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Drill Cuttings Injection and Monitoring for Remote Pad Drilling Operations at Environmentally Sensitive Sites in Cashiriari, Peru

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Abstract

Performance and environmental assurance of cuttings injection programs require monitoring and periodic analysis of injection formation response. Such programs provide operational oversight and the ability to recognize and respond to changes in performance or trends, providing for modification of operating parameters to optimize performance and minimize potential negative impacts.

Such a process was implemented on a remote pad in a nature preserve in Peru. The development of gas reserves at Cashiriari has extreme environmental sensitivity and DCI was recognized as a technically and environmentally acceptable alternative for waste management. The paper will discuss the issues encountered during the DCI project at Cashiriari. Higher than anticipated injection pressures were indicative of the regional stress regime and required adjustments with respect to operating parameters and performance expectations. Performance has been contingent on successful inhibition of the reactive clays adjacent to the relatively thin sandy target zones. Projections of closure pressure trends associated with batch injection and predictions of performance and disposal capacity have been possible through continuous performance monitoring. Monitoring operations have allowed for performance improvement and/or minimization of potential problems. The operation successfully injected over 200,000 bbls of cuttings on the first pad through careful management of batch attributes and adaptation to operating realities.

Recognition of the need for well designed programs to monitor injection performance is critical for the industry. Operational and environmental assurance derived from such programs provides long term operational viability and social acceptance of cuttings injection as a safe means of waste management.

Introduction

Assurance of a successful and environmentally sound long-term cuttings injection program requires monitoring and periodic analysis of injection performance response.[1,2] Such a program provides for operational oversight and the ability to identify changes in performance response or trends, thereby providing for modification of operating parameters to optimize performance and minimize the negative impact of unexpected responses.[3,4,5] An implementation of this process was instituted for a remote, pad-drilled site located in a nature preserve in the Amazonian rainforest of Peru. The development of natural gas reserves at Camisea has extreme environmental sensitivity and injection of the generated drill cuttings was recognized as a technically and environmentally acceptable alternative for drilling location waste management.

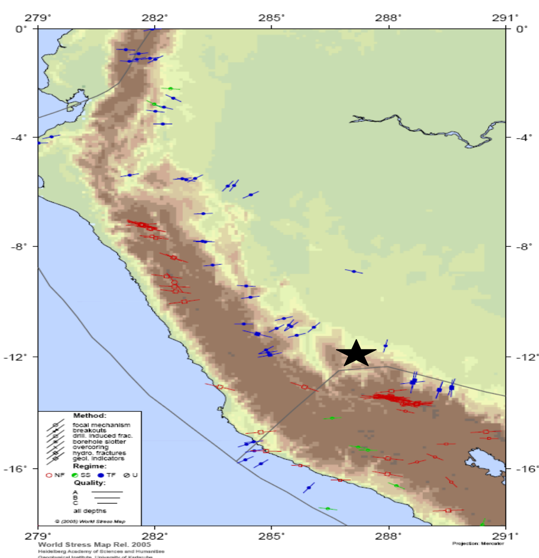

Figure 1: Location of Camisea, Peru

A number of issues were encountered in implementing and operating the DCI project at Cashiriari. Higher than anticipated initial injection pressures were indicative of the stress regime of the region and required an adjustment in thinking with respect to operating parameters and performance expectations.

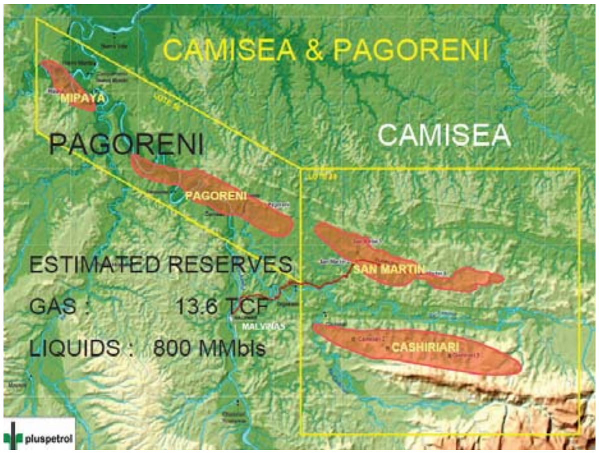

Figure 2: Camisea Reserves

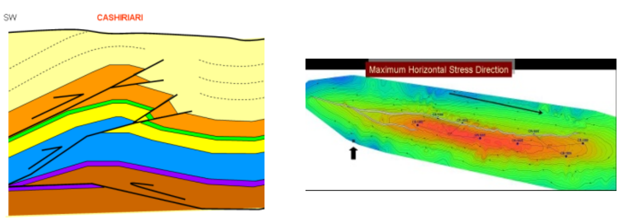

Figure 3: Cashiriari Faulting and Stress Orientation

Performance has been contingent on successful inhibition of the reactive clays adjacent to the relatively thin sandy target zones. Continuous monitoring has allowed projections of the closure pressure increases associated with batch injection through time, providing a prediction of future performance and disposal capacity. Information gathered from monitoring operations has allowed for performance improvement and/or minimization of potential problems identified. The operations at Cashiriari 1 successfully injected over 218,000 bbls of cuttings through careful management of batch attributes and adaptation to operating realities.

Preliminary Studies

Geomechanical models of the potential disposal lithologies were developed as part of engineering feasibility studies. Formation mechanical properties were evaluated and stress profiles developed that identified potential disposal zones during engineering design studies for each of the sites.

Operating parameters, such as pump horsepower, injection rate, flush and slurry batch sizing, as well as the impact of formnation cooling, were considered in determining recommended injection parameters and procedures.

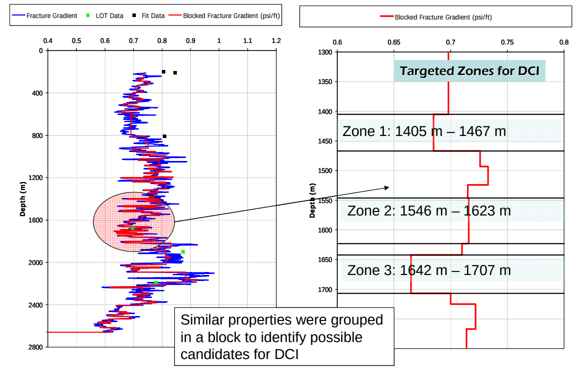

Figure 4: Generated Stress Profile and Potential Injection Targets; Cashiriari 1

Injection was performed in a very thin, sandy clay-laden formation surrounded by young clay and claystone formations with little disposal capacity. Simulations were run with @frac, a fully 3-D injection fracture simulator, to predict formation performance over a range of the parameters evaluated. The results for Cashiriari 1 yielded information identifying the critical impact that rate would have in maintaining injection performance, and that existing pump availability would be stretched to perform as recommended. Monitoring of performance pressure responses then became even more critical in terms of ensuring that injection could continue such that drilling operations could be maintained on schedule.

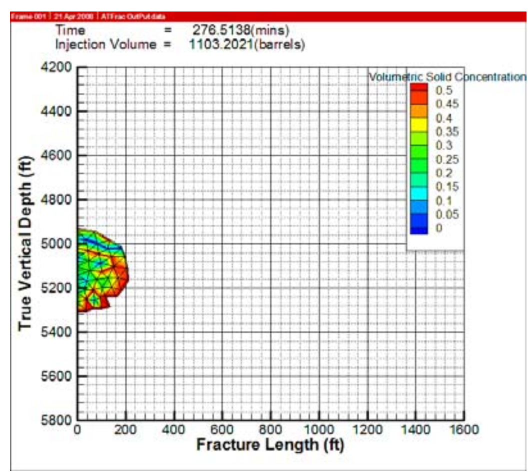

Figure 5: Sample @frac Simulation Output; Cashiriari 1

Following a similar engineering design study for the Cashiriari 3 site, injection testing and analysis, followed by continuous monitoring of injection performance was also implemented at that second phase site. The first formation interval perforated was a somewhat cleaner clayey sand than at Cashiriari 1, more isolated above and below by clay and claystone formations.

Ensuring Success through Monitoring

Monitoring Scheme

Building on the completion of an engineering study and commissioning of a cuttings injection project, the next step forward is the performance of initial injection testing. This process kicks off the monitoring program for the asset. The recommended operating parameters have been based on the best data available, but until the well is tested and begins operations, operating procedures and parameters cannot be finalized.

Initial testing, prior to commencement of injection operations, included the performance of formation breakdown tests, Step Rate Tests (SRT's), and extended falloff tests. These tests provide information/confirmation of anticipated pressures and stress levels in the targeted zone, as well as a determination of formation flow properties and injection performance characteristics. Following review of these data ad any warranted modifications to plan, an initial set of operating parameters can be implemented for early injection batches.

Monitoring and analysis of early injection is critical to maximize future injection performance. The analyses gathered will provide the most accurate picture of injection system dynamics, if the injection parameters in effect maximize performance. Monitoring of all batches at Cashiriari 1 was done on a near continuous basis, with data provided daily for analysis of each batch injection sequence. For Cashiriari 3, an added benefit was the implementation of web-based real time monitoring of the operation, which provides another level of ability to keep an eye on ongoing operations from a remote site while sitting in an office a continent away.

Pressure is the primary continuously monitored parameter, as it is the best real-time gauge of ongoing performance. In addition, injection rate and slurry rheology (including solids content and viscosity) are other parameters of primary importance.

Continuous monitoring of rheology requires frequent sampling, unless inline rheometers are implemented. While basic mud properties, including Marsh Funnel Viscosity, density and retorted solids have value in these operations, low shear rate rheology measure by a viscometer/rheometer can provide much more accurate and beneficial information.

As part of a monitoring program, there are basic analyses used in evaluating day to day performance. For slurry injection in a fracture, two primary analyzed values, which are reviewed and compared daily, are closure pressure and apparent fracture length. The closure pressure provides a handle on the existing stress level in the formation and apparent fracture lengths, as determined with simple analytical functions on a daily basis, provides a comparative description for the health of the injection zone and well.

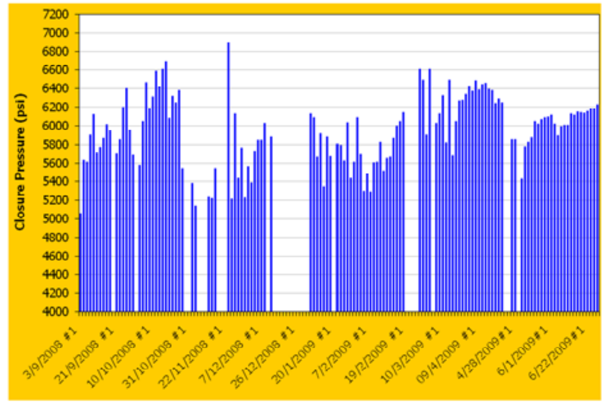

Figure 6: Closure Pressures through Time, Cashirari 1

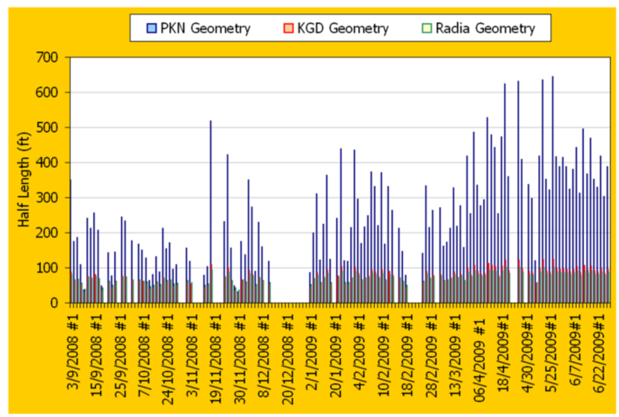

Figure 7: Analytical Fracture Length Estimates, Cashirari 1

Field Results

When injection tests were run, fracture pressures were found to be in excess of 1.0 psi/ft at a depth in excess of 6,000 ft, likely due to the atypical orientation of stresses in the Andes region and the orientation of the wellbore, as well as the presence of plastic clays in the injection zone. Monitoring of early injection batches showed that the small batches and reduced rates were generating rising closure pressures, indicating rapidly increasing stress in the near wellbore region.

Due to the unanticipated formation properties and operational problems that developed, the first and second perforated intervals that were targeted had to be abandoned. The second set of perforations was sanded up due to insufficient slurry rheology when the slurry was left static in the wellbore. Due to the lack of equipment at a remote site to perform remedial work, a third interval was perforated.

Re-analysis was performed to determine if injection could proceed at a lower rate than planned (3.5 bpm vs. 5 bpm), given the limitations of the equipment on hand. Assurance that injection could proceed was required in order to continue with the drilling program. Slurry rheology control, coupled with other operational changes, was recognized as a concern.

Batch size was determined to be a critical factor that could help compensate for the limitations of the equipment on site. Significantly larger batches were recommended and a means to operate in a manner approaching continuous processing was determined to be feasible in the field. When the recommended larger batches were implemented, the rapid increase in closure stress was alleviated. Maintaining slow and controlled increase in closure pressure under the modified operating parameters translated into greater available disposal capacity, allowing drilling to proceed.

Analysis of closure pressures illustrate the impact that smaller batch sizes have on the potential disposal capacity, as shown in Figure 5. The implementation of larger batch volumes altered the slope of the pressure increase trend, which yielded a significant increase in estimated disposal capacity under the existing pressure limitations.

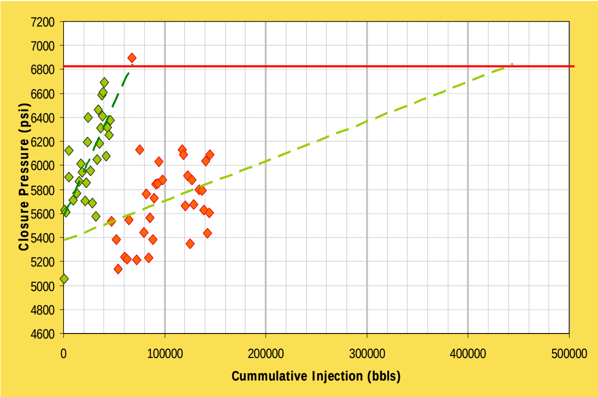

Figure 6: Closure Pressure Responses for Small and Large Injection Batches

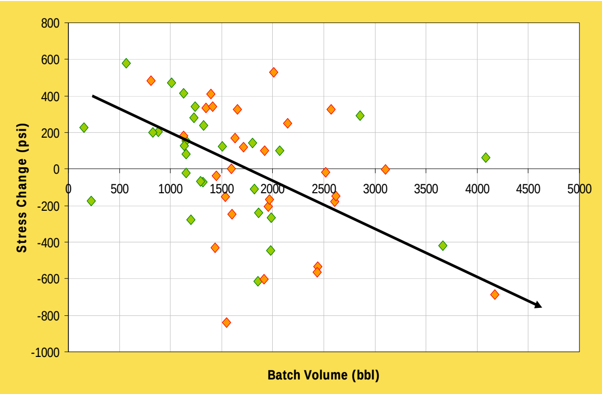

Figure 7: Stress Change vs. Batch Volume

A simple evaluation of the impact of batch size did not however, yield results anywhere near as dramatic. The trend and spread of batch volumes plotted against stress change per batch shows somewhat greater spread than expected. Other factors clearly impacted the stress generated, including batch properties, flush volume and batch sequencing. One indication may be that it takes only a few small batches to have a significant impact. The formation response points to the critical importance of early batch injection parameters on opening and extending the initial fracture in order to achieve maximum injectivity and optimal injection performance. Failure to ensure this occurs could jeopardize an injection project. Real time, or near real time, monitoring of early injection should be a standard and high priority function.

A later plot of closure pressures shows a sharp increase in the slope of the pressure rise over time in February 2009. The monitoring of injection performance resulted in an alert to determine the unknown cause of the increase. Investigations identified an unreported change in the clay inhibitor used, resulting in limited activation of clays within and surrounding the disposal zone.

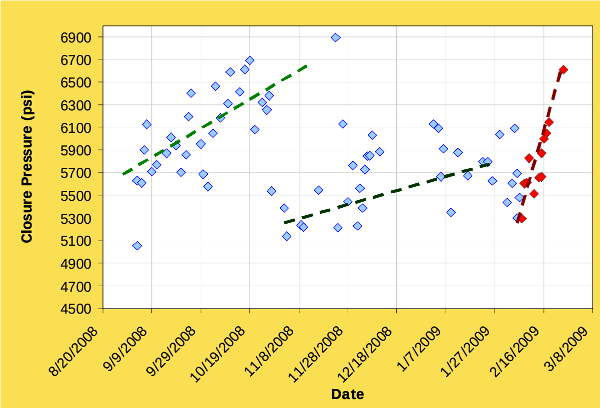

Figure 8: Closure Pressure Monitoring Indicating a Sharp Increase in Slope

On multiple occasions, the monitoring program was able to identify operating issues involving reactive clays and inhibition system changes. Lack of inhibition, or a change in the inhibition program, resulted in measurable increases in closure pressures. Resulting changes in inhibitors greatly moderated the rapid increase in closure pressure and injection pressures.

Subsequent inhibition was standardized and maintained, with the eventual result being a decrease and relative stabilization of closure pressure performance. When another rapid increase in closure pressure occurred again in April 2009, clay inhibition issues were again suspected and confirmed. Further review showed that a reduction in batch size for several days prior to the inhibitor change had reduced the length of fractures being opened and left the system more susceptible clay activation damage. In this particular instance, changes to the inhibition system and larger batches were both implemented to remediate injection performance. Multiple inhibition systems were tried before a return to a previously sufficient system and concentration.

While the multiple changes colors the response somewhat, the significant reduction in closure pressures noted from larger batches and changing inhibition in April and May 2009, it is clear that the correct inhibition system provided for much more stable performance and a lower slope of pressure increases through June 2009.

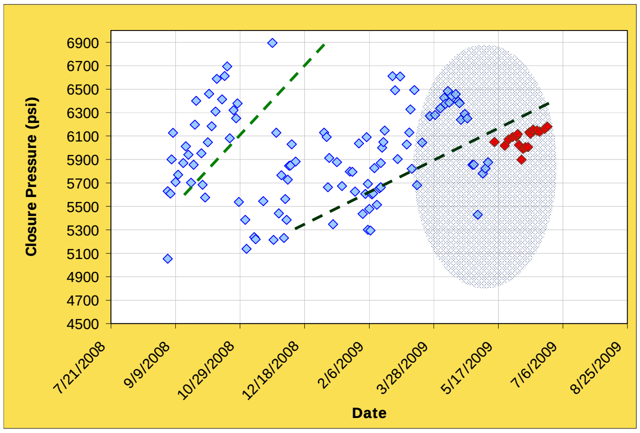

Figure 8: Closure Pressure Monitoring; Increased Batch Size and Inhibitor Adjustment Returns Slope to Desired Trend

Returning to a plot of Closure Pressure versus Time, identification of the inhibitors and concentrations utilized through the time shows that some inhibitors performed notably better than others. Some generated rapidly increasing closure pressures, while others appeared to be providing the desired level of control, at least at sufficient concentrations.

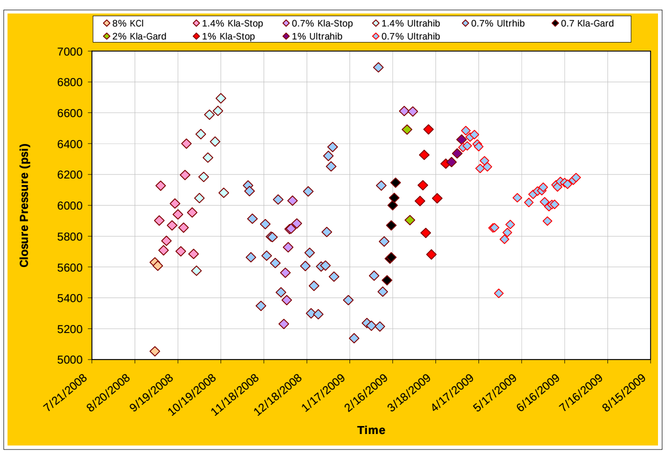

Figure 9: Closure Pressure Responses for Various Clay Inhibition Systems and Concentrations

The presented results are somewhat clouded by the formation response associated with increasing pressures associated with ongoing injection into a particular fracture over a period of time, which is then followed by a pressure breakdown as another fracture is opened, or extension is made, either laterally or vertically, into new disposal volume. As the targeted formation was bounded by thick, young clay formations, a new fracture or lateral extension of an existing one would be the likely candidates explaining the basic cyclical pressure response.

Data Mining: Sensitivity Analyses

For this reason, it was decided to perform some sensitivity analyses employing some limited data mining techniques. In addition to the observed closure pressure response, during the course of the Cashiriari 1 injection project, there were instances when the pressure during shut-in would creep upward. There was also some apparent correlation with some of the clay inhibition system changes that had occurred. This generated interest in determining, or confirming, that the inhibition system was the affecting factor in these occurrences. It should be noted that increasing pressure was observed after the inhibition system had been standardized, which was thought to indicate that the concentration of inhibitor was at the minimum tolerable concentration. In order to investigate these occurrences, the sensitivity analyses were performed to determine the critical parameters affecting the increase in pressure.

While the sample data set was relatively small and did not lend itself to some analyses, those performed identified the type of inhibitor as the primary correlator with increased pressures. Flush volume was identified as the next most significant parameter. The flush is made up of the inhibited water. Inhibitor is not added to the slurry, as inhibition in the waste mud component generally has sufficient inhibition remaining to provide the required protection.

Profile	Inputs	Hidden	Accuracy
PNN	17	80	75 %

Inhibitor Ordering	
Coded	Inhibitor Type and Concentration
1	8% KCL
2	1.4% Kla-Stop
3	0.7% Kla - Stop
4	1.4% Ultrahib
5	0.7% Ultrahib
6	0.7% Kla - Gard
7	1.4% Kla - Gard
8	2% Kla - Gard
9	1% Kla - Stop

- In this model, Inhibitor was ranked as the most affecting variable on the increase in the pressure, followed by the Flush Volume.
- The accuracy of the model is 75 % and the 17 input variables were identified as having effect on the increase in the pressure during the shut in time.

Variable Name	Rank	Direction
Inhibitor	1	+
Flush Volume (bbls)	2	+
Flush Pressure (psi)	3	+
Pad Volume (bbls)	4	-
Shut-in Time (min)	5	+
Flush Rate (bpm)	6	+
Slurry Volume (bbls)	7	+
Slurry Vol. / Flush Vol.	8	-
Cumulative Injected Volume (bbls)	9	+
Total batch Vol. (bbls)	10	+
Slurry Rate / Flush Rate	11	+
Cumulative Slurry Volume (bls)	12	+
Pad Pressure (psi)	13	-
Slurry Density (ppg)	14	+
Pad Rate (bpm)	15	-
Slurry Rate (bpm)	16	+
Slurry Pressure (psi)	17	+

Figure 10: Sensitivity Analysis

Principle component analysis was also used to investigate the relationship between some of the components studied. Flush Pressure, which is dependent on flush rate, was found to be closely correlated with the type of inhibitor in affecting the observed pressure rise. As flush volume is not as significant, this would support the belief that the inhibitor is the primary contributing factor in the observed pressure responses.

These analyses provide some confirmation and insight into issues relevant to injection performance. The process of data mining may also provide more information if performance is evaluated over a much extended period of time.

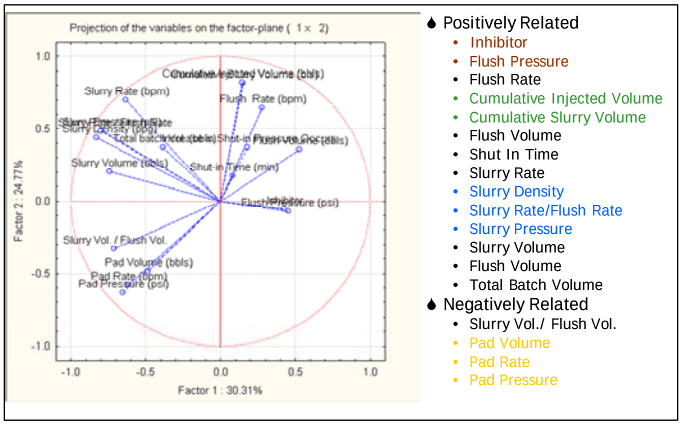

Figure 11: Principle Component Analysis

The injection experience at the Cashiriari 1 pad provided guidance in moving forward with the plan for Cashiriari 3. The lessons learned on the importance of available pump capacity in a high stress regime, maintaining inhibition and the value of monitoring ensured that improvements would be made. The second phase operates with a larger capacity pump and at generally higher rates than in the first phase. The inhibition program has been standardized and has remained constant throughout the ongoing project. Monitoring capabilities have been improved with the aforementioned real time access to injection data through a secure web link. As such, a more consistent picture of injection performance has been made available. The drilling program is over half finished at Cashiriari 3, and injection has been maintained in the initially perforated formation with pressures being maintained at lower levels, despite the fact that injection is taking place at grater depth.

Summary

Throughout the course of the first project, monitoring was essential in ensuring continued operation of the injection program. Injection was performed in a very thin, sandy clay-laden formation surrounded by claystone formations with little disposal capacity. Early injection testing identified issues that required review and consideration before going forward with a plan including modified operating parameters based on engineering analyses and simulations.

The monitoring program was able to provide early notification of potential problems with the ongoing injection operations and ensure that drilling of production wells could continue by providing that the only available means of drilling site waste disposal remained viable. Daily review and monitoring of trends over the course of the project allowed for a constant view of the health of the injection system and operations and recognition of deviations in the expected performance trends. Analyses provided confirmation of the cause of observed deviations, as well as providing a basis for the observed trends and recommendations for actions to be taken to maintain or improve performance.

There is little doubt that the successful injection of over 212,000 bbls of waste at Cashiriari 1 would not have occurred without the implementation of the monitoring program, which provided a window into ongoing performance. The performance of the engineering feasibility study provided for the development of adaptable operating parameters, which provided a basis of understanding of the system. The operation was a success because it allowed the planned drilling program to proceed while providing an environmentally sound and economically acceptable means of waste management. Environmental impact to the preserve was minimized through downhole disposal of generated wastes, requiring minimal footprint and onsite management. Improvements to procedures and capabilities based on first phase performance will help ensure that similar environmental and economic success will be realized throughout the ongoing Cashiriari 3 injection operations.

Conclusions

The Cashiriari 1 drilling program was successfully completed with the complementary success of the drilled cuttings injection operation, which provided acceptable environmental and economic waste management for the operation. The monitoring program implemented and extended to Cashiriari 3 has been a key to achieving success.

- An engineering design study provided workable operating parameters based on formation properties and equipment capabilities.
- Initial testing and monitoring and analysis of early injection batch provided for successful alterations to planned operating parameters and procedures and improvements in performance.
- The ongoing monitoring program repeatedly gave notice of existing or developing issues and provided a way forward to remediate them.
- Monitoring of fracture closure pressure provided a means of identifying inhibition issues, which were confirmed through sensitivity analysis using data mining methodologies.
- Operations on the Cashiriari 3 pad benefited from improvements identified through the operation and monitoring of the Cashiriari 1.

Acknowledgments

The ongoing success of these projects would not have been possible without the input and guidance of Stanley Barrett. Zongyu Zhai was instrumental in the original engineering analyses. Ongoing monitoring, data review and analysis for Cashiriari 3 is provided by Nahla Helmy.

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