

The Design of a New Class of Drilling Fluid Lubricant Specifically Optimized for High Salinity Brines

Jay Brockhoff, Matthew Taylor, Stuart Dubberley, Kuangbiao Ma and Cory Jaska, Secure Energy

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Abstract

The drive to reduce freshwater consumption is an important goal in the oil and gas industry. As part of this program, the use of waste produced water streams as brine-based drilling fluids has received considerable attention over the past several years. However, conventional lubricants typically exhibit diminished performance in such high salinity brines. This paper describes the design and development of a new class of lubricant specifically optimized for use in high salinity drilling fluids.

A comprehensive literature review and a detailed laboratory testing program were undertaken to investigate the mechanism of drilling fluid lubricants under downhole conditions. The knowledge gained from this study was used to design a new class of lubricant that undergoes a chemical reaction with high salinity brines in order to activate the lubricant species and maximize performance.

A series of field trials were conducted in Western Canada on wells targeting the Montney formation. The drilling fluids consisted of solids-free sodium chloride, calcium chloride, and produced water brines with densities ranging from 1080 – 1380 kg/m³. The wells had lateral lengths ranging from 1580 – 4000 meters. The new lubricant significantly out-performed conventional lubricants on 100% of the field trials and was able to achieve friction factors close to those of oil-based drilling fluids. A series of case studies are provided which highlight the unique performance characteristics of this novel drilling fluid lubricant.

Introduction

The number of wells being drilled with solids free brine-based drilling fluids has increased significantly in North America over the past several years due largely to the high rates of penetration (ROP) these systems can provide (Dubberley 2020). In addition, operators are keen to use waste streams such as high salinity produced water brines as base fluids for drilling in order to minimize fresh water consumption (Heath 2023).

However, brine-based drilling fluids typically exhibit higher coefficients of friction (COF) than oil-based drilling fluids (OBM) and the majority of wells drilled with high salinity brines require the addition of chemical lubricants in order to drill efficiently. Unfortunately, conventional lubricants generally provide only modest performance in brine-based

drilling fluids due to the high salinity adversely impacting lubricant dispersibility and performance (Patel 2013). While lubricants designed specifically for brine-based drilling fluids exist, these lubricants are essentially designed to “tolerate” high salinity conditions and a demand for a lubricant that is truly “optimized” for high salinity conditions exists. A research and development program was therefore undertaken to develop a new class of drilling fluid lubricant that exhibits enhanced performance in high salinity brines.

Results and Discussion

The Mechanism of Drilling Fluid Lubricants

While a large number of studies have measured the performance of specific drilling fluid lubricants under various conditions, surprisingly little work has been done to elucidate the actual lubrication mechanism(s) operating under downhole conditions. Tribology theory indicates that three different lubrication regimes can exist between two lubricated surfaces: boundary, mixed, and hydrodynamic lubrication (Hutchings 2017). While a detailed description of lubrication regimes is beyond the scope of this paper, a brief overview will be provided. Hydrodynamic lubrication typically occurs under low load and high speed conditions. In this regime, the two surfaces are separated by a continuous lubricant film and no direct solid-solid contacts exist. Conversely, boundary lubrication generally occurs under high load and low speed conditions. In this regime, direct solid-solid contact exists between the lubricated surfaces and the lubricant forms only a very thin (molecular) film. Finally, mixed lubrication can be regarded as an intermediate regime that falls between hydrodynamic and boundary lubrication. These lubrication regimes can be viewed graphically in a Stribeck Curve that plots coefficient of friction (COF) against Hersey Number (Figure 1).

The requirements of a lubricant operating under boundary conditions differ significantly from the requirements under hydrodynamic conditions. It is therefore important to select the correct type of lubricant based on the lubrication regime operating in a specific situation. While limited work appears to have been conducted on downhole lubrication regimes, work by Lan (2018), Egberts (2019) and Ramirez (2020) suggests that, while all three lubrication regimes can potentially operate downhole, boundary lubrication is expected to dominate.

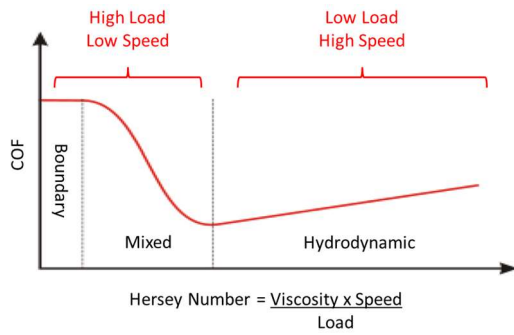


Figure 1 – Lubrication Regimes (Stribeck Curve)

Boundary lubricants can be divided into two broad categories: organic friction modifiers and extreme pressure additives. Organic friction modifiers function by strongly adsorbing onto the contacting surfaces in order to reduce friction and are typically based on surfactant chemistry. Extreme pressure additives are primarily designed to reduce wear rather than lower friction and function by forming a protective film that is chemically bonded to the contacting surfaces.

Drilling fluid lubricants are typically designed around surfactant molecules which function as organic friction modifiers (Figure 2). In addition, an optimized drilling fluid lubricant will also possess several other key characteristics: minimal impact on drilling fluid properties, low toxicity, stable under operating conditions, and suitable cost.

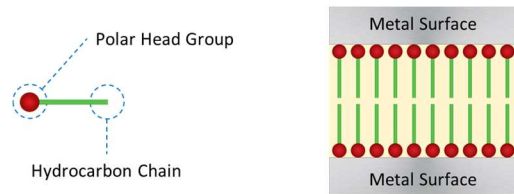


Figure 2 – Surfactant Molecule Operating as Boundary Lubricant

The Design of a New Drilling Fluid Lubricant

The information obtained from a detailed technical review was used to design a new drilling fluid lubricant for use in high salinity brines. The new lubricant was designed to undergo a controlled chemical reaction with high salinity brines in order to form an activated lubricant species - during this activation process the liquid lubricant is converted into a semi-solid species that exhibits an extremely high affinity to exposed metal and rock surfaces. This activation process is summarized in Figure 3.

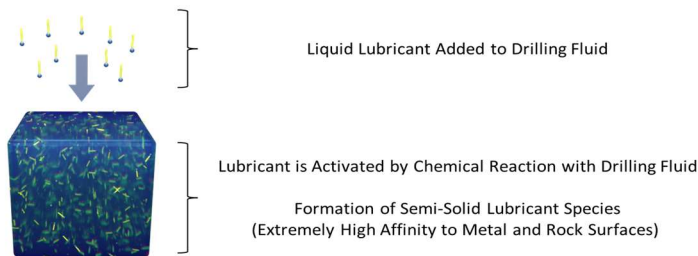


Figure 3 – Chemical Activation of the New Drilling Fluid Lubricant

Laboratory Testing

Once the new lubricant had been designed, its performance characteristics were measured under laboratory conditions. This testing was conducted using a synthetic brine with the composition detailed in Table 1. Initial testing investigated the chemical reaction between the lubricant and the high salinity brine. The lubricant package was systematically modified during this testing until the reaction proceeded smoothly and yielded a uniformly dispersed activated lubricant species.

Table 1 – Synthetic Brine Used in Laboratory Testing

Ion	Concentration (mg/L)
Na ⁺	64,900
K ⁺	2,670
Ca ²⁺	6,920
Mg ²⁺	1,100
Cl ⁻	117,945

The performance of the new lubricant was then measured using an OFITE lubricity tester under various conditions and a selection of results are summarized in Table 2 (synthetic brine at 150 in-lbs applied force and 60 rpm). These results demonstrate the extremely high performance of the new lubricant in a high salinity drilling fluid.

Table 2 – Lubricity Testing Under Laboratory Conditions

Lubricant	Coefficient of Friction
None	0.32
2% Commercial Lubricant	0.18
2% New Lubricant	0.03

The chemical structure of the activated lubricant species was also examined using various analytical techniques. This allowed the proposed structure of the active species to be confirmed and resulted in a more detailed understanding of how this class of lubricant functions and how it should be utilized in the field.

Field Testing

Following the design and testing stages summarized above, the new lubricant was subjected to a series of field trials to evaluate its performance under real world conditions. These field trials were conducted on wells targeting the Montney formation in Western Canada. In order to maximize ROP, operators typically aim to drill the lateral interval of these wells with solids free brine-based drilling fluids. However, these fluid systems result in higher levels of downhole friction and demand the use of chemical and/or physical lubricants in order to drill the intervals successfully. Unfortunately, despite the use of various lubricants, it is also frequently necessary to switch to an oil-based drilling fluid (with enhanced lubricity) to drill the final portion of the lateral interval. These wells therefore provided an excellent opportunity to evaluate the performance of the new drilling fluid lubricant.

The performance of the new lubricant was evaluated on over two hundred wells, for several operators, using sodium chloride, calcium chloride and produced water drilling fluids with densities ranging from 1080 – 1380 kg/m³. The wells had lateral lengths varying from 1580 – 4000 meters. The addition

of the lubricant at surface was carefully controlled and modified throughout the field trials in order to ensure that the lubricant activation step (reaction with high salinity brine) occurred in a controlled fashion. In addition, the chemistry of the lubricant package was systematically modified throughout the field trials in order to develop detailed structure-activity relationships.

A detailed analysis of drilling parameters was performed on all of the field trial wells in order to quantitatively evaluate lubricant performance. This analysis showed that the new

lubricant significantly out performed conventional lubricants on 100% of the field trials and was able to achieve friction factors close to those of oil-based drilling fluids. A selection of representative case studies are included below.

Case study 1 was a well containing a 2417m long lateral interval drilled using produced water at a density of 1140 kg/m³. A drilling torque plot (zoomed in on lateral interval) is provided in Figure 4.

Case Study 1 - Drilling Torque Plot

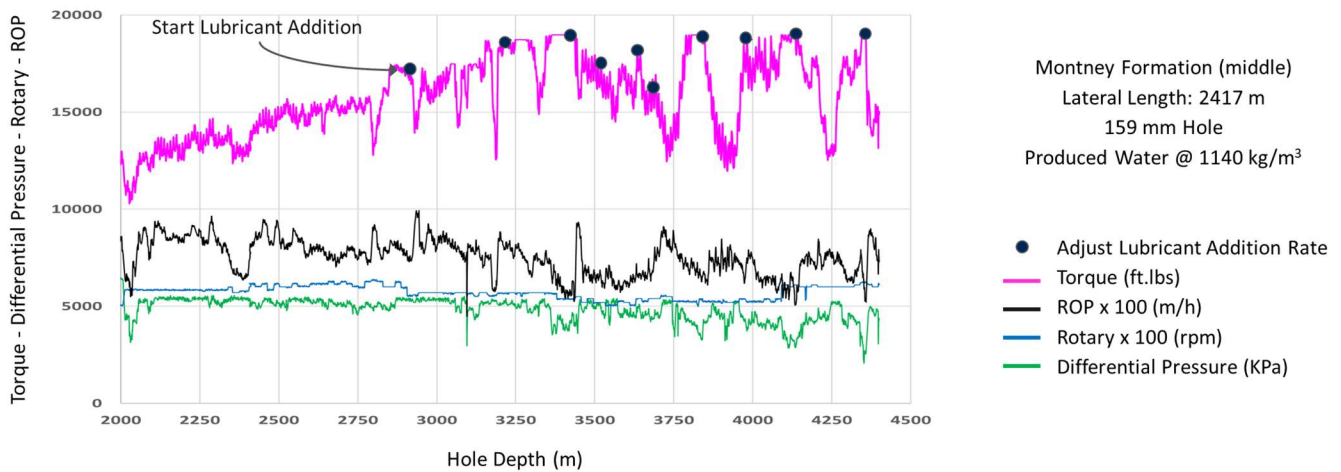


Figure 4 – Drilling Torque Plot for Case Study 1

The data in Figure 4 shows how torque originally increased as the lateral interval was drilled, and that at ~2900m the decision was made to start lubricant additions in order to remain below the operators torque ceiling of approximately 20,000 ft.lbs. As can be seen, the initial lubricant addition did not reduce the torque significantly. However, following an adjustment at ~3250m the lubricant addition rate was optimized and the operator was able to drill the remaining part of the lateral while maintaining a steady torque of ~17,500 ft.lbs. The additional parameters included in the plot (rate of penetration,

rotary speed, differential pressure) demonstrate that the lubricant did not negatively impact drilling performance. The well was successfully drilled to total depth (TD) without the need to switch to oil-based drilling fluid.

In addition to drilling to total depth, it was also important that liner could successfully be run in the brine-based fluid (produced water). In order to achieve this goal, the new lubricant was added to the drilling fluid during the wellbore cleanout cycle and the results from this operation are summarized in Figure 5.

Case Study 1 - Off-Bottom Torque Plot During Wellbore Cleanout

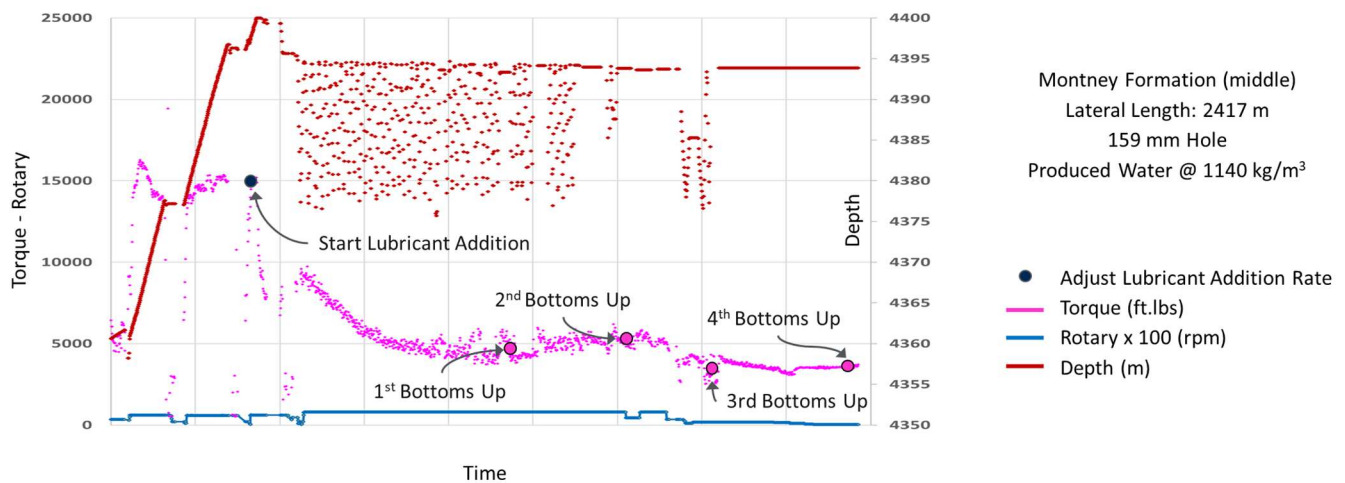


Figure 5 – Off-Bottom Torque Plot for Case Study 1

The data presented in Figure 5 shows that extremely low torque values were obtained once the wellbore cleanout cycle was completed (< 5000 ft.lbs). This significant torque reduction is attributed to a combination of lubricant performance and hole cleaning. Following the success of the wellbore cleanout, no problems were encountered running casing to bottom in the brine-based drilling fluid. This is a representative example, and a 100% success rate was achieved when running casing in brine throughout the field trials.

In addition to monitoring drilling torque, friction factors were also calculated for the field trial wells and a plot for case study 1 is included in Figure 6. This plot overlays an array of calculated drilling torques computed using various friction factors (0.1 – 0.3) with the actual measured drilling torque. The drilling friction factor for this well was calculated as approximately 0.20 which is very low and falls within the typical range of an oil-based drilling fluid (0.17 – 0.25) (Samuel 2010).

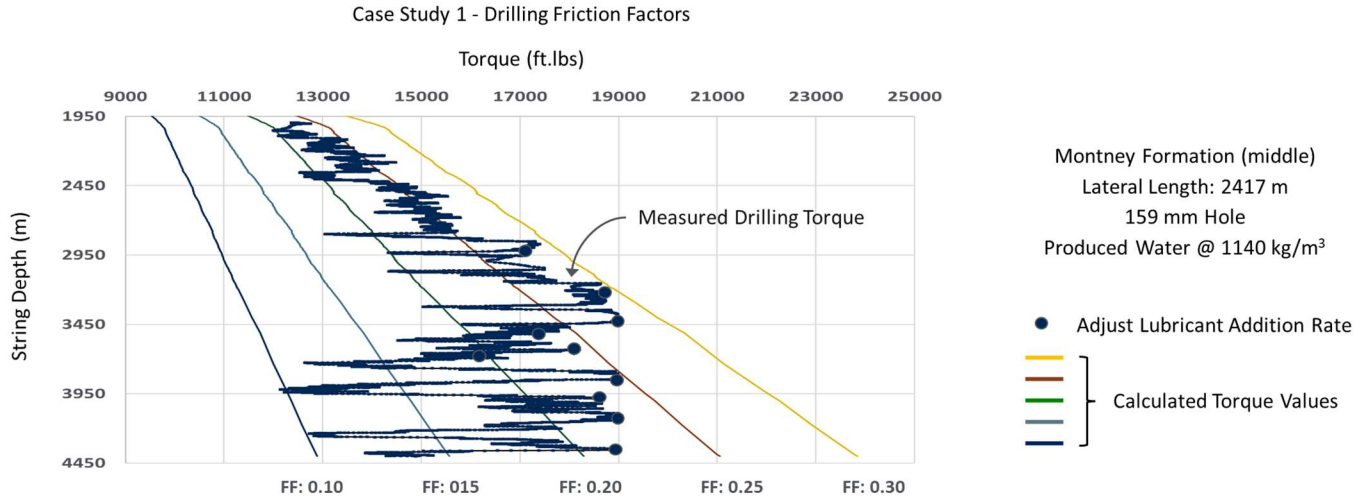


Figure 6 – Calculated Friction Factor for Case Study 1

The data provided in case study #1 is representative of how the new lubricant performed throughout the field trials. As

further examples, a selection of additional drilling torque plots are provided in Figure 7.

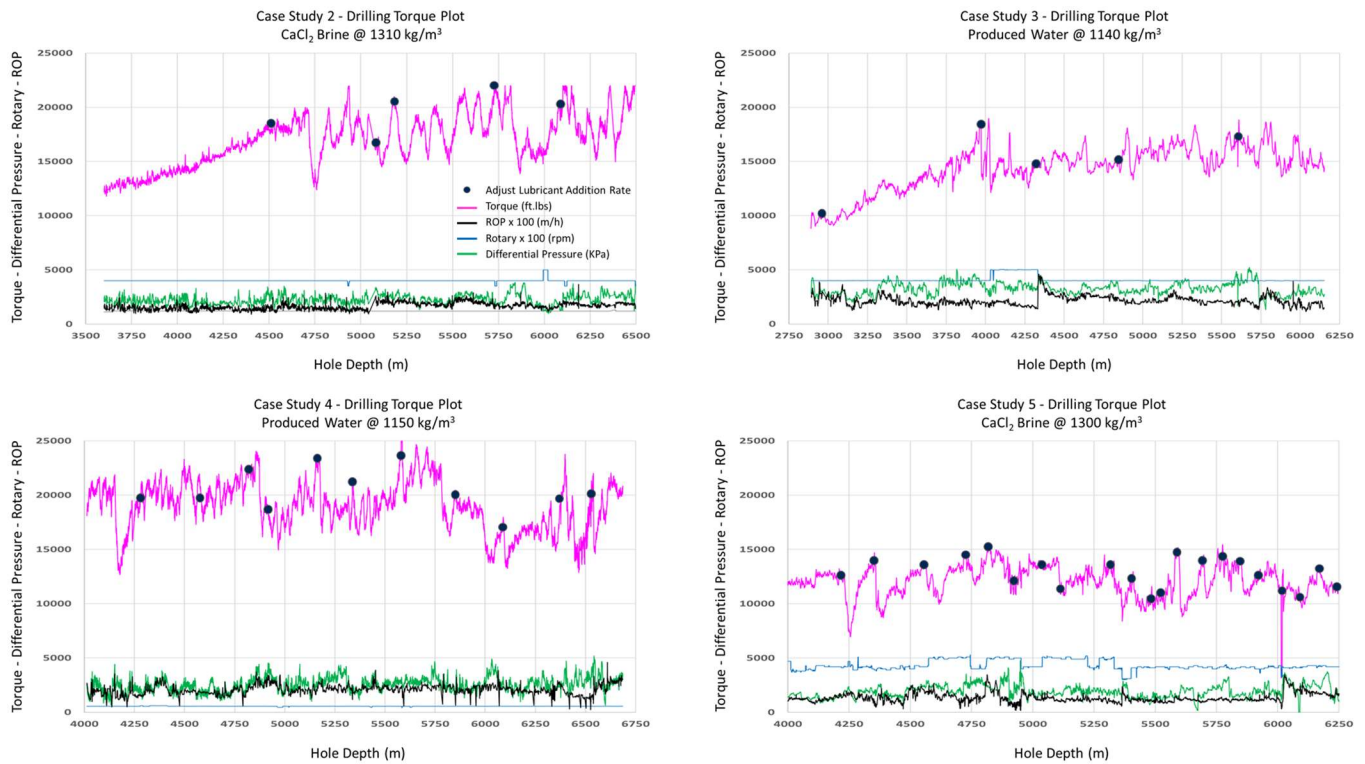


Figure 7 – Drilling Torque Plots for Case Studies 2 - 5

The plots in Figure 7 demonstrate how drilling torque could be easily controlled and maintained at a given setpoint simply

by adjusting the addition rate of the new lubricant. This ability to rapidly control torque allowed lubricant additions to occur

only when required and thus eliminated the costs associated with lubricant overtreatment.

The performance of the new lubricant eliminated the need to displace to oil-based drilling fluid to reach TD on approximately 90% of the field trial wells. However, some operators selected to continue this practice and a drilling torque plot for a displacement from calcium chloride brine to oil-based drilling fluid is provided in Figure 8. The graph shows that

switching to OBM did reduce torque, however, the reduction was only modest (~ 10%) which once again highlights the performance of the new lubricant. It should also be noted that switching to OBM resulted in a significant drop in the ROP (> 50%). This observation was typical, and it was noted that solids free brines typically drilled 2 – 4 times faster than oil-based drilling fluids on Montney laterals over 5000 meters measured depth.

Case Study #6 - Drilling Torque Plot (Displacement to OBM)

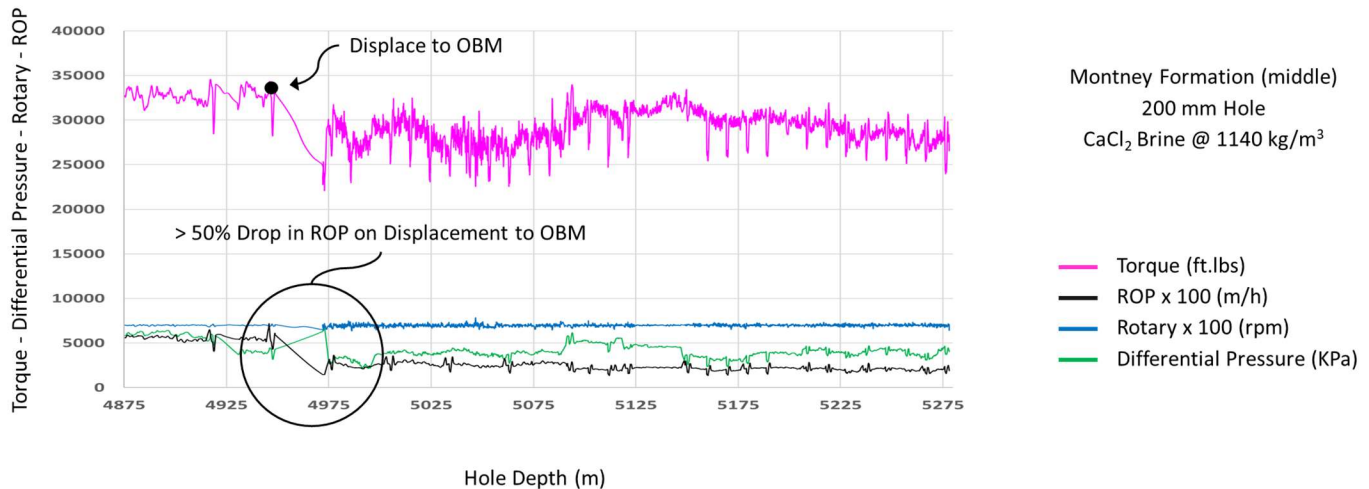


Figure 8 – Drilling Torque Plot Highlighting Displacement to OBM

The new lubricant also allowed operators to significantly reduce or eliminate the need for mechanical lubricants on all of the field trial wells. An example of the cost savings associated

with the elimination of polymer beads is summarized in Tables 3 – 5. (The tables are broken out into D1 – D3 horizons to allow for accurate comparisons).

Table 3 – Cost Savings for Montney (D1) Lateral Intervals

	Montney (D1) Laterals Drilled with CaCl ₂ Brine		
	Total Well Length (m)	Polymer Beads + Recovery Unit	Liquid Lubricant
Conventional Lubricant	6588	\$ 44,606	\$ 33,810
Cost / Meter		\$ 11.90	
New Lubricant	6357	\$ 0	\$ 34,500
Cost / Meter		\$ 5.43	

Table 4 – Cost Savings for Montney (D2) Lateral Intervals

	Montney (D2) Laterals Drilled with CaCl ₂ Brine		
	Total Well Length (m)	Polymer Beads + Recovery Unit	Liquid Lubricant
Conventional Lubricant	6475	\$ 57,126	\$ 42,630
Cost / Meter		\$ 15.41	
New Lubricant	6497	\$ 0	\$ 69,000
Cost / Meter		\$ 10.62	

Table 5 – Cost Savings for Montney (D3) Lateral Intervals

	Montney (D3) Laterals Drilled with CaCl ₂ Brine		
	Total Well Length (m)	Polymer Beads + Recovery Unit	Liquid Lubricant
Conventional Lubricant	6390	\$ 44,380	\$ 27,930
Cost / Meter		\$ 11.31	
New Lubricant	6177	\$ 0	\$ 38,300
Cost / Meter		\$ 6.20	

Conclusions

This paper describes the development of a new class of

lubricant that is specifically designed for use in brine-based drilling fluids. The lubricant undergoes a chemical reaction

with high salinity brines which activates the lubricant and maximizes performance.

The performance of the new lubricant was evaluated on over two hundred field trial wells targeting the Montney formation in Western Canada. The wells were drilled using various high salinity brines (sodium chloride, calcium chloride, produced water) with densities ranging from 1080 – 1380 kg/m³. It was found that the lubricant activation step (reaction with high salinity brine) could be fully controlled by regulating the addition of the lubricant into the drilling fluid system. The new lubricant significantly out performed conventional lubricants on 100% of the field trails and was able to achieve friction factors close to those of oil-based drilling fluids. This allowed operators to eliminate the need to switch to OBM to reach TD on approximately 90% of the field trial wells. In addition, the new lubricant also allowed operators to significantly reduce or eliminate the need for mechanical lubricants which lead to significant cost savings. Finally, a 100% success rate was achieved when running casing in brine on the field trial wells.

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