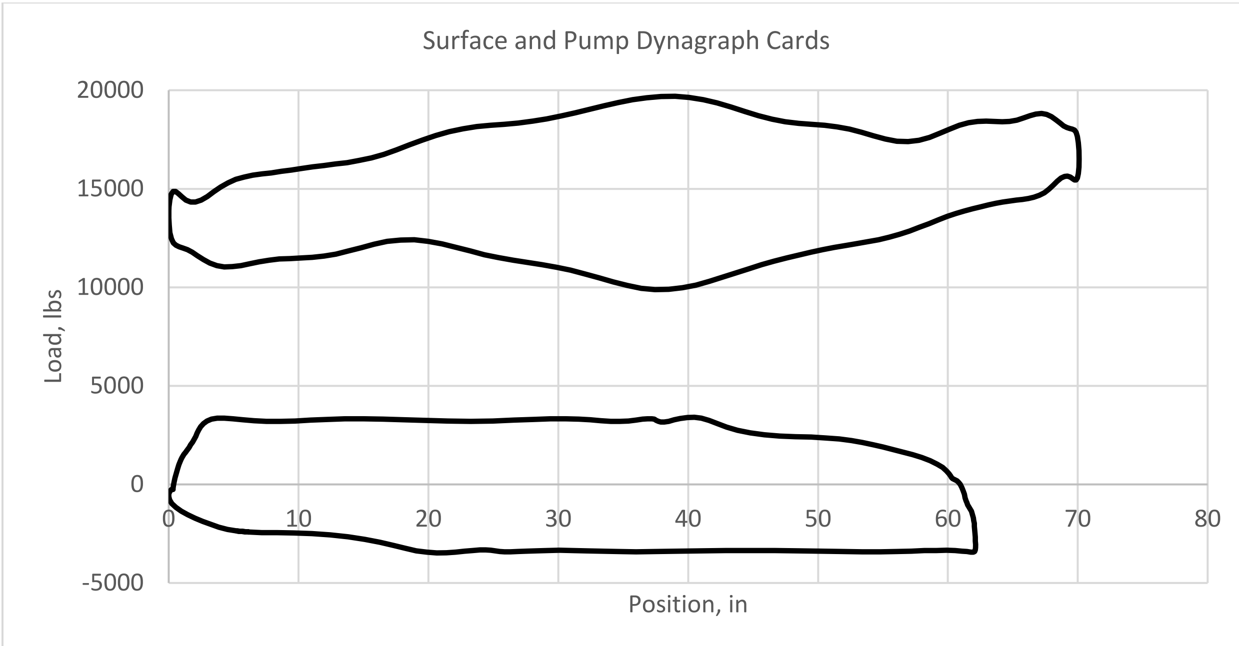

Figure 21.

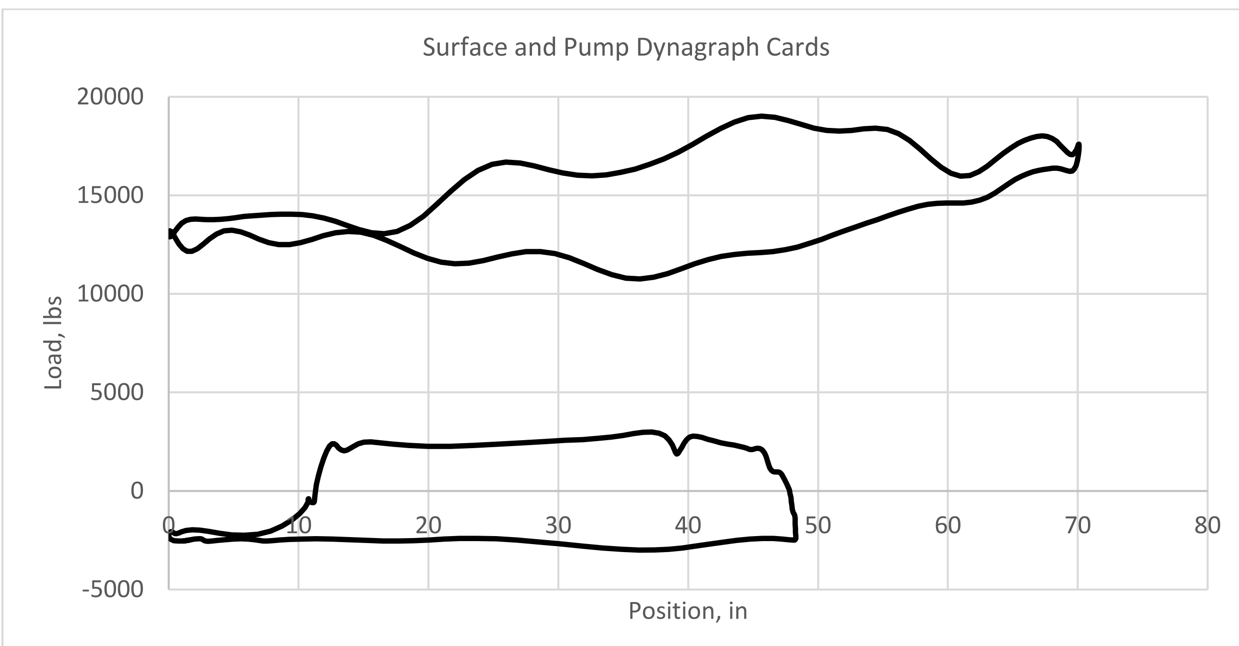

Figure 22.

INTRIGUING EXAMPLES

Suppose we wanted to see combinations of conditions that can occur at the surface and/or the downhole pump to build our knowledge. One of the most common cards that is observed is stuffing box friction. Since this friction occurs at the very top of the rod string at the polished rod, it will cause the most severe leftward lean on the pump card, as well as both a stroke length and a fluid load that are longer than and higher than the truth. See Figure 21 which shows the rod pump system with full liquid fillage, 17 BPD traveling valve leakage and 1000 lbs of stuffing box friction.

In Figure 22 we demonstrate the ability of the software to combine multiple pump conditions, none of which can be modeled by any of the industry programs. In this example, we simulate a delayed traveling valve closure that occurs early into the upstroke, combined with 37 BPD traveling valve leakage, and a bent pump barrel/sticking pump in the upper portion of the pump stroke, where this last condition manifests itself on both the upstroke and the downstroke, causing the loads to be 500 lbs heavier and 500 lbs lighter, respectively.

CONCLUSIONS

There is a serious need for a state of the art software program that can model the variety of conditions that a sucker rod pump system can experience. While the existing industry programs provide good estimates for ordinary examples, when real word modeling is required, neither of the two main software programs that are available can deliver anything close to a sufficient model.

The state of the art software that has been introduced in this paper quickly eclipses the capabilities of both leading programs. This new software can provide unprecedented accuracy with respect to prediction and design of rod pump systems with a multitude of different conditions at the surface, along the rod string, and at the pump.

The new program offers new ways to analyze and optimize the performance of sucker rod pump systems. This was demonstrated by showing that only the new software can properly mimic real world data. Without the two current industry software programs' abilities to properly mimic data from the field, any further changes to the parameters in the program will not yield results that can properly optimize the existing system.

When it comes to training production personnel on the basic functionality of the rod pump system, as well as providing sensitivity analyses and other deep dives into the nuances of rod pumps, only this state of the art program can accomplish this task. Many different surface and downhole pump conditions were discussed in this paper, and still even more conditions exist that the program can properly execute to help the user in understanding the different pump conditions and other operational interdependencies of the rod pump system.

The case studies presented in this paper barely scratch the surface on the utility of the new software. These studies discussed the changes in the rod pump system as leakage rates increased with an incompletely filling pump and the nuances of inward load spikes and how they translate to looking like horns on the pump card. Others considered how pump leakage and the shape of the pump card is related to pump leakage. Some concluding instances were given to show the ability of the program to model combined occurrences of stuffing box friction with leakage in one case and a delayed traveling valve closure with both traveling valve leakage and a bent pump barrel/sticking pump.

The application and value of this new state of the art software program is unlimited, not only to the topics discussed in this paper, but also to the emerging field of machine learning and artificial intelligence.

REFERENCES

1. J.J. DaCunha, *Decoding 7 mysteries of downhole pump cards*, Brex, LLC, Austin, 2021.
2. J.J. DaCunha, Fundamentals of rod pumping with dynagraph interpretation and designing rod pump systems [Online Course], Brex, LLC, https://jeff-dacunha.teachable.com. Accessed 2023.
3. J.J. DaCunha, “Brex software,” Brex, LLC, 2023.
4. Lufkin Automation. “SROD,” *Lufkin Automation*, version 8.8.0, 2022.
5. Theta. “RODSTAR,” *ChampionX*, version 4.21.1, 2022.