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An Overview of Drill Cuttings Re-Injection – Lessons Learned and Recommendations

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ABSTRACT

Drill cuttings re-injection (CRI) into a suitable geological formation through hydraulic fracturing is attracting considerable attention as a cost-effective and environmentally friendly means of complying with environmental legislations. Some of the advantages of CRI or deep well waste-disposal operations are:

- It can achieve zero discharge as no waste is left on the surface.
- There are no transportation risks, as opposed to transportation to another facility and temporary storage.
- There are no future clean-up liabilities once the disposal well is plugged.
- The operator has total control over the waste management process.
- This drilling waste management technology is not limited by location and it has been operated from the Gulf of Mexico to Alaska, from the North Sea to the Sakhalin Islands.
- It often has favorable economics.

Because of these advantages many CRI projects have been carried out worldwide and CRI technology has advanced beyond the development phase and is entering a high growth phase from its development period. While CRI technology is advancing rapidly bringing with it more and larger CRI projects, it also poses a number of challenges as these larger projects are more complicated or critical. CRI project assurance is always a major part of any drilling waste disposal project and can be greatly increased by following a well-planned and integrated process to place adequate barriers and quality controls to prevent potential risks/hazards passing through the barriers to undesirable consequences. This paper presents an integrate assurance process to illustrate the challenges, recent advances, lessons learned and recommendations in CRI project assurance.

BACKGROUND

Oil and gas exploration and production (E&P) companies are responsible for managing drilling wastes in a safe and environmentally acceptable fashion that complies with regulation requirements. Tightening environmental legislation worldwide and operators' environmental policies are reducing options for disposal or increasing discharge costs to the extent that discharge of drilling wastes may not be a future option. Re-injection of oil-contaminated drill cuttings and other associated E&P wastes is attracting considerable attention as a cost-effective means of complying with environmental legislation concerning discharges of drilling waste. Basically, cuttings re-injection (CRI) is similar to loss of circulation of drilling fluids in drilling operations or to conventional hydraulic fracturing operations.

There are many reasons CRI is becoming the often preferred drilling waste management option, including:

Zero discharge: In a broader sense, CRI returns the oily-contaminated cuttings to their place of origin and at the end of a CRI operation, nothing is left on the surface. CRI technology can achieve true zero discharge.

Total operator control: E&P operators are legally responsible for drilling waste management or are liable for any mismanagement of drilling wastes. Since CRI technology manages drilling wastes at the drilling site, the on-site operators have the total control over the process and the CRI contractors, greatly reducing the chances of mismanagement of drilling waste during or after the process.

Worldwide applications: CRI technology is not limited by location; it has been proven to be an environmentally safe and long-term solution for drilling waste management from drilling operations in the Gulf of Mexico (1) to Alaska (2), from the North Sea (3) to the Sakhalin Islands.

Favorable economics: CRI often has favorable economics and this is especially true for multiple well drilling programs. For example, for a twenty-well program in the Gyda/Ula Field, Minton and Last (4) showed that re-injection of cuttings slurry would cost approximately $9.6 million versus $18 million for onshore processing and $39 million for using water-based mud. For two similar wells on the Ewing Bank in the Gulf of Mexico, drill cuttings injection for one well ($104,200) saves 46% over the land disposal for a similar well ($193,700).

RISKS AND RISK MANAGEMENT IN CRI

Although there are many advantages with cuttings re-injection technology, there are without any doubt risks or uncertainties associated with CRI operations. Problems have occurred in some CRI operations and can still occur if not engineered or operated correctly. Some of those include:

- There have been instances where CRI injection wells have become plugged due to improper slurry rheology and improper operational procedures.
- Accidental releases of injected slurry to the environment have occurred in the past.
- Excessive erosion wear from long-term slurry injection has caused some well integrity failures.

In fact, there are many risks and uncertainties associated with any subsurface project and this is especially true for most CRI projects. The uncertainty is in part because drilling waste management plans have to be in place before there is much drilling experience or available geology information. Following are the major challenges and the lessons learned from CRI projects:

Waste containment: Subsurface and fracture simulations are the keys for identifying the suitable injection zones, waste containment and fracture-arrest formations. Good cementing practices also are the key in the assurance process of waste containment, as releases of injected slurry behind casing have occurred during annulus injections.

Slurry design: Slurry rheology design includes insuring the correct slurry viscosity, solid carrying or suspension capacity and optimal particle size distribution. The slurry must have adequate viscosity and carrying capacity to avoid plugging along the wellbore or in the fracture.

Operation procedure design: The injection rate should be high enough to avoid cuttings plugging of the fracture or settling and forming solid beds the along injection annulus or tubular. Due to the intermittent nature of CRI operations, the suspended solids-laden slurry sometimes must be displaced with a solid-free fluid to avoid cuttings settling and loss of injectivity when the suspension time is too long.

Disposal well capacity: Determining the disposal well capacity is the most asked questions and one the hardest to answer precisely. Recent advances in storage mechanisms, modeling and monitoring have made it possible to address this question with an improved confidence.

Equipment sizing and design: Surface equipment failures may be the largest source of CRI problems, ranging from lost time of less than an hour to nearly a day. Grinding may be the most challenging part (but particle size is a very important element to avoid cuttings settling and plugging) in cuttings slurrification operations. There has been limited success with small to medium sized units.

Monitoring and verification: Problems may happen even with the best engineered and executed projects. Monitoring and verification of CRI operations are integral parts of the operation's quality assurance process, and often can lead operational procedure changes and minimize or avoid many problems.

The key for managing the potential risks/hazards is to place multiple barriers or controls between the hazards and undesirable consequences, as shown schematically in Figure 1, to prevent the potential hazards from becoming undesirable consequences. Multiple quality controls or risk management procedures include valid geology and well data evaluation, advanced hydraulic fracturing modeling, injection well testing and model validation, and monitoring during the CRI operation, as shown in Figure 2. The rest of this paper will address some of the issues raised here.

GEOLOGY EVALUATION AND CONTAINMENT ASSURANCE

In any drilling waste disposal operation, safe containment of the injected waste must be assured. The extent of the fracture created by CRI operations must be predicted with confidence.

This is often accomplished with hydraulic fracturing simulators. Owing to the large volumes of waste slurry injected, the created fracture can be very large, thereby making fracture extent prediction critical in containing the waste to the desired formation. Waste containment mechanisms must be evaluated during feasibility studies to identify the possible disposal zones and fracture containment zones. Thorough evaluation of the geology and well information includes logging, well testing, and core analysis along with rock mechanics testing. The geo-mechanics model for hydraulic fracturing simulations must be based on the geology evaluation results as shown schematically in Figure 3. Hydraulic fracturing simulations are used to identify containment formations. Three fracture containment mechanisms are particularly important in selecting disposal formation:

Stress barrier: Formations with fracture gradients larger than the fracture gradient in the target injection zone can often prevent the fracture from going into the high stress zones. Figure 4 shows a case example of fracture containment due to a stress barrier. Overlaying formations with increased fracture gradients such as salt formations are ideal containment or sealing formations.

Modulus barrier: Figure 5 shows a case example from a CRI well in Nova Scotia, Canada. In this case, the fracture is contained by a limestone formation which has a higher elastic modulus. Once the fracture approaches or enters the harder or stronger formation, the width of the fracture in and near the stiffer formation is reduced, hence the frictional pressure is increased, preventing or slowing fracture growth into the formation (5).

Permeability barrier: Figure 6 shows an example from a North Sea CRI well, where the fracture is contained by a high permeability formation. As illustrated, the fluid leaks into the high permeability formation and the cuttings particles are left behind, thus preventing the fracture from growing in the high permeability formation (6). However, as formation damage increases with continued slurry injection, this original barrier may not continue to act as a barrier.

The key in identifying the containment formation in cuttings re-injection projects is to conduct hydraulic fracturing simulations based on valid geology and operational data.

MODELING OF UNCERTAINTIES

In general, the drilling waste management plan for a CRI project must be in place before drilling commences, thus leading to uncertainties in sub-surface information. Therefore, modeling of uncertainties and risks are particularly important for CRI design and engineering.

Since each uncertainty has different distribution and its impacts on CRI operation or assurance parameters are different, a probabilistic approach has been developed recently to generate a risk-based result (7). Figure 7 shows the risk analysis results on the prediction of fracture extent from a sample wellbore. As shown in Fig. 7, there is a 90% confidence that the fracture extent from the wellbore will be larger than 230 ft and smaller than 270 ft, while the P50 value of the fracture extent is 250 ft. Based on this result, it is safe to say that a well spacing of 300 ft may be adequate to avoid drilling a live well into a disposal fracture.

This risk-based approach can be applied to modeling of other important CRI parameters. Figure 8 shows a case example of disposal capacity with different levels of confidence. As shown there is a 90% confidence that at least 31,000 bbl of cuttings can be safely injected into this well. Assuming 20% cuttings by volume in the slurry, this means that it is safe to say that disposal capacity of this well is at least 155,000 bbl of slurry, because the injection zone is permeable sandstone formation and fluid can readily leak off, thus the fluid volume impact on disposal capacity can be disregarded in this case.

SLURRY RHEOLOGY AND OPERATIONAL PROCEDURE DESIGN

One of the major risks in CRI operations is that the injection well could potentially become plugged if the cuttings particles settle on bottom, which is especially risky in deviated wells. This settlement is a result of inadequate slurry viscosity, inadequate injection rate, large particles or long residence time. Following are keys to avoiding settling and plugging:

Slurry rheology: The Fann Model 35 viscometer is used to measure the slurry rheology properties, such as apparent viscosity at different shear rate and gel strength at different temperatures. Low-shear-rate slurry viscosities and gel strengths at different temperatures are also required in cuttings settling models to simulate settling during shut-ins between batch injections. Therefore, to provide realistic modeling information, the slurry must be representative, both from the drilling of shale formations and from the drilling of sandstone formations.

Particle size distribution: Particle size distribution (PSD) has a significant impacts on particle settlings and is required for cuttings transport and settling simulations. PSD should be measured in the laboratory from slurries generated from drilling the sandstone formations because particle size from sandstone is often the largest.

Operational procedure design: A numerical simulator has been recently developed to simulated cuttings transport in CRI operations and manage the settling risk by optimizing the slurry viscosity, particle size distribution, and designing the residence time or shut-in time between injections. Figure 9 shows a CRI injection well trajectory. During the shut-in periods between injections, the particles can settle on the lower side of the well, forming a solid bed and sliding down the well. The shut-in times between injections must be designed such that it is short enough to avoid plugging of the perforations from the settling of cuttings. Figure 10 shows a numerical simulation results on solids bed formation and bed-sliding velocity.

MONITORING AND FEEDBACKS

Problems can still happen even with the best engineered CRI projects. Monitoring and timely feedbacks to drill cuttings injection operations are an integral part of the operation’s quality assurance process. The extent to which various regulatory bodies require monitoring and verification vary considerably by jurisdiction and would probably be included as a specific stipulation of the permit. However, irrespective of regulations, it is in the interest of the operator to have a well-defined monitoring program to ensure good quality control of slurry properties and strict adherence to operational procedures. It is very helpful in assessing and validating fracture extent if the operational data, such as injection pressure and rate, are monitored and recorded continuously (Figure 11). Detailed analyses on the pressure decline data after slurry injections could show fracture height recession over multiple zones during the shut-in periods. For example, the pressure and pressure derivative plots versus G-function as shown in Figure 12 have the signatures of fracture height recession over multiple zones (8).

SUMMARY

1. If engineered or operated correctly, cutting re-injection is an environmentally safe, cost-effective and long-term solution for drilling waste management option.
2. There are always risks and uncertainties associated with CRI projects. The key for managing the potential risks is to place multiple barriers or controls between the hazards and the consequences to prevent the potential hazards from reaching the undesirable consequences.
3. Waste containment modeling, based on valid geology and operational data, is a must in CRI assurance and engineering process.
4. A risk-based modeling of important parameters is an important step in CRI assurance.
5. Loss of injection well from cuttings settling and plugging can be avoided by proper design of slurry rheology and operational procedures. A cuttings transport numerical model can assist in designing the slurry and operational procedures.
6. Monitoring and timely feedbacks to CRI operations are an integral part of the operation assurance process to minimizing problems.

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REFERENCES

1. Louviere, R.J. and Reddoch J.A., “Onsite Disposal of Rig-Generated Waste Via Slurrification and Annular Injection,” SPE 25755, SPE/IADC Drilling Conference, Amsterdam (February 23-25, 1993).
2. Guo, Q., Abou-Sayed, A.S., and Engel, H., “Feeling the Pulse of Drill Cuttings Injection Wells – A Case Study of Simulation, Monitoring and Verification in Alaska,” SPE 84156, 2003 SPE Annual Technical Conference and Exhibition, Denver (October 5-8, 2003).
3. Minton, R.C. and Secoy, B., “Annular Re-Injection of Drilling Wastes,” SPE 25042, 1992 European Petroleum Conference, Cannes, France (November 16-18, 1992).
4. Minton, R.C. and Last, N.C., “Cuttings Slurrying & Re-Injection - Two Years of Experience from the Gyda Platform,” 7th Annual Offshore Drilling Technology Conference, Aberdeen (November 1993).
5. Guo, Q., Dutel, L.J., Wheatley, G.B., McLennan, J.D. and Black, A.D., “Assurance Increased for Drilling Cuttings Re-Injection in the Panuke Field Canada: Case Study of Improved Design,” IADC/SPE 59118, 2000 IADC/SPE Drilling Conference, New Orleans (February 23-25, 2000).

6. Abou-Sayed, A.S., Guo, Q., McLennan, J.D. and Hagan, J.T., "Case Studies of Waste Disposal Through Hydraulic Fracturing," Three Dimensional and Advanced Hydraulic Fracturing Modeling Workshop, Seattle (July 29, 2000).
7. Guo, Q., Geehan, T. and Ovalle, A., "Increased Assurance of Drill Cuttings Re-Injection - Challenges, Recent Advances and Case Studies," IADC/SPE 87972, IADC/SPE Asia Pacific Drilling Technology Conference, Kuala Lumpur, Malaysia (September 13–15, 2004).
8. Nolte, K.G.: "*Reservoir Stimulation,*" 3rd Edition, M.J. Economides and K.G. Nolte (editors), Chapter 9, 40 – 44 (2000).

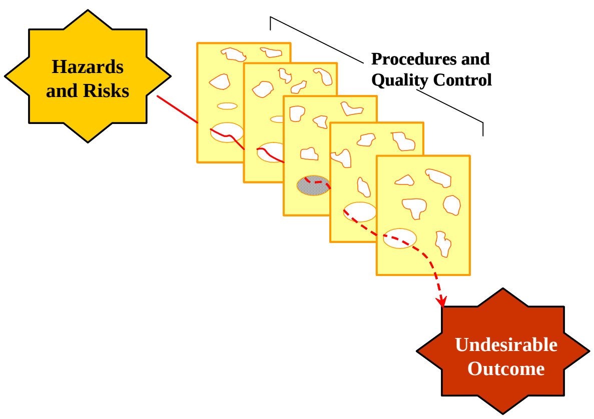

Figure 1. Schematic of barriers and controls to prevent risks from causing consequences.

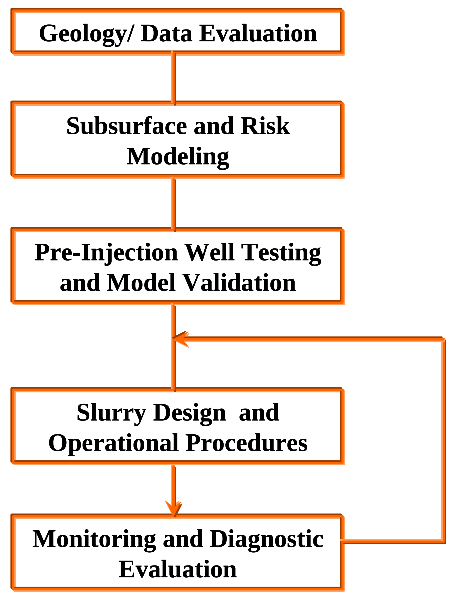

Figure 2. An integrated CRI assurance process and flowchart.

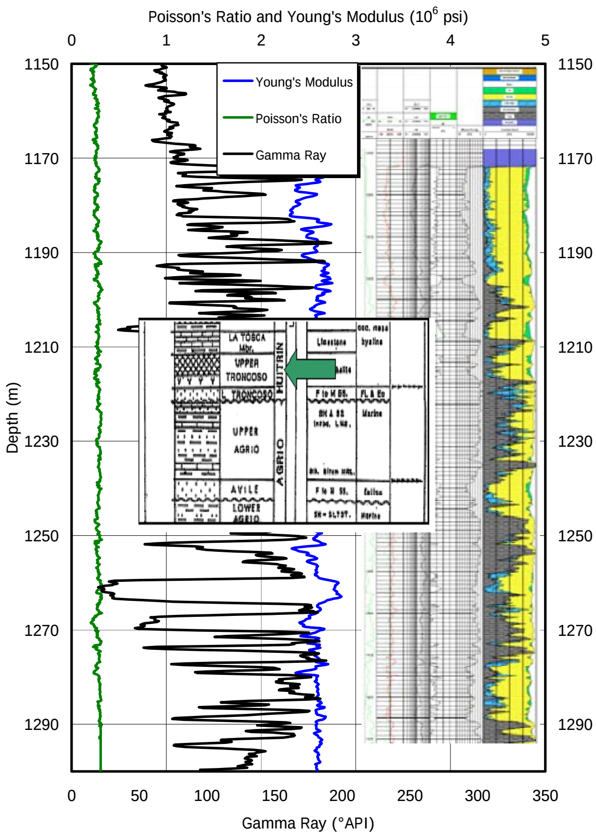

Figure 3. An example of geology evaluations for hydraulic fracturing model setup.

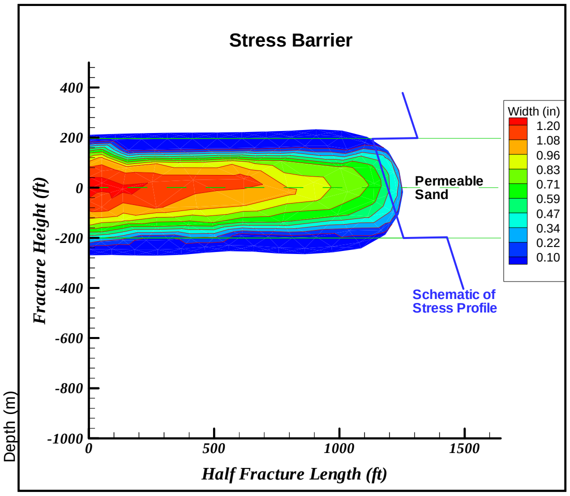

Figure 4. Fracture containment due to stress barrier.

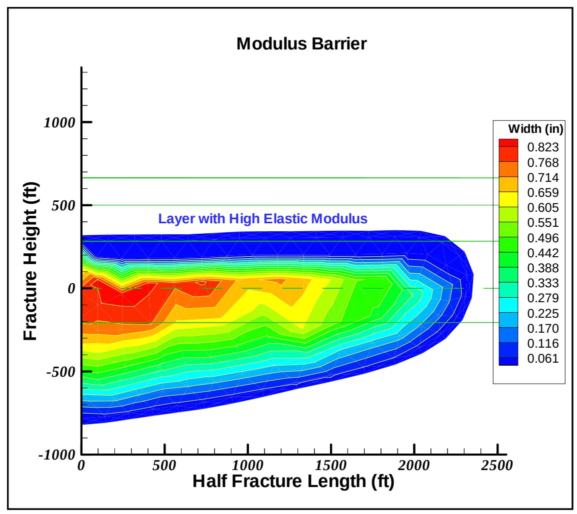

Figure 5. Fracture containment due to modulus barrier.

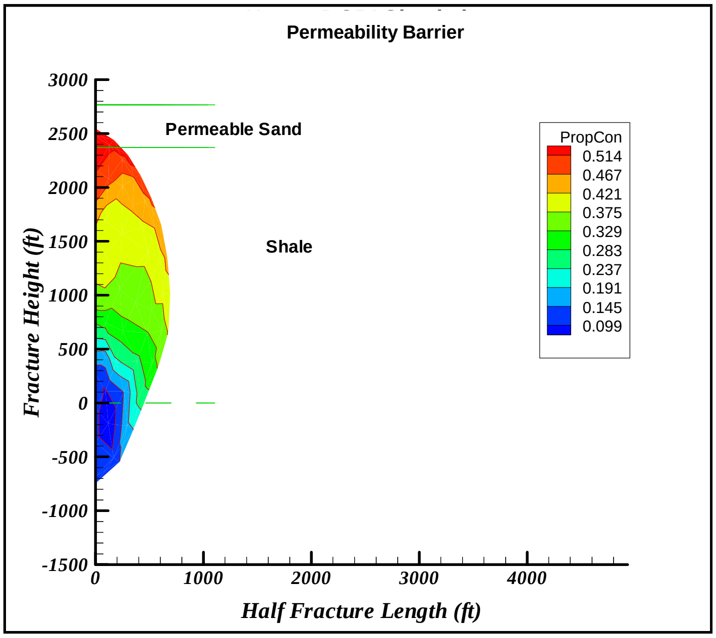

Figure 6. Fracture containment due to high permeability barrier.

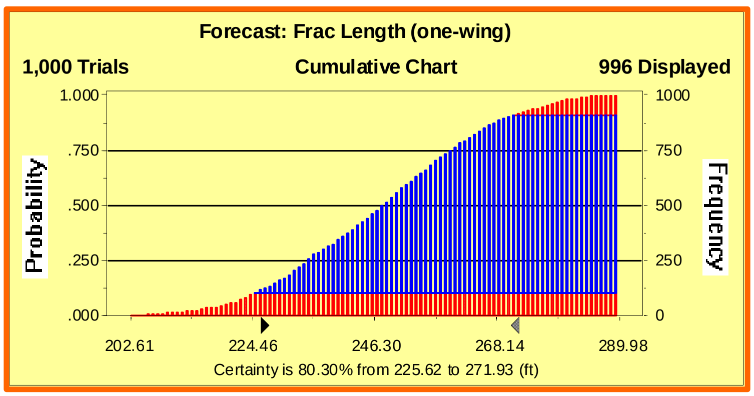

Figure 7. A case study of risk-based modeling of important CRI operation and assurance parameters.

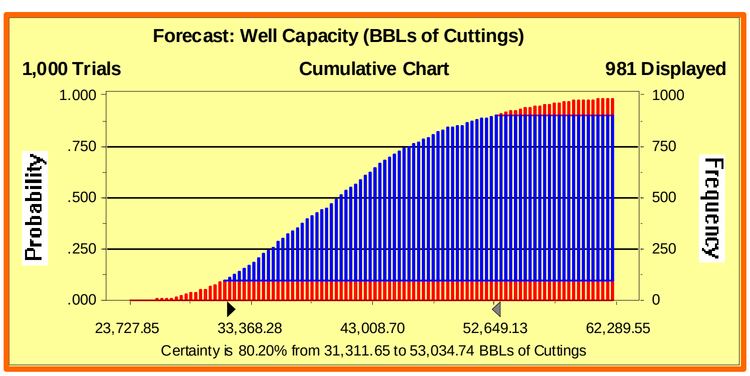

Figure 8. A case example of risk-based modeling of disposal well capacity.

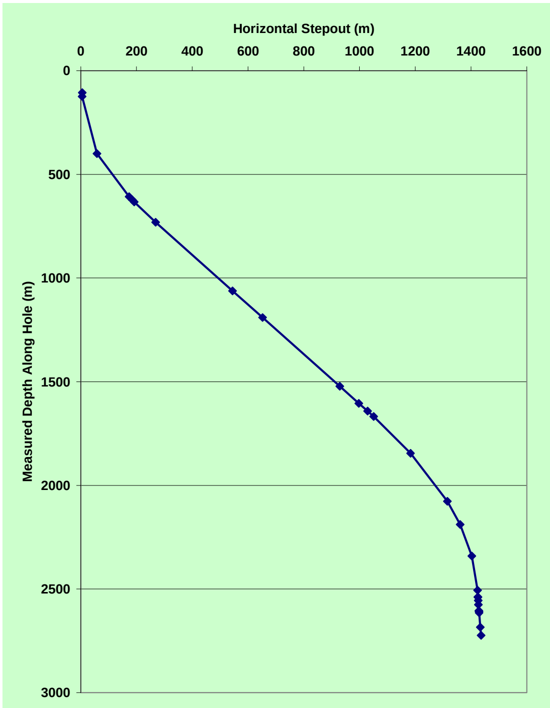

Figure 9. Well trajectory for a solid transport simulation.

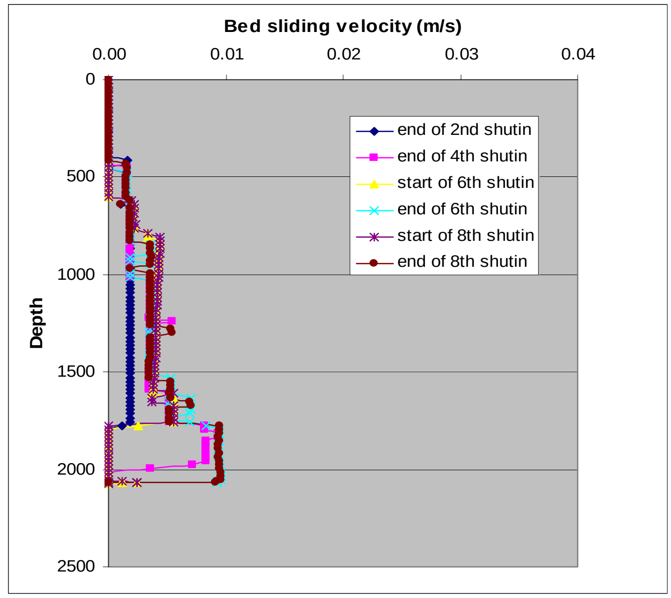

Figure 10. An example of numerical simulation results on solid bed sliding before and after shut-ins.

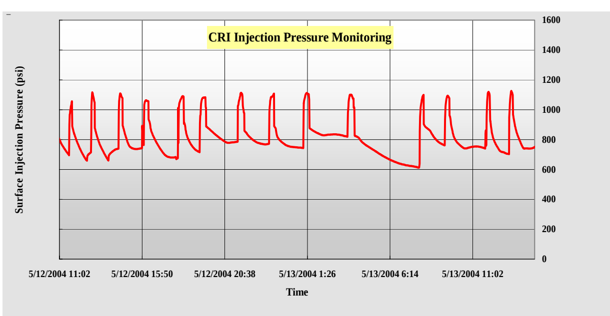

Figure 11. CRI injection pressure data monitoring.

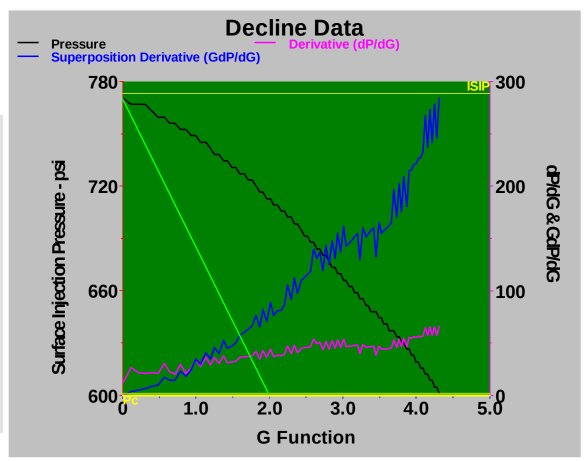

Figure 12. Pressure decline data analysis and fracture extent monitoring using G-function. The pressure data shows features of fracture height recession over multiple zones.