International Journal of NanoScience and Nanotechnology.
ISSN 0974-3081 Volume 8, Number 1 (2017), pp. 59-71

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The Effect Of MoS_2 -And Graphene Nanoparticles On The Properties & Performance Of Polymer /Salt Treated Bentonite Drilling Fluid

Stanislaw Wrobel
University of Stavanger
Stavanger, Norway

Mesfin Belayneh
University of Stavanger
Stavanger, Norway

ABSTRACT

Among others, properly designed drilling fluid is a key for a success of drilling operation. The rheology, and lubricity of drilling fluids control the hydraulics, hole cleaning and the mechanical friction between string and wellbore.

In this paper, the effect of Molybdenum disulfide (MoS_2)-and Graphene nanoparticles on conventional water based drilling fluid systems have been studied. The coefficient of frictions have been measured at 20^0,55^0 and 70^0 C.

The results showed that the addition of 0.2gm (0.04 wt. %) MoS_2 and 0.1gm (0.02wt%) graphene reduced the average friction coefficient of the conventional nano-free drilling fluid by an average of -44 % and -34%, respectively. The torque and drag simulation studies showed that the reduction of coefficient of friction increased drilling depth by +26% and +7.7%, respectively.

1 INTRODUCTION

An evaluation of drilling fluids is an essential part of planning oil and gas wells. In rotary drilling operation, the drilling fluid has several functions. Amongst others drilling fluid is used to maintain well pressure, to transport cutting and cool well & drill bit and to form filter cake around the borehole. Properly designed drilling fluid reduces fluid loss by forming good mud cake and increase well strength. The quality of filter cake depends on its packing and mechanical properties. A typical conventional drilling fluid contains viscosity, density and fluid-loss control additives. However, conventional water based drilling fluids do not completely solve drilling related problems such as shale swelling and formation damage.

In the recent years, the application of nanomaterials (1nm -100 nm) is attracting the oil and gas industry. The nanomaterials research shows improved performance of cement and drilling fluid, as well as Enhanced Oil Recovery potential. This technology is believed to have a potential of solving technical challenges of the conventional technology in the Oil and gas industry. Through chemical and physical process, nanomaterials have shown an ability to create materials with improved properties such as thermal, mechanical, electrical, and rheological properties. The surface area to volume ratio of the nano-system is significantly higher than the micro/macro sized particles systems (Amanullah et al, 2009) [1]. The effect of nanoparticles on the conventional cement slurry with regards to fluid loss reduction and improved cement properties are documented (Ruhal et al, 2011 [2], Ershadi, et al (2011) [3], Li, et al (2003) [4], Rui et al. (2015) [5]. Some of the nano based drilling fluid research results have also been documented in the literature such as Katherine et al., (2012) [6] Li et al (2012) [7] Zakaria et al (2012) [8] Charles et al, (2013) [9] Sharma et al, (2012) [10] Taha et al (2015) [11].

However, in the present work, we have evaluated the performance of graphene having low concentration in the drilling fluids which is not being studies in the previous studies [11]. In addition, the dry lubricity of MoS_2 has been documented in the literature [12]. The present paper evaluates the impact of nano-sized MoS_2 particle on the conventional water based drilling fluid. The evaluation of the formulated drilling fluid will be done based on the experimental and performance simulation studies.

2 EXPERIMENTAL INVESTIGATION

Conventional drilling fluid is formulated with viscosifieres, fluid loss, salt and weighting additive materials. In this paper, except with weighting control material, we used these additives to formulate drilling fluids. For the selection of bentonite concentration, at first a literature review has been performed. Ahmed et al [13] has reviewed about 200-field water based drilling fluid. Their study showed that the amount of bentonite used in drilling mud varied up to 14% and the most of the studies used 6% bentonite and the average was 5%.

In this paper, drilling fluids have been prepared by mixing the fluid ingredients with a Hamilton beach mixer, and were aged for 48 hours until bentonite swell well. All the tests were carried-out according to API RP 13B-1 [14] standard. For the experimental investigation, a conventional nano-free water based drilling fluid were formulated as a reference. The impact of nanoparticle on the reference system has been studied by adding a 0.02-0.08 wt. % Graphene-and MoS_2 nanoparticles. The next sections present the description of the fluid additives, drilling fluid formulation, measurements and characterization.

2.1 Materials characterization

2.1.1 Molybdenum disulfide (MoS$_2$) nanoparticle

Molybdenum disulfide (MoS_2) is an inorganic compound. It is composed of molybdenum and sulfur elements. Dilute acids and oxygen do not affect MoS_2 and it is relatively chemically unreactive. In appearance, molybdenum disulfide is similar to graphite. It is used as a solid lubricant, since it has low friction properties [12]. Therefore, in this paper, the performance of these particles is tested in drilling fluid. **Figure 1** shows the SEM analysis of MoS_2, which is being purchased from EPRUI Nanoparticles and Microspheres Co. Ltd [15].Based on our knowledge this system is not being used in drilling fluids in the previous studies.

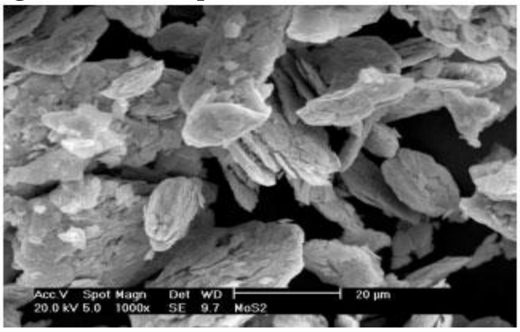

Figure 1: SEM analysis of MoS_2 particles

2.1.2 Graphene nanoparticle

Graphene is an allotrope of carbon. In atomic scale, graphene has a honey-comb lattice. **Figure 2** shows the SEM analysis of graphene nano-plates, it can be seen in the figure that these plates have large surface area. Graphene has many amazing properties. Graphene has superior mechanical properties such as tensile strength and Young's Modulus and higher melting point. Recently its application in cement [16] and drilling fluids [11] has been documented. However, the formulation of drilling fluids in this paper are different from previous findings [11]. Therefore, these particles are selected in higher bentonite water based drilling fluid, which is based on the reviewed field drilling fluids [13].

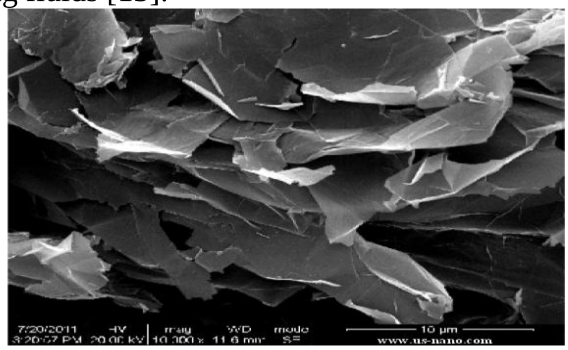

Figure 2: SEM analysis of Graphene

2.1.3 Bentonite

Bentonite is used as viscosifier additive in water-based mud. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the prime factor to determine their properties. Most clay has a mica-type structure, with flakes composed of tiny crystal platelets. A single platelet, called a unit layer, consists of an octahedral sheet and one or two silica tetrahedral sheets [17]. Oxygen atoms tie the sheets together by covalent bonds**.** The aggregation of clay platelet determine the rheology and filtrate loss properties of drilling fluid. The effect of nanoparticles, polymer and salt on the aggregation of clay will be studied later.

2.1.4 Xanthan gum Polymer

Xanthan gum is a water-soluble polymer. It is used to thicken water based drilling mud due to its viscous properties. Xanthan gum composes of a five-ring structure: A three-ring side chain with a two-ring backbone. Coupled to the side chain are different functional groups such as carbonyl and hydroxyl. This unique branching structure gives Xanthan gum thixotropic properties. The polymer branches are bonded by hydrogen bonding. Due to weaker hydrogen bonding, they will break when shear is applied to the system. Under low shear rate conditions, the hydrogen bonds will form again , and viscosity goes back to initial state. [17]

2.1.5 CMC Polymer

Carboxymethyl cellulose (CMC) is derived from cellulose, which is carboxymethyl groups (-CH_2-COOH) bound to some of the hydroxyl groups. CMC has linear structure and is a polyelectrolyte. It is formed by the reaction of sodium salt of monochloroacetic acid ($ClCH_2COONa$) with cellulose. In drilling fluids, where bentonite is a component, CMC can be used to increase the viscosity, control the fluid loss and maintain adequate flow properties at high temperatures [18, 19].

2.1.6 Salts-KCl

For water, sensitive shale formation, the potassium based water based drilling fluids are the most widely used. Potassium chloride is more effective in reducing swelling than other salts such as sodium chloride (NaCl) at the same concentration. [20]. The K^+ ions attach to clay surfaces and the size can fit the plates of clay.

2.2 MOS_2 and Graphene Nanoparticle treated drilling fluid formulation and Characterization

The conventional drilling fluid system (nano-free) has been formulated by mixing 500gm fresh water (H_2O), 2.5gm salt (KCl), 0.5gm polymer and 25gm bentonite. This fluid was considered as the reference–nanoparticle free fluid (**Ref**). Nano-based drilling fluids have been prepared by adding MOS_2 -and Graphne nanoparticles to the reference fluid. **Table 1** displays the formulation of the MoS_2 based drilling fluid. The formulation of the fluids was as follows:

- Reference[Ref]-Fluid (1) = 500gm H_2O + 2.5gm KCl + 0.5g CMC + 25gm Bentonite
- Nano-Treated-Fluids (2-5) = Reference fluid (1) + (0.1-0.4) gm MoS_2

Ingredient	Fluid 1 Ref	Fluid 2 Ref + 0.1gm MOS2	Fluid 3 Ref + 0.2gm MOS2	Fluid 4 Ref + 0.3gm MOS2	Fluid 3 Ref + 0.4gm MOS2
H2O[gm]	500	500	500	500	500
Nano - MoS_2[gm]	0	0,1	0,2	0,3	0,4
CMC[gm]	0,5	0,5	0,5	0,5	0,5
KCl[gm]	2,5	2,5	2,5	2,5	2,5
Bentonite[gm]	25	25	25	25	25

Table 1: Test matrix of Molybdenum disulfide nanoparticles (MoS_2) with CMC polymer.

Similarly, Graphene based drilling fluids has been formulated as provided in **Table 2**.

- Reference fluid (1) = 500gm H_2O + 2gm KCl + 0.5gm XG + 25gm Bentonite
- Nano-treated fluids (2-5) = Reference fluid (1) + (0.1-0.4) gm **Graphene**

Ingredient	Fluid 1 Ref	Fluid 2 Ref + 0.05gm Graphene	Fluid 3 Ref + 0.10gm Graphene	Fluid 4 Ref + 0.15gm Graphene	Fluid 5 Ref + 0.20gm Graphene
H_2O[g]m	500	500	500	500	500
Nano - **Graphene** [gm]	0	0,1	0,2	0,3	0,4
XG[gm]	0,5	0,5	0,5	0,5	0,5
KCl[gm]	2,5	2,5	2,5	2,5	2,5
Bentonite[gm]	25	25	25	25	25

Table 2: Test matrix of **Graphene Nano particles** with Xanthan gum polymer.

2.2.1 Rheology and filtrate loss evaluation -Graphene and MoS_2

Figure 3 and **Figure 4** displays the measured viscometer responses of the formulated fluid systems provided in **Table 1** and **Table 2** respectively. As shown on the figures, the viscometer responses increase as the concentration of MoS_2 increases. On the other hand, the viscometer response of the drilling fluids display a non-linear relationship as the concentration of Graphene varies. Please note that these behaviors are observed in the considered polymers (i.e Xanthan Gum and CMC).

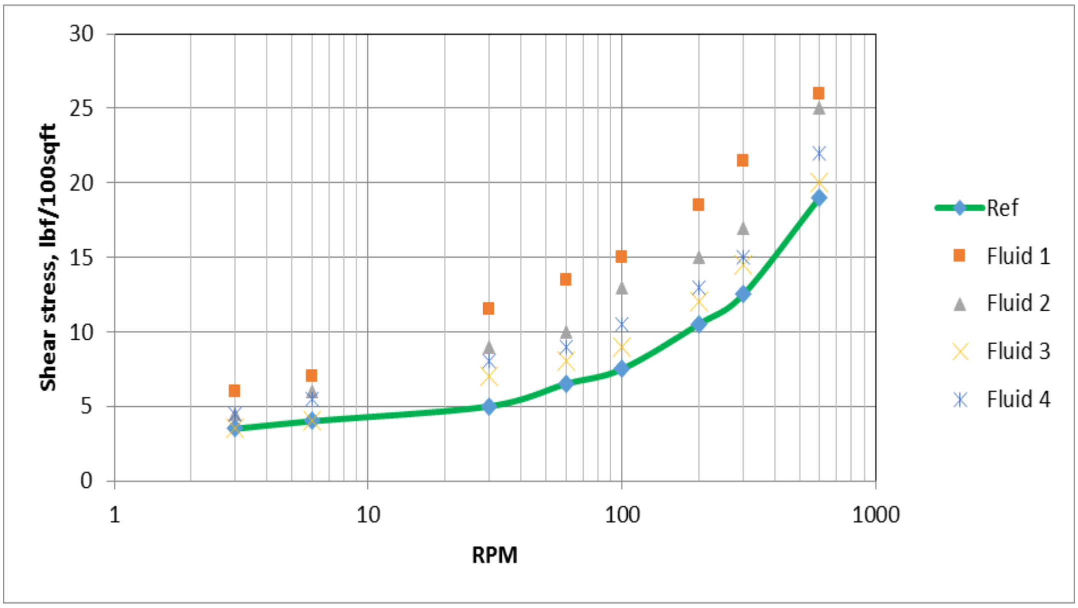

Figure 3: Viscometer measurement of test matrix –Table 1.- **MoS_2**

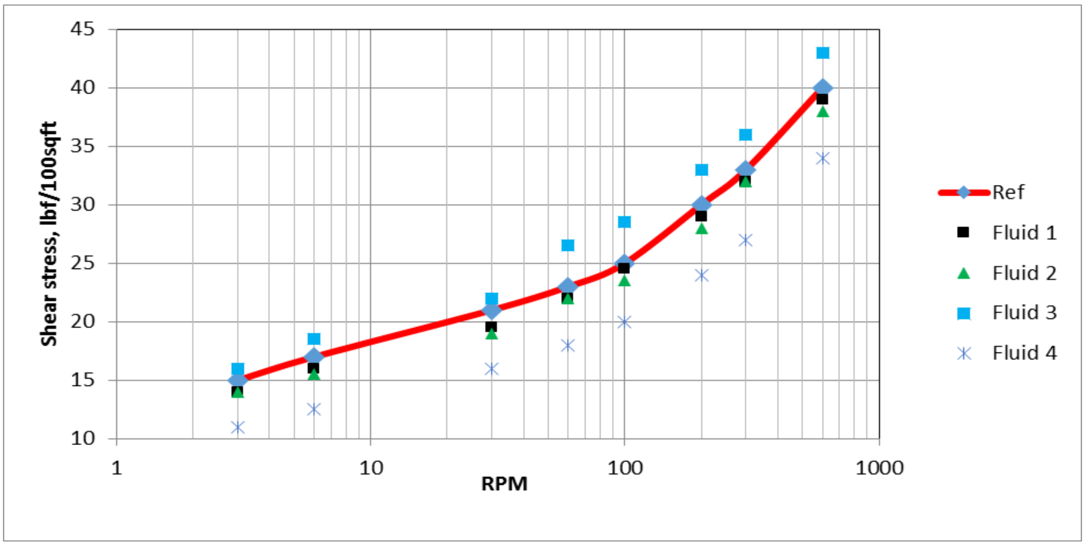

Figure 4: Viscometer measurement of test matrix –Table 1. **Graphene**

The impact of nanoparticle additives on the conventional drilling fluid has been evaluated based on the measured rheology and fluid loss parameters. These are important parameters since they are associated with fluid flow behavior and formation damage. The parameters are extracted from Bingham/Power law rheology models and measured from API filter press. The measurements were performed at room temperature. **Table 3** shows the parameters obtained from MoS_2 nanoparticles treated fluids. Unlike the viscometer responses (**Figure 3**), in general as can be seen on Table 3, the effect of nano--additives on the rheology parameters is a non-linear behavior as nanoparticles concentration increases. None of the additives show any impact on the filtrate loss. However, the addition of 0.1gm MoS_2 shows an impact on the Yield strength, and consistency index significantly.

Fluid	PV cP	YS lbf/100sqft	LSYS lbf/100sqft	K $lbf.s^n/100sqft$	n []	7.5min Filtrate loss, ml
Reference	6,5	6,0	3,0	0,3	0,6	7,5
Fluid 1=(Ref + 0.1gm MoS2)	4,5	17,0	5,0	3,9	0,3	7,8
Fluid 2=(Ref + 0.2gm MoS2)	**8,0**	**9,0**	**3,0**	**0,5**	**0,6**	**8,0**
Fluid 3=(Ref + 0.3gm MoS2)	5,5	9,0	3,0	0,8	0,5	7,5
Fluid 4=(Ref + 0.4gm MoS2)	7,0	8,0	3,5	0,5	0,6	7,5

Table 3: Test matrix of nano- **MoS_2** with CMC polymers

Similarly, **Table 4** shows the rheology parameters obtained from Graphene nanoparticles treated drilling fluids (**Figure 4**). As the viscometer response, the effect of nanoparticles additives on the rheology parameters also shows a non-linear behavior as nanomaterial concentration increases. Except with fluid 4, the 0.1gm-0.3gm nanoparticles additives do not significantly modify the plastic viscosity, yield strength, lower shear yield strength and the flow index. The addition of the 0.4gm nanoadditives reduced the yield strength, lower shear yield strength and consistency index by -23%, -27 % and -42% respectively. In general, the Nano additives in the considered salt/polymer system increases the filtrate loss.

Fluid	PV cP	YS lbf/100sqft	LSYS lbf/100sqft	K $lbf.s^n/100sqft$	n []	7.5min Filtrate loss, ml
Reference (Ref)	7,0	26,0	13,0	5,9	0,3	6,5
Fluid 1=(Ref + 0.1gm Graphene)	**7,0**	**25,0**	**12,0**	**5,4**	**0,3**	**8,0**
Fluid 2=(Ref + 0.2gm Graphene)	6,0	26,0	12,5	6,8	0,3	7,4
Fluid 3=(Ref + 0.3gm Graphene)	7,0	29,0	13,5	7,3	0,3	7,0
Fluid 4=(Ref + 0.4gm Graphene)	7,0	20,0	9,5	3,4	0,3	8,0

Table 4: Test matrix of nano- **Graphene** with Xanthan gum polymers

2.2.2 Effect of nanoparticles on the Coefficient of friction

CSM tribometer [21] was used to measure the friction coefficient of the drilling fluids. The measurement was on ball and plate surface contact in the presence of drilling fluid. The steel ball is an alloy of 6-chromium and 6mm diameter. The experiments have been lasted for 8.35min, at the linear speed of 4cm/s, which corresponds a linear distance of 20m. For all tests, a constant normal force of 10N was applied on the tribometer arm.The lubricity of the formulated drilling fluids has been measured at 20 ^{0}C, 50 ^{0}C and 70 ^{0}C . For each testing, a repeat tests has been perofrmed with the objective of obtaining a representative average values.

Figure 5 dispalys the measured average coefficient of friction of drilling fluids fomulated in **Table 1**. As shown, the considred wt% MoS_2 nanoparticle additives increased the lubricity of the drilling fluids. However, one can also observe that the lubricity is a non-linear function of MoS_2 nanoparticles concentration and temperature. Among the nano-additives, the 0.1wt % system shows the lowest coefficient of friction. We have analyzed if there is a correlation between the rheology parameters with the coefficent of friction. However, we found out inconsistent correlations. Up to this level of research, the paper does not look into the non-linear lubricity behaviors and the future work will be focussed on the underlying mechanism for this non linear behavior. However, the variation could be due to the internal structure of the fluid components association, which also influence the rheology and the filtrate performances.

For better comparisons, the avarage coefficient of friction measured at three temperatures are calculated and displayed on **Figure 6.** As clearly shown on the figure, as the concentration of MoS_2 nanoparticles increases, the coefficient of friction is decreasing. For this system, the 0.2gm was found out to be the optimized best nanoparticles concentration, which reduced the coefficient of friction by -44 %.

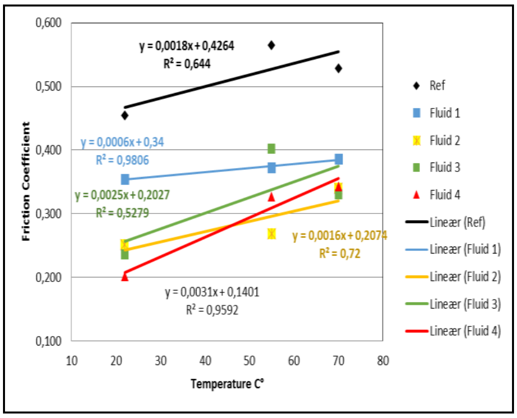

Figure 5: MoS_2 treated and reference drilling fluids average friction coefficients

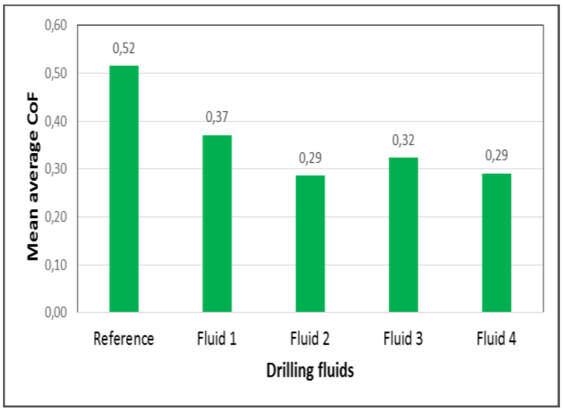

Figure 6: Average friction coefficients of the three temperature data

Figure 7 shows the measured average coefficient of friction of drilling fluids formulated on **Table 2.** The calculated mean coefficient of friction obtained from the three temperatures are displayed on **Figure 8**. Comparing the nano-free reference fluids in CMC (**Figure 6**) and Xanthan gum (**Figure 8**), the coefficient of friction is higher in CMC system than the XG system.

As shown on **Figure 8**, as the concentration graphene nanopartciles increases, the coefficient of friction in general decreases in a non-linear manner. However, the 0.1gm nanoadditives was found out to be the optimized concentration, which reduces the friction coefficient by -34 %.

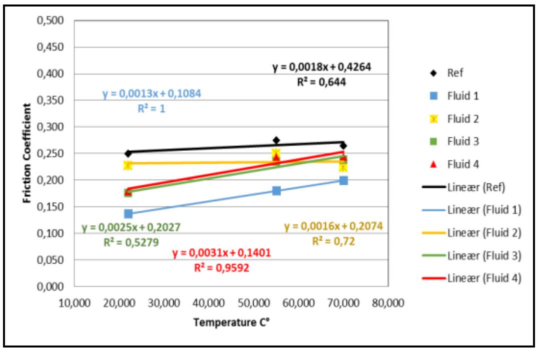

Figure 7: Graphene treated and reference drilling fluids average friction coefficients

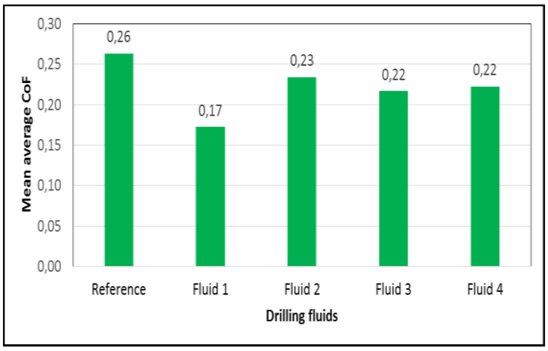

Figure 8: Average friction coefficients of the three temperatures data

3 NANOFLUIDS DRILLING PERFORMANCE SIMULATION

Using Landmark/Wellplan™ software [22], the torque and drag forces in the considered well trajectory has been evaluated in order to investigate the impact of the lubricity of the nanoparticles treated drilling fluid. The well is a typical drilling trajectory with a maximum inclination of 36deg, with various azimuth variations. During simulation, the tripping in / out speeds and drill string rotation were 60 ft/min and 40 RPM respectively. The 5'' OD size of E-75 grade drill string was used for the simulation. The drilling fluids have been pumped in the simulation well at the rate of 500gpm. The coefficient of friction between the drill string and the casing, drill string and the open hole were assumed constant

The primary objective of this simulation is to evaluate how far one can drill with the considered drilling fluids. The maximum drilling length obtained by simulating the torque, drag and the Von-Mises stresses of the drill strings provided that they are within a safe operational window. Among the three simulation results, it has been find out that torque has reached to the torque makeup limit and hence will only be presented here.

The drilling fluids used for the evaluation are the reference and the 0.4m MoS_2 nano-additives (Fluid 4). In terms of coefficient of friction, fluid 2 and fluid 4 have the same values. The coefficient of friction obtained from the coefficient of friction of these drilling fluids are displayed in **Figure 6** were 0.52 and 0.29 respectively.

Figure 9 shows the simulation results obtained from the nanoparticles free-reference drilling fluids. As displayed on the figure, for the 9900ft drillling depth, the torque reaches the limit eventhough the drag and von-Mises are far more within safe window. Under the given simulation operational parameters, one can not drill exeeding this drilling depth. Similarly**, Figure 10** shows the simulation result while drilling with the 0.4gm MoS_2 treated drilling fluid. Due to the lower coefficient of friction, the torques are within the safe operational window until the maxmum drilling depth is 12500ft.

Similarly, for the effect of graphene nanoparticles, the nano free-reference and the 0.1gm graphene nanoparticle drilling fluids were considered. The avarage coefficient of friction used for the simulation are displayed in **Figure 8**, which are 0.26 and 0.17, respectively. **Figure 11** shows the maximum drilling depth (i.e 13000ft) drilled with the reference drilling fluid without exceeding the operational window. The addition of 0.1gm reduced the coefficient of friction by -34 % and hence allowed to drill 14000ft.

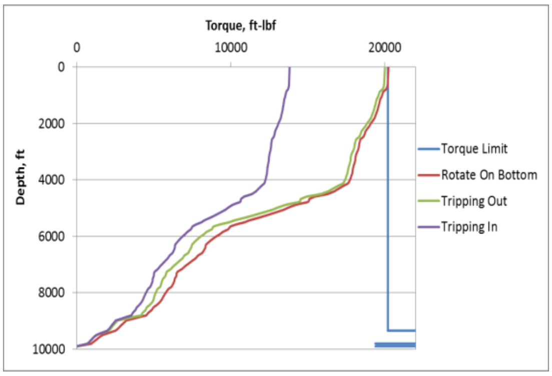

Figure 9: Maximum length drilling with the reference fluid without exceeding the torque limit

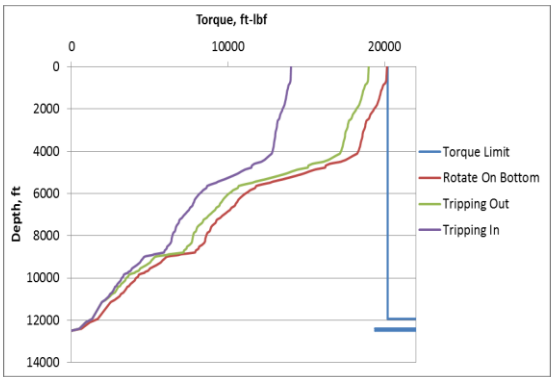

Figure 10: Maximum length drilling with the 0.2gm MoS_2 Nano powder treated fluid

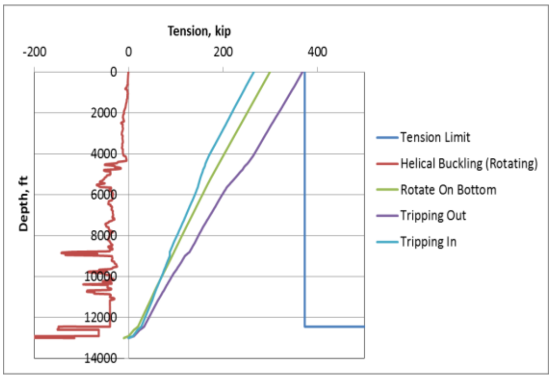

Figure 11: Maximum length drilling with the reference fluid without exceeding the tensile limit

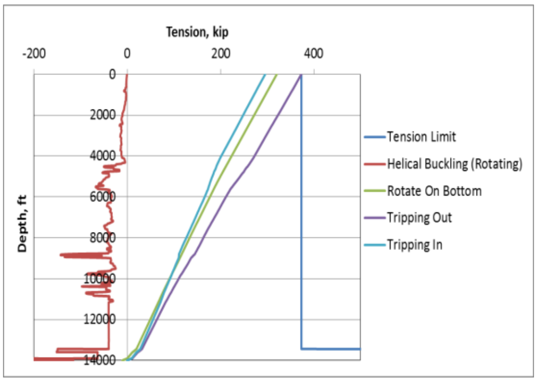

Figure 12: Maximum length drilling with the 0.1gm nano-Graphene treated fluid

Table 5 compares the maximum depths of the two drilling fluids. As shown, the addition of 0.4gm (+0.08wt%) MoS_2 allows to drill 2600ft longer than the nano-free drilling fluid. This means that the drilling length is increased by about 26% due to the reduction of the coefficient of friction by -44%. The result presented here illustrates the huge potential of nanotechnology in improving drilling performance.

Similarly the effect of grapane nanoparticles in drilling the reference drilling fluid yields a longer offset which we also simulated and the results are summarized in **Table 6**. As shown, the addition of 0.1gm Graphene (+0,02wt%) reduced the coefficient of friction by -34% and hence improved the drilling length by 7.7%.

Drilling fluid	Coefficient of friction	Maximum drilling length, ft	Change in length,ft	% Change
Ref CMC	0.52	9900	2600	26.3
Ref CMC + 0.4 gm MoS_2	0.29	12500		

Table 5: Effect of MoS_2 on maximum drilling depth and relative % change comparison

Drilling fluid	Coefficient of friction	Maximum drilling length,ft	Change in length,ft	% Change
Ref XG	0.26	13000	1000	7.7
Ref XG + 0.1g Graphene	0.17	14000		

Table 6: Effect of Graphene on maximum drilling depth and relative % change comparison

4 SUMMARY

In this paper, the effect of graphene -and MoS_2 nanoparticles in 25gm bentonite /500 gm H_2O treated with Xanthan gum XG and CMC polymers/salt systems have been studied. The rheology and the lubricity of the drilling fluids have been measured.

The results showed that the type and concentration of nano-additive influence behavior of the nano-free reference system. One clear observation is that the performance of the nano-additive displays a non-linear effect as the concentration increases.

From the overall test and simulation results, the performance of the selected optimized nano-treated drilling fluid system is summarized as follows.

- The graphene and MoS_2 nanoparticles additives in general increased or showed no effect on the filtrate loss of the considered bentonite drilling fluid.

- The addition of 0.1gm graphene decreased the coefficient of friction by -34% and the simulation results showed that the nano-additive allows drilling depth increase by 7.7% relative to the nano free system.

- The addition of 0.2gm MoS_2 decreased the conventional drilling fluid's coefficient of friction by -44% and the simulation results showed that the nano-additive increases drilling depth by 26% more than the nano free system.

Nanomaterials based drilling fluids can be more expensive than the conventional ones. However nanomaterials based drilling fluids may have the potential to improve performances of drilling operation. Which compensate for higher expenses of these systems.

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