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Nano Graphene Application Improving Drilling Fluids Performance

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Abstract

Scomi together with the technical partner had developed series of nano graphene engineered product in mass production scale, one of the latest product that had been field trial successfully in the region is a graphene enhanced product that provides superior lubricity and thermal stability to the water based drilling fluids. It is a blend of proprietary surfactants engineered with nano graphene, where graphenes will penetrates into microscopic pores of the tubular metal, crystalized in layers under high pressure, forming a protective film to improve lubricity, prevent bit balling, improve BHA's life span, improve ROP, and most important of all improving fluids' thermal stability.

Laboratory performance test with EP/Lubricity Tester indicated 70–80% torque reduction on a water based salt polymer mud system, compared to conventional lubricants of only 30–40% reduction. The product had been field trial in a HTHP onshore well with temperature up to 176°C (349°F), and hard formation reducing the bits' life span to only 2–3 days. During the field trial, it's agreed that 2–3% of the product had improved ROP 125%, actual reaming torque reduction of 20%, bit's life span increased >75%, also noticed by the fluids company Scomi that fluids loss reduction of 30% with 40% polymers concentration reduction compared to planned mud formulation, which are additional benefits observed and yet to be continously monitor in future subsequent field trials. The improvement in drilling performance and bits' life span had reduced operator's operational time and cost.

With the success of the first field trial on nano graphene engineered drilling fluids, Company is in the midst of developing series of graphene enhanced product to cater more challenging drilling and production conditions.

Introduction

Graphene, a superlative two dimentional crystal of pure carbon. It's the thinnest and strongest substace known to science, approximately 100 times stronger than steel by weight. It's also a good conductor of electricity and heat. Back in 1947, Graphene was studied in theory and named as Graphene in 1987. Only until year 2003 where Andre Geim and Kostya Novoselov discovered the extraction method of graphene that won them the 2010 Nobel Prize in Physics and technology organizations started to develop techniques to make graphene a commercially usable product.

Graphene has potential applications in the industries such as biological systems, electronics, ultra-filtration, construction metallurgy, solar power panel, energy storage, quantum computers, automotive, aeronautics, drilling fluids and many others application. Several oil and gas drilling fluids companies have worked with institutions to develop graphene in drilling fluids, main focusing on producing functionalized graphene oxide to improve fluids loss control. Whereas Scomi worked with technical partner to develop a graphene enhanced product that provides superior lubricity and thermal stability to the conventional drilling fluids system.

Graphene itself has superior mechanical properties such as tensile strength of 130 gigapascals, weight of 0.77 mg/m^2, Young's Modulus of 0.5 TPa, specific strength of $4.7 - 5.5 \times 10^7$ N.m/kg, melting point of 4510K. Obviously graphene will be a very robust material for drilling and exploration activities. Considering material cost, application methodology, as well as HSE concerns, nano graphene has chosen to be suspended in the surfactant based carrier fluids prior introduced into the drilling fluids. And thus the product limitation will based on the limitation of the carrier fluid instead of graphene material. This graphene enhanced lubricant is biodegradable, thermally stable up to 300°C, suitable for moderate salinity drilling fluids up to approximately 140,000 mg/l of chloride content.

The lubricant forms a lubricating film known as tribofilm by both physical adsorption (i.e. physisorption) and chemical adsorption (i.e. chemisorption) which involves physical and chemical changes of both solids and lubricant molecules that are influenced by tribological conditions. The chemical reaction leading to boundary lubrication is initiated by temperature, pressure or mechanical contact (shearing forces and drilling).

The lubricant is designed to find areas of high friction, shear or pressure and its effective concentration is high at the point of friction. The carrier fluid is formulated to facilitate migration of protective nanoparticles to the metal surface. The lubrication mechanism is controlled by chemical structure of nano materials and their ability to form a strongly bonded protective film on the rubbing surfaces. The film is stable at extreme pressure and temperature. The nano graphene will invade into the microscopic spaces and chemically bonded to the metal surface, allowing the tubulars to tolerate extreme heat, and abrasions. Upon high pressure and temperature, the lubricant containing nano graphene gets crystallized in layers, causing the tubular surface shear and slide easily, thus lowering the friction coefficient. The crystallized nano graphene layers also prevent direct contact between metal surfaces, hence minimizing metal wear. The nano graphene coating also prevent oxidation, where the nano particle will displace the rust and carbon varnishes. They also change the morphology and surface characteristics of metal surface, creating a self healing friction barrier. The nano graphene coating also balling of the ″fines″ onto the metal surface, preventing bit balling and allowing the bit to freely cut the new formation. Once the nano graphene film is formed on the metal surface, it doesn't depends on the carrier fluid, it will remained on the metal surface disregard fluids contamination such as water and solids that might affect the carrier fluid. This differentiate the product from other liquid or solids type of lubricants where its depletion rate is low and also low dosage is required.

In one of the Myanmar onshore block drilling campaign, the reservoir section consisted of sand interbedded with shale is classified as hard formation, causing slow ROP and consumed several bits during the reservoir drilling in the first few wells. In order to reduce client's operating cost and improve ROP, Scomi has offered the operator graphene enhanced lubricant solution and after performing a comprehensive laboratory test.

Laboratory Evaluation

Based on the chemistry of the lubricant carrier fluid, this graphene enhanced lubricant is recommended for non-disperse polymer water based mud system which achieve the optimum performance. The lubricant had been evaluated for several different type of water based drilling fluids including the lubricity performance using standard EP/Lubricity Tester, its impact towards mud properties, formation damage test, shale compatibility test, etc.

A standard 10 lb/gal Salt Polymer WBM had indicated the superior performance of the graphene enhanced lubricant compared to market well-known ester based lubricant, where 5% by volume of each product had been introduced into the 10 lb/gal Salt Polymer Mud individually and the mud with graphene enhanced lubricant achieve torque reduction as high as 80%, whereas the ester based competitor's product achieve torque reduction of 30–40%.

Referring to Figure 1, based on the torque reduction observed between the ester based lubricant and the graphene enhanced lubricant, graphene enhanced lubricant outperformed the ester based lubricant 2 times the performance in every single different product concentration ranging from 1% to 5%. Based on the results also indicated that the optimum product concentration is 5% by volume since then the torque reduction had been maintained in the range of 80%.

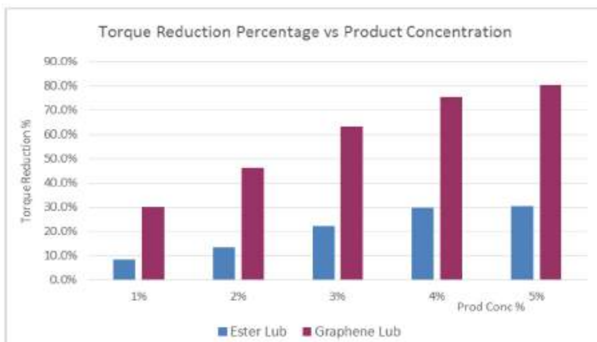

Figure 1—Torque reduction percentage vs product concentration comparing ester based lubricant and graphene enhanced lubricant in 10 lb/gal Salt Polymer Mud

From Table 1, graphene enhanced lubricant increase the rheology readings of the 10 lb/gal Salt Polymer base mud in the range of 40 – 60%, and API Fluids Loss is improved with the addition of the graphene enhanced lubricant, this could be the synergization between the nano graphene materials with the fluids loss control polymers. During the stress test of the mud system consisting the graphene enhanced lubricant, contamination with citric acid and cement bring the most significant impact on the mud properties especially the rheology and fluids loss, at the mean time torque readings increased could be due to loss of suspension capability of the fluids. Cement contamination as well as acidic environmental will definitely affect the mud properties, causing the fluids losing the suspension capability, thus affecting the performance of the graphene enhanced lubricant.

Table 1—Mud formulation and properties of 10 lb/gal Salt Polymer Mud, with lubricants and contaminants

Product	order	time	Base		T1: Ester Lube		T2: Graphene Lube		T3 = T2 + Caustic Soda		T4 = T2 + Citric Acid		T4 = T2 + Cement	
Fresh Water	1	-	302.86		302.86		302.86		302.86		302.86		302.86	
Sodium Carbonate	2	1	0.50		0.50		0.50		0.50		0.50		0.50	
Vacuum Salt	3	2	93.99		93.99		93.99		93.99		93.99		93.99	
Low Viscosity Polyanionic Cellulose	4	5	1.50		1.50		1.50		1.50		1.50		1.50	
Regular Viscosity Polyanionic Cellulose	5	5	0.50		0.50		0.50		0.50		0.50		0.50	
Xanthan Gum	6	5	1.15		1.15		1.15		1.15		1.15		1.15	
Sodium Hydroxide	7	2	0.50		0.50		0.50		0.50		0.50		0.50	
Drill Solids	8	5	20.00		20.00		20.00		20.00		20.00		20.00	
Lubricant	9	5			17.5mL		17.5mL		17.5mL		17.5mL		17.5mL	
Initial properties/AHR/ASA @ 200F	**Spec**		**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
Mud density, lb/gal			10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Rheological properties at 120F			120F	120F	120F	120F	120F	120F	120F	120F	120F	120F	120F	120F
600 RPM			60	41		42		57		57		35		45
300 RPM			42	29		30		41		39		25		28
200 RPM			34	24		24		34		32		19		22
100 RPM			24	18		18		25		24		14		15
6 RPM	6-8		7	6		6		9		9		3		5
3 RPM			5	5		5		7		7		2		4
PV, cP	<25		**18**	**12**		**12**		**16**		**18**		**10**		**17**
YP, lb/100 ft^2	15-25		**24**	**17**		**18**		**25**		**21**		**15**		**11**
Gel 10 sec, lb/100 ft^2	5-7		5	5		5		8		9		2		6
Gel 10 min, lb/100 ft^2			7	7		6		10		11		3		9
API Fluid Loss, mls	<4		3	2		4		2		3		6		6
pH mud			8.6	7.3		6.9		6.8		8.6		6.0		9.8
Mud Lubricity coefficient (10min)				0.33		0.23		0.06		0.06		0.06		0.06
Torque reduction, % (10min)						30.4		80.3		80		58		54

In order to test the performance of the graphene enhanced lubricant in a standard 13.5 lb/gal 350°F HTHP WBM, both ester based and graphene enhanced lubricant also being tested in the mud at various concentration and hot roll at 350°F. Compared to the 10 lb/gal Salt Polymer mud, torque reduction achieved for both ester and graphene enhanced lubricants are slightly lower (average 50% range compared to 80% range in 10 lb/gal mud), due to higher solids content and higher viscosity of the mud. Comparing with ester based lubricant, again graphene enhanced lubricant achieve 50% higher torque reduction within the same product concentration ranging from 1% to 5%. For the 13.5 lb/gal HTHP WBM, 4% to 5% of concentration is recommended for best product performance (refer to Figure 2).

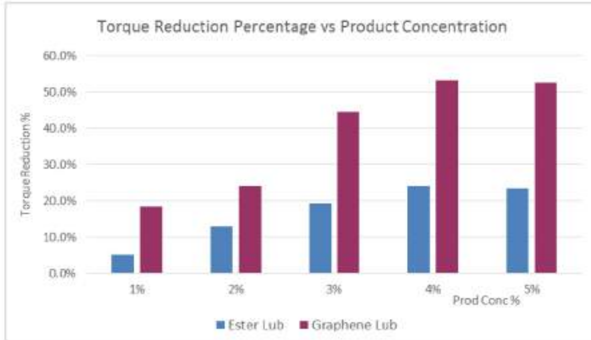

Figure 2—Torque reduction percentage vs product concentration comparing ester based lubricant and graphene enhanced lubricant in 13.5 lb/gal HTHP WBM

Table 2—Mud formulation and shale recovery results of 10 lb/gal Salt Polymer Mud, with different graphene enhanced lubricant concentration

Product	Base	T1: 1% Graphene Lub	T2: 2% Graphene Lub	T3: 3% Graphene Lub	T4: 4% Graphene Lub	T5: 5% Graphene Lub
Fresh Water	302.86	302.86	302.86	302.86	302.86	302.86
Sodium Carbonate	0.50	0.50	0.50	0.50	0.50	0.50
Vacuum Salt	93.99	93.99	93.99	93.99	93.99	93.99
Low Viscosity Polyanionic Cellulose	1.50	1.50	1.50	1.50	1.50	1.50
Regular Viscosity Polyanionic Cellulose	0.50	0.50	0.50	0.50	0.50	0.50
Xanthan Gum	1.15	1.15	1.15	1.15	1.15	1.15
Sodium Hydroxide	0.50	0.50	0.50	0.50	0.50	0.50
Drill Solids	20.00	20.00	20.00	20.00	20.00	20.00
Lubricant		3.5mL	7mL	10.5mL	14mL	17.5mL
Shale Recovery % (Pierre Shale)	**%**	**%**	**%**	**%**	**%**	**%**
Shale Recovery %	62.0	61.0	64.0	71.0	72.0	71.0

Graphene enhanced lubricant improve the low end rheology of the 13.5 lb/gal HTHP WBM in the range of 200% without affecting the Plastic Viscosity and Yield Point readings, which is good to improve the hole cleaning and weighting materials suspension capabilities. API Fluids Loss is improved with the addition of the graphene enhanced lubricant, this could be the synergization between the nano graphene materials with the fluids loss control polymers. During the stress test of the mud system consisting the graphene enhanced lubricant, contamination with citric acid and cement bring the most significant impact on the mud properties especially the rheology and fluids loss, at the mean time torque readings increased could be due to loss of suspension capability of the fluids. Cement contamination as well as acidic environmental will definitely affect the mud properties, causing the fluids losing the suspension capability, thus affecting the performance of the graphene enhanced lubricant. Refer to Table 3 for detailed results.

Table 3—Mud formulation and properties of 13.5 lb/gal HTHP WBM, with lubricants and contaminants

Product	order	time	Base		T1: Graphene Lub		T2: T1 + Cement		T3: T1 + Citric Acid		T4: T1 + Caustic Soda	
Fresh water	1		267.84		267.84		267.84		267.84		267.84	
Sodium Carbonate	2	2	0.20		0.20		0.20		0.20		0.20	
Bentonite	3	5	4.00		4.00		4.00		4.00		4.00	
Sulphonated Copolymer	4	2	1.00		1.00		1.00		1.00		1.00	
Synthetic Resin Lignite	5	2	8.00		8.00		8.00		8.00		8.00	
Synthetic Polymer #1 for Fluids Loss	6	5	1.00		1.00		1.00		1.00		1.00	
Synthetic Polymer #2 for Fluids Loss	7	5	1.75		1.75		1.75		1.75		1.75	
Sodium Hydroxide	8	2	0.15		0.15		0.15		0.15		0.15	
MEA	9	2	2.00		2.00		2.00		2.00		2.00	
API Barite	10	5	261.29		261.29		261.29		261.29		261.29	
Drill Solids	11	5	20.00		20.00		20.00		20.00		20.00	
Lubricant	12	5			14.0mL		14.0mL		14.0mL		14.0mL	
Oxygen Scavenger	13	-	2.00		2.00		2.00		2.00		2.00	
Initial properties/AHR/ASA @ 350F	**Spec**		**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
Mud density, S.G	13.5		13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Rheological properties at 120F				120F		120F		120F		120F		120F
600 RPM				105		110		95		81		103
300 RPM				67		70		57		50		63
200 RPM				49		54		41		40		49
100 RPM				29		35		25		26		32
6 RPM	8-12			5		15		5		11		15
3 RPM				4		14		4		10		14
PV, cP	<40			**38**		**40**		**38**		**31**		**40**
YP, lb/100 ft^2	15-28			**29**		**30**		**19**		**19**		**23**
Gel 10 sec, lb/100 ft^2	6-10			5		15		5		12		16
Gel 10 min, lb/100 ft^2				16		26		14		19		28
API Fluids Loss, mls	<3			2		2		6		7		3
pH mud	9-9.5			9.6		9.4		11.4		8.9		10.0
Lubricity test												
Mud Lubricity coefficient				0.25		0.07		0.16		0.16		0.07
Torque reduction, %						53.2		34.6		35.5		54.6

Effect of introducing graphene enhanced lubricant into drilling fluids also being evaluated in formation shale compatibility to ensure the new product doesn't bring any negative impact to the formation. The same 10 lb/gal Salt Polymer mud and 13.5 lb/gal HTHP WBM had been tested for shale dispersion test and swelling test with various concentration of lubricant. Shale dispersion test had been conducted under dynamic condition at 200°F under dynamic condition using Pierrer Shale, whereas linear swelling test using OFITE Linear Swell Meter using shale pallets. For 10 lb/gal Salt Polymer Mud, the mud achieved 62% shale recovery, 1–2% of the graphene enhanced lubricant doesn't affect the shale recovery until 3–5% of the lubricant only approximately 10% increased from 62% to 72% of the shale recovery observed (Table 2). For 13.5 lb/gal HTHP WBM, same testing conditions were conducted with Pierre Shales, and the mud achieved 61% recovery, same trend observed where 1–2% of the lubricant doesn't affect the recovery, until 3–5% of the lubricant concentration approximately 10% of shale recovery observed (Table 4). OFITE Linear Swell Meter was used to evaluate the shale swelling condition in the two said mud systems with graphene enhanced lubricant concentration from 1–5%. Based on the test results indicated in Figure 3 and 4, shale exposed in 10 lb/gal Salt Polymer mud will have approximately 40–50% swelling (Fresh Water Bentonite Mud cause >100% clay swelling, Synthetic Based Mud cause 0% clay swelling as benchmark), introduction of graphene enhanced lubricant apparently reduce the clay swelling in 2–10%

range, better results with increasing concentration of lubricant. Same trend was noticed for the 13.5 lb/gal HTHP WBM, where clay exposed to the mud has 40–50% swelling, and introduction of the lubricant is able to reduce the clay swelling in 2–10% range. Based on the results observed, apparently the graphene might have interaction between the platlet of the clay, inhibiting it from being dispersed and swelled.

Table 4—Mud formulation and shale recovery results of 13.5 lb/gal HTHP WBM, with different graphene enhanced lubricant concentration

Product	Base	T1: 1% Graphene Lub	T2: 2% Graphene Lub	T3: 3% Graphene Lub	T4: 4% Graphene Lub	T5: 5% Graphene Lub
Fresh water	267.84	267.84	267.84	267.84	267.84	267.84
Sodium Carbonate	0.20	0.20	0.20	0.20	0.20	0.20
Bentonite	4.00	4.00	4.00	4.00	4.00	4.00
Sulphonated Copolymer	1.00	1.00	1.00	1.00	1.00	1.00
Synthetic Resin Lignite	8.00	8.00	8.00	8.00	8.00	8.00
Synthetic Polymer #1 for Fluids Loss	1.00	1.00	1.00	1.00	1.00	1.00
Synthetic Polymer #2 for Fluids Loss	1.75	1.75	1.75	1.75	1.75	1.75
Sodium Hydroxide	0.15	0.15	0.15	0.15	0.15	0.15
MEA	2.00	2.00	2.00	2.00	2.00	2.00
API Barite	261.29	261.29	261.29	261.29	261.29	261.29
Drill Solids	20.00	20.00	20.00	20.00	20.00	20.00
Oxygen Scavenger	2.00	2.00	2.00	2.00	2.00	2.00
Lubricant		3.5mL	7mL	10.5mL	14mL	17.5mL
Shale Recovery % (Pierre Shale)	**%**	**%**	**%**	**%**	**%**	**%**
Shale Recovery %	59.0	61.0	60.0	69.0	71.0	68.0

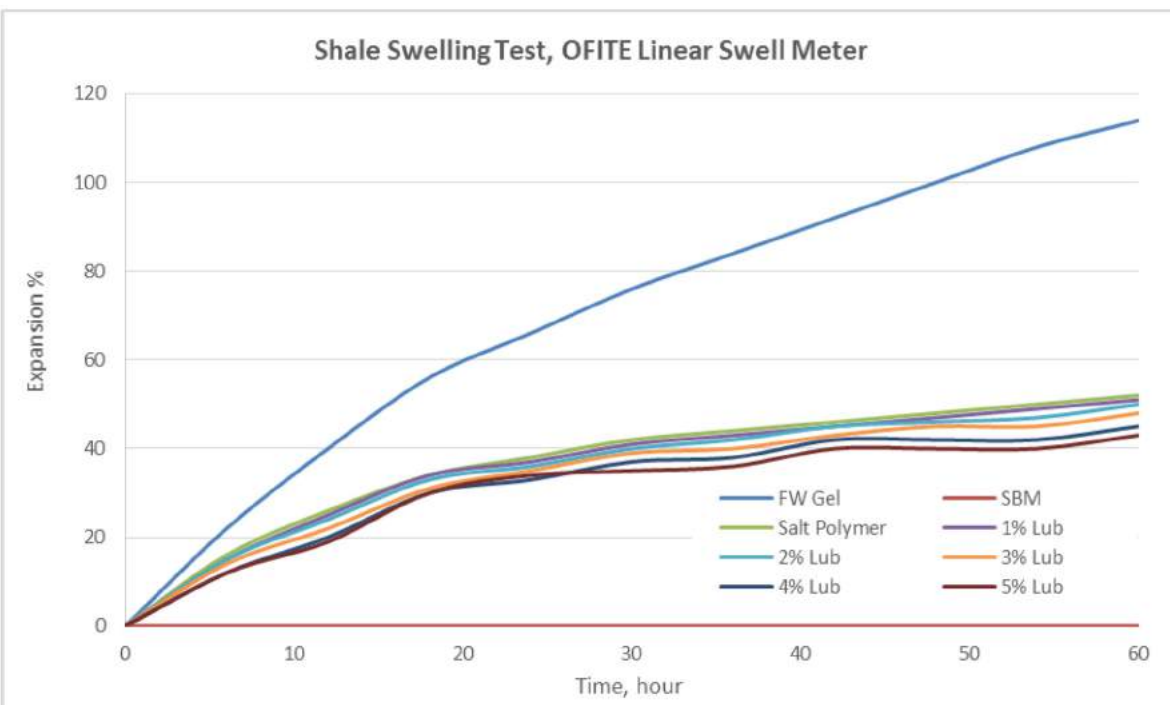

Figure 3—Shale swelling test using OFITE Linear Swell Meter, Pierrer Shale, for Fresh Water Gel Mud, SBM as base, comparing 10 lb/gal Salt Polymer Mud that has different concentration of graphene enhanced lubricant

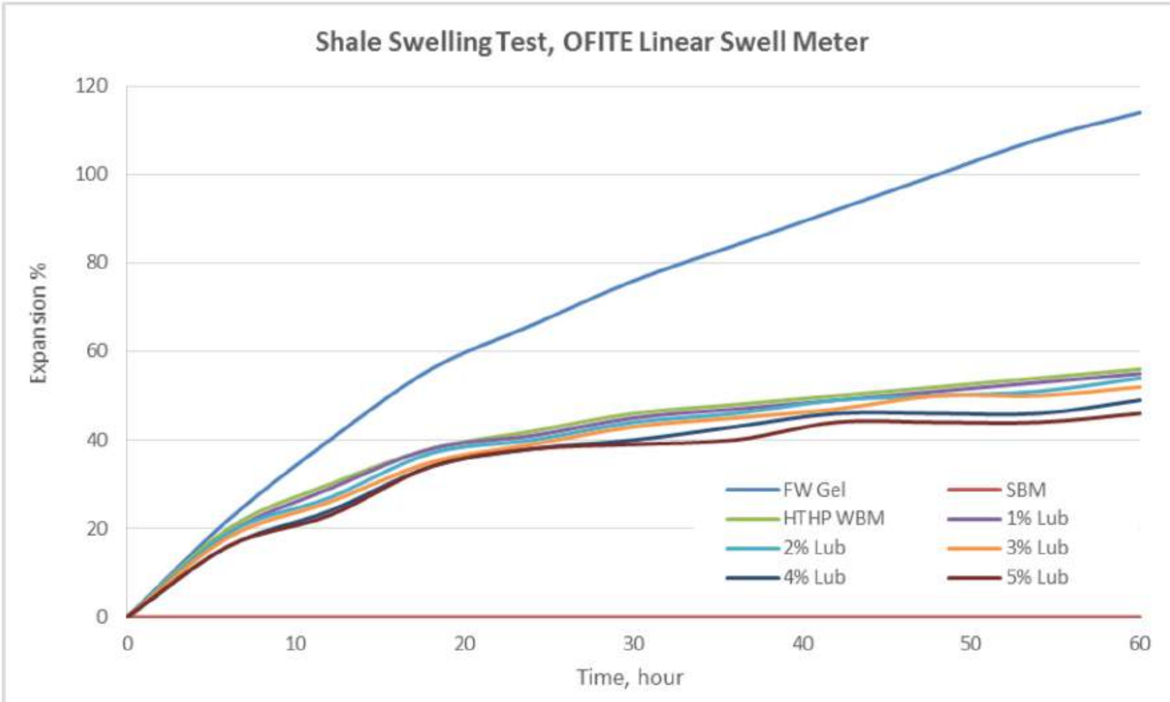

Figure 4—Shale swelling test using OFITE Linear Swell Meter, Pierrer Shale, for Fresh Water Gel Mud, SBM as base, comparing 13.5 lb/gal HTHP WBM that has different concentration of graphene enhanced lubricant

Formation damage test also conducted for both the ester lubricant and graphene enhanced lubricant in the water based Drill-In Fluid using a 20 micron aloxite disc. The 11 lb/gal Sodium Formate based Drill-In Fluid consist of Sodium Formate as base fluid, clarified xanthan gum and starch, together with sized Calcium Carbonate as bridging and weighing materials (Table 5). Initial permeabiliy of the 20 micron ceramic disc was measured, then a filter cake from the 11 lb/gal Drill-In Fluid had been formed on the disc and return permeability had been measure then retaind permeability as a comparison measurement to the initial permeability had been calculated as the base. After that 11 lb/gal Drill-In Fluid consist of 3% each of the ester lubricant and graphene enhanced lubricant had been prepared and repeated the same to measure the return and retained permeability (refer to Figure 5, 6, 7 and 8). Coefficient of friction and torque reduction for all the mud also being measured. It's observed that the mud formulated with ester based lubricant had severe foaming issue even with the introduction of silicone and alkohol based defoamer. The base 11 lb/gal Drill-In Fluid had a friction coefficient of 0.267, retained permeability of 5% without any breaker treatment. The ester based lubricant manage to reduce torque reading approximately 13.64%, achieved retained permeability of 49%. Whereas graphene enhanced lubricant reduced torque reading 36.36%, with retained permeabiity of 41%. Based on research done by other industrial experts, the ester based lubricant and the carrier fluid of the graphene enhanced lubricant consist the surfactant molecule that inhibits the absorption of polymers on the in-situ surface area of reservoir, reduce surface properties between filter cake particles to enhance the ease of natural cake liftoff.

Table 5—Mud formulation, Coefficient of Friction Results, and Retained Permeability Results for the 11 lb/gal Drill-In Fluid, with 3% of lubricants

WBM DIF, 11ppg	BASE	T1 - Graphene Lub	T2 - Ester Lub
Water	261.99	261.99	261.99
Sodium Formate	117.38	117.38	117.38
Clarified Starch	6	6	6
MEA	1	1	1
Clarified Xanthan Gum	1	1	1.5
Magnesium oxide	1	1	1
25 Micron CaCO3	15	15	15
50 Micron CaCO3	15	15	15
150 Micron CaCO3	20	20	20
Graphene Lubricant	-	10.5	-
Ester Lubricant	-	-	10.5
Coefficient of friction	0.2266	0.1442	0.1957
Lubricity Improvement		36.36%	13.64%
Initial Permeability, mD	1203		
Return Permeability, mD	60	497	591
Retained Permeability, mD	5	41	49

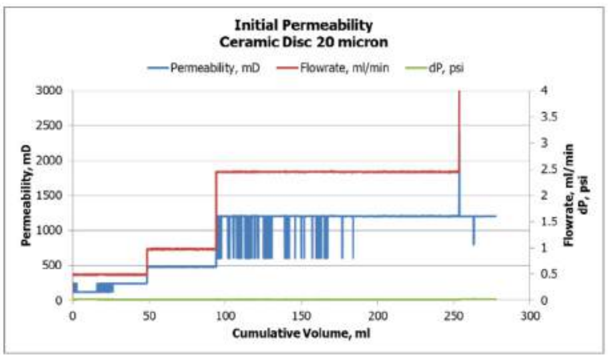

Figure 5—Initial permeability measurement of 20 micron ceramic disc

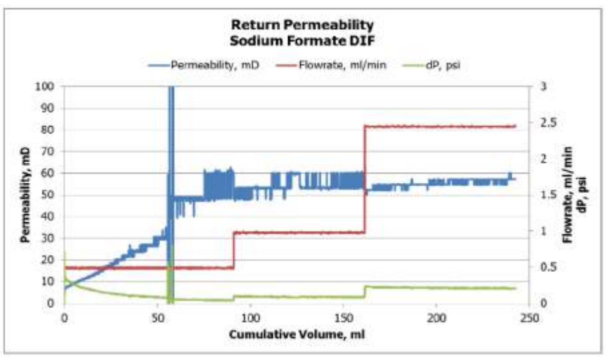

Figure 6—Return permeability measurement of 20 micron disc after forming a filter cake with 11 lb/gal DIF (without breaker)

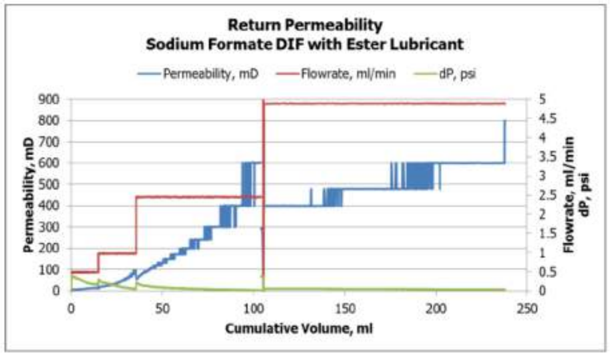

Figure 7—Return permeability measurement of 20 micron disc after forming a filter cake with 11 lb/gal DIF with 3% ester based lubricant (without breaker)

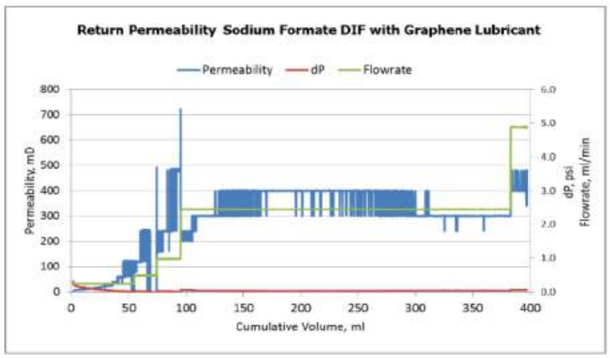

Figure 8—Return permeability measurement of 20 micron disc after forming a filter cake with 11 lb/gal DIF with 3% graphene enhanced lubricant (without breaker)

Field Performance

During the drilling of an onshore exploration campaign in Myanmar, the operator had experienced extremely hard formation in the reservoir section where every 3 to 4 days the drill bit need to be changed. Slow ROP and high torque reading also being observed, and several type of lubricants had been used without significant improvement. Graphene enhanced lubricant was proposed and accepted by the operator for one of the well’s 6″ reservoir section after detailed laboratory performance evaluation test conducted.

After 170 meter drilled in the 6″ reservoir section with 6″ PDC bit, another set of 6″ same model PDC bit was changed and ran in where graphene enhanced lubricant started injecting into the circulating system at the start up concentration of 2% by volume. Compared to previous 170 meter drilled, after introduction of the graphene enhanced lubricant, the weight on bit (WOB) was maintaining the same, but rate of penetration (ROP) had improved from previous average 3–4 m/hr to 9 m/hr (maximum instantaneous ROP is 5 m/hr) referring to Figure 9. During the field trial, the product concentration had been monitored closely against the drilling parameters. Based on the observation, the drilling performance especially torque and ROP readings were directly proportional to the product concentration, once the product concentration reduced to below 2% by volume, rate of penetration also reduced and the torque readings increased, thus 2% of minimum concentration will be required to be in the system for the product to be effective.

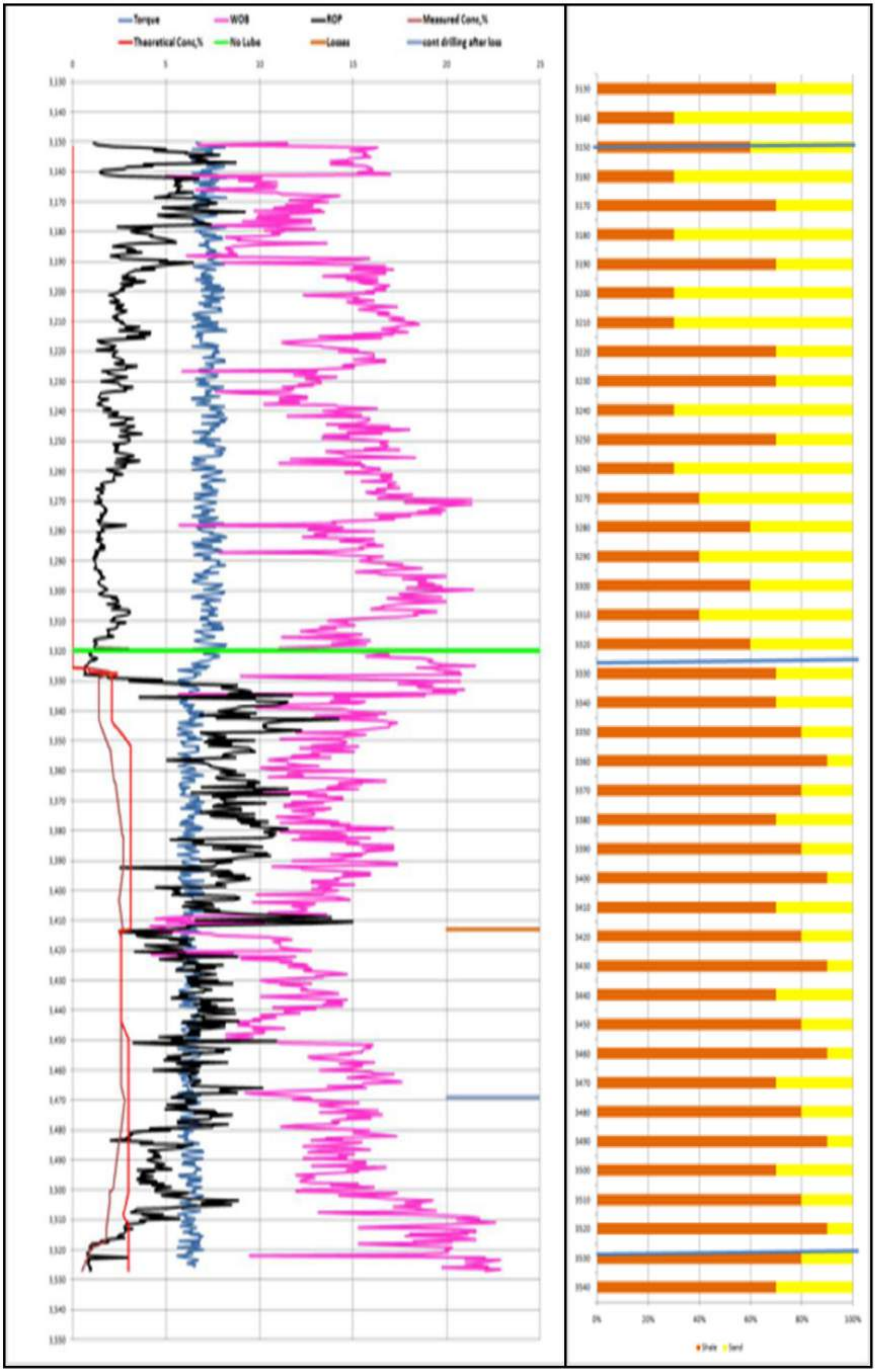

Figure 9—Drilling parameters and formation lithology vs graphene enhanced lubricant product concentration for the field in Myanmar

During the field application, product concentration had been monitored using the conventional retort kit. Based on the known concentration of the carrier fluids in the graphene enhanced lubricant, back calculation can be conducted for the product concentration once the carrier fluids concentration is determined from the retort test. This conventional method had provided an indeed accurate concentration monitoring. Depletion rate of the product had been monitored, and it's at the range of 30 liter or 7.9 gallons per meter drilled. Water based mud high dilution rate, losses with the drill solids over the shakers, as well as high downhole temperature contributed to the depletion rate.

Besides product concentration monitoring, an EP/Lubricity Tester also had been placed on board to monitor the coefficient of friction (CoF) of the active system, and it's been recorded that the coefficient of friction had reduced from 0.21 to 0.08, which is close to CoF reading of a conventional synthetic based mud (typical synthetic based mud's CoF is <0.1, whereas water based mud CoF ranging from 0.2 – 0.6). Torque simulation had been performed indicating that 44% of torque reduction can be achieved with such reduction in coefficient of friction (Figure 10 and 11), indeed the recorded actual average reaming torque had been reduced 20% (Figure 14). During the pulling out of bit, the bit was noticed in good condition without severe worn out compared to previous bits, and no bit balling observed on the BHA (Figure 17, 18, 19).

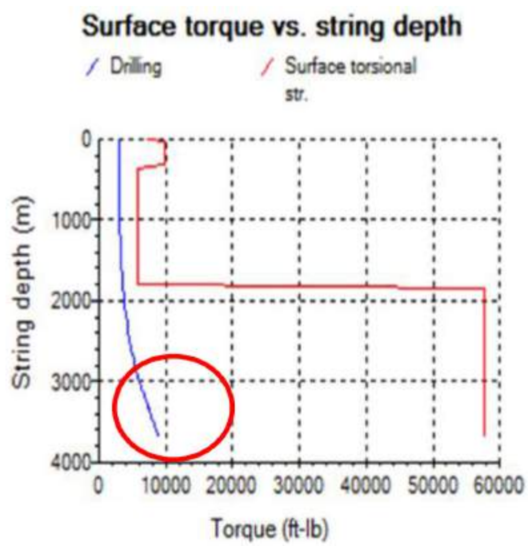

Figure 10—Simulated torque based on the Coefficient of Friction of the actual field mud used without graphene enhanced lubricant

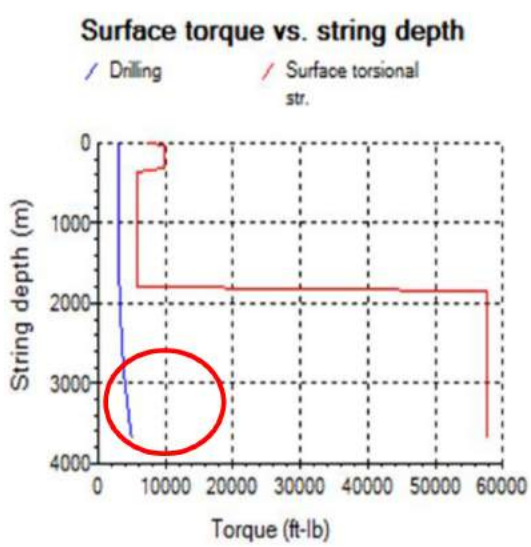

Figure 11—Simulated torque based on the Coefficient of Friction of the actual field mud used with graphene enhanced lubricant

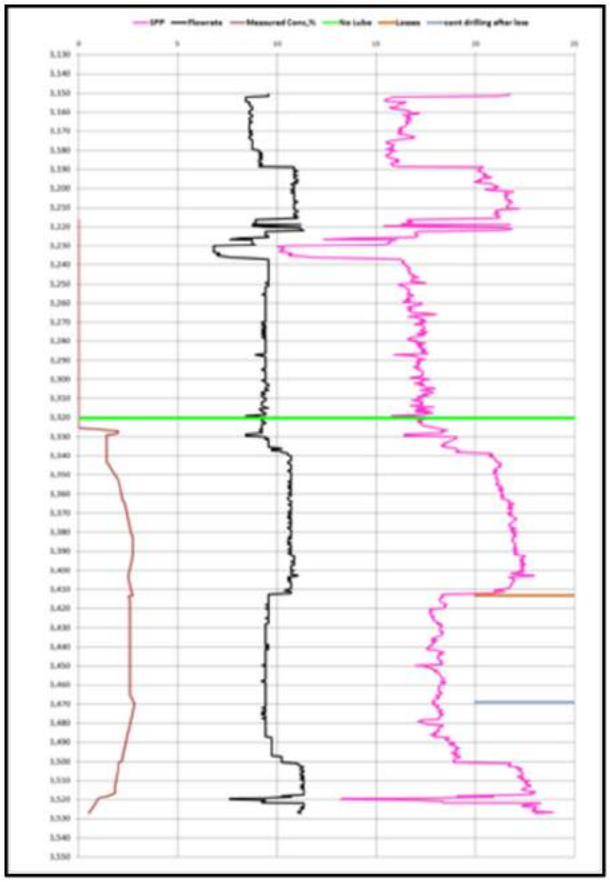

Figure 12—Stand pipe pressure (SPP) during the field trial of the graphene enhanced lubricant

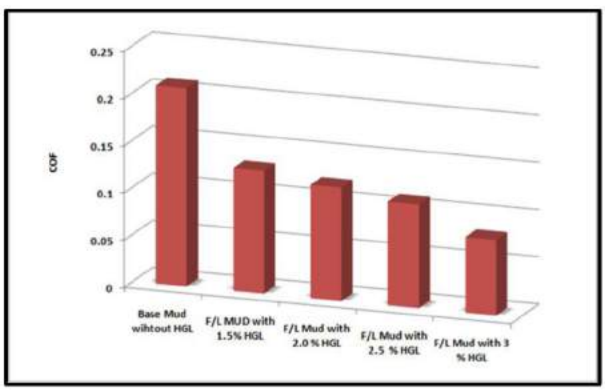

Figure 13—Actual coefficient of friction readings of the field mud with different concentration of graphene enhanced lubricant

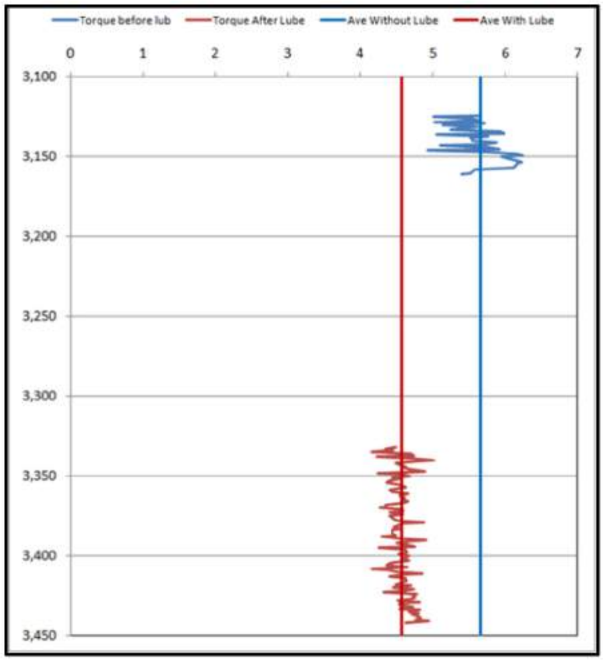

Figure 14—Actual reaming torque reading with and without the graphene enhanced lubricant

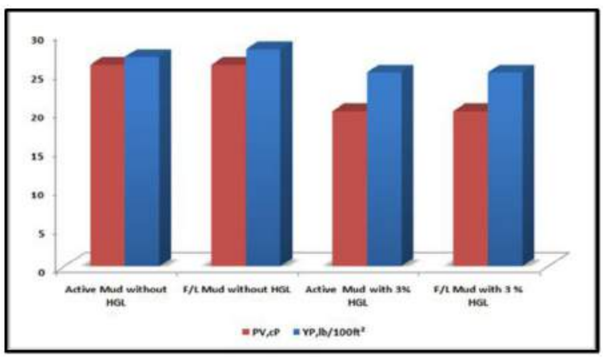

Figure 15—Actual field mud rheology properties (PV, YP) with and without the graphene enhanced lubricant

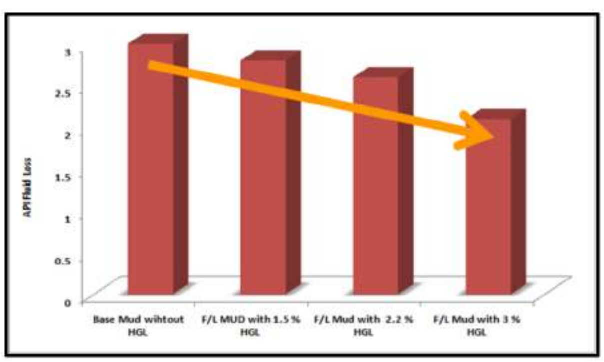

Figure 16—Actual field mud API fluid loss with and without the graphene enhanced lubricant

Figure 17—6″ drill bit condition after pull out of hole, without the graphene enhanced lubriant. Bit was worn out with lots of solids sticking on it

Figure 18—6″ drill bit condition after pull out of hole, with the graphene enhanced lubriant. Bit was in good condition and cleared from any solids

Figure 19—BHA condition during pull out of hole with graphene enhanced lubricant in the mud. BHA is cleared from any cuttings

During the well planning stage, the anticipated bottom hole temperature is 150°C (302°F) in the 6″ reservoir section, thus no extra high temperature products had been planned for this section. But actual recorded bottom hole temperature drilling into the reservoir was 176°C (349°F). As a good heat conductor agent, graphene is theoretically able to reduce localized heat generation, thus elongating the life span of the water based mud polymers. As the drilling fluids service provider, Scomi has observed internally as an additional performance remarks for the graphene enhanced lubricant besides lubricating the bit, 3% by volume of the product also able to reduce 25% of Plastic Viscosity but maintaining low end rheology (Figure 15), reducing 30% of fluids loss with 40% reduced concentration of the fluids loss control polymers (Figure 16). During an extensive wireline logging that was conducted more than 24 hours at

176°C (349°F), no mud deterioration and barite sagging observed. The improvement of polymers performance due to introduction of the graphene enhanced product will need to be continuously monitored in subsequent field application.

During the application of the graphen enhanced lubricant, stand pipe pressure (SPP) and equivalent circulating density (ECD) was stable, without significant increment or reduction (Figure 12). This is due to graphene enhance lubricant was forming a layer of graphene coating on the metal surface to improve torque and ROP, but not as a friction reducer within the drilling fluids to improve the fluids friction or hydraulic drag. The proprietary surfactant blends carrier fluid contain low molecular weight inorganics, during extreme high temperature condition (e.g. retort test up to 1000°F), these inorganics will decomposed and release mild plastic scent, which is not considered hazardous. But in order to avoid uncomfortable situation due to long period of exposure/inhalation of the scent, it's recommended to run retort test in fume hood or with proper ventilating system.

Conclusions

Graphene has proven to have many potential in oil and gas industry, whilst lots of research work had been on-going for the product, Scomi had developed a graphene enhanced lubricant and successfully applied in the field. The nano particles graphene is blended and suspended in a proprietary surfactants, upon high pressure sliding forces, the nano particle graphene will penetrates into microscopic pores of the metals, forming a tribofilm on the metals to improve lubricity, improve ROP, prevent bit balling, improve bit's life span, and improves fluids' thermal stability.

Laboratory test indicated that the product is able to reduce torque in 70–80% on a 10 lb/gal conventional salt polymer mud, 50% torque reductioin a 13.5 lb/gal HTHP WBM. Shale dispersion and linear swelling test also conducted on the salt polymer and HTHP WBM that doesn't contain any Potassium Chloride or shale inhibitor in order to evaluate whether the product will affect shale inhibition, results indicated 60–70% of shale dispersion and 40–50% swelling are better than the base mud. Formation damage test also conducted on a water based Drilll-In Fluid with and without the graphene enhanced lubricant. Apparently 3% of the product reduce 36% of torque, and achieve retained permeability of 41%, whereas base mud only achieve 5% of retained permeability without any breaker solution. All test in the laboratory had indicated that the product achieved better torque reduction, improve mud properties, never cause any shale inhibition issues, as well improving the retained permeability.

The product had been field trial in a HTHP onshore well with temperature up to 176°C (349°F). During the field trial, it's agreed that 2–3% of the product had improved ROP 125%, actual torque reduction of 20%, improve bit's life span >75%. And it's noticed by Scomi that fluids loss reduction of 30% with 40% polymers concentration reduction compared to planned mud formulation, which are additional benefits observed and yet to be continously monitor in future subsequent field trials. The improvement in drilling performance and bits' life span had reduced operator's operational time and cost.

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