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A Novel Invert Emulsion Lubricant: Review, Design, and Delivery

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Abstract

A novel invert emulsion lubricant was successfully developed and deployed on multiple wells to deliver sustained torque reduction. While water-based drilling fluid lubricants are ubiquitous, invert emulsion lubricants have a mixed track record of inconsistent and inconclusive results. This new lubricant was designed to address these shortcomings with successful field trial results.

Despite the continued advancements of oilfield technology, the current limits of typical drill pipe and today's drilling rig capabilities are difficult to overcome as well complexity and depths constantly grow. In an environment where records for length of lateral section drilled are seemingly set daily, the ability to extend the payzone by a few hundred feet can vastly improve well economics.

Attempts to utilize commercial additives failed to deliver consistent results. Some additives created dramatic thinning or thickening of invert emulsion systems. Many of the additives had strong oil-wetting capabilities that diminished rapidly after exposure to drilling activity. A thorough investigation into the effect of lubricants in oil-wet, invert emulsion systems was performed through chemistry screening, compatibility testing, and coefficient of friction measurements on a lubricity evaluation monitor (LEM). This revealed a distinctive chemistry that provided sustained torque reduction prior to and after dynamic ageing.

The new lubricant was deployed to the field for several trials. Initial data demonstrated up to a 25% reduction in torque readings and a significant increase in rate of penetration. Additional benefits include improved directional tool performance and reduced pipe wear.

Introduction

The increasing shift towards longer laterals in U.S. shale development, and throughout the industry at-large, is a broadly recognized trend. E&P operators continue to push the limits of drilling technology to maximize production relative to cost. This push to improve well economics quickly runs into the limitations of physics as extended-reach and super-lateral wells become more common.

Advancements in drilling equipment, such as high-torque drill pipe and high-horsepower mud pumps, offer some performance improvement. However, the predominant limitation includes elevated torque and drag preventing necessary weight-on-bit to cut more rock. This is particularly limiting in non-rotating activities such as slide drilling. Influences on torque and drag values include hole geometry, directional path (doglegs), drilling parameters (hole cleaning/cuttings removal), poor drilling fluid properties, and excessive coefficient of friction (CoF).

Invert emulsion fluids (IEFs) provide superior lubricity to water-based drilling fluids (Burrow, Jagroop, and Jamison 2008). The inherent lubricious nature of the base oil and the oil-wetting properties of the IEF additives deliver a lower CoF. Despite these benefits from IEFs, torque and drag challenges increase with longer laterals.

IEF lubricants offer the potential to further reduce CoF and friction factor, delivering more energy to the bit for increase rate of penetration and improved directional tool response (Dupreist et al 2011).

Several IEF lubricants have been developed throughout the years, each with a mixed track record. The development of a new, novel IEF lubricant is discussed in this paper. A review of lubricant chemistry, development process, and a summary of the successful field deployment are detailed in this paper.

Lubricant Options and Limitations

Due to an existing oil-wet environment, improving the lubricity of an IEF presents challenges. Most lubricants come in two different forms: solid or liquid. Solid or particulate types, such as ground walnut shells, are often utilized with varying degrees of success in the field (Robertson 2005). Graphite and walnut shell both work via a "sliding" mechanism where the lubricating compresses and deforms between surfaces. Glass, ceramic, polymeric, or carbon-based beads typically provide lubricity through a "ball-bearing" mechanism (Zhou 2012), retaining mechanical integrity to reduce the contact area between surfaces.

Solid lubricant performance is field-proven, however some aspects of solid particles limit the application and success rate. Most solid lubricants require continuous addition due to constant removal at the shaker screens. Other factors contribute to performance limitations, such as the material resiliency, and risk deformation as friction is applied. Solid lubricants are often inherently water-wet. This requires an oil-wetting agent to disperse them throughout the drilling fluid system. The increase in solids loading can negatively impact fluid properties, such as rheology.

Surfactants, such as strong wetting agents, are the most common liquid lubricants for IEFs. These molecules often provide an initial reduction in CoF, but deplete rapidly after addition. As drilling proceeds, surfactants move from metal surfaces and attach themselves to other solids (Growcock et al 1999). In addition, the lubricant surfactant membrane seeks to attach itself to the non-continuous droplets (Figure 1). This emulsification and depletion on solids can often result in a precipitous reduction in performance.

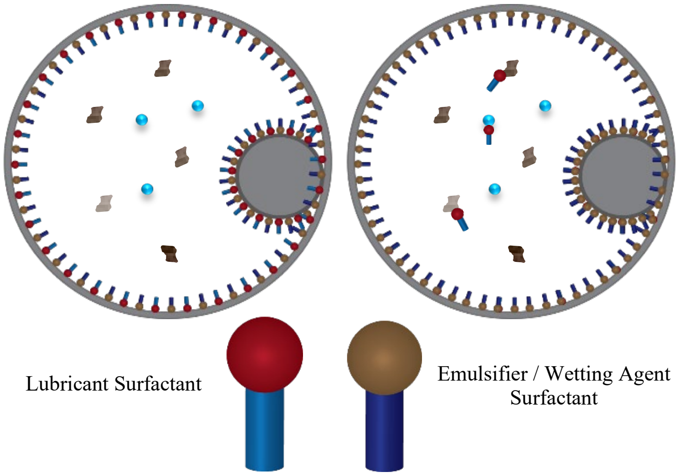

Figure 1 – Illustration of surfactant-based lubricants adhering to solids and internal-phase droplets over time

Design Criteria

The primary evaluation benchmark for lubricant performance includes the impact on CoF relative to a baseline value (untreated). The baseline CoF of IEFs can vary considerably with standard laboratory equipment based on several factors, including base oil type (diesel, mineral oil, synthetic), solids loading (often characterized by fluid density and condition), and other fluid properties. Viscosity, electrical stability, and oil:water ratio all impact CoF. Further, lab equipment involves inherent variability from test to test, despite a rigid test design and work method. The steel/steel CoF for a standard IEF typically falls within the range of 0.10 - 0.20 (Growcock 2017).

Table 1: Design criteria for candidate lubricants

Criteria	Evaluation Method/Indicator	Target
Initial CoF Reduction	LEM	>20%
Sustained CoF Reduction	LEM	>10%
Fluid Compatibility	Viscosity, Fluid Loss, Emulsion Stability	None

Initial CoF Reduction

It is challenging to predict fluid behavior in the field based on laboratory testing. This is, in part, due to lab equipment limitations and the inability to mimic downhole conditions at scale with 100% accuracy (Redburn 2013).

As part of the screening process for candidate lubricants, a minimum 20% reduction in the CoF relative to an untreated baseline IEF was used as the initial design criteria. After this screening, supplemental testing differentiates those that meet the minimum qualification.

Sustained Reduction

Additional design criteria included the ability to provide sustained lubricity. Figure 2 illustrates the reduction in CoF of IEF lubricants after the fluids have been hot-rolled at 250°F. None of the products tested provide a reduction after hot roll exceeding typical test error. This is common with many surfactant-type chemistries - an initial CoF reduction is observed, but performance quickly diminishes when the fluid becomes subjected to downhole conditions. Candidate lubricants were required to achieve sustained CoF reduction of >10% relative to untreated baseline IEF.

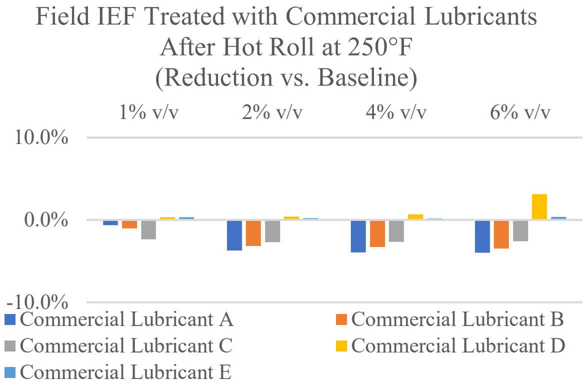

Figure 2 – Example of un-sustained CoF reduction after IEFs containing commercial lubricants are hot-rolled at elevated temperature to simulate downhole conditions

Fluid Compatibility

Lubricant evaluation criteria also included compatibility testing to ensure the product does not cause any detrimental changes to fluid behavior. Figure 3 and 4 illustrate how some lubricant chemistries can cause dramatic thickening/thinning effects once subjected to downhole conditions, where rheological values such as the plastic viscosity, yield point, and low-end rheology can be significantly impacted. Other compatibility criteria include the lubricants effect on electrical stability and HTHP fluid loss.

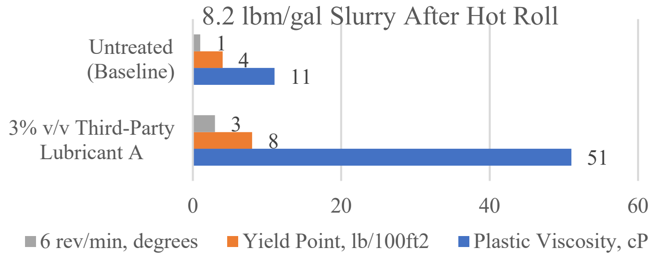

Figure 3 – Example of lubricant incompatibility by causing a significant increase in rheology

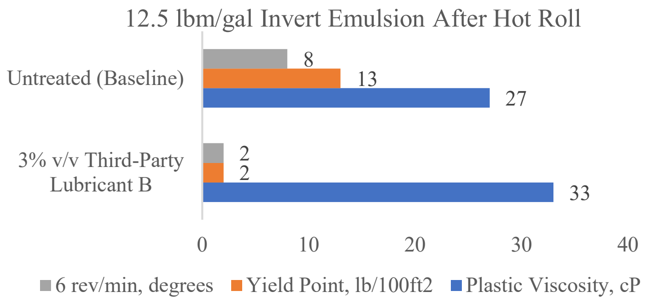

Figure 4 – Example of lubricant incompatibility by causing a significant decrease in rheology

Laboratory Evaluation

Laboratory evaluation included the use of the OFI Lubricity Tester, the Lubricity Evaluation Monitor (LEM), and various other standard laboratory equipment to confirm lubricant compatibility.

LEM and Lubricity Meter

The OFI Lubricity Tester was used to perform a standard lubricity coefficient test on each candidate. A standard test with this equipment includes the application of 150 in-pounds of force between two hardened steel surfaces - a block and a ring rotating at 60 RPM (Figure 6).

The LEM was also used to measure CoF of various IEFs treated with candidate lubricants (Figure 5). A standard LEM test provides a contact force of 30 lbs to a steel bob of 1.5 inches long - the equivalent of 20 lbf/inch normal force. The LEM also provides the ability to circulate the test fluid while applying force, while the OFI Lubricity Tester conducts testing with the block/ring immersed in a static fluid. The frictional surfaces can be interchanged on the LEM - steel/steel (drill pipe on casing) or steel/core rock (drill pipe on formation).

Figure 5 & 6 – The LEM (left) and Lubricity Meter (right) were the primary lab equipment machinery used to evaluate candidate lubricants

The LEM is modified to include a syringe pump (Figure 7), allowing liquid products to be automatically injected into the test fluid at pre-determined concentrations. CoF reduction is observed as lubricant concentration is increased. For lubricant evaluation purposes, each LEM test is performed in the below manner:

- Initial baseline (untreated)
- 1.0 % /vol. injected
- 2.0%/vol. injected
- 4.0%/vol. injected
- 6.0%/vol. injected

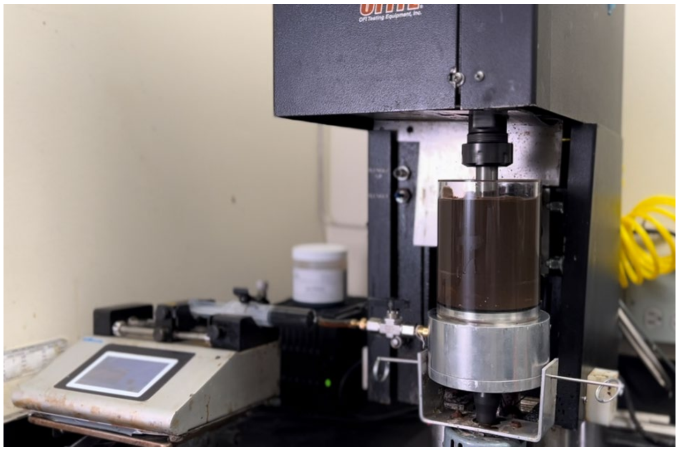

Figure 7 – Image of LEM setup with auto-syringe pump affixed (left)

Verification of Compatibility

Performance evaluation also included the use of several baseline IEF fluids. While diesel oil is the predominant base oil of use in unconventional drilling in the United States, other IEFs utilizing alternative base oils were tested on candidate lubricants. Percentage of solids by volume can also impact a lubricants effectiveness. Fluids with varying densities were tested to account for 'low' and 'high' solids content.

Products Evaluated

- Graphite-based particles
- Nanoparticles
- Surfactants
- Blends

Laboratory Results

Several solid-state products were evaluated for performance. High performers included graphite-based lubricants which currently exist in the marketplace. Other solid-state lubricants showed promise but were eliminated because of cost factors or due to fluid incompatibility (Figure 8).

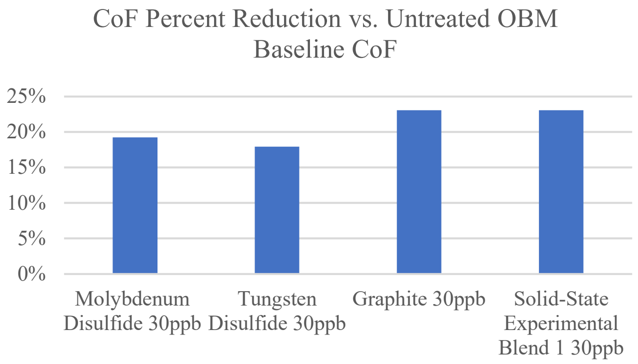

Figure 8 - LEM test results of various solid-state lubricants

Figure 9 highlights notable results from testing over 15 candidate chemistries on the LEM. Many candidates were eliminated from the testing matrix due to poor reduction in CoF, despite treatment levels of up to 6%/volume.

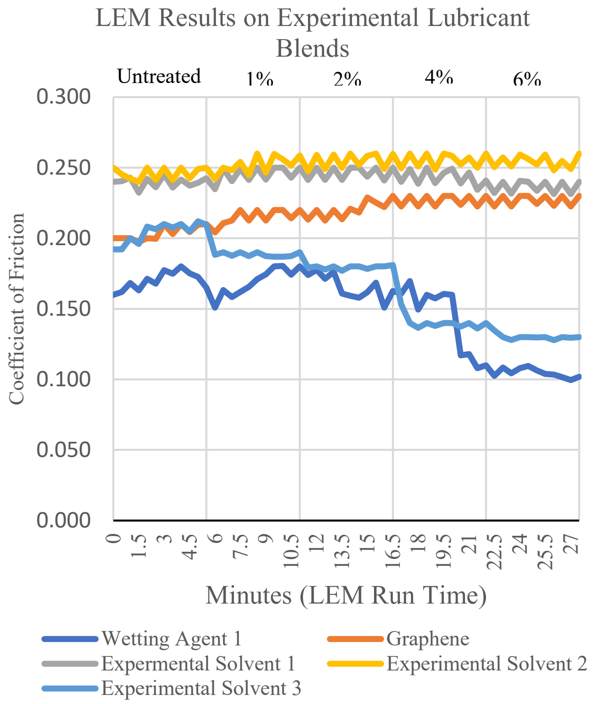

Figure 9 - LEM test results of various candidate lubricants

In conjunction with LEM testing, candidate lubricants were tested for compatibility with the baseline IEF. Several candidates were eliminated due to detrimental impact to fluid properties, including emulsion stability as indicated by an overall increase in HTHP fluid loss and water within the filtrate (Figure 10).

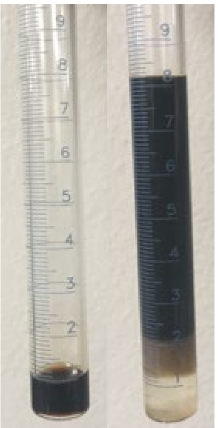

Figure 10 – 30 min. HTHP Fluid Loss Results at 250°F on Baseline OBM (left) and OBM with 3%/vol. Experimental Solvent 4 (right), indicating emulsion destabilization

Throughout testing, Experimental Solvent 3 provided consistent CoF reduction. Figure 11 shows a significant CoF reduction of 23.8%, 36.8%, 28.2%, and 22.6% at 1%, 2%, 4%, and 6% by volume treatment levels.

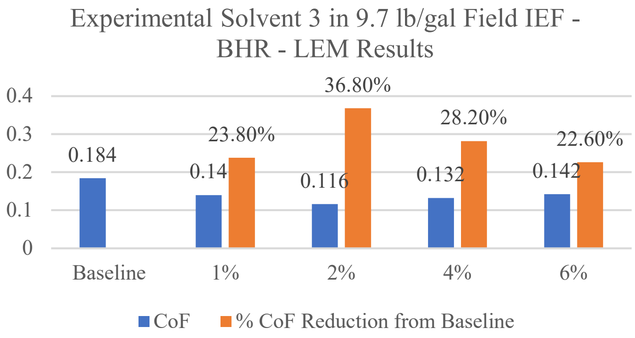

Figure 11 – Experimental Solvent 3 providing CoF reduction with varying concentration loads

Figure 12 shows confirmation of sustained lubricity with the same base IEF using 3%/vol of Experimental Solvent 3. After a 16-hour hot roll at 250°F, the CoF remained below the baseline - reduced by 13.4%. This same result was captured using a 'high' density fluid in Figure 13.

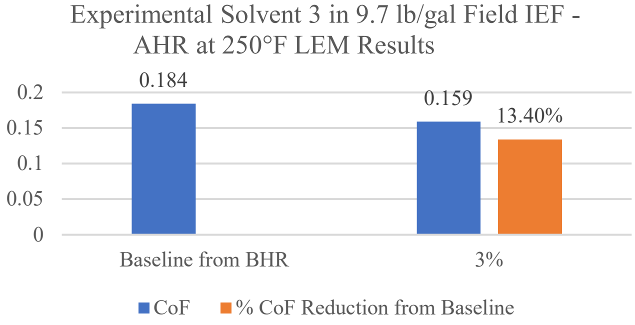

Figure 12 – Sustained CoF reduction using Experimental Solvent 3 in a 9.7 lbm/gal field IEF

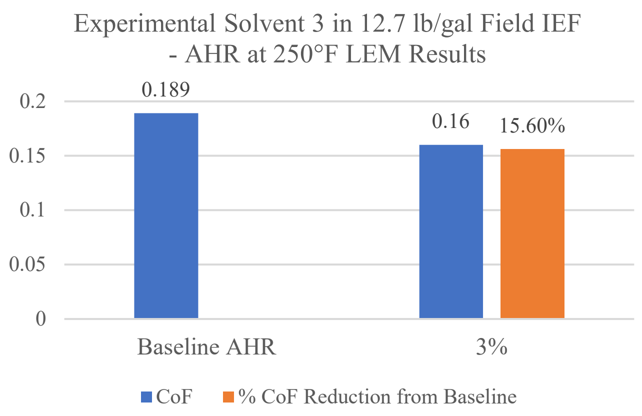

Figure 13 – Sustained CoF reduction using Experimental Solvent 3 in a 12.7 lbm/gal field IEF

Compatibility testing with Experimental Solvent 3 resulted in no significant changes to fluid characteristics. Rheological values of both 'low' and 'high' density IEFs treated with 3%/volume remained within expected range after 16-hour hot roll at 250°F (figure 14 and 15). No impact to fluid loss or electrical stability were observed.

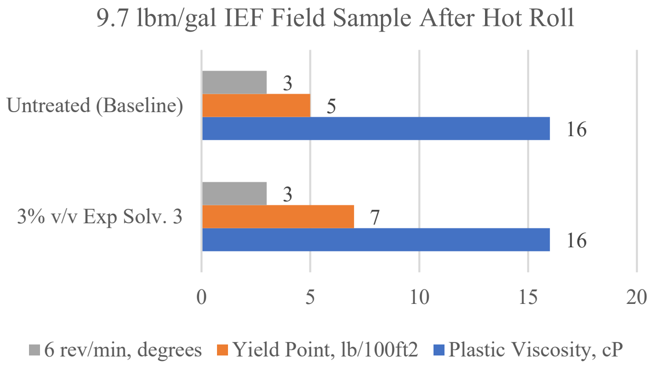

Figure 14 – Verification of rheological compatibility in 9.7 lbm/gal field IEF

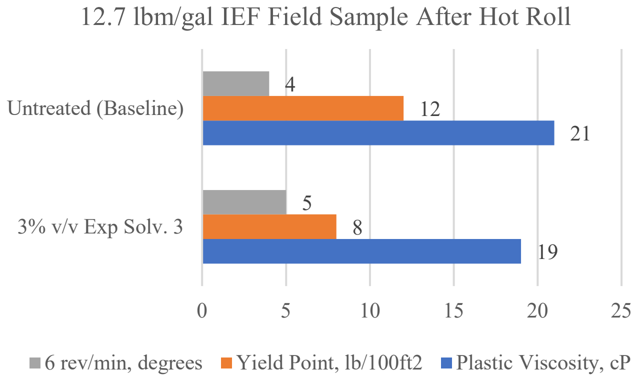

Figure 15 – Verification of rheological compatibility in 12.7 lbm/gal field IEF

Further data captured indicated that solids % by volume had little-to-no impact on the performance of Experimental Solvent 3. Figure 16 shows a significant reduction in CoF among multiple barite-laden IEF field samples with varying solids % (as indicated by density).

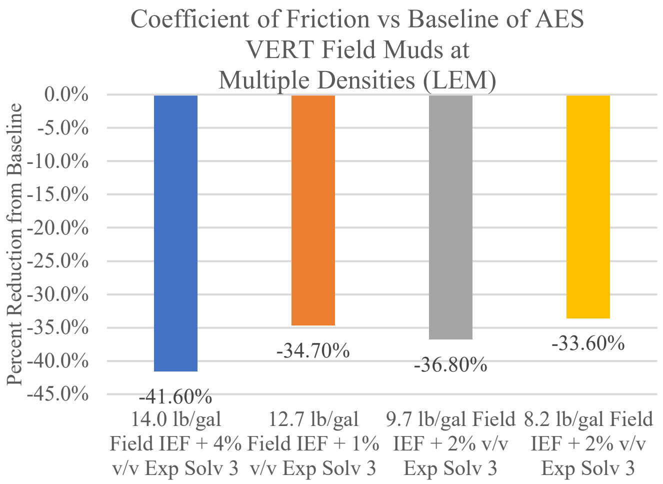

Figure 16 – CoF reduction with Experimental Solvent 3 across multiple density fluids

Experimental Solvent 3 achieved all required testing benchmark criteria. Further stress testing was performed in advance of a field trial opportunity. This included verification with other field IEF samples and exposure to common contaminants.

Field Success Criteria

Ultimate validation of an experimental product is achieved at the well site through a field trial application. Experimental Solvent 3 was given an experimental product name for field use, EXPL 9050. Proper benchmarks were set ahead of a field trial opportunity to ensure success. Documentation of the below criteria were utilized for the field trial:

- Significant reduction in torque and drag (>10%)
- Achieve desirable weight-on-bit (WOB)
- Ease of use, i.e. ability to mix directly into active fluid
- Improved directional tool orientation (sliding)
- Impact on fluid properties
- General feedback, including anecdotal commentary on lubricious effect

Case History #1

An operator in New Mexico was attempting to drill a 15,000 foot lateral section with an oil-based mud. Issues began to arise related to poor weight-on-bit and inability to slide based on excessive torque values. The directional BHA progressively required more and more "wraps" to orientate and slide the drill string - a method where the drill pipe must be turned several times on surface in order to rotate the BHA downhole. Based on trends, torque values would exceed drill-pipe makeup torque of ~26,000 ft-lbs well ahead of TD. To avoid over-torquing the drill pipe, drilling parameters would be significantly reduced, effectively lowering ROP and requiring much more time to reach TD. Graphite-based material was pumped at 5 lb/bbl with no success.

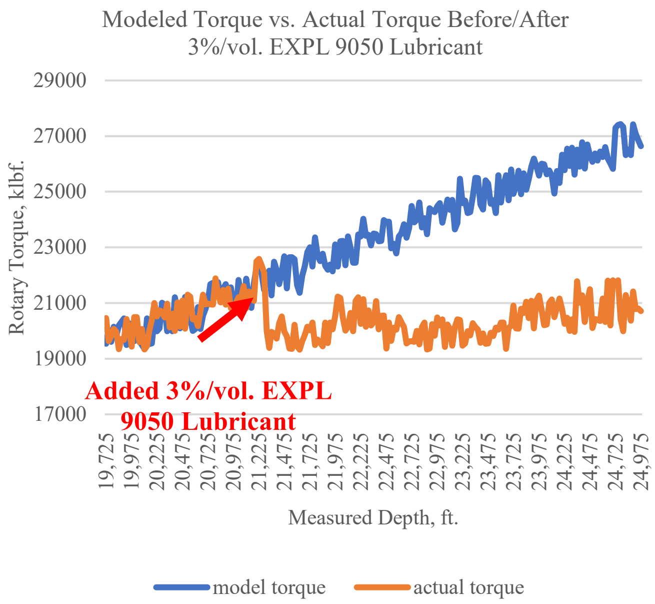

Figure 17 – Torque chart comparing model vs. actual torque values using EXPL 9050

EXPL 9050 was added at 3.0%/volume into the active system. Figure 17 illustrates the impact with an immediate 15% reduction in rotary torque versus actual values recorded just prior to treatment. Torque values remained well below modeling values; >20% torque reduction at total depth. This torque reduction promoted better drilling parameters, optimizing ROP. No significant changes to the fluid properties were encountered (Table 2). Anecdotal commentary included the directional drilling company stating a much-improved ability to slide/orientate directional tools.

Table 2: Properties of OBM taken from DMR before and after treatment with EXPL 9050 lubricant

Property	DMR 20	DMR 21
EXPL 9050 % conc.	0%	3.0%
Density, lbm/gal	12.0	12.0
Plastic Viscosity, cP	22	21
Yield Point, lb/100ft^2	11	11
Electrical Stability, volts	419	457
HTHP Filtrate (cm/30 min @ 250°F)	3.0	3.2

Conclusions

1. EXPL 9050, a novel invert emulsion lubricant, provides >20% reduction in CoF at 1-3%/volume
2. Contrary to other IEF lubricants, EXPL 9050 provides sustained lubricity. Novel chemistry performs different from other surfactant-based lubricants - performance remains elevated after exposure to downhole conditions
3. Successful field trial demonstrates the lubricant's impact on real torque values

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