Drilling in environmentally sensitive areas of East Africa requires operators to consider both technical and environmental criteria when treating and disposing of cuttings and excess drilling fluids. In less technically demanding exploration wells, Tullow Oil sought drilling fluids with green credentials, but recognised that a system with improved technical performance was necessary to drill more demanding, high angle and extended reach wells.

**Drilling fluid selection for environmentally sensitive areas**

In a thorough study of shale characterisation and inhibition testing, seven drilling fluids—including six water-base muds (WBM) and one synthetic-base mud (SBM)—were evaluated to determine a simple ranking for technical and environmental performance as well as treatment and disposal options for each fluid.

The SBM was the strongest technically, followed by an amine-modified high-performance WBM system. Both systems can be combined with technoeconomically feasible treatment and disposal options that minimise environmental impact.

**Introduction**

Tullow requested a fluid selection study with cores from fields of interest. The study was conducted to support the drilling fluid design and recommendations for future development of an East African basin. A total of 108 core samples were available, with 15 selected based on depth and fields with the most similar properties as the zones of interest.

Selected core samples from two wells were used to evaluate the rock/fluid interaction of formation samples with different drilling fluids. Six laboratory techniques evaluated the stability of the rock samples. Samples from Well A were used for testing with base fluids (brines) and the samples from Well B were used for testing with the fully formulated drilling fluids.

Testing was split into two phases, with the first examining formation material and surmising the best fluid-rock interaction. The second phase determined the rock behavior with the selected fluids.

**Shale characterisation**

In Phase 1, shale characterisation was determined by the shale mineralogy and Cation Exchange Capacity (CEC) data using the semi-quantitative X-Ray Diffraction (XRD) analytical method. These tests provided information on minerals and their relative abundance in the shale and shale reactivity. Thin section analyses of core samples from the field provided a more qualitative description of the rock with respect to principal mineral, mineral with distribution of the rock, qualitative description of the rock, presence of fractures and orientation, and grain size ranges.

Phase 2 included a shale inhibition and stability study. With the XRD/Thin Sections and CEC results, the fluid formulation was optimised for enhanced shale inhibition study. Tests to evaluate the formation and drilling fluids included examination of bulk hardness, dispersion testing, accretion testing, linear swelling, immersion testing, capillary suction tests, X-Ray Diffraction, and CEC.

Fluid systems for study included:

- Fluid 1: Fresh Water/PHPA/PAC/XCD WBM
- Fluid 2: Fresh water/potassium Acetate/PHPA/PAC/XCD WBM
- Fluid 3: Amine-base high performance WBM
- Fluid 4: SBM
- Fluid 5: High performance WBM-low conductivity (modified amine)
- Fluid 6: Fresh water/potassium chloride/PHPA/PAC-polymer mud
- Fluid 7: Fresh water/low potassium acetate/PHPA/PAC/XCD polymer WBM

The team applied elements of several quality targets from various published discharge guidelines in the country and also applied internationally recognised treatment targets for determining the appropriate conditions of solid and liquid effluent released to land and water. Regulatory guidelines allowed the team to compare the fluids against a benchmarked goal during development and assessment.

Common elements of concern found in drilling and completions fluids when assessing the environmental impact of the waste included: total suspended solids (TSS), salts/ions, hydrocarbons, heavy metals, waste minimisation and treatment of the waste, the methods available to treat the wastes, and identifying benefits of the treatment.

To consider environmental impacts, the study...
focused on the two phases of the system, the solid cuttings and the liquids (mud and water) that are used, separated and disposed of during the operation.

**Immersion test**

For the immersion test, the sample in the paraffin-base oil was not affected by the fluid. The sample in the 10 per cent KCl was the less affected for water-base fluids. Immersion testing showed that 10 per cent KCl minimum was needed to keep the sample intact. The addition of amine improved inhibition. The paraffin-base oil showed the best inhibition.

Fluids containing amine and the SBM showed no or negligible accretion. The potassium acetate/low molecular weight PHPA (LMW-PHPA) exhibited 8.1 per cent accretion while the freshwater/low molecular weight PHPA fluid showed 37.2 per cent.

Bulk hardness testing showed that Fluid 4 and the Fluid 3 system exhibited the best results. High dispersion tendency in freshwater and a significant increase in recoveries were obtained with the drilling fluids. Data showed that the PHPA/PAC system had the lowest performance.

Lowest conductance was exhibited by Fluid 4 and the high performance Fluid 5, 0.5 μS/cm and 1.2 mS/cm, respectively. The lowest Capillary Suction Test (CST) values were obtained utilizing fluids: 5 ppb potassium acetate in freshwater,

25ppb potassium acetate in freshwater, and 25 ppb (seven per cent wt) KCl.

Thin sections analyses indicated pore sizes mainly ranged from 50 to 130 microns. The maximum pore size is ~150 microns. XRDs showed that the formation consisted mostly of quartz and kaolonite. The cores were unconsolidated plugs with the presence of clay. The presence of kaolonite is generally the cause for fines migrations when producing the well.

A variety of fluids were considered technically capable of drilling the zone, but the team questioned whether their environmental rankings complemented the practicality after considering constituents of concern in each fluid, the total waste volume and the treatment options. The fluids all shared many of the same components

**Fluid rankings**

Fluid 1 was given an environmental ranking of an A because of its low electrical conductivity (ion content), the high potential for biodegradation of the suspended solids in the form of polymer, and the minor impacts that would occur from an unplanned release or spill of the fluid. Negative points were given because of the potentially large volume created and required for disposal.

Fluid 2 received a D ranking. Although it has a high potential for degradation and a high rank for inhibition, the electrical conductivity is very high, especially in the liquid phase. With low intensity treatment on site it would take several months to treat the water to acceptable discharge levels, making it impractical for operations.

Fluid 3 received a B ranking. The electrical conductivity is originally much lower than the acetate while still providing good inhibition. However, the fluid would need to be treated to remove residual conductivity and the biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The treatment may not be able to achieve the low values set for water discharge in a reasonable timeframe.

Fluid 4 had a rating of 10. Lab tests indicated that the SBM provides a very high amount of inhibition. The expected washout in the hole would be very low (roughly 10 per cent or less depending on the formation), greatly reducing the cuttings generated. With the high inhibition, the amount of dilution to maintain the low solids in the active mud system should be low and solids control should be able to remove the majority of solids, allowing the base mud to be reused for other wells.

A rating of nine was given to Fluid 5 as the lab test indicated that the amine-base high performance WBM provides a high amount of inhibition. The expected washout in the hole would be in a low range (roughly 15 per cent or less), reducing the cuttings. With the high inhibition, the amount of dilution to maintain the low solids in the active mud system should be low.

A rating of eight was given to Fluid 6. Lab tests indicated that Fluid 6 provides high inhibition. The expected washout in the hole would be in a low range (15 per cent or less) with reduced cuttings and low dilution required to maintain low solids.

The environmental ranking is a D due to the high initial electrical conductivity of the fluid and the low potential for biodegradation of the ions once they enter the environment. The ranking also
Lab tests indicated that the SBM provides a very high amount of inhibition.

reflects the lack of adequate treatment to remove the source of contamination.

The rating of eight to nine in lab tests of Fluid 7 indicated that the WBM provides a high amount of inhibition with an expected washout in the hole of 15 per cent or less, with reduced cuttings and a low amount of dilution required. The fluid was given an environmental ranking of C. Even after lowering the potassium acetate content the initial exchange capacity was still high. The minimisation of the additive improved the ranking from the previous formula. A biological treatment onsite is required before discharge. The acetate is organic and will biodegrade. There is minimal waste generation. A summary of environmental and drilling performance can be seen in Figure 1.

Recommendations

Drilling performance of the fluids was evaluated on the shale inhibition (bulk hardness, dispersion, accretion and swelling tests) results while the environmental evaluation was based on chloride content, conductance and waste disposal methods.

From the summary of the results of the different shale inhibition testing with all the fluids, the Fluid 4 was rated 9.7 of a maximum 10 points as the most inhibitive drilling fluid, followed by Fluid 3 rated at 8.0.

Fluid 6 was rated 6.5, while Fluid 5 was rated 6.4 and Fluid 6 scored 6.0. Fluid 7 scored 5.6, whereas the least inhibitive WBM, scoring 2.8, was Fluid 1.

Treatment and disposal

Dewatering and water treatment can be utilised on location to reduce waste generation and recycle water on location for Fluid 1. Treatment of mud to releasable water would be reasonably easy. Some treatment for excess polymers and some aeration may be required to attain most regulatory parameters for release.

Unless a significant amount of barite has been used and high levels of heavy metals are detected, then the cuttings can be blended with soil and land farmed or buried with little to no impact due to contaminants. Cuttings with barite may require some blending with soil to reduce the concentration to an acceptable level.

For Fluid 2, the dewatering and water treatment process will not remove the excess acetate in the treated water, requiring a secondary bioremediation and aeration process that can take as long as 20 to 45 days per batch. Onsite and timely treatment may require a centralised treatment plant to treat high concentration potassium acetate mud. Drill cuttings will retain a level of potassium acetate that can be bio-remediated with some soil blending and soil enhancement with amendments.

For Fluid 3, onsite dewatering and water treatment will not remove the amine in the treated water, which would have a conductivity level of 6,000 to 8,000 mS/cm, above the suggested level of 2000 mS/cm or lower in many countries. Past projects have shown that a dilution of 70 +/- percent will bring the conductivity to a level of 2,000 mS/cm. Aeration can assist in reducing the amine but will take time. If dilution can’t be performed, a secondary bioremediation process will be required to promote the removal of the amines in the water. The drill cuttings will retain a low level of amine that will be able to be bio-remediated with some soil blending and soil enhancement with amendments.

Conclusion

Based on the above analysis, Fluid 4, the SBM, was the strongest technically, followed by Fluid 5. It was shown that both can be combined with technoeconomically feasible treatment and disposal options that minimise environmental impact.

Authors: Paul Burden and Klisthenis Dimitriadis, Tullow Oil; Kayli Clements, Chau Nguyen, Tony Staples, Seye Thomas; M-I SWACO, A Schlumberger Company