



Current Journal of Applied Science and Technology

28(6): 1-9, 2018; Article no.CJAST.35139

ISSN: 2457-1024

(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843,
NLM ID: 101664541)

Evaluation of the Effects of Nanofluid on the Lubricity of Oil-based Mud

Fadairo Adesina^{1*}, Ogunkunle Temitope¹, Abraham Victoria¹,
Oladepo Adebowale¹ and Lawal Babajide²

¹Department of Petroleum Engineering, Covenant University, Ota, Nigeria.

²Oil and Gas Risk Evaluation, PricewaterhouseCoopers, USA.

Authors' contributions

This work was carried out in collaboration between all authors. Author FA designed the study, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Author OT performed the statistical analysis and wrote the first draft of the manuscript. Authors AV, OA and LB performed the statistical analysis. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2018/35139

Editor(s):

(1) Dr. Chang-Yu Sun, Assistant Professor, China University of Petroleum, China.

Reviewers:

(1) Richard Amorin, University of Mines and Technology, Ghana.

(2) Ariffin Samsuri, Universiti Teknologi Malaysia, Malaysia.

Complete Peer review History: <http://www.sciencedomain.org/review-history/26034>

Original Research Article

Received 29th June 2017
Accepted 8th September 2017
Published 28th August 2018

ABSTRACT

Nanofluids are applied where heat transfer, drag reduction, binding ability for sand consolidation and corrosion control is of utmost priority. This paper discusses the experimental work carried out on a pre-conditioned base fluid (ethylene glycol and ethanol) with silicon-oxide powder as a nanofluid to investigate the nanofluid effect on lubricity enhancement in the oil based mud. The lubricity test was carried out using Ofite EP lubricity tester which simulates the speed of rotation of drill pipe and the pressure with which the pipe bears against the borehole wall.

The result shows that nanofluids prepared using ethanol and ethylene glycol exhibited different rheological behaviors. But ethylene glycol treated with nanoparticles and oil based mud treated with nanofluid shows improved lubricity coefficients that falls within the obtainable lubricity coefficient observed in oil-based mud. Increase in weight percent of the nanoparticles in ethylene glycol resulted into decrease in the lubricity coefficient for the oil-based mud. It has been found that the weight percent of the nanoparticles and the type of continuous phase (ethylene glycol or ethanol) have an important effect on the lubricity of the oil-based mud. From the results, it can be concluded

*Corresponding author: E-mail: adesinafadairo@yahoo.com, adesina.fadairo@covenantuniversity.edu.ng;

that, there is a non-linearity relationship between lubricity coefficient and particle weight. Percent in the mud treated with Nanofluid. The lubricity reduction effect observed in pre-conditioned oil-based mud can be said to be as result of combined effect of both the nanoparticles and the based fluid.

Keywords: Oil Based Mud (OBM); lubricity coefficient; torque; ethylene glycol; ethanol; nano-technology.

NOMENCLATURES

ETH : Ethanol Base Fluid for Nano-particle Preparation
EG : Ethylene glycol Base Fluid for Nano-particle Preparation
NF : Nanofluid
OBM : Oil-based Mud
ETH 5%NF : Nanofluid with 5% w/w nanoparticle +Ethanol
ETH 10%NF : Nanofluid with 10% w/w nanoparticle +Ethanol
ETH 15%NF : Nanofluid with 15% w/w nanoparticle +Ethanol
EG 5%NF : Nanofluid with 5% w/w nanoparticle +Ethylene-glycol
EG 10%NF : Nanofluid with 10% w/w nanoparticle + Ethylene-glycol
EG 15%NF : Nanofluid with 15% w/w nanoparticle + Ethylene-glycol
5%NF+OBM : Mud sample (OBM) with 5% w/w nanoparticle +Ethylene-glycol
10%NF+OBM : Mud sample (OBM) with 10% w/w nanoparticle +Ethylene-glycol
15%NF+OBM : Mud sample (OBM) with 15% w/w nanoparticle +Ethylene-glycol

1. INTRODUCTION

Drilling fluids are an integral part of drilling oil and gas wells. A drilling fluid is typically pumped through the drill string and is subsequently introduced to the bottom of the bore hole as it squirts out from the drill bit nozzles [1]. This action cools and lubricates the drill bit and helps to convey rock debris/drill cuttings from the drilling area to the surface [2-6].

Increase in demands of hydrocarbon and attempt to deplete sub-surface reservoirs on time, requires oil and gas operator to search for oil in deeper formation and in extremely challenging reservoirs with extreme downhole conditions that affects drilling mud stability [4-5]. The major challenge in drilling into such formation (deep, ultra-deep reservoirs and unconventional shale plays) is how to manage the frictional forces encountered. Though, oil-based/or synthetic muds offers adequate lubricity for the drill strings, they possess inherent challenges in terms of cost of formulation and production, expensive infrastructure and growing environmental concerns [7]. The mechanical limit of drilling tool can also be exceeded through excessive drag and torque experienced while drilling in extended-reach wells and directional wells, this could limit the maximum horizontal displacement of such wells. In drilling, drag and torque are caused by frictional forces acting between the drill string and the wellbore or casing. Lubricity coefficient (dimensionless parameter) is a key factor in quantifying the drag and torque effect

[8] in oilfields. The knowledge of this coefficient is required in drill string and well path design, and even in mud formulation by service companies for torque and drag reduction. In static condition, lubricity coefficient is the ratio of force needed to initiate flow or movement to the normal force binding the surface together, while the dynamic or kinetic coefficient of friction is the ratio of force needed to continuously move the surfaces to the normal force holding the surfaces together [7]. Drilling fluids serve to reduce the lubricity coefficient, and its ability to reduce lubricity coefficient depends on the mud composition. For water based mud, lubricity coefficient is between 0.15 – 0.40, while for oil-based mud is between 0.15 – 0.20, but generally vary between 0.20 – 0.28. The lower the lubricity coefficient, the easier it is to initiate or sustain movement of the two surfaces. In oil well drilling, reduction in lubricity coefficient will allow an operator to easily move and rotate the drill string in the wellbore, result in longer laterals; less expensive equipment, reduce wear on tools, reduce casing wear, increased tool life, and reduce vibration.

Current researches have shown that the application of nanofluids (generally nano size particles) in challenging areas have proved to be efficient. Some field applications are in the areas of high heat transfer, gel formation, drag reduction, binding ability for sand consolidation and corrosion control [9], nano-fluids are selected in numerous studies due to its extremely high surface area to volume ratio and high thermal conductivity. It can be produced by

adding Nano-sized particles in low volumetric fractions to a fluid. Nano-fluids for oil and gas field applications are defined herein as drilling, drill-in, completion, stimulation or any other fluids used in the exploration and exploitation of oil and gas that contain at least one additive with particle size in the range of 1-100 nm [10]. Numerous research has been done on the effects of these fluids on rheological properties of muds, but little has been done on using Nanofluid to improve the lubricity of drilling muds: Luckhman, and Rossi [11] reported in their work on an investigation of HPHT rheology of bentonite clay suspensions with addition of electrolytes such as KCl, LiCl and NaCl, increase in Yield Point was reported for the modified bentonite clay suspension with electrolytes. More recently, Hassiba and Amani [12] reported their work on the effect of Salinity on the rheological properties of water based mud under HPHT for drilling offshore and deep wells, they concluded that NaCl contaminated samples had higher shear-stress – shear rate curves than ordinary water-based mud. Krishnan et al. [13] focuses on the application of boron-based nanomaterial enhanced additives in water-based mud system. The additives were formulated to improve filtration, torque and hydraulic drag during drilling, upon field application, the additives gave about 36.36% torque reduction compare to commercial lubricant that gave around 13.64% torque reduction; Sifferman et al. [14] developed water-based mud system that approaches the performance of oil-based mud using starch lubricant composition, they reported an approximate coefficient of friction values close to that of an average oil-based mud; Alford et al. [15] reported work on systematic investigation of both lubricity characteristics of silicate drilling fluids and the effect of silicate-base systems on the formation production and evaluation, their results show promising applications. A novel biotechnological method was developed by Schuh et al. [16] using encapsulating oil in polysaccharide-based polymer that delivers high pressure lubricity, it was designed to improve lubricity in horizontal wells using non-reactive lubricant product additives. Recently, Nano graphene application in improving drilling fluids performance was reported by Taha and Lee [17].

Most experiental work on improving mud properties using Nanomaterial are done by adding the nano-particle directly into the mud, this can lead to increase in total dissolved solid that could affects the plastic viscosity and lubricity coefficient, furthermore, it has been shown from previous studies on nanofluids that the properties and behaviours of nanofluids depend on the properties of the base liquid and the dispersed phased, particle concentration, size and morphology [9]. Therefore, this paper rather discusses the experimental work carried out on a pre-conditioned base fluid (ethylene glycol and ethanol) with silica powder as a Nanofluid to investigate the silica effect in lubricity improvement in the oil-based mud.

2. DRILLING MUD (OBM)

The drilling mud used in this work is an oil based mud. The chemical composition is presented in Table 1. The mud contains a mixture of mineral oil (EDC 99), bentonite, API barite (4.2 g), CaCl₂, lime (to regulate the pH) and certain additives like invermul (aids in reducing fluid loss), ezmul and versamul (works as an emulsifier) and geltone (acts as a viscosifier) which are all selected to suit the typical wells of depth in Nigeria (average of 9000 ft) [18]. The mud was formed under certain pressure and temperature conditions and went through a 24 hrs aging at 150°F to 350°F. Table 2 shows effect of various lubricant oil on lubricity coefficient of drilling fluid.

Table 1. Mud sample compositions

Composition	Mud + Geltone concentration
EDC 99 (Base oil)	210 ml
Invermul	6 ml
Ezmul	2 ml
Lime	2.5 g
Geltone	9 g
Barablok	2 g
Caco ₃ +brine	93 ml – water and 34 g-CaCO ₃
API Barite (4.2 g)	120 g
Rm 63	0.6 ml

Table 2. Effect of various oil on lubricity coefficient of drilling fluid

Oil	Concentration bbl/bbl	Into mud	High shear mixing	Base oil no oil
Diesel	0.1	0.08	0.25	0.25
Mineral	0.1	0.08	0.25	0.25
Kerosine	0.1	0.08	0.25	0.25
Crude	0.1	0.08	0.25	0.25

(Kercheville et al. [19])

2.1 Nanofluid

Silica nanofluid (SiO_2) was formulated via the two-step formulation method [9] by adding silicon nano particles of uniform size ($50 \pm 4 \text{ nm}$, Surface area = $60.2 \text{ m}^2/\text{g}$, 99.8% purity) (choice of nanoparticle and solvents were based on availability as at time of experiment) into a base fluid of De-IONIZED (DI) water and then into ethylene glycol (40:60) as sample one and sample two was prepared using silica nanoparticle with De-IONIZED water in ethanol. Different concentrations of the nanofluid (silicon oxide) were formulated (5%, 10% & 15% by weight of glycol and ethanol), the mixture was thoroughly mixed using magnetic stirrer at a about 3000 rpm for half an hour to achieve uniform mixing and dispersion of the nano particles in the base-fluid without further mechanical damage to the uniform sized particles. Modification of the oil-based mud with silica Nanofluid was done by adding 5%, 10% and 15% volume fraction of the Nanofluid into the already prepared mud and thoroughly mixed using Hamilton beach mixer before subjecting the samples to lubricity test.

2.2 Lubricity

For this work, OFITE EP (Extreme Pressure) lubricity tester (Fig. 1) was used to take the torque readings at different resolution per minute from where the lubricity coefficient was determined for different mud samples prepared. To test for the effect of Nanofluid friction reducing ability of the mud, the Ofite lubricity tester was first calibrated with deionized water at room temperature and the torque reading was taken as follows:

Deionized water torque reading at 25°C = 36.9 which falls within the range for lubricity of standard deionized water.

3. ANALYSIS OF RESULTS

Lubricity tests were carried out on oil-based mud treated with different concentrations of nanofluids using standard mud density between 10.1 ppg and 13.5 ppg. The oil-based mud without nanofluid was used as base case or control experiment. Table 1 gives the composition of the mud. The nanofluid addition was varied between 5% - 15% by volume. Before the addition of the nanofluid to the drilling mud, the rheology of the nanofluids prepared was carried out, while just the lubricity of the mud before and after addition of Nanofluid was estimated to have a basis for comparison.



Fig. 1. Ofite EP lubricity tester

3.1 Effect of Nanoparticle Addition on the Rheology of Ethylene Glycol and Ethanol

From the results, Fig. 2 shows the rheological behavior of the base fluids and their responses upon addition of nanoparticles. The Plastic Viscosity (PV) defines the ease of flow of any fluid and in drilling, determines the pump pressure at the surface. Plastic viscosity was estimated for the base fluids used in the preparation of nanofluid, that is- ethanol and ethylene glycol. Ethanol exhibits a relatively low plastic viscosity compared to ethylene glycol, but upon addition of nanoparticles between 5 – 15 wt%, it was observed that the viscosities of ethanol-silicon oxide nanofluid showed increasing trend with an average of 4 cP but still within the API approved standard of < 65 cP. On the contrary, ethylene glycol showed relatively high viscosity. Addition of nanoparticles initially reduced the plastic viscosity with glycol base fluid (5wt.% nanoparticle) but gradually upsurge with increase in weight. fraction of nanoparticles in the glycol base fluid, this is generally due to increase in the volume of solids (nanoparticles) dissolved in the glycol (Fig. 2). The Yield Point (YP), which is a measure of the solid suspending capacity of a fluid, in drilling, determines mud cuttings carrying ability was also evaluated. It was observed that the Yield Point of ethylene glycol experienced reduction upon addition of nanoparticles which remains fairly constant with increase in percentage weight fraction of the nanoparticles in the fluid. For ethanol the Yield Point show increasing trend upon addition of nanoparticles (Fig. 2). Generally, for the all the nanofluid concentrations the yield points were found to be below the API standard window of between 15 – 45 but the reduction in plastic viscosity observed in ethylene glycol with 5 wt.%

Nanoparticles encouraged the study of its effect on the lubricity of the mud used in this study.

Fig. 3 shows the temperature effects on the all nanofluid concentrations prepared using the two base fluids. The trend observed was generally reduction in both plastic and apparent viscosity upon rise in temperature. Evaluation of the temperature effects on the rheological properties of nanofluid with ethanol base fluid was not further evaluated beyond ethanol's boiling point, because, it was observed that ethanol was burning off at a temperature above its boiling point (60°C), this implies that its field application is limited since most drilling activities are at temperatures above 60°C. Therefore, ethylene

glycol with nanofluid was used for subsequent analysis of lubricity of the OBM while other experiments using ethanol with nanoparticle was just for comparison. For the tribology experiment, it was assumed that all lubricity coefficient results are based on the mechanical effect of the fluid composition.

3.2 Analysis of Lubricity Coefficient

Fig. 4 shows a plot of lubricity coefficient for various Nanofluid samples and OBM treated with pre-conditioned nanofluids at different RPM. (Table 3), Fig. 5 shows the mean lubricity coefficient obtained addition of Nanoparticle to Ethanol, Ethylene-glycol and Oil-Based Mud respectively.

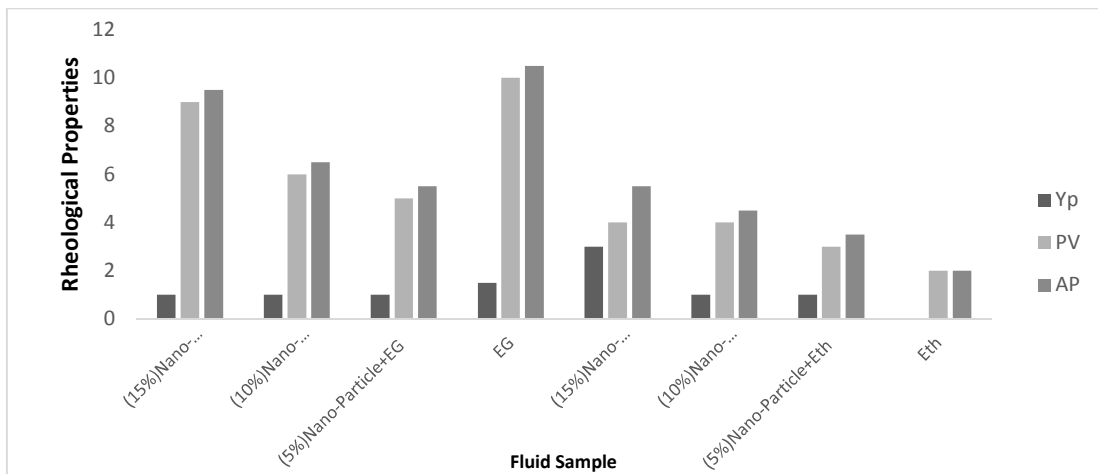


Fig. 2. Rheological properties of fluid samples

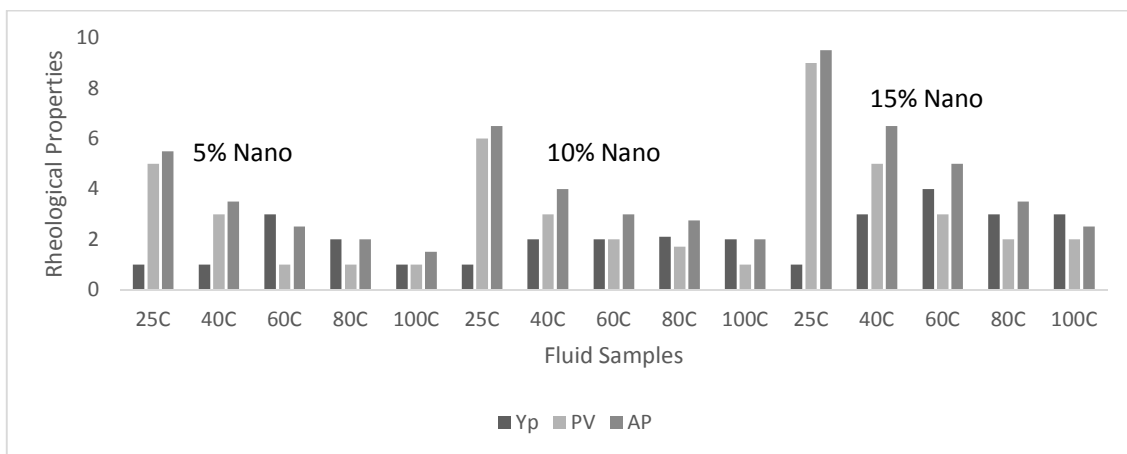


Fig. 3. Temperature effects on rheological properties of different concentrations of ethylene glycol nanofluids

3.3 Nanofluids (Ethanol and Glycol Base Fluids)

Nanofluid with ethanol base fluid recorded a beneficial reduction in lubricity coefficient upon addition of 5 wt.% nanoparticles (Table 3). Fig. 5 shows that addition of silicon-oxide nanoparticles reduced the lubricity coefficient of ethanol but there was a gradual increase in the lubricity coefficient as the weight percent of solids in the base fluid (ethanol) increased to about 10 – 15% wt. fraction.

For ethylene glycol base fluid, the lubricity coefficient recorded was rather low (0.1368 – 0.1555) (Fig. 4) and generally below what is obtainable for a typical mud. This was improved

upon addition of 5 wt.% silicon-oxide nanoparticles and thus remain fairly constant up to a total solid content of about 15% wt. fraction (Fig. 5).

Since it is generally believed that nanoparticles could increase the wettability of a base fluid and might be responsible for the large increase in the critical heat influx as observed in experiments [9], the high specific area (60.2 m²/g) and adjustable properties by varying particle concentration of the nanofluid could be said to be responsible for the reduction in lubricity observed in this experiment, this shows that there is a threshold concentration of nanoparticles for optimum lubricity to be achieved that depends on the specific area to volume ratio.

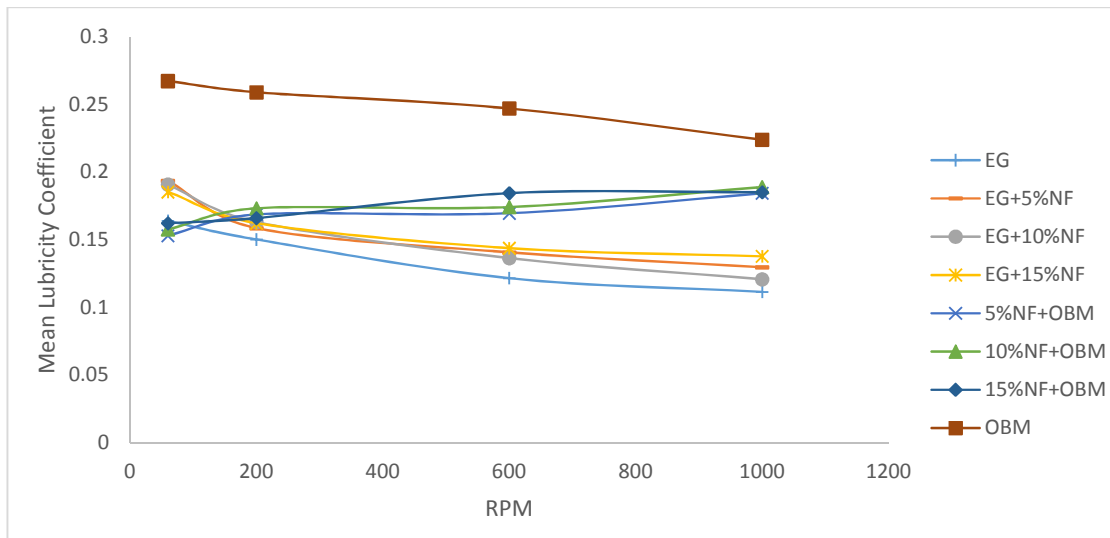


Fig. 4. Lubricity coefficient for different mass fraction of silicon-oxide nano-particle in ethylene glycol and oil-based mud

Table 3. Average friction coefficient values for different fluid samples

Lubricity coefficient report			
Fluid type	Mean	N	Std. deviation
ETH	0.3823848	4	0.05983234
ETH+5%NF	0.2662873	4	0.10993487
ETH+10%NF	0.3653390	4	0.09993343
ETH+15%NF	0.3632658	4	0.07146846
EG	0.1368293	4	0.02443038
EG+5%NF	0.1555243	4	0.02797814
EG+10%NF	0.1527303	4	0.03078439
EG+15%NF	0.1572018	4	0.02137309
OBM	0.2492411	4	0.01883100
5%NF+OBM	0.1688483	4	0.01279789
10%NF+OBM	0.1734553	4	0.01279789
15%NF+OBM	0.1743772	4	0.01201579

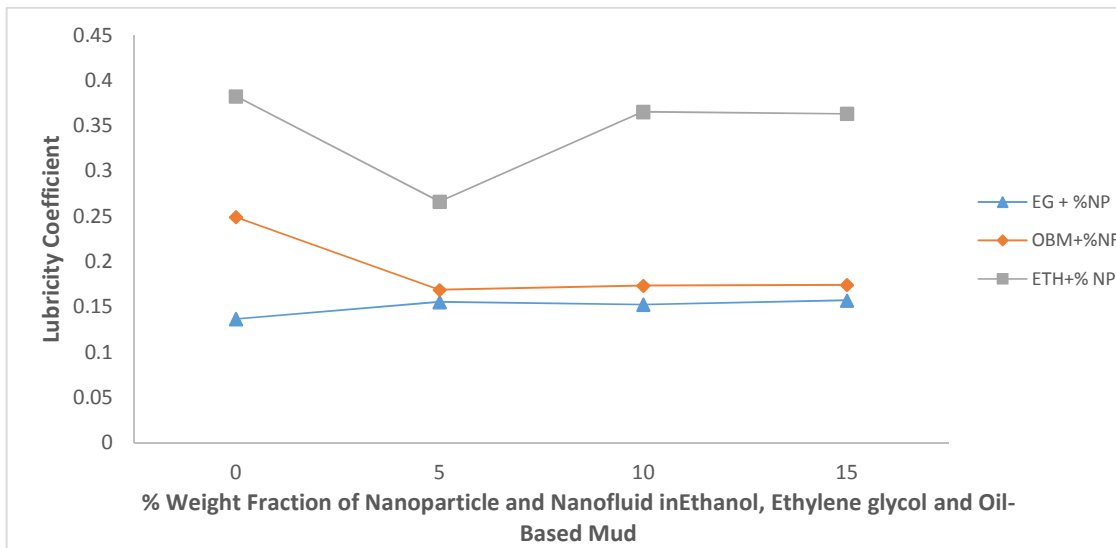


Fig. 5. Lubricity coefficients against percentage nanoparticles and nanofluid in ethanol, ethylene glycol and oil-based mud respectively

3.4 Oil-Based Mud with Silicon Oxide-Ethylene Glycol Nanofluid

Table 3 summarized the results of the lubricity test by averaging the lubricity coefficient for the different lubricants at four RPM. The oil-based mud was a locally made mud and so exhibit generally low lubricity coefficient which falls below the range (0.15 – 0.28) for oil based mud.

Fig. 4 through 5 shows the lubricity response of the pre-conditioned mud using nanofluid prepared by addition of different weight fraction (5, 10 & 15) of silicon oxide nanoparticles in a base fluid of ethylene glycol. The analyses of the effects of addition of silicon-oxide nanoparticles at different weight fraction in the base fluid of ethanol and ethylene was discussed earlier. Addition of different concentrations of the nanofluids on the oil-based mud showed improvement in the lubricity coefficient by way of reducing the oil-based mud lubricity coefficient from around a mean value of 0.2492411 to about 0.16685 for pre-conditioning with 5 wt.% silicon oxide + ethylene glycol nanofluid, 0.17346 for 10 wt.% silicon oxide + ethylene glycol nanofluid pre-conditioning and 0.17438 for 10 wt.% silicon oxide + ethylene glycol nanofluid pre-conditioning. Furthermore, it was observed from the plot of lubricity coefficient against percentage weight fraction (Fig. 5) that increase in weight percentage from 5% to 15% showed lubricity coefficients that remained fairly constant which was the same effect addition of silicon

nanoparticle had on the ethylene glycol nanofluid's base fluid (ethylene glycol), though in the latter case, there was an initial slight increase in the recorded lubricity coefficient (Fig. 5).

The observed beneficiary effects could be explained to be due to the particle's specific area (silica = 60.2 m²/g). Surface area to volume ratio plays important role in lubricity coefficient and as observed in the OBM with different weight. Percent of nanofluids, surface to volume ratio allows low concentration of the particles in the base fluid to achieve a beneficial effect. Increasing particle volume will definitely lead to increase in lubricity coefficient which can be later seen in the increase observed in the calculated coefficients from 5 – 15 wt.%.

4. CONCLUSIONS

In this study, experimental and data analysis on effects of nanofluid prepared by addition of silicon-oxide nanoparticles to different base fluids on the lubricity of oil-based mud was carried out. Previous authors reported the results of lubricity test on water-based mud with nanoparticles effect by direct addition of the particles to the mud. The results of this work show that nanoparticles could act as friction reducer and viscosifiers in the same mud based on reduction in the rheological properties determined for the nanofluids alone. This allow for reduced amount of other fluid components in a drilling mud. This is because a small quantity of nanoparticle is required to achieved increased viscosity,

therefore, the total solid requirement in a drilling mud is reduced. For lubricity test on the pre-conditioned mud, the results of this work show that addition of silicon oxide particle/ethylene glycol - nanofluid resulted in reduced lubricity coefficient of the mud at different weight fractions.

For these reasons, the following conclusions can be inferred.

- Lubricity efficiency of oil-based mud can be conditioned using carefully prepared Nanofluid
- Nanofluid (Silicon-oxide nanoparticles with ethylene glycol) addition in OBM gives a reduction in lubricity coefficient upon identifying the optimum particle concentration.
- Nanoparticles as additive in drilling fluids could act as viscosifiers substitute and friction reducer at the same time.

5. FUTURE WORK

Because we could not ascertain in this work, if the lubricity reduction observed in the preconditioned mud was due to just nanoparticle effect or combined effects of both base fluid, future work on this topic will be to analyze separately the effect of both nanoparticles and ethylene glycol on the lubricity coefficient of the mud.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Management of Covenant University Ota Nigeria for financial support and the management team of Fatherheroz Forte Nig. Ltd. for their technical support towards the successful completion of this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Fadairo Adesina, Orodu OD, Falode O. Investigating the carrying capacity and the effect of drilling cutting on rheological properties of jatropha oil based mud. SPE Paper 167551, SPE Nigerian Annual International Conference and Exhibition, Lagos; 2013.
2. Bourgoyne AT, Millheim KK, Chenevert ME, Young FS. Applied drilling engineering. SPE Foundation. 1991;508.
3. Fadairo A, Adekomaya O, Falode O. Effect of drilling cuttings transport on pressure drop in a flowing well. SPE/IADC Middle East Drilling Technology Conference, Bahrain. 2009; 125707.
4. Fadairo A, Falode O, Ako C, Adeyemi A, Ameloko A. (Croatia) Novel formulation of environmentally friendly oil based mud. New Technologies in Oil and Gas Industry In Tech Publisher. 2012; (Chapter 3).
5. Fadairo Adesina, Ameloko Anthony, Adeyemi Gbadegesin, Ogidigbo Esseoghene, Airende Oyakhire. Environmental impact evaluation of a safe drilling mud. SPE Middle East Health, Safety, Security, and Environment Conference and Exhibition held in Abu Dhabi, UAE; 2012.
6. Fadairo A, Tozunku KS, Kadiri TM, Falode O. Investigating the effect of electrolytes and temperature on rheological properties of jatropha oil based mud. SPE Nigeria Annual International Conference and Exhibition (NAICE), Nigeria, 6–8 August 2012, SPE 163027; 2012.
7. Redburn M, Dearing H, Growcock F. Field lubricity measurements correlate with improved performance of novel water-based drilling fluid. Offshore Mediterranean Conference and Exhibition. 2013-159 OMC Conference Paper; 2013.
8. Andrew D, Hale A, Mahajan S. Lubricity and wear of shale: Effects of drilling fluids and mechanical parameters. SPE/IADC Drilling conference. Society of Petroleum Engineers. 1993;501-511.
9. Wen D, Lin G, Vafaei S, Zhang K. Review of nanofluids for heat transfer applications. Particuology. 2009;7(2):141–150.
10. Amanullah M, Al-Tahini AM. Nanotechnology its significance in smart fluid development for oil and gas field application. SPE Saudi Arabia Section Technical Symposium. SPE 126102-MS; 2009.
11. Luckhum PF, Rossi S. The colloidal and rheological properties of bentonite suspensions. Advances in Colloidal and Interface Science. 1999;82(1):43-92.
12. Hassiba KJ, Amani M. The effect of salinity on the rheological properties of water based mud under high pressures and high

- temperatures for drilling offshore and deep wells. *Earth Science Research*. 2012;2(1): 175.
13. Krishnan S, Abyat Z, Chok C. Characterization of boron-based nano-material enhanced additive in water-based drilling fluids: A study on lubricity, drag, ROP and fluid loss improvement. SPE/IADC 178240, Middle East Drilling Technology conference and Exhibition; 2016.
 14. Sifferman T, Muijs H, Fanta G, Felker F, Erhan S. Starch-lubricant compositions for improved lubricity and fluid loss in water-based muds. International Symposium on Oilfield Chemistry SPE 80213; 2003.
 15. Alford S, Dzialowski A, Jiang P, Ullmann H. Research into lubricity, formation damage promises to expand applications for silicate drilling fluids. SPE/IADC 67737 Drilling Conference; 2001.
 16. Schuh F, Coragliotti A, Diccico C, Nagatani R, Rea A, Carlton T, Noble R. Characteriation of encapsulated oil as an additive to water-based drilling fluids: operational improvements in lubricity, drag and ROP. SPE Western North American and Rocky Mountain Joint Meeting SPE 169547; 2014.
 17. Taha N, Lee S. Nanographene application improving drilling fluids performance. International Petroleum Technology Conference IPTC 18539. 2015;1-16.
 18. Adekomaya OA, Anifowose DM, Wale T. Experimental study of the effect of temperature on flow properties of normal oil based muds in Niger Delta formation. *Petroleum & Coal*. 2011;53(2):140-145.
 19. Kerchevile JD, Hinds AA, Clements WR. Comparison of environmentally acceptable materials with diesel oil for drilling mud lubricity and Spotting fluid formulations. IADC/SPE Drilling Conference Dallas: SPE 14797; 1986.

© 2018 Fadairo et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

*The peer review history for this paper can be accessed here:
<http://www.sciencedomain.org/review-history/26034>*