PREVENTING FOULING AND CORROSION DURING MILL-OUT OPERATIONS: PERMIAN CASE STUDIES

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While the importance of water and chemical optimization is well understood and managed during fracturing operations, those practices are inconsistently applied during post-frac operations. The water used in mill-out or drill-out operations, (the process of removing the plugs placed during hydraulic fracturing operations) is often left untreated. Standard best practices have not been adopted and limited testing is being performed to determine optimal water quality or disinfection treatments for these operations.

Once hydraulic fracturing operations of a well are completed, two to three frac tanks (~1500 bbl.) are topped off with the water used during frac and are left for use during mill-out operations. The cleanliness of those tanks can lead to contamination of the water (Sherman, S. 2015). If the operator was using an on-the-fly disinfection treatment during their frac, the water left in the tank has been pre-treated and has low bacteria counts. Otherwise, no disinfection treatment is performed, and water is used as-is. While mill-out operations occur immediately post-frac, it is common for delays to take place, resulting in water which has been left to sit with no treatment for several days. If an oxidizer was used, no residuals are left from post-frac treatment to provide any long-term protection. With any delay in water use, high fouling is expected with these waters and with no mitigation, can introduce bacteria into the well, which can lead to MIC (microbially-induced-corrosion) and H_2S (Seal, C. 2015).

Additional challenges exist with the re-use of the same water over a period of several days and in some cases for the entire mill-out of a three to four well pad (Edillon, L. 2015). Water quality diminishes as the water becomes saturated with high levels of solids and mill-out chemicals, such as friction reducer or gel. Over-saturated waters are typically managed by diluting them with several truckloads (~120-240 bbl.) of new freshwater. However, the process is not standard across operations and is often completed at the discretion of the company man. In other instances, water is lost to the formation and new freshwater is constantly being added, minimizing the effects of water re-use. The guar or xanthan gels used, which are biopolymers, act as a food-source for bacteria and create an environment in which bacteria can flourish. Those favorable conditions can be exacerbated by warm weather, with water in the frac tanks reaching over 100°F in the summer, resulting in exponentially higher bacteria growth rates. These operational challenges can vary by operator and are all dependent on the water, disinfection treatment, chemicals, and equipment selected to perform the mill-out.

Studies of mill-out operations for two Permian based operators were conducted and the findings are reported. The studies focused on the mill-out method (workover rig vs coiled tubing), tank set up, water quality, and chemical usage. Water monitoring programs were implemented to identify changes in injection and return water quality at various intervals of the mill-out. The changes to water quality along with impact on equipment and chemical performance are presented. Key parameters which contributed to equipment damage, stuck-pipe incidents, and reduced chemical performance are identified and the results of mitigation controls are discussed.

FILED MONITORING AND TESTING

A process was implemented for two operators in the Permian basin to monitor water composition and bacteria levels during their mill-out operations. Mill-out operations were monitored over a year period across various areas of operation for both operators.

Water quality was monitored real-time by measuring water pH, total dissolved solids (TDS), and chloride levels of injection and return waters at various intervals of the mill-out.

Real-time bacteria monitoring was performed utilizing an ATP (Adenosine Triphosphate) test method, which provides a snapshot of microbial loads. The test method used measures cATP, (cellular ATP), which is present in all living microorganisms, and provides a measure of total microbial load in the fluid. This method provides quick evaluation of disinfection efficiency and allows for on-the-fly adjustments to treatment programs. Parameters for the program were developed based on generally accepted cATP criteria values, where levels greater than 100 indicate poor microbial control. The type of disinfection method, dosage, and average kill time were also considered. Oxidizers such as chlorine dioxide can take up to 1 hour to achieve desired kill depending on dosage and application type. Conventional biocides provide a less immediate kill and can take up to 24 hours depending on the chemistry and dosage used. For the studies, target cATP levels were set for the injection water at less than 1000 cATP, which allowed for bacteria loads that could be controlled within one hour. For water returns, targets were set at less than 10 cP based on expectation that disinfection treatments would provide a log 2 reduction in bacteria counts.

RESULTS

Baseline disinfection efficiency cases for Operator A and B coiled tubing mill-out are shown in Figure 1 and Figure 2 respectively. Based on their existing infrastructure, Operator A selected to use the existing oxidizer treatment used on their hydraulic fracturing operations. Mill-out tanks were filled immediately post-frac and treated with an oxidizer as tanks were filled. An oxidizer was also added when new freshwater was added to top-off the tanks once the mill-out was underway. Operator B implemented a pre-job oxidizer disinfection treatment immediately prior to the start of the mill-out along with on-the-fly biocide addition. Results showed the choice of treatment had significantly different results, with Operator B's combination oxidizer and on-the-fly biocide treatment yielding the most effective kill. Operator A's process did not achieve the target of a cATP value of 1000 or less for the injection water. The initial disinfection treatment had been performed two days prior and new freshwater was not added until the mill-out had been in progress for 35 hours. Operator B's frac tank water was within the target range and the effectiveness of the oxidizer treatment along with on-the-fly biocide was successful with the water maintaining low cATP values for the duration of the job.

Operator B also utilized workover rigs for their mill-out operation in certain regions and wanted to implement the same treatment plan across their operations. A study was conducted to determine effectiveness of the treatment program for their workover rig and coiled tubing mill-outs.
Initial evaluation of the operational processes for each mill-out identified key parameters that influenced the quality of the water over the course of the mill-out. A diagram of the equipment layout and flow of water for each operation is shown in Figure 3**.** Workover operations utilized three times more frac tanks than coil tubing operations and the water was replaced at the end of each well. The tanks were all equalized, allowing for more dilution of the water for the duration of the 36 to 54-hour operations. In contrast, coiled tubing operations re-used the water well to well and diluted with freshwater at a ratio of ½ a frac tank of freshwater in between well mill-outs.

A comparison of the efficiency utilizing the same treatment during a coiled tubing mill-out and a workover rig on the injection waters is shown in Figure 4. Results suggested that a more robust treatment program and changes in operational processes were required to achieve adequate bacteria control for coiled tubing operations. The same treatment program was implemented for both operations, with an oxidizer pre-treatment step and on-the-fly biocide dosage of 0.1 gal/10 bbl. Bacteria cATP target was not met for coiled tubing operations even with doubling of the biocide concentration on-the-fly. Additionally, the reduced water volumes used, and limited dilutions contributed to faster contamination of the water. Gel sweeps were also run at every plug for coiled tubing versus every four to six plugs for workover units. Biopolymer based gels, such as Xanthan, act as a food source for bacteria, providing a favorable environment for bacteria growth. While attempts were made to divert the gel sweeps to the waste pit/tank, not all the gel was removed from circulation. In contrast, bacteria cATP target was met for the workover rig mill-out utilizing the same treatment process. Additional optimization was performed to meet the treatment target rates for Operator B's coiled tubing mill-out operations.

The effectiveness of water dilution on the disinfection program for Operator B coiled tubing mill-out operations was monitored and results are shown in **Fig. 5.** Treatment target rates were met with the new operational setup. Equipment layout was kept the same, but frequency of freshwater dilutions was increased to one tank replaced every 12 hours, while maintaining biocide dosage at a constant 0.1 gal/10 bbl. The increase in dilution rate of water throughout the job improved treatment effectiveness.

Disinfection targets could be met with increased dilution and effective chemical treatments; however, surface operations processes impacted the success of the implementation. Optimal disinfection was achieved when the mill-out was treated just prior to the start of the mill-out as tanks were being filled. A lack of circulation in the frac tanks limits the effectiveness of treatment directly into the tanks. If tanks had already been filled, pre-treatment with biocide added directly to the tanks required for tanks to be circulated through a transfer pump ("rolled") for several hours to ensure proper mixing. This also introduces more oxygen into the system, which can contribute to an increase in corrosion rates.

Additionally, the type of disinfection treatment (oxidizer vs. conventional biocide) had different levels of effectiveness. While oxidizers provide excellent quick-kill, they do not provide long-term protection needed for water that will be re-used over a period of several days. For Operator B, a combination of both methods proved to be most effective, with an oxidizer pre-treatment providing the fastest kill, and a conventional biocide providing sustainable control for the length of the job (Figure 6a and 6b). Results in Fig. 6a, suggested that biocide treatment did not provide a quick enough kill to reduce the bacteria levels in the water at the start of the job. Once the job was started and water was being circulated through the system, bacteria levels stayed above the target range. When an oxidizer treatment was implemented at the start of the job (Fig. 6b), bacteria levels were greatly reduced (less than 100 cATP) and levels were well maintained with a low, on-the-fly dosage of biocide. Managing the fouling levels throughout the process can reduce potential for introduction of bacteria into the wellbore.

As part of the monitoring process during the mill-out, changes in water composition were also monitored through measurement of water pH, chlorides, and TDS. Results showed that throughout the operation, composition of the return water changed, with those samples showing higher chlorides content and TDS than water being used at start of the job. This suggested the potential for commingling of mill-out water with formation/frac water in the wellbore. A comparison of mill-out water composition for Operator A injection and return water are shown in Figure 7. During this mill-out, the water composition of the returns was the same for first four hours, afterwards there was an increase in both the chloride levels and TDS of the return fluids. Chloride levels increased from 2500 ppm to 25,000 ppm within 6 hours of the start of job. The TDS levels increased from ~5000 ppm to 75,000 ppm over the same interval. Similar results were observed in various wells during mill-out operations for Operator A and Operator B. The change in water composition between the injection and return water was not observed in all wells studied, 35% of the wells evaluated showed no change in water composition between injection and return samples. Further investigation is needed to determine if these differences are due to the well formation or zone that was completed.

Changes in water composition over the duration of the job can also affect the performance of the chemicals used. In the case of Operator B, changes in water composition affected the ability of their friction reducer-based gel sweeps to meet their target fluid viscosity. Testing was conducted on-site with the water used by the chemical mixing plant to determine the effect on the product performance. Viscosity was measured for the gel sweep at various times during the mill-out with a marsh funnel and a rotational viscometer. Results (Figure 8) show the change in sweep viscosity as the fluid composition (chlorides and TDS) changed throughout the mill-out operation. The data identified product tolerance limitations to salinity, which resulted in sweep viscosity below the marsh funnel target of 54. When water composition exceeds the tolerance range of these products, higher chemical dosages are required to meet specifications and results in increased chemical costs. When water quality was left unmonitored, Operator B experienced several stuck pipe events which could have been a result of poor well cleanout due to low sweep viscosities.

Water composition can also affect the integrity of equipment, both at the surface and in the wellbore. Changes in the chloride levels of the water can increase the potential for corrosion of the work string, which can lead to shortened equipment life. During workover rig mill-outs, Operator B was incurring replacement costs for corroded pipe joints, which averaged $60,000 per 3 wells. To determine if the water used during the mill-out contributed to the corrosion of the pipe, a trial was conducted with a corrosion inhibitor. Well 1 was completed using the existing chemical program and Well 2 had corrosion inhibitor dosed on-the-fly at a rate of 0.1 gal/10 bbl. for the duration of the job. The pipe joints for Well 2 had noticeably less visible corrosion and no replacement costs were incurred for the joints used on the well. Use of the corrosion inhibitor was then implemented for subsequent wells with the same success.

Changes in water composition along with continued re-use of the water can further hinder the performance of the chemicals used. Solid contaminants can be removed with the use of filter pods; however, they do not remove any dissolved solids or chemicals present in the water. When little or no dilution was used on the mill-out water, water contamination was prevalent. The changes in water quality affected the performance of the chemicals used, led to high fouling, and the development of iron sulfide post sample collection. Samples collected during Operator B mill-outs where no dilution or disinfection treatments were used vs. those where a treatment program was implemented. For Well C, no water treatment was performed and within hours of starting the mill-out, iron sulfide was present in waters that had not been treated. Well D, had the oxidizer/biocide combination treatment program in place and no traces of iron sulfide were detected in the water returns.

Water contamination is also a result of chemical overtreatment, resulting from the use of the same fixed volumes of water. The same 1500 bbl. of mill-out water were kept in continuous circulation over a three-day period, with chemical being dosed on-the-fly over that same period. This resulted in water containing up to eight times the concentration of chemical additives, which resulted in over-saturated waters. These waters make it more difficult to meet performance target, forcing the service providers to increase the chemical loadings until targets are met.

Findings from the data collected during the mill-outs prompted Operator B to implement a continuous monitoring program that included pre-job and on-the-fly disinfection and the use of a corrosion inhibitor. To-date, 55 wells have been successfully treated and the data generated on-site is being used as tool to provide early-time diagnostics for production chemical treatment needs. Operator A's program is still under evaluation and the use of produced water to complete the mill-outs is currently being monitored.

CONCLUSIONS

Evaluation of case study results for Operator A and B in the Permian basin suggest that mill-out water re-use processes can lead to an increase in fouling and corrosion of the wellbore and equipment. These changes can also impact chemical performance, resulting in low product performance and an increase in chemical usage

Fouling and corrosion can be managed by:

- Implementation of monitoring and treatment programs tailored to the mill-out operation
- Effective disinfection through improvements in operational set up and water management practices
- Limiting the length of water re-use and implementation of dilution practices can also aid in reduction of corrosive properties of the water and the impact of higher TDS on chemical performance.
- Performing a pre-millout evaluation to identify fouling and corrosion risks.
- On-site monitoring and establishment of target key performance indicators for the water composition and product performance.

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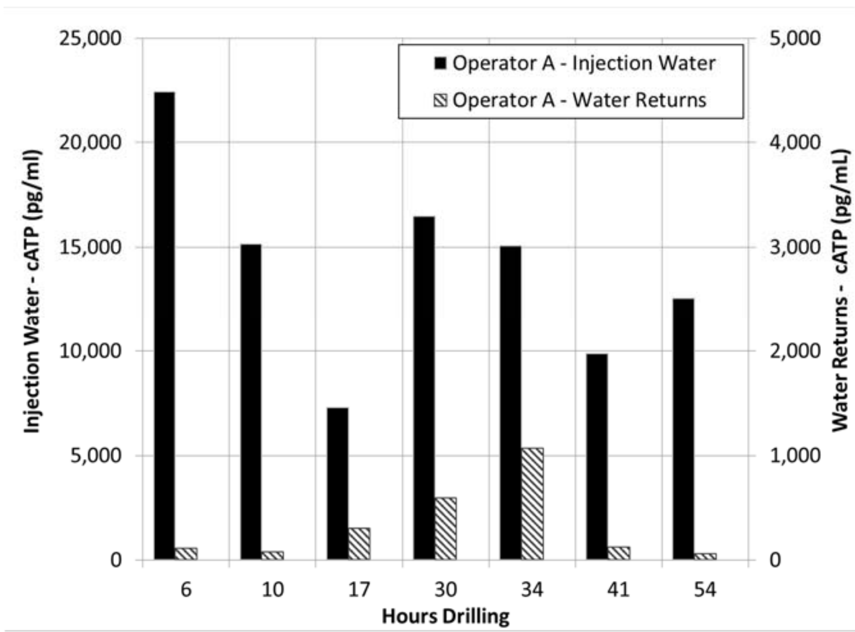

Figure 1 —Results of Operator A bacteria level during coiled tubing mill-out.

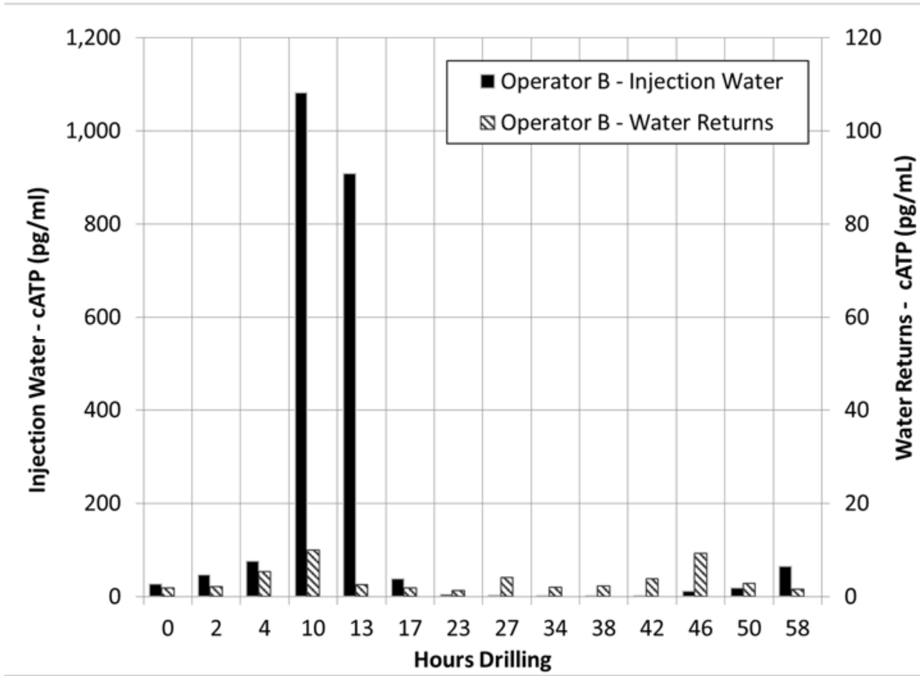

Figure 2 — Results of Operator B bacteria level during coiled tubing mill-out.

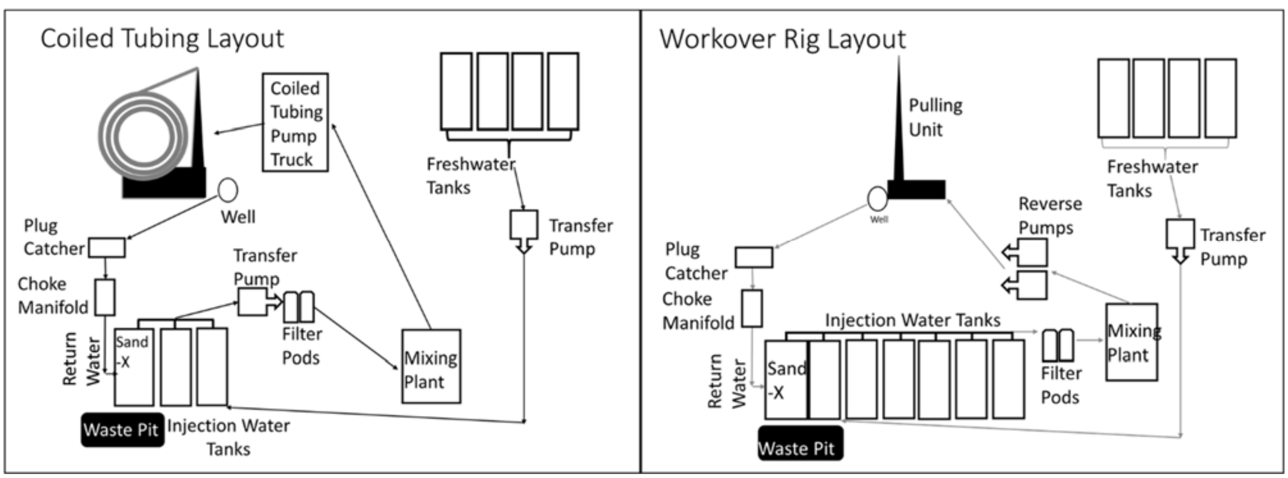

Figure 3 — Diagram of equipment setup for mill-outs utilizing coiled tubing units and workover rigs.

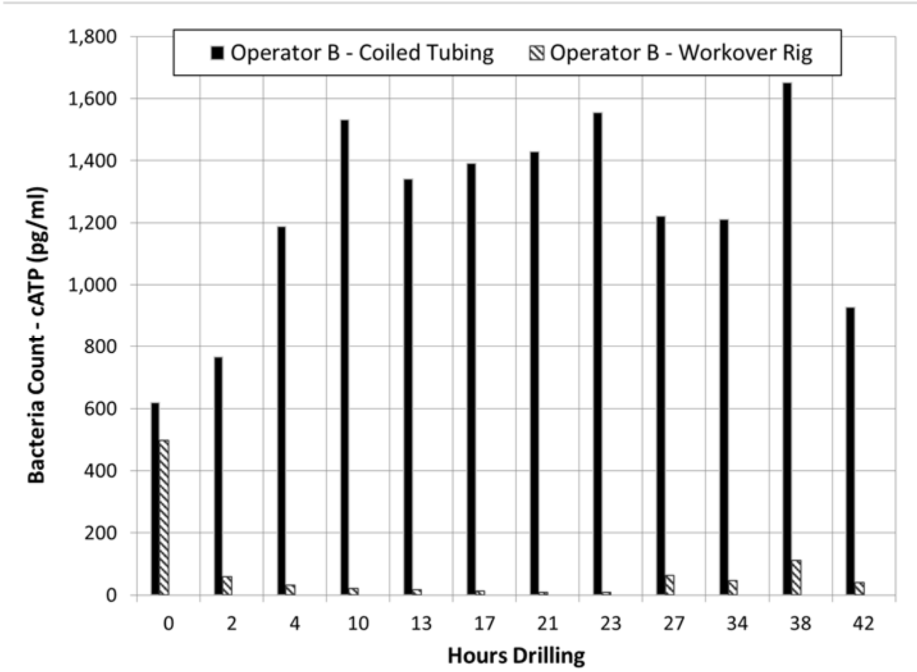

Figure 4 — Comparison of Operator B water treatment efficiency on injection water coiled tubing vs. a workover rig mill-out.

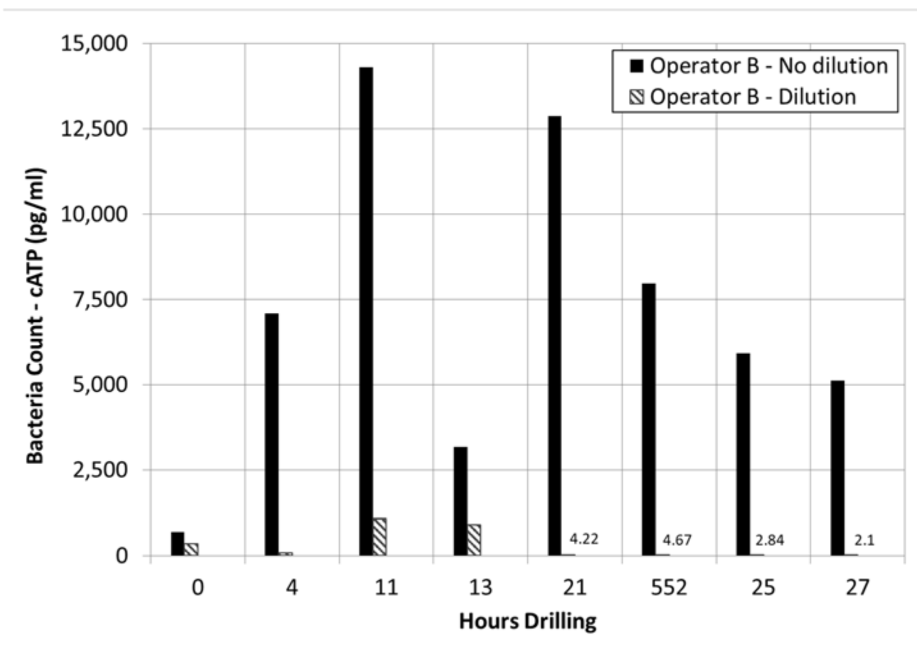

Figure 5 —Operator B water treatment efficiency with improved water management process

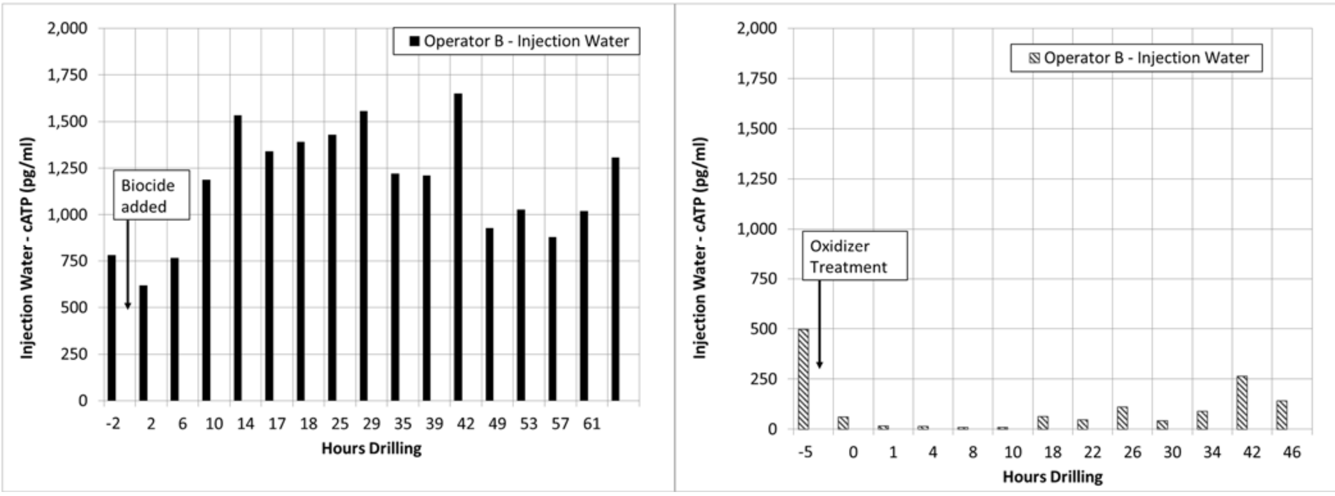

Figure 6a — Operator B water treatment with no oxidizer and 6b — with oxidizer and biocide combination treatment.

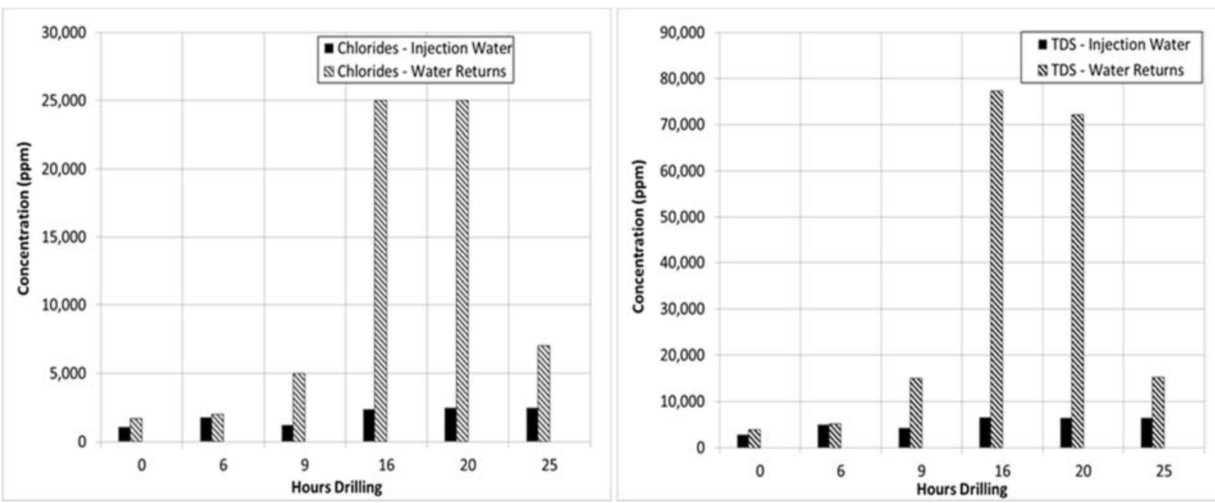

Figure 7 — Chloride and Total Dissolved Solids Concentration of Operator A's injection and return waters during coiled tubing mill-out.

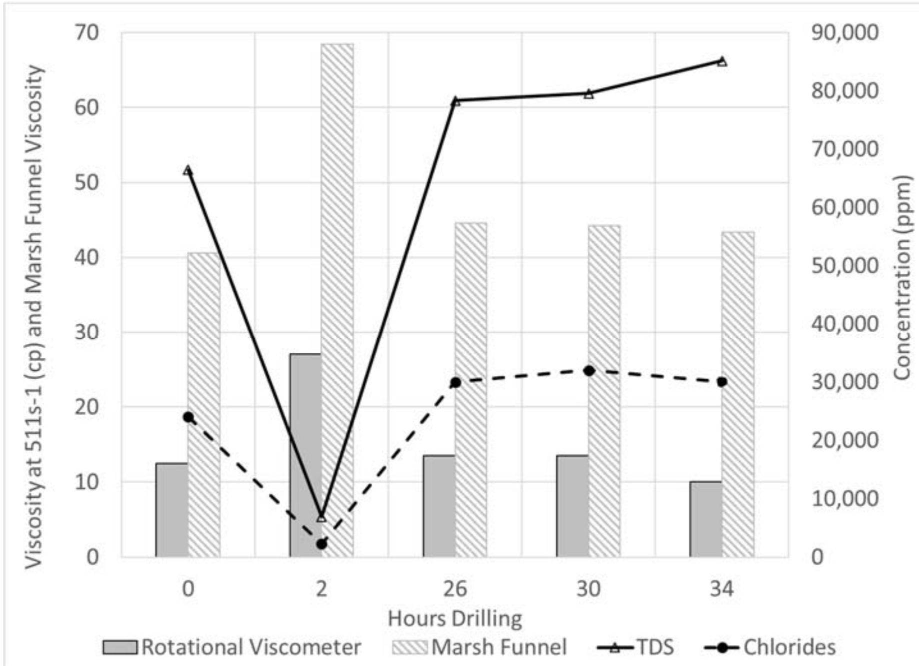

Figure 8 —Viscosity of gel sweeps at 7 gal/10 bbl. during a mill-out operation