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AADE 2009-NTCE-16-01: DO'S AND DON'TS IN DRILLING WASTE INJECTION WITH CASE EXAMPLES

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Abstract

Drill cuttings re-injection (CRI), or more generically drilling waste injection into subsurface strata often is the preferred safe and cost-effective option for handling wastes generated during the drilling operation. Owing to its capacity to return oily cuttings to their place of origin, this technology allows operators to safely and economically achieve zero discharge. When the technology started about a decade ago, injection into a single well had a maximum slurry volume of approximately 30,000 bbl. Now, particularly in very large projects, several million barrels of slurry may be injected into a single well, which, in comparison, represents more than 1,000 times the volume of a typical hydraulic fracturing job or more than 100 times that of earlier cuttings re-injection jobs.

While CRI operations have continued to gain acceptance around the globe by providing a safe and environmentally acceptable means of oilfield waste disposal, if the technology is to maintain its excellent track record it is critical that operations follow best practices for evaluation, design, implementation and monitoring. This is particularly important for CRI projects in remote or environmentally sensitive areas as often this technology is the only economical option and any mishaps with the operation could prove very costly on a number of fronts.

This paper describes the challenges faced in CRI operations and the recent advances and experiences gained in tackling these challenges. Case examples will be presented to illustrate the lessons learned and the best-practice recommendations to ensure successful CRI operations.

Introduction

Drilling waste injection, commonly known as cuttings re-injection (CRI) plays a vital role in drilling waste management within the E&P industry. Although the injection of cuttings and other drilling wastes into sub-surface formations may not be applicable to every drilling operation in every region, waste injection provides a proven means for the disposal of drilling waste in a safe and environmentally acceptable manner. This is especially true for drilling operations in remote, environmentally sensitive and/or logistically challenging regions. For example, in zero-discharge situations, only two viable options are available to the operator. First, the solids can be collected and shipped to shore in the so-called skip-and-ship process, after which they are treated or disposed of in available landfill. These operations require accessible land-based waste management facilities and transportation logistics. Alternatively, waste materials can be injected downhole, ultimately returning these materials to their source.

Major Drivers for Adopting Waste Injection

Although waste injection operations have significant benefits, they are not a universal panacea. The major drivers for adopting waste injection option are:

- ***Regulatory/Economic Requirements:*** Many of the waste injection projects in the North Sea[1,2] were selected because it was either impossible for other drilling waste disposal options to meet local regulatory requirements or else they were prohibitively expensive.
- ***Remoteness and Logistics:*** An illustrative example of this driver is drilling operations in the Sakhalin Islands,[3] which is ice-free only about six months of the year. Owing to the harsh climate, other drilling waste management and onshore treatment options would limit the drilling operational window. Drilling waste injection allows year-round drilling operations.
- ***Environmental and Weather Related:*** Arctic operations in Alaska and elsewhere clearly illustrate this driver.[4,5] The logistics and environmental sensitivity under arctic conditions also made other options either impossible or prohibitively expensive.
- ***Availability of Other Options:*** A major reason drilling waste injection is not widely adopted in the Gulf of Mexico is the extensive availability of other more cost-effective drilling waste management options available.

Major Risks Associated with Waste Injection

The major barriers to adopting drilling waste injection into subsurface strata are the below surface and operational risks associated with this technology. Subsurface risks include uncertainties and risks from geology, containment of injected waste and disposal well capacity, among others. Further, since drilling waste injection is nearly always in the overburden formation above the reservoir, which is the primary focus of formation logging and evaluation, subsurface uncertainties also include those related to subsurface geology and formation properties. Failure to manage subsurface uncertainties can cause a sudden loss of the injection well and/or environmental contamination from breaching of the injected waste.

The surface and operation risks relate to failures of slurry processing and pumping equipment. Any failure in the waste injection operation potentially can bring the drilling operation to a halt and, consequently, lead to very expensive non-productive time (NPT).

A proven approach to managing surface and operation risks is to de-couple the drilling and injection operations, including incorporating cuttings storage in the injection operation. Accordingly, if any temporary failure in slurrification or injection occurs, the cuttings generated from drilling can be stored, processed and injected later without any interruption to the drilling operation.

Risk Management and Case Examples

Potential waste injection uncertainties and risks may be identified and managed through the systematic approach shown schematically in Fig.1.[6] As illustrated in the example:

- First, a solid understanding of the geologic venue is acquired from drilling experience, core data, logging data, and other sources. An evaluation of the geological parameters affecting potential injection operations, along with other basic project data, such as the drilling plan and cuttings generation schedule, is performed to provide a 'first pass' assessment project feasibility for the designated area.
- Next, the acquired data may be used to construct a geomechanical model for use in an injection simulator. Ranges of operating parameters are established on the basis of the "first pass" evaluation. Simulations subsequently are run and sensitivity analyses performed to predict optimum operating parameters based on the assumptions made and the anticipated volumes of injected waste. Numerical simulations are used to investigate issues such as where to inject, how much can be injected, fracture extension, potential risks and so on.
- The optimal operating parameters determined in the model are used to define the injection equipment, facilities configuration and operating specifications required to optimize performance of the injection well. Logs of the actual well are evaluated and the completion depths and planned operating procedures are refined. Any variances from the anticipated geological profile are noted for consideration during the validation procedures. Based on the defined equipment, facilities, well parameters and predicted subsurface performance, operational procedures and protocols are developed and implemented to provide operational assurance for the project.
- Before the actual waste injection, injectivity tests should be performed on the disposal well to ascertain the real formation properties and anticipated responses. These findings are used to validate the geomechanical and injection models and could aid in fine tuning operating parameters before the injection is implemented.
- During operations, injection-pressure monitoring and assessment of injection performance provide the basis for any necessary adjustments to procedures caused by any anticipated changes and unforeseen upsets that might be indicated in analyses. If potential or developing risks are indicated, mitigation procedures can be implemented to avoid or minimize negative impacts. The mitigation options may include supplementary monitoring technologies, as well as changes in operational procedures.

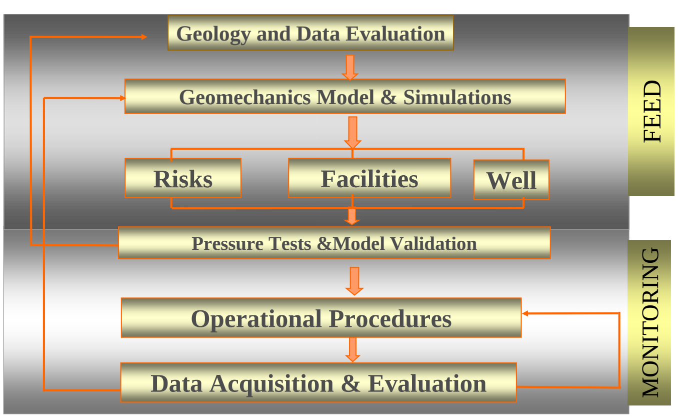

Figure 1: An integrated injection risk management and assurance process flowchart.

Case Example 1

This example from the Norwegian sector of the North Sea demonstrates the value of a feasibility study in identifying the suitable injection formation to ensure the safe containment of injected wastes. The operator had attempted cuttings injection operations, but after two incidents of releasing the injected slurry through the seabed, questions arose on the suitability of the selected injection formation. Consequently, a feasibility study was commissioned with the following major objectives:

1. Identify the suitable injection formation and the waste containment formation.
2. .Evaluate how much can be injected into the disposal formation safely without risking waste containment failure.

The challenges in this study were that the data from the offset wells were incomplete and inconsistent. Correlations had to be created and extrapolated to get a complete suite of logs for analysis to derive the information for the set up of a geomechanics model. This created additional uncertainties, and thus sensitivity analyses had to be carried out to identify which ambiguity had the biggest impact and how to reduce the uncertainty from data acquisition during drilling of the injection well.

The logging analysis identified a strong chalk formation, both in terms of elastic modulus and fracture gradient. Hydraulic fracturing stimulations showed a sandy shale formation approximately 500 ft below the chalk formation would be a suitable injection formation. The chalk formation would then serve as the waste containment barrier. Formation integrity tests during drilling of the injection well confirmed the logging analysis results on fracture pressure and thereby assured the waste injection containment analysis. Injection operations in the last 4 years in the field verified waste containment assurance.

Case Example 2

An example from the UK sector of the North Sea demonstrates the value of risk identification and management through injection pressure monitoring and evaluation. In this annular injection well, injection pressure was recorded continuously during pumping and shut-in. Evaluation of the pressure showed the signature of a blockage between the annulus and the injection zone. The potential risk was complete loss of the injection well without any available backup plan.

A review of the drilling and completion records showed the cementing volume was calculated incorrectly, allowing it to intrude into the supposedly open annulus, which was validated by a review of the cement bond log. The log showed the cement had entered the supposedly open annulus for about one meter, therefore blocking the open connection between the annulus and the injection zone. The injected drilling cuttings slurry was entering the disposal formation through thin channels between the casing and the cement that got into the annulus.

Once the problem was identified, the drilling waste injection operation was modified to keep the annulus operational as long as possible, before the second open annulus became available. The review also noted that:

- No loss circulation materials (LCM) would be allowed to be injected into this injection well. The LCM was used in the drilling operations and recovered material was earmarked for injection in the disposal well, as per the original injection operation procedure. Once the blockage was identified from the monitoring, no LCM injection was allowed.

- Seawater injection every 12 hr was commenced, and later every 6 hr, to cool the well and keep the thin channels open.
- The annulus was kept open for approximately two months before a second open annulus became available for drill cuttings injection. In fact, the previous annulus was lost just when the second became available. Were the blockage not identified from monitoring and evaluation, unexpected loss of the previous injection annulus would cause logistics problems and drilling non-productive time.

Case Example 3

An injection operation in the Sakhalin Islands[7] demonstrates the value of integrating an engineering study, monitoring and operation to manage a high-risk injection project. A host of uncertainties and risks existed in this injection project, not the least of which was the lack of any offshore cuttings injection experience in this area. The only onshore waste injection project showed extremely high injection pressure and several incidents of complete loss of injectivity. Previous attempts in three injection wells from this drilling platform ended with failures with the first unable to reach the targeted injection formation due to drilling problem. The second attempt failed to accept the injected fluids when the pressure reached its limit. While the third injection annulus commenced successfully, it plugged from cuttings settling after a short period of slurry injection. The only available option was to convert a deviated well to a cuttings injection wellbore, which was intended for future use as a producer. Therefore, the well was not ideal and posed a number of risks related to the proposed drilling waste injection operation. Making things worse, this well is the only option and loss of this well would have delayed the drilling program for at least a year. Therefore, managing the risks and uncertainties was critical.

Since the previous injection annulus failed unexpectedly, it was essential to establish successful injection operations as soon as possible. The CRI contract was awarded while the dedicated injection well was being drilled and the surface facilities already installed and commissioned. This mandated designing suitable slurries and appropriate operational procedures to match the facilities, thus imposing additional constraints on operational procedures for risk management. Accordingly, the implemented risk management and assurance plan initially was extremely conservative so the injection operation could be reinitiated and drilling operations could be resumed as soon as possible – all without plugging the well. For example, the initial plan required a pumping rate of 6 bbl/min, which was the maximum rate the pump could deliver for a short period of time. Further, at the outset the required slurry was specified with high low-shear-rate viscosity while good grinding of the cutting particles was requested to avoid particle settling and plugging of the injection well. Injection pressure data from every injection was recorded and analyzed for the first couple of weeks. Based on the monitoring results, the operational requirements were relaxed with confidence. The pumping rate, for example, was reduced from 6 bbl/min to 5 bbl/min and finally to 4 bbl/min within two days, thus avoiding a high possibility of injection pump failure while operating at 6 bbl/min. Furthermore, the slurry rheology requirement was relaxed after a week, thereby reducing the difficulties of slurry processing. Careful engineering and monitoring made this high risk injection project a big success. The injection well is still operational after almost five years, with no subsurface problems and only a few minor equipment problems related to slurry processing and handling.

Summary and Concluding Remarks

- Drilling waste injection into subsurface strata may not be the best option for every drilling operation, but can be particularly attractive for certain projects, such as drilling remote or environmentally sensitive areas.

- The barriers to adopting this drilling waste management option are the risks and uncertainties associated with the subsurface and the injection operations.

- The key to the success of CRI operations is to manage the subsurface and injection operation risks through feasibility studies, pressure monitoring and de-coupling drilling and injection operations.

- Field examples demonstrated that the approach proposed is cost effective and beneficial.

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