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Optimization of Single Trip Milling Using 2-Inch Coiled Tubing

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Abstract

Conventionally, the same best practices from coiled tubing cleanout interventions in vertical wells have been applied to horizontal wells; pumping a high volume of viscous gel sweeps and performing a number of wiper trips in an effort to remove debris from the wellbore. Very often this practice leaves a significant amount of solids behind as a result of inadequate fluid rheology, increasing not only the risks of the operation but the overall completion cost of the well, while falling short from accomplishing the main objective of the Coiled Tubing (CT) intervention.

With the added pressure of reduced oil prices, operators are looking for ways to increase efficiency and reduce cost. Larger diameter CT has recently been used to perform millouts due to its improved set-down force and increased annular velocities for cleanout purposes. Service companies and operators have reduced the amount of wiper trips when using larger diameter coil to save time and money. Milling efficiency using 2 inch CT can be drastically improved by maintaining proper fluid rheology throughout the operation. By doing so, 2 inch CT has been used to successfully perform single trip millouts reducing operational time by 40%.

This paper will provide an analysis of the theoretical process and time comparison of multiple verse single trip millouts using 2 inch CT. The fluid rheology required to adequately clean out horizontal wells relies on the effective utilization of chemicals and correct fluid control throughout a given operation.

Introduction

As the price of oil continues to decline operators in the DJ Basin of Northern Colorado, USA and Williston Basin of Northwestern North Dakota, USA push to reduce cost and operational time while increasing efficiency of coiled tubing milling operations. The majority of wells in both locations are cased with 7 inch down to a 4.5 inch horizontal liner and some have a 4.5 inch fracturing string to surface. The conventional method of multiple wiper trips and gel sweeps using 2 inch CT has been the go to method since horizontal millouts began. This method was not sufficiently cleaning the wellbore and in turn leaving the millout incomplete. To solve this problem, operators required larger CT for its improved set down force.

While the operators required larger CT the majority of service companies only had 2 inch CT for the wells still scheduled. In order to reduce cost and time for the operators the service company implemented optimized fluid rheology to perform single trip millout operations using 2 inch CT. The optimized system reduced chemical consumption and total operational time by decreasing, and in some cases, eliminating wiper trips. A rheology control unit was incorporated into the water system to control and maintain the optimized fluid rheology.

Eighteen wells were completed using optimized single trip milling. Six of the wells were done in a single trip and reduced operational time on average by 40%. The majority of wells completed were in the DJ Basin with measured depths (MD) ranging from 9,000 feet to 16,000 feet and total vertical depth (TVD) of 6,000 feet, while the Williston Basin wells averaged MD of 20,500 feet with TVD of 10,500 feet. The chemical injection system along with real time monitoring optimized chemical utilization enabling adequate Reynolds numbers and fluid rheology for each operation. To confirm the superior cleaning capabilities of the optimized single trip millouts the operators performed venturi basket runs after two of the completed wells. The baskets came back virtually empty.

Fluids

The main objective of CT operations in horizontal wells is to completely clean the lateral of any debris without compromising the well's integrity. The first and most important component of single trip millout operations is correct fluid rheology. This system is comprised of the annular velocity (AV), Reynolds number (RE), and fluid viscosity. With correct utilization of chemicals and proper AVs the fluid system allows sand and debris to travel out of the wellbore.

The RE determines the flow regime as laminar, transitional, or turbulent. Turbulent flow is characterized by the swirling of the water called eddies which agitate the settling bed enabling sand and debris to flow out of the lateral and in turn out of the well. RE can be broken into three components: fluid velocity, hydraulic diameter (flow area between casing and coil), and kinematic viscosity (funnel viscosity). In this case the hydraulic diameter is predetermined by 2 inch CT working in 7 inch to 4.5 inch cased wells leaving the velocity and viscosity dependent on each operation.

Field tests and Paper URTeC 2155463 found to adequately move debris and sand the RE must stay above 20,000 by having AVs above 175 feet per minute (fpm) in the horizontal and viscosities less than 4 centipoise (cP). It was also found that as the RE increases so does the transport efficiency for larger solid debris. In 4.5 inch casing with 2 inch CT the minimum return rate required was 2 barrels per minute (bpm) or 170 fpm, since pump rates averaged 2.5 bpm or higher for each job this did not prove to be a problem. The ideal flowback set up includes 3 inch return iron, two junk/plug catchers for redundancy, and a separator with the capacity necessary for the return rate. During operations flowback would confirm the return rate every 30 minutes and clean the junk/plug catcher every two hours after the first sleeve was milled. One tool used to attain additional insight on the amount of solids returned was an acoustic monitor installed on the flowback return line. The acoustic monitor ″hears″ the debris in the return line and outputs a signal value from 0 to 2,000,000. The manufacturer has determined that the monitor hears fresh water at a signal of 1800 giving a baseline to start with. In order to quantify the amount of debris being returned, a sample was taken at flowback and correlated to the acoustic monitor's output signal. The higher the signal read the more debris passing by.

When pumping any treatment fluid through CT a fluid n reducermust be continuously pumped to reduce frictssure generated from pumping fluid through a restricted area. The FR decreases the circulating pressure enabling higher pump rates to be achieved. A rheology control unit uses electric variable frequency drive pumps for high precision to add FR and other chemicals to the fluid and the ability to change dosage on the fly. These pumps are accurate down to the thousandths of a gallon enabling higher chemical utilization in smaller doses. The chemicals are direct injected into the flow then inline mixers enable shearing of the chemical to attain consistent mixing. Direct injection and inline mixers eliminate the unnecessary waste and over saturation of chemicals seen when using conventional mixing tubs. This optimized fluid increases the longevity of the recirculated water while maintaining a high RE, in turn decreasing the cost to the operator. Fresh water has a Marsh funnel time of 26 seconds. The effective viscosity (μ_{eff}) is then found using the following equation:

$$\mu_{eff} = \rho(t - 25) \tag{1}$$

Where:

μ_{eff}	= Effective viscosity (cp)
ρ	= Density (g/cm^3)
t	= Marsh funnel time (sec)

Fresh water has a funnel time of 26 seconds and effective viscosity of 1 cp and is the lowest possible viscosity of any treatment fluid. Samples of the fluids were taken every 3 hours to check the density, acidity, chlorides, and hardness before additional chemicals were injected to help the optimization of chemicals. Samples of the fluid, after chemical injection, were also taken once an hour to ensure the Marsh funnel time stayed close to 26 seconds or an effective viscosity as close to 1 cp as possible. When the viscosity increased greater than 4 cp the RE would drop below 20,000 hindering the fluid rheology. Fresh water was added to the system or chemical rates decreased to keep the correct RE depending on each operation.

Another common practice of conventional millouts was to send multiple linear gallant (gel) sweeps throughout the lateral. The objective was to increase the viscosity of the fluid to lift sand and debris out of the well. It has been realized that the more viscosious gel sweeps lead to laminar flow which is not conducive to moving sand and debris in the lateral. The laminar fluid flows over debris enabling it to settle and stay in the lateral section of the well. Gel sweeps have viscosities of 20 cp or greater compromising the RE down below 20,000. Since the viscosity is high and RE too low to transport sand and debris, gel sweeps were limited during optimized single trip millouts.

Operations

The optimization process was first applied in the field on a three well pad in the DJ Basin by progressively reducing the number of wiper trips from well to well, and performing a single trip millout on the final well. The wells were completed with 7 inch casing landed at 5,800 feet, a 4.5 inch liner at TD of 9,600 feet and TVD of 5,580 feet. A 2 inch CT string was utilized to remove 17 sleeves performing 2 wiper trips in the first well and one wiper trip in the second well while implementing the optimized downhole fluid rheology. A venturi basket run was performed on the second well to assess the effectiveness of the technique, confirming the superior cleaning capabilities of the system. Figure 1 shows the amount of debris in the venturi basket.

Figure 1—Debris from Venturi Run

The process was also performed in the Williston Basin using 2 inch CT on one well with a 4.5 inch fracturing string to surface, a TVD of 10,783 feet and TD of 20,580 feet. The 29 plugs were milled using two wiper trips and optimized downhole fluid rheology.

The DJ Basin lent the remaining wells, eight wells completed with 7 inch casing landed at 5,900 feet then a 4.5 inch liner with average TD of 11,000 feet including 20 sleeves, and six wells landed with a 4.5 inch fracturing string with average TD between 13,000 feet and 16,000 feet, including 30 to 40 sleeves. Six of the eighteen wells were optimized single trip millouts. One component out of the control of the optimized system was the choice of bottom hole assembly (BHA), that was decided on by the operators. The length of the lateral determined what went into the BHA so in the following comparisons the milling time and BHA tripping time were not controlled by the system.

Results

Single Trip Wells

Table 1 compares the average time spent on conventional millouts compared to optimized single trip millouts of the same depth and sleeve number. It can be seen that single trips saved 47% more time. The table also compares the average chemical usage. The optimized chemical injection system reduced FR usage by 94% and the correct fluid rheology reduced gel usage by 96%.

Table 1—Single Trip vs. Conventional Millouts

	Conventional	Single Trip	Percent Saved
Time (hrs)	23.6	12.5	**47%**
FR (gals)	248.5	15.5	**94%**
Gel (gals)	112	5	**96%**

Six wells ranging from 9,600 feet to 13,300 feet were completed in a single trip. Low viscosity and sufficient AV allowed high RE and superior cleaning of each wellbore. Figure 2 is a breakdown of operational time of the single wells into run in-hole (RIH)/ and pull out of hole (POOH) time, mill time, travel between sleeves time and in one case BHA tripping time. It can be seen that the RIH/POOH times on each well are within 2 hours despite the different MDs. The milling time of the six wells averaged at 3.5 hours for 17 to 30 sleeves. Well 5 spent more time traveling between plugs because it had a longer lateral than the other ones. Well 6 was the only well that included a trip for a new BHA. The BHA failed on sleeve one so the rest of the well was completed with the optimized single trip.

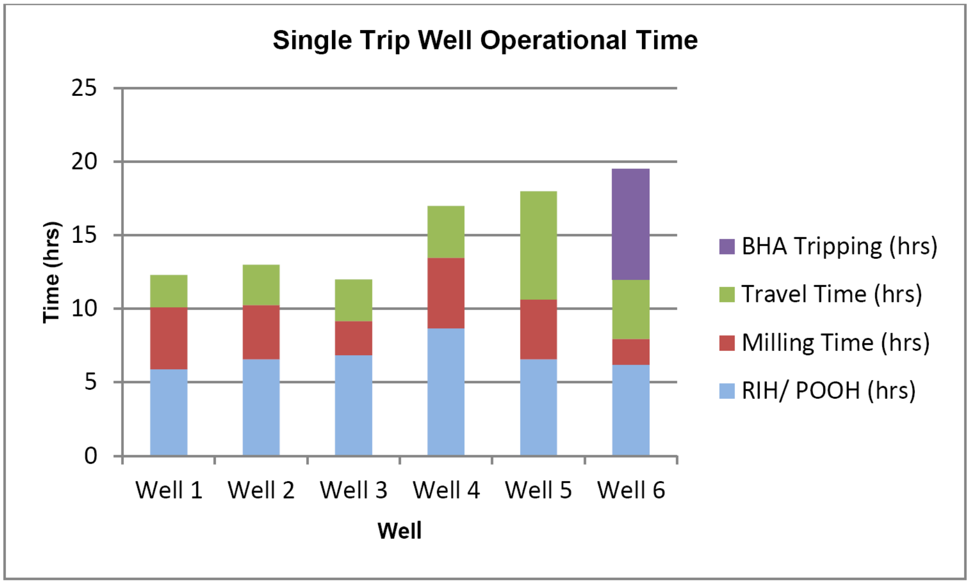

Figure 2—Single Trip Well Comparison

The first single trip well was cased with 7 inch landed at 5,800 feet with a 4.5 inch liner at TD of 9,600 feet. This well had 17 sleeves milled in 12 hours, used 15 gallons of FR and 5 gallons of gel. Figure 3 illustrates the Orion Data of the depth, circulating pressure, and wellhead pressure from the first single trip millout.

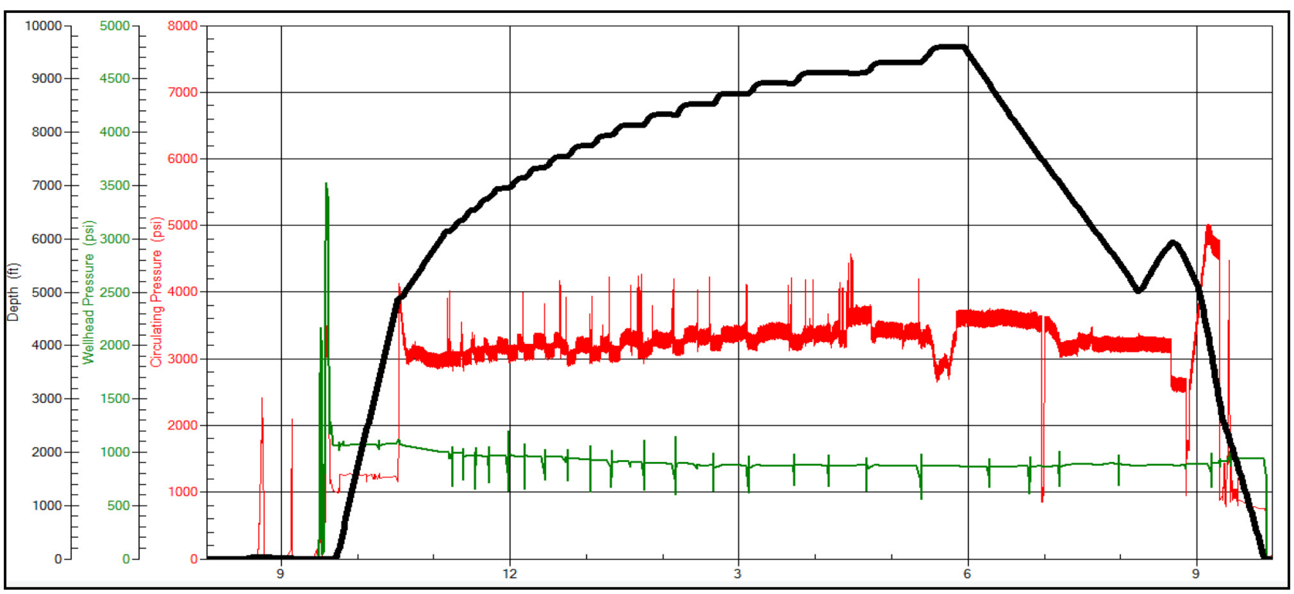

Figure 3—Job data for first single trip millout

Figure 4 illustrates how the RE stays above 20,000 the entire job until TD when a 5 gallon gel sweep was sent. The Marsh funnel time stayed at 28.2 seconds for majority of the job until the sweep was pumped, at which point the time increased to 40 seconds.

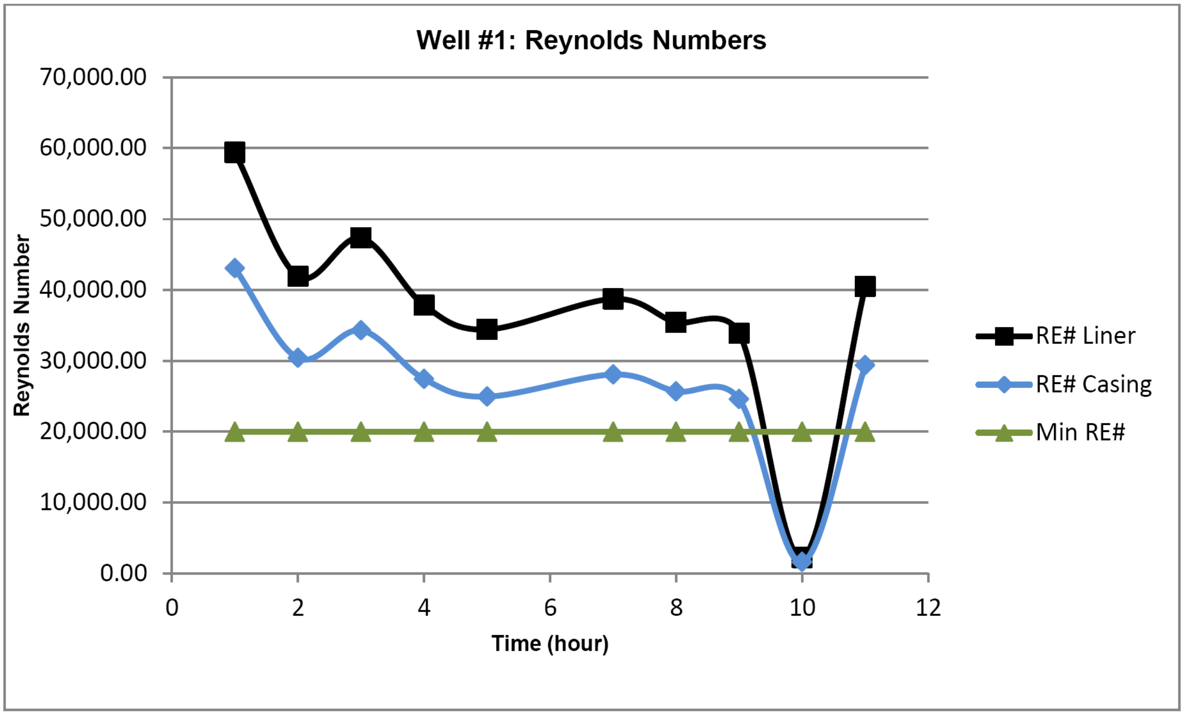

Figure 4—RE first single trip millout

Figure 5 illustrates the acoustic signal recorded from the first single trip well.

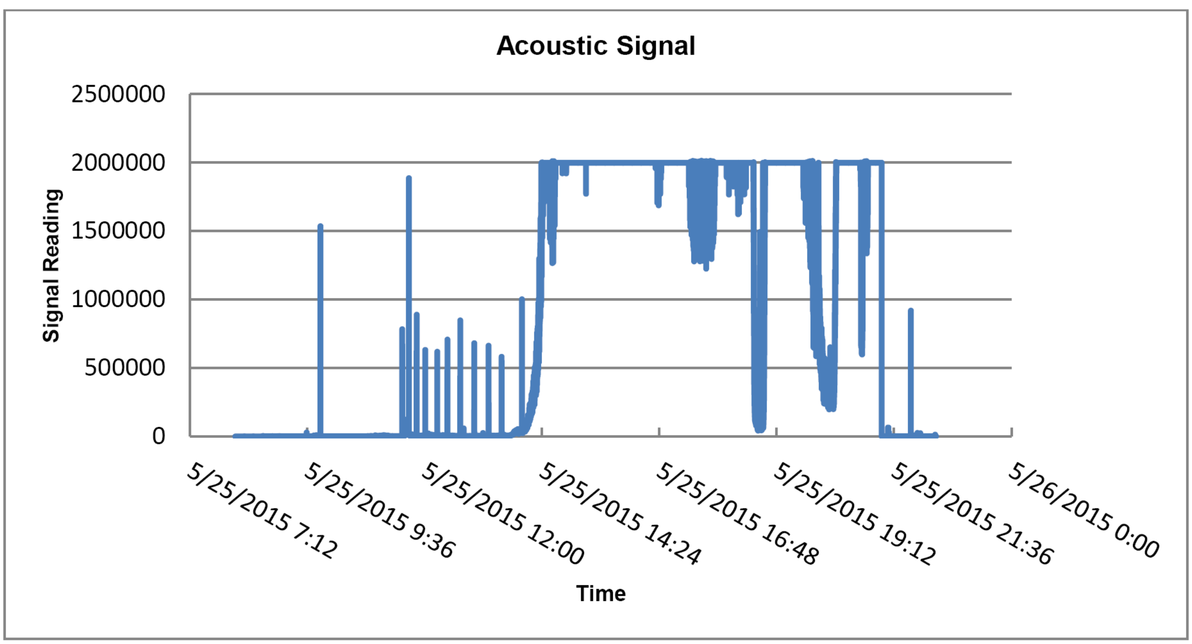

Figure 5—Acoustic Signal data for first single trip millout

The next well completed in a single trip was cased with 7 inch landed at 5,900 feet then a 4.5 inch liner to TD of 11,000 feet including 20 sleeves. The total operational time was 12 hours. The total amount of FR used was 13 gallons and no gel was used. Figure 6 shows the depth, circulating pressure and wellhead pressure from the second single trip millout.

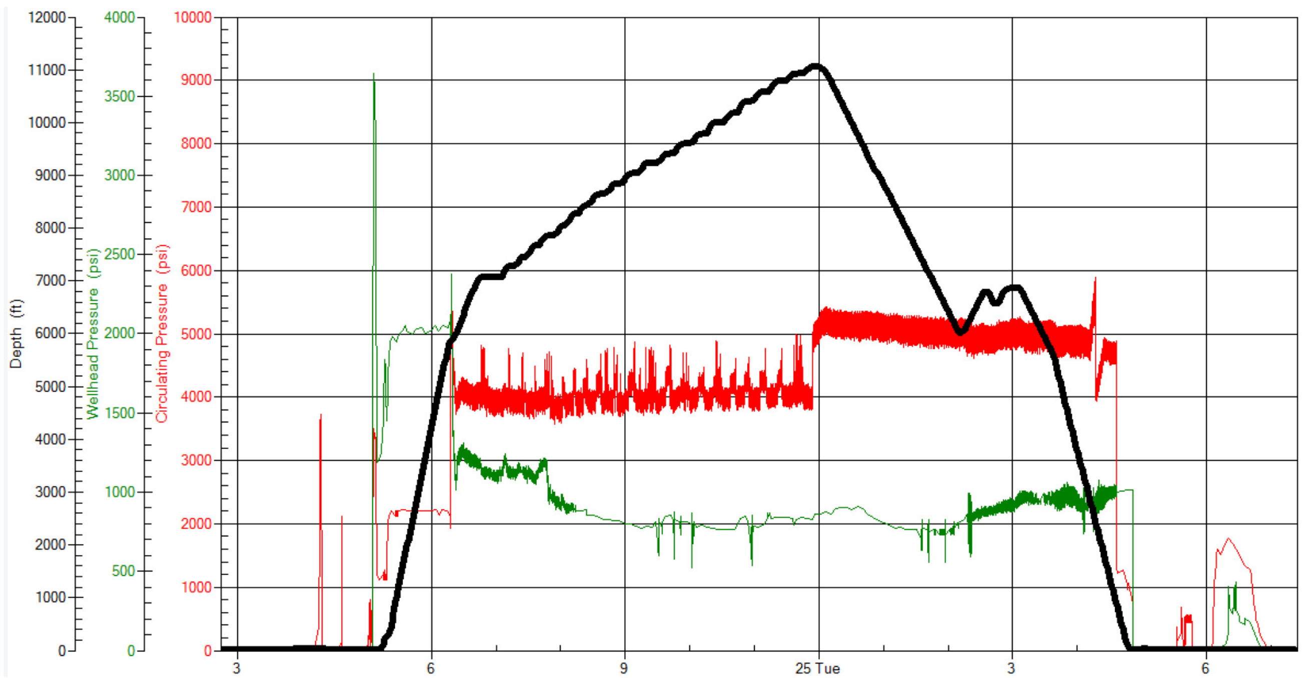

Figure 6—Job data for second single trip millout

The funnel time was maintained at 28 seconds and Figure 7 shows the RE of the liner averaged 70,000 and the casing RE at 50,000.

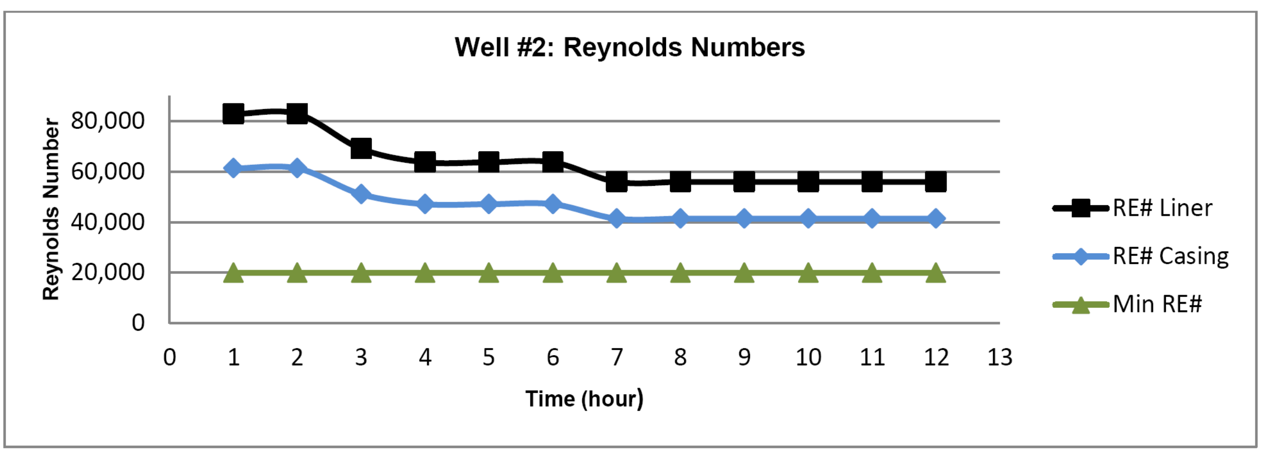

Figure 7—RE second single trip millout

Figure 8 shows the acoustic single from the second single trip milllout. The signal rapidly reaches over 1,800,000 and stays at heavy debris until the job was complete.

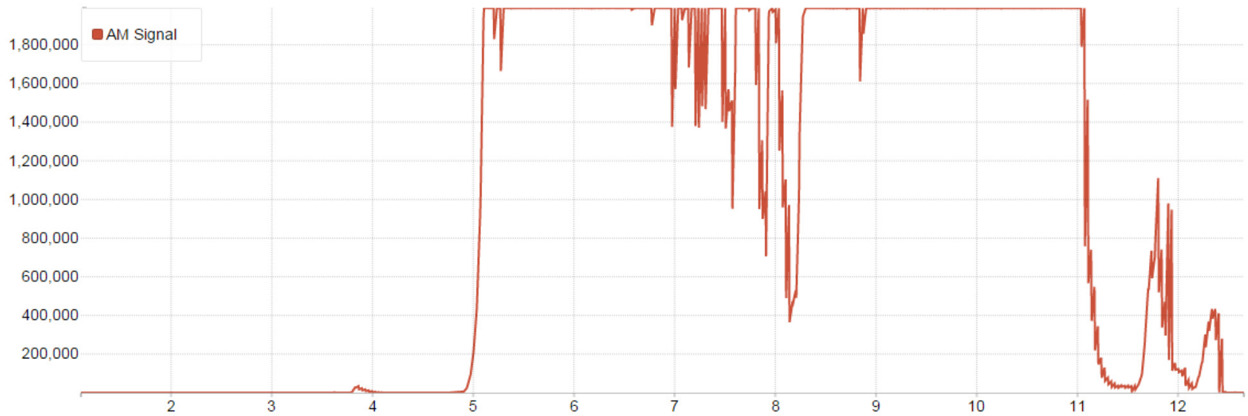

Figure 8—Acoustic signal data for second single trip millout

Multiple Wiper Trip Wells

Sometimes operators were hesitant to perform a particular millout in a single trip. In other cases, issues such as BHA failures occured and had to be replaced resulting in a trip to surface. Even with multiple wiper trips, precise chemical injection and correct fluid rheology reduced operational time by 18% and increased chemical efficiency by 90%. Table 2 represents the average time and chemical amounts used on wells with similar depths. The remaining 12 wells ranged from depths of 11,000 feet to 20,500 feet.

Table 2—Optimized vs. Conventional Millouts

	Conventional	Optimized	Percent Saved
Time (hr)	66	54	18%
FR (gal)	418	60	86%
Gel (gal)	184	6	97%

Figure 9 breaks down the operational time spent RIH/POOH, milling, travel between sleeves, wiper trips, and BHA tripping. The travel time between plugs in some cases was twice as long as other wells; this is discussed later in the paper. The wiper times are different because some wells had longer or more wipers performed than others. Three of the wells did have BHA failures and trips were made to surface change tools out.

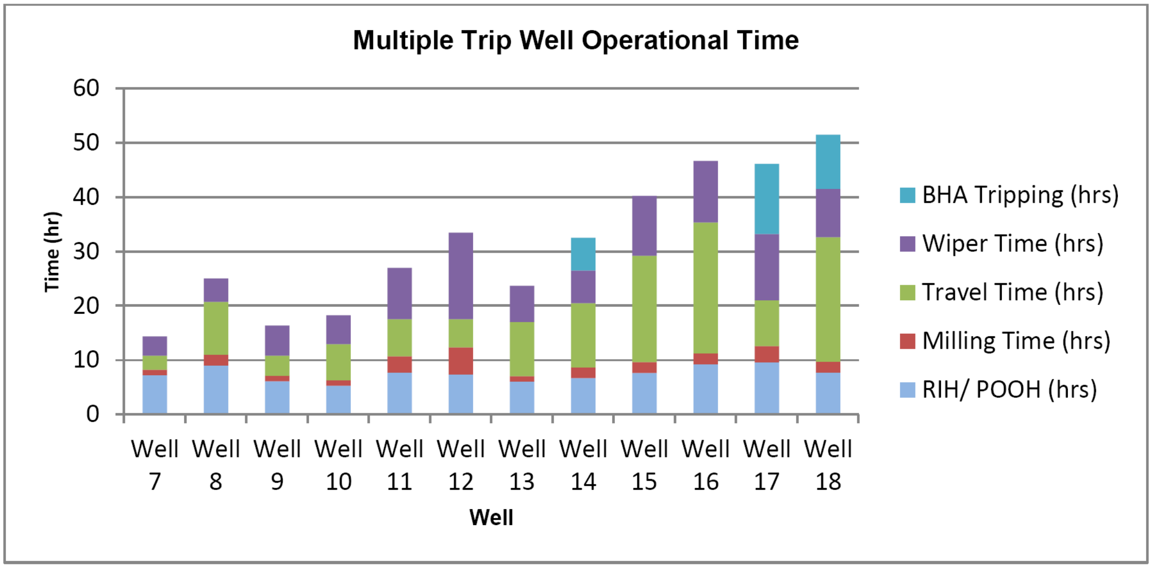

Figure 9—Multiple Trip Well Comparison

The first well in the Williston Basin incorporated three wiper trips: two planned and one due to insufficient fluid storage on the return side. The well had a 4.5 inch fracturing string to a depth of 20,500 feet with 29 plugs. Operation time for the job was 25 hours which included one hour waiting on flowback. The total amount of FR used was 59 gallons for the duration of the job. The following figures (10 and 11) show the job data and acoustic data for the Williston well.

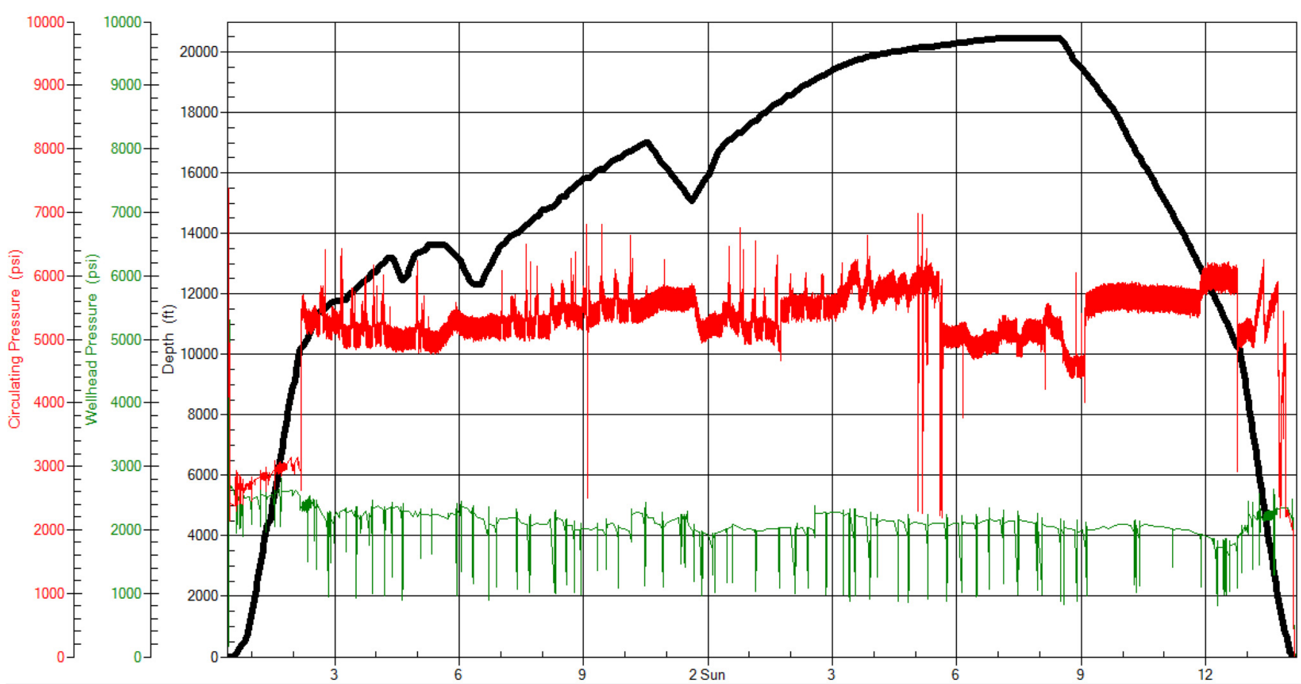

Figure 10—Williston Basin well job data

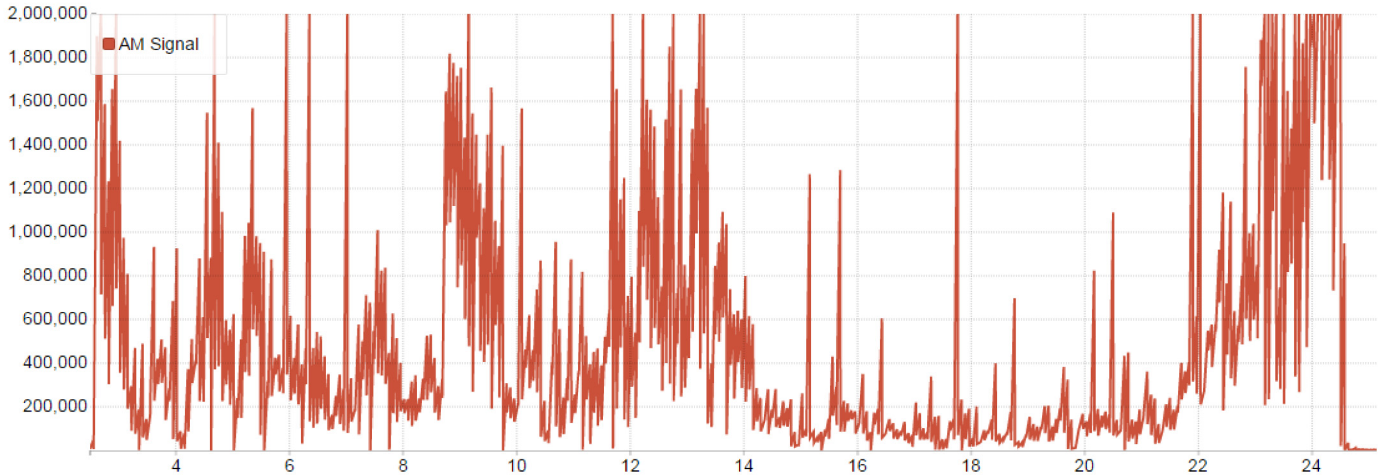

Figure 11—Williston Basin well acoustic signal data

As it can be seen in Figure 11, the acoustic monitor read light to heavy debris throughout the millout. The RE for the Williston Basin well is shown in Figure 12 below. The point at which the RE decreases below 20,000 is at TD when a gel sweep was pumped at the end of the job. The Marsh funnel time averaged 27.7 seconds for the duration of the job.

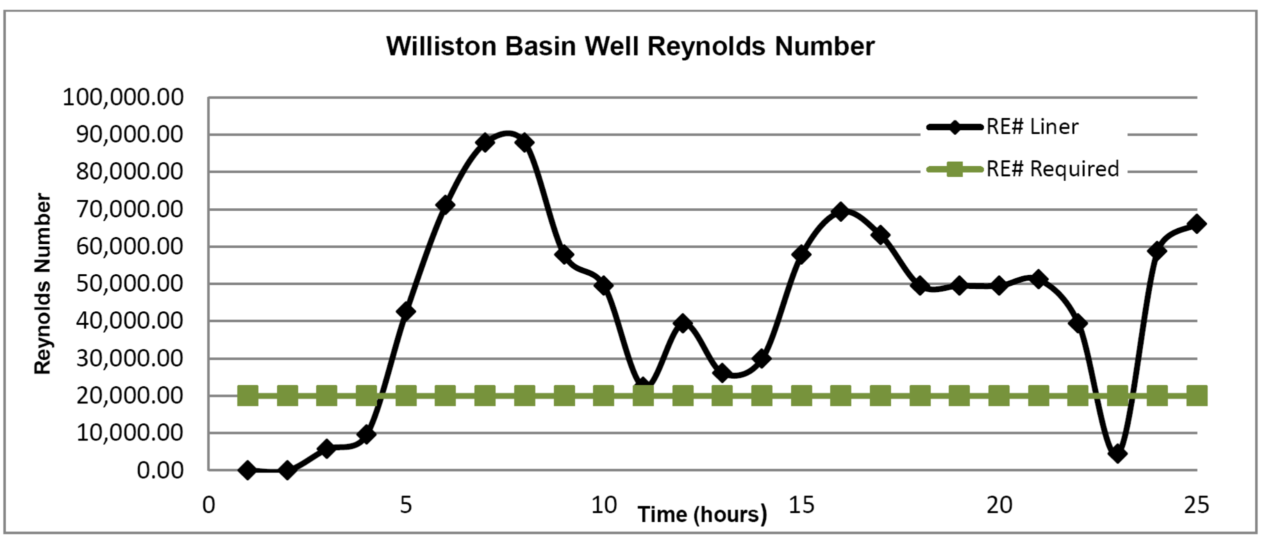

Figure 12—Williston Basin RE

Operators were concerned that heavy debris would be left in the wells because no gel was being used to ″carry″ debris out of the well. Figure 13 below shows the heavy debris (cast iron slips) returned from the Williston well.

Figure 13—Williston Basin returns

On the DJ Basin wells with 8,800 feet laterals the operator did not trust doing single trips and in the cases of those wells, two to three wiper trips were performed. During optimized millouts of these wells the contact friction factor increased compared to conventional millouts. While the usage of gel was down 97% the same amount of metal on metal friction reducer, sometimes refered to as pipe-on-pipe friction reducer (POP) was used. The question arrises: why was the contact friction higher on optimized wells while using the same amount of POP and less gel? Lubricity tests were performed and found that conventional gel sweeps provide a small amount of friction reduction for metal on metal surfaces. Since optimized millouts do not use gel the friction factor increased. To account for the loss in friction reduction the study also found that POP must be dosed at higher concentrations which could potentially create a negative effect on overall fluid rheology during a job. Further tests concluded that higher concentration of the specific POP used during the optimized millouts did not increase the viscosity of the fluid therefore the rheology was not compromised.

Challenges

Although an optimized single trip millout is ideal, every well is different and caution must be taken when performing any well intervention operation. There are challenges that can be foreseen and mitigated while there are some that cannot.

The foreseeable problems should be addressed before attempting an optimized single trip millout. Flowback must be set up to accommodate more frequent debris being returned throughout the job. There should be 3 inch return iron and a redundant junk/plug catcher system that can be cleaned to ensure debris is returning to surface and not plugging off return lines. Another problem that can occur during single trip millouts results from an unplanned interruption in circulation through the coil and up the annulus. Once pumping stops, turbulent flow is lost and debris begins to settle along the bottom of the casing and around the coil. When the debris starts to settle the fluid rheology is compromised so a wiper trip should be performed until circulation is established. One caveat to performing a wiper trip when circulation is lost is the potential for wellbore debris to begin to pile up as the coil is being pulled through it. In this circumstance the coil operator needs to be cautious of the coil weight. Any abnormal increase in coil weight should result in the coil being stopped. Once circulation is established to the point of turbulent flow a minimum of two bottoms up should be pumped prior to moving the coil to ensure the debris is being moved hydraulicly out of hole. A big obstacle encountered on location was combating the conventional thought process of using multiple gel sweeps to clean the well. Gel sweeps compromise the RE and allow debris to settle due to the transition from turbulent to laminar flow. On one particular well this problem occurred, as shown by the job data in Figure 14 below. The well was shut in and the CT was able to pull free. This is an example of how using excessive amounts of gel compromises the integrity of the optimization process for 2 inch single trip millouts.

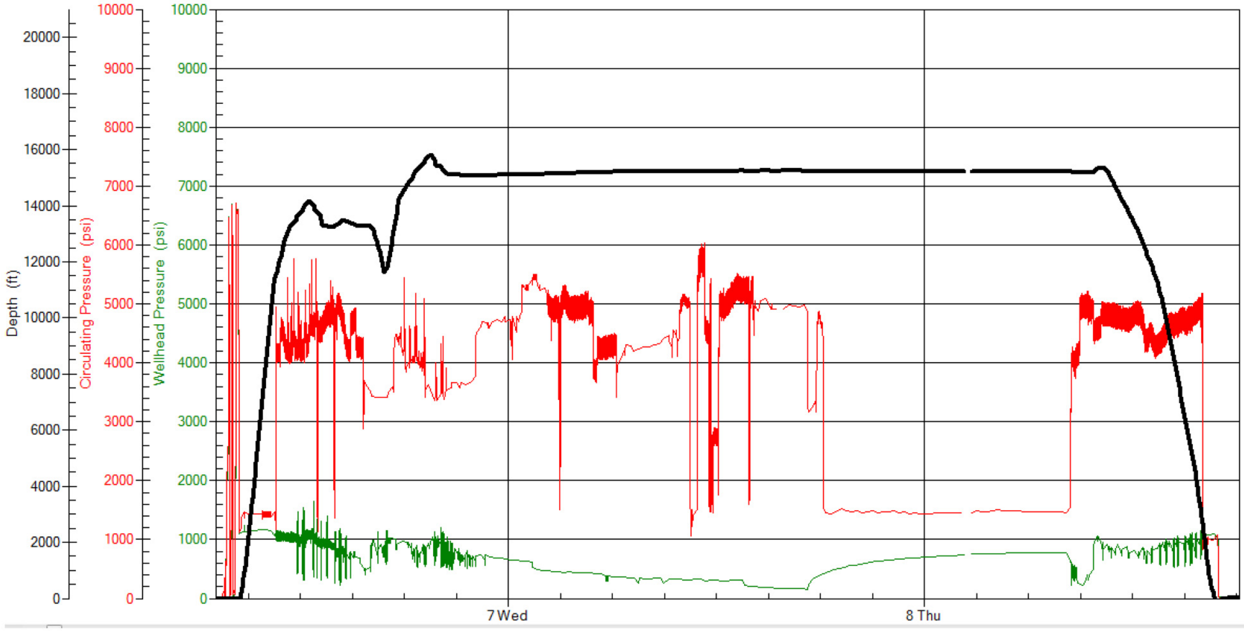

Figure 14—Challenge well job data

Two gel sweeps with funnel time of 50 seconds and higher were sent before and after the return rate dropped. Flowback detected the loss but by that time debris was already settling around the CT. Figure 15 illustrates the change in AVs along with the funnel time viscosity of the treatment fluid.

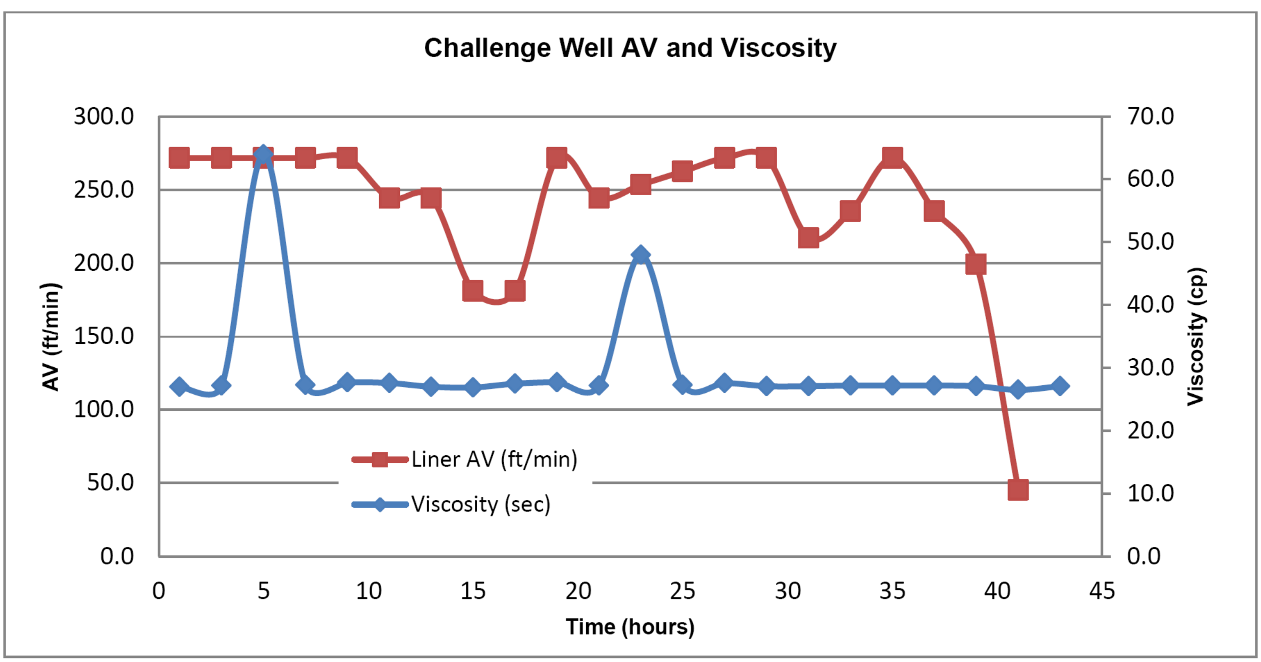

Figure 15—Challenge well AV and viscosity

Figure 16 shows that the gel sweeps lowered the RE to almost zero at two different times during the job, allowing debris to settle and build up.

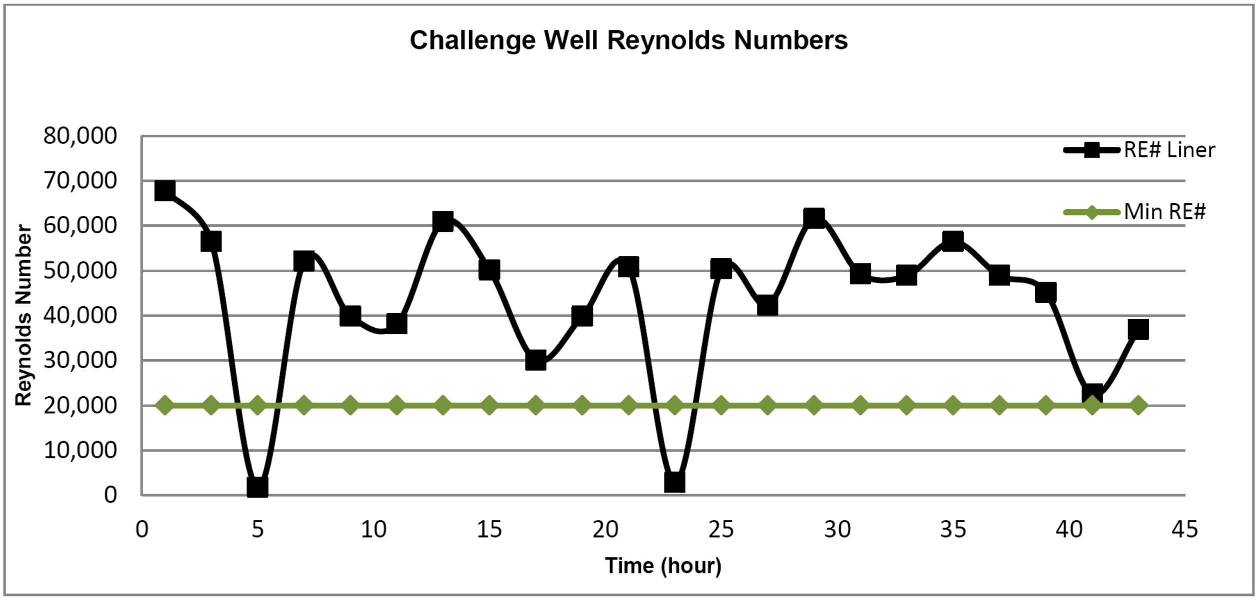

Figure 16—Challenge Well RE

The unforeseeable problems can occur anytime in the well and that is when the single trip must be reevaluated. When there is a drop in wellhead pressure or loss of return rate a wiper should be performed until the problem is resolved. If during a wiper trip the CT shows signs of encountering debris the wiper should be extended until there is no sign of issues. Another wiper should be performed after the initial one to ensure debris is traveling out of the well. Debris can accumulate in one location due to changing wellbore conditions so it is important to manage the factors that directly affect AV and fluid rheology to continually transport debris.

Conclusion

The process of optimizing single trip millouts using 2 inch CT is a dynamic technique with many variables. Not every operator was convinced that optimized single trip millouts were possible, let alone cost and time effective. At the conclusion of this paper, six wells were completed with single trips using 2 inch CT, saving 47% more time than conventional millouts which require multiple wiper trips. Fluid rheology is a major component of single trip optimization that must be closely monitored for a successful operation.

The rheology control unit used during these millouts provided a methodical approach to control chemical usage and deliver more efficient wellbore cleaning while saving time. The ability to monitor pumping fluids real time and adjust accordingly allowed CT operations to keep continuously milling without losing time on wiper trips. The acoustic monitor provided qualitative flowback information, which is a commonly neglected part of any coil operation and has the most room for development to further enhance the results of current 2 inch single trip optimized millouts. If the monitor signal dropped during the job, flowback could be alerted before there was a major issue.

Single trips are ideal and save the most time and money but not every well can be completed with a single trip. Engineering along with CT operators must still be vigilant of changing well conditions. It is sometimes necessary to perform wipers due to changing well conditions. The optimized single trip 2 inch

CT millout saved time and increased efficiency by optimizing fluid rheology and reducing chemical usage.

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