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Innovative Use of Common Lab Equipment to Show Chemical Benefits of the Reduction of Stick-Slip

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Abstract

Stick-slip is a mechanical oscillation or vibration which reduces drilling performance and increases drilling cost. This oscillation usually occurs at the cutting surface, or bit, and is heavily influenced by both rotational speed (RPM) and weight on bit (WOB). Even though there is refined equipment to monitor both surface RPM and mud motor rotational speed, it is still difficult to monitor and control instantaneous bit speed. To further aggravate issues, non-optimal WOB also increases the tendency to encounter a stick-slip situation.

Several mechanical tools have been developed to help aid in the reduction of stick-slip. These tools show mechanical advantages in simulations, small-scale testing, and even downhole applications, but have not yet become commonplace in the field. Another approach is to select drilling fluids and additives that show an ability to decrease the potential for stick-slip. However, traditional drilling fluid additives' testing has been limited to general testing for lubricity without much focus on the reduction of stick-slip.

A common tribology tester, trusted throughout the industry, combined with data acquisition modifications, can be used to test the stick-slip reduction of drilling fluids. By modifying the testing procedure of the tribology tester, a stick-slip scenario can be initiated between the rotating ring and block. This paper will describe the development of a new laboratory methodology along with successful field examples showing a reduction in stick-slip occurrences.

Introduction

A lubricity tester is often used to evaluate and predict the impact on friction, or the lubricating ability, of specific drilling fluids and additives. Contact of the drillstring with the formation is simulated using a rotating ring and stationary block which are immersed in the drilling fluid. Typically, fixed levels of contact forces are used for laboratory studies. Controlling the drilling fluid lubricity within specified ranges and comparing the CoF (coefficient of friction) to wellbore torque and drag provides broad insight into the performance of a drilling fluid in critical applications.[1]

The effects of friction are very dependent on the instantaneous circumstances. However, most friction modeling scenarios, such as determining the CoF, generalize the characteristics of friction, reporting the CoF as a single number for comparison purposes.

An improved approach is to develop a tool which can screen and evaluate the impact of drilling fluid additives on alleviating those instantaneous situations such as occur in stick-slip situations. Applying the resulting test method to both lab and field provides valuable insights into both fluid design and adds a new dimension to fluid monitoring in the field. This paper describes the new methodology of using a lubricity meter as a tribology device to initiate a stick-slip scenario and measure the impact different fluids can have in the outcome.

Stick-Slip

Stick-slip is a subset of friction that is defined by a powerful fluctuation of energy causing torsional oscillation due to momentarily stopping the rotation of the drillstring or, more commonly, the bit. Stick-slip occurs when rotation is not consistent and thereby creates large and even violent movements which can harm the drillstring, cause bearing filter housings to back off, or complete tool failure.[2]

In stick-slip incidents, energy or torque delivered to the bit is insufficient to overcome the formation friction causing the bit to slow or momentarily stop. This results in high amounts of energy being stored within the drillstring as the top drive continues to rotate while the bit is stopped. The high energy level causes whipping or twisting of the drillstring until the bit breaks free. When this energy is released, the rotational speed of the bit and bottomhole assembly (BHA) can be double or triple that of the drillstring higher in the wellbore.[2] This creates severe vibrations coupled with that of axial or lateral vibrations which have damaging effects on rate of penetration (ROP), bit wear, tool failure, and material fatigue. These damaging effects generally lead to increased repair costs and higher non-productive time (NPT).

Drilling operations can minimize stick-slip by adjusting drilling parameters including the weight on bit (WOB). Unfortunately, doing so frequently leads to a low ROP or other non-optimal drilling situations. A different approach is to select drilling fluid additives that can minimize the stick-slip potential by providing lubricity to reduce the bit-formation friction under downhole conditions.

The lubricating effects of the drilling fluid become even more important while slide drilling to alleviate some of the drag forces experienced by the larger contact surface involved.

Lubricity Meter

Drilling fluid tribology can be measured by several different devices which report results in some form of friction or lubricity coefficients. The most common tribology testers in the oilfield, the FANN or OFITE Model 112 lubricity tester, are high-quality instruments designed to simulate rotational contact and consist of a rotating ring and stationary block which are immersed in the drilling fluid. Both the rotational design features of these lubricity testers and their common adoption across the oilfield make them ideal candidates for adapting to the new methodology for stick-slip testing. A recent update to the OFITE lubricity meter included a data acquisition module which allows for continuous sampling of the torque value throughout the test duration. Improvements in reducing the variation of results has been witnessed with the OFITE model so this will be the meter of choice for this work.[3]

The lubricity meter is used in the field on the premise that the lubricity coefficient that is recorded simulates downhole conditions and a lower CoF indicates a lower torque condition. The normal procedure is for the lubricity meter ring to be rotating before any load is applied. However, while drilling we know this situation does not exist. Thus, the first task was to look at how drilling fluids react, as in a wellbore, where a load (torque) is applied (static forces reacting with the pipe) and then rotation begins. Below is a chart (Fig. 1) showing both the rotational speed in RPM and the results (lubricity) in CoF for four basic drilling fluids.

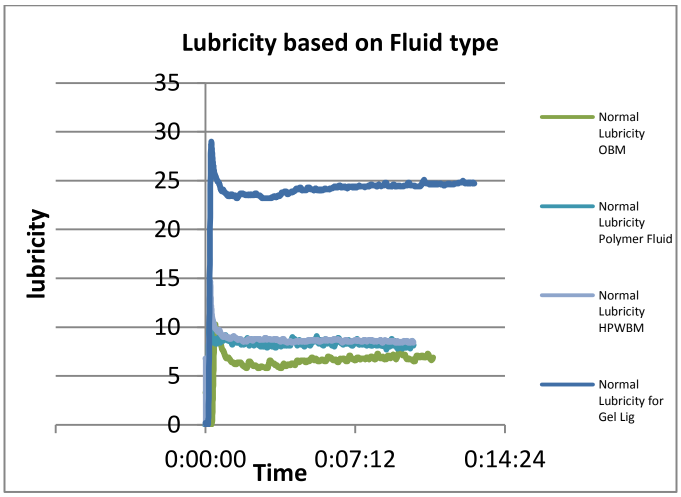

Fig. 1: Results of normal lubricity tests with multiple fluids. Running time was 10 min for the gel-lignite drilling fluid, 7 min for the other three fluids.

The common testing protocol for the lubricity tester involves a load of 150 in•lb to be applied to a torque arm resulting in roughly 600-psi load on a rotating bearing cup at 60 rpm.[4]

For the tests shown in Fig. 1, a rotational speed of 60 rpm was initiated; not much variance in lubricity was shown except at the beginning of the test when the load was applied. Original running time was 3-7 minutes per manufacturer guidelines for lubricity testing. However, prior testing indicated that a change in protocol to increase the running time to 10-min duration increases accuracy because it allows the CoF to be averaged over a span of 3 to 5 minutes.

Development of the New Torque Stick-Slip Protocol

An R&D project was undertaken to look into the potential for improving existing tribology testing – to find a measurement device that could replicate field outcomes identifying differences in tribology measurements including those associated to the reduction of stick-slip occurrences. The focus of the project was not on developing a new device, but to enhance an existing meter, preferably one with widespread usage in the oilfield.

Portability of the equipment increases its value as it can be moved to the rigsite and used to follow the ever-changing dynamics of the fluids as part of routine fluid monitoring. Because changing wellsite conditions affect fluid lubricity, analyzing the lubricity of the formation-contaminated fluid at a lab, later and remotely, provides little benefit in solving immediate downhole drilling issues. Thus, portability and a protocol that can be implemented in the field were deemed critical to the success of the project.

The following were determined to be the key criteria for the new torque stick-slip (TSS) protocol:

- Correlate and differentiate stick-slip scenarios based on friction conditions
- Validate a decrease in friction with field results using downhole tools measuring shock, vibration, or stick-slip
- Applicable for field use

The goal was to analyze the fluids ability to reduce stick-slip friction by establishing lubricity tester values that could be correlated with drillstring vibration. This in turn would allow for optimizing treatment levels at the rigsite using the portable lubricity meter.

The modification to the existing test protocol was to reduce the rotation speed of the lubricity ring assembly to 1 RPM. Accurate measurements of 1 rpm are seen when no contact forces are on the ring, also within the test data, results are shown that a 1 rpm reading is achieved once steady state has been reached. Reducing the desired rotation speed of the instrument induces an oscillation in the speed of the lubricity ring assembly, varying from 0 to 10 RPM. When the instrument detects that the rotating assembly has stopped moving, the instrument will incrementally increase torque until the rotating assembly begins to move again. When this occurs, often the instrument will over-correct and rotate at a relatively high speed. This replicates the violent oscillations that can occur during stick-slip friction downhole.

The test matrix involved testing with several fluids, some known from prior field experiences to reduce stick-slip. Testing was conducted across multiple appraisers and devices to ensure a variety of personal inferences to the test methods; these learnings were in-turn incorporated into the protocol. In addition to the above TSS testing, the formulated fluids were also subject to fluids performance testing (lubricity, filtration, rheology, contamination tolerance, thermal stability, etc.) to evaluate their overall performance and differences.

The final result of this research and development project was a new protocol for the lubricity meter which exhibited laboratory performance characteristics which could then be related and compared to field results. As a final step, the low-RPM TSS protocol was taken to the field to verify that the results could be used to identify drilling fluid additives that reduce stick-slip occurrences in the field.

TSS Test Protocol

1. Clean the lubricity test ring and the lubricity test block with a cleaner such as acetone and rinse both thoroughly with deionized (DI) water. All parts of the machine in the sample area (block holder and shaft) must be completely clean before starting a test.
2. Place the lubricity test ring squarely onto the tapered portion of the main shaft. Secure the test ring retainer nut with a 15⁄16-in. wrench. Make sure the ring seats squarely on the taper of the shaft.
3. Place the lubricity test block in the block holder with the concave side facing out away from the torque shaft. The face of the block should not be touched with a bare hand. Do not let the ring and block contact each other.
4. Turn on instrument and set the motor speed to 60 RPM.
5. Fill the sample cup with DI water and place on stand. Raise the cup stand until the test ring, test block, and block holder are fully submerged in the water. Tighten the thumb screw to secure the cup stand. Set torque to zero and have the instrument rotate freely for 15-20 minutes.
6. Calibrate the instrument with DI water. Fill the sample cup with 270-mL DI water and position the torque arm so that it is in the torque arm clamp. Turn the torque arm adjustment handle until the torque arm gauge reads 150 inch•pounds. Allow running time of 5 minutes and the torque reading should be 34 (± 2) on the control panel. At the end of the calibration period, release the torque arm by turning the torque arm adjusting handle counter-clockwise until the torque arm gauge reaches zero. Lower the stand and completely dry all parts before loading sample.
7. Fill the dry, stainless-steel sample cup with 270 mL of test fluid and place it on the lowered cup stand. Raise the cup stand until the test ring, test block, and block holder are fully submerged in the test fluid. Tighten the thumb screw to secure the cup stand.
8. Start new test on software.
9. Data acquisition should be set to collect a data point every 0.10 second.
10. Zero the torque reading and adjust the motor speed to 1 RPM.
11. Position the torque arm handle so that it fits inside the concave portion of the torque arm clamp. Check to make sure the test block is fully aligned.
12. Turn the torque adjust handle clockwise until the torque gauge on the torque arm reads 150 inch•pounds. Do not apply torque to the test ring unless it is submerged in fluid.
13. Zero the time.
14. Let the machine run for the desired time and then save the torque readings from the control panel. The data should be in graphical form. This allows for the ability to see the differences in RPM, torque, and the time duration it takes to reduce the data oscillation. Torque in this measurement is actually a coefficient of friction as it is unit less.
15. Release the torque on the arm.
16. Adjust the motor speed back to zero.
17. Lower the cup stand and discard the fluid. Thoroughly wipe clean and dry any remaining fluid from the sample cup, block, block holder, and test ring.

Lab Testing and Validation

Validation of the new TSS methodology started with using the meter to initiate a stick slip scenario as seen below. Fig. 2 records a variation of RPM from 0-8 with the resulting extreme swings of COF from 9-20. After 10 minutes, a period of oscillation still existed within the torque but the RPM maintained a steady level of approximately 4, and the maximum and minimum torque readings also became more consistent at an average difference of 4.

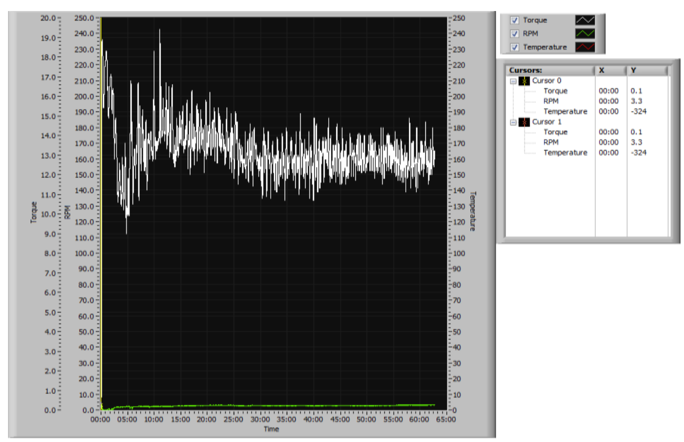

Fig. 2: Test results showing episode of stick-slip.

Validation of the TSS protocol included the ability to differentiate between fluids and additives regarding the stick-slip potential. A general study was made across multiple fluids and their tendency to reduce torque or supply lubriciousness during the stick-slip scenario. Figures 3 through 6 show the TSS results from four basic types of drilling fluids.

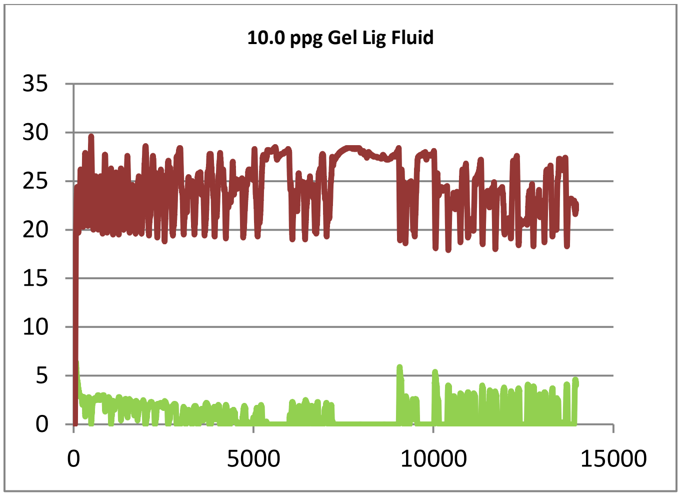

Fig. 3: Results of TSS test on 10.0-lb/gal gel-lignite drilling fluid showing Torque (red line) and RPM (green line).

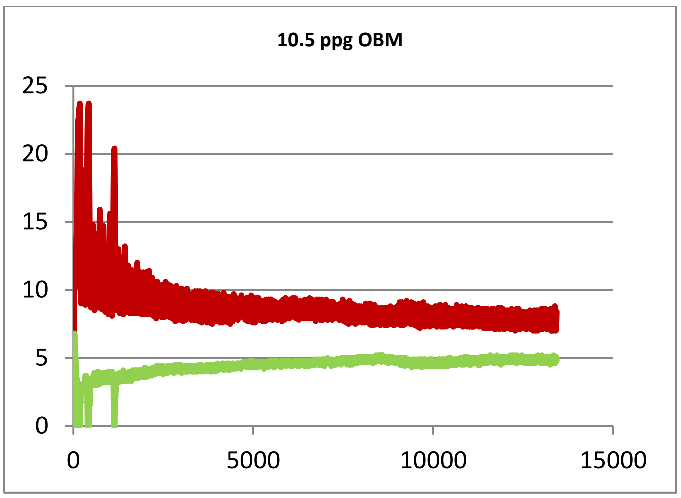

Fig. 4: Results of TSS test on 10.5-lb/gal diesel non-aqueous field drilling fluid showing (red line) and RPM (green line).

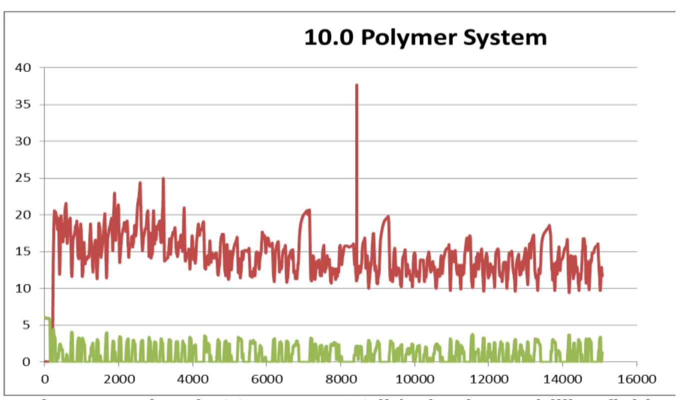

Fig. 5: Results of TSS test on 10.0-lb/gal polymer drilling fluid showing Torque (red line) and RPM (green line).

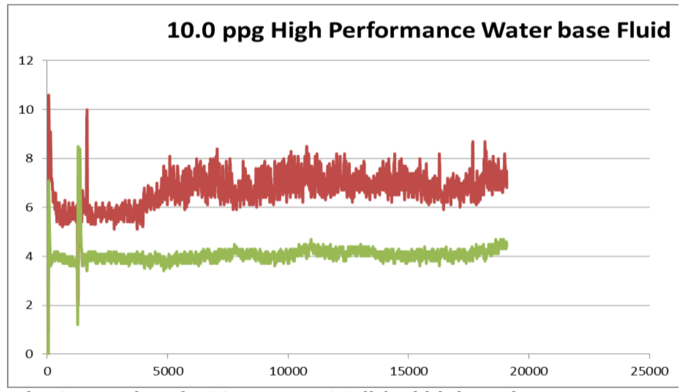

Fig. 6: Results of TSS test on 10.0-lb/gal high performance water-based fluid showing Torque (red line) and RPM (green line).

Following the initial testing, averages were again looked at to confirm statistical control of the measurements. The use of the 1-rpm setting within the TSS test protocol allowed for a cyclic loading until the ring was coated with the fluid then seemed to still have some sort of a cyclic rotational difference based on the increasing torque or “lubricity coefficient”. It seemed that reaction times to reduce the hard, initial cyclic loads differed for all 4 of the fluids (Fig. 7) but tended to trend towards reflecting field performance of the fluids.

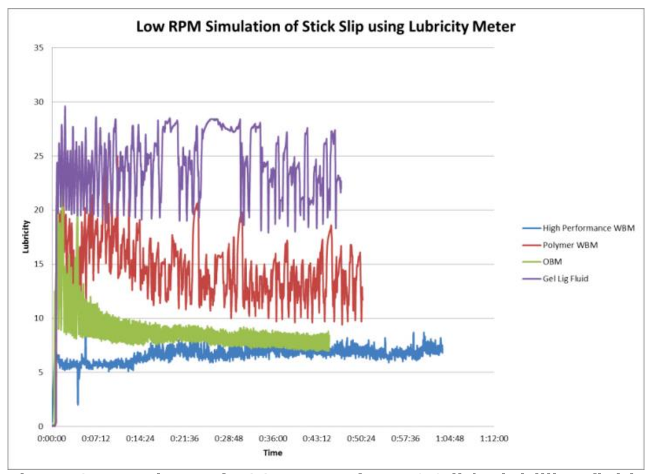

Fig. 7: Comparison of TSS test on four 10.0-lb/gal drilling fluids showing the reduced torque. The high-performance water-based fluid (blue line) showed the most lubricious properties of the four fluids in overcoming the stick-slip situation.

Case History

The Pinedale anticline in the northwestern corner of Wyoming’s Wind River Basin is known for its technically challenging drilling. Recognized as one of the top five largest natural gas fields in the U.S., it contains more than 5,000 feet (1,524 m) of vertical producing formation.[5]

Prior drilling experience in the area has identified a novel polyglycerol internal phase (Fig. 8-Fig. 10) drilling fluid which showed the ability to minimize stick-slip and reduce NPT.[5] Unlike conventional lubricity testing, the TSS tester was able to show a clear reduction in friction when testing the novel lubricant in different NAF fluids (Fig. 8).

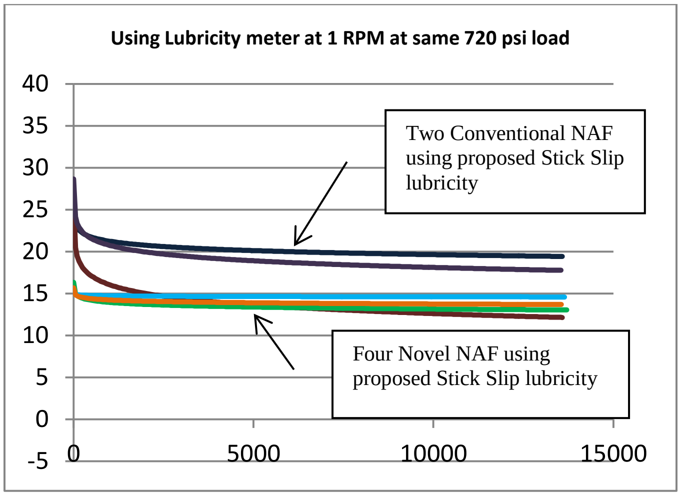

Fig. 8: TSS testing conducted to show the difference between two conventional non-aqueous fluids and 4 different polyglycerol NAF all using the novel stick-slip reducing lubricant at 720 psi load and 1 RPM.

After the initial validation of the novel combination of polyglycerol NAF and proprietary lubricant was completed using the TSS tester, the tester was moved to the field where the work could be conducted simultaneous with drilling operations. Success was measured by a reduction in the shocks to the downhole tools. Figures 9 and 10 show the significant reduction in the 50-G shocks recorded in real time by the downhole tools.

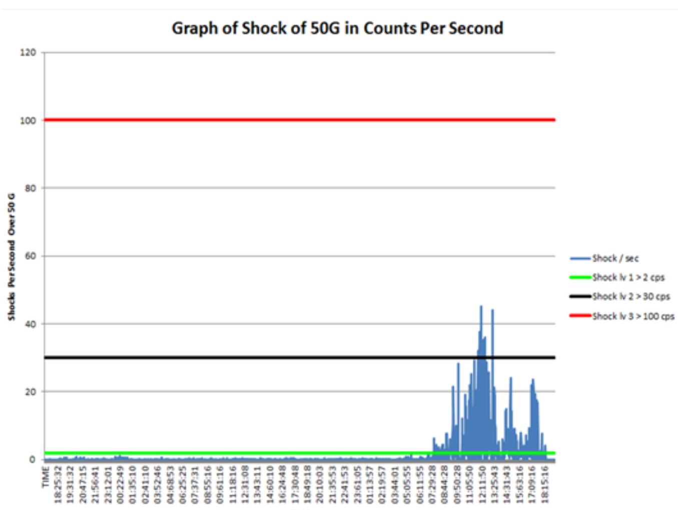

Fig. 9: Shock of 50 G with use of conventional NAF drilling fluid.

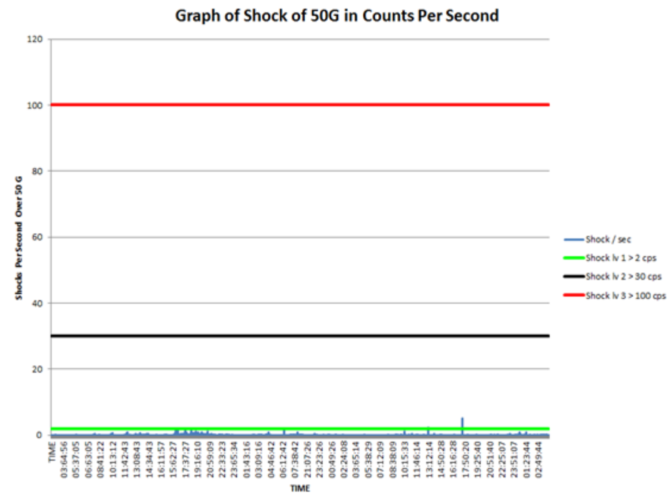

Fig. 10: Shock of 50 G with use of Novel NAF known to reduce stick-slip.

A data set of wells in the Pinedale Anticline has information on over 600 wells with over 300 of those wells utilizing the novel NAF combination. Results in the lab and in the field demonstrated a reduction in stick-slip occurrences. The data set shows an impressive 25% reduction in friction when comparing the novel NAF combination to a conventional NAF.

Conclusions

- Lubricating products should be evaluated in multiple ways to reflect downhole situations encountered by drilling operations.
- Using a test meter to induce friction and interrupt rotation in a stick-slip simulation provides useful insights into torque and stick-slip friction.
- The new TSS protocol allows a common lubricity meter to be used for these tests both in the lab and the field.
- The new TSS protocol has been shown to identify fluids and lubricants that can successfully reduce stick-slip occurrences, thus improving drilling operations and reducing cost and NPT.

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Nomenclature

BHA = *Bottomhole Assembly*
COF = *Coefficient of Friction*
DI = *Deionized Water*
NAF = *Non-Aqueous Fluid*
NPT = *Non-Productive Time*

ROP = *Rate of Penetration through the formation*
RPM = *Rotations per Minute*
TSS = *Torque Stick-Slip*
WOB = *Weigh on Bit*

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