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Production of water-based mud for drilling operation application

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ABSTRACT

A successful drilling operation is heavily dependent on the effectiveness of the drilling fluid's design in use. This study attempts to evaluate the rheological and filtration properties of water-based drilling mud (WBDM) upon the addition of Stearyl Acrylate-Behenyl Acrylate (SABA) copolymer, silicon dioxide (SiO2), and nickel (III) oxide (Ni2O3) nanoparticles. This SABA copolymer-nanofluid was prepared by dissolving the nanofluid in a SABA polymer solution and homogenizing it using ultrasonication. The properties were studied using mud balance, viscometer, and low-pressure low-temperature (LPLT) filter press. The rheological and filtration properties of SABA copolymer were found to imply that it could improve drilling fluid performance. However, the addition of nanoparticles gave a better performance of rheological and filtration properties on WBDM. SABA copolymer with 5000 ppm concentration shows the best performance due to showing the highest viscosity compared to basic drilling fluid. Also, the addition of 800 ppm of Ni2O3 concentration into 5000 ppm of SABA shows the lowest fluid losses. The experimental results indicate that SABA copolymer shows a great potential application and the addition of nanoparticles shows that nanotechnology has a lot of potentials to improve WBM performance.

1. Introduction

Crude oil or petroleum has been discovered in different parts of the world over the years, resulting in the creation of procedures and equipment to improve and boost the production of this raw material. One of these developed technologies is drilling fluid (mud), which regulate drilling pressure, stabilize the wellbore, and control fluid losses during drilling (Nwaiche, 2015; Suliman et al., 2020). In petroleum engineering, drilling fluid is a thick and viscous fluid mixture used in oil and gas drilling operations (Hasan et al., 2018). Improvements in drilling technology, including more reliable and effective drilling fluids, has made it possible to implement cost-effective systems in the well-construction process and enabled deeper, longer, and more difficult wells. Drilling fluid is well known for its gel or thixotropic properties, which allow it to undergo a reversible transformation from high to low viscosity when exposed to shear stress. These transformations will eventually restore the bit's microstructure (Akinade et al., 2018). WBDM has received more recognition in recent years due to its lower cost and greater environmental friendliness than oil-based drilling mud. On the other hand, water is a low viscosity fluid with poor tribological properties, resulting in high corrosion and excessive torque values between the casing and drill string, limiting the life of drilling machines and their relative motion (Ji et al., 2018).

Wellbore instability has been a worldwide issue affecting the oil exploration industry, resulting in more than one billion dollars in economic losses per year (Zhang et al., 2020). Well stability is one of the most challenging obstacles to overcome among the many difficulties and challenges faced during drilling operations.

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Reference (Aggrey, Asiedu, Adenutsi, & Anumah, 2019) states that according to the literature concerning instability challenges in the wellbore, shales (which make up more than 75% of drilled formations) are the primary cause of over 90% wellbore-stability issues. This is because clay-rich shales, which make up most of the formation (75%), have been drilled.

Most drilling issues, such as stuck pipe, high torque and drag, surge and swab pressures, bit balling, shale swelling, and loss circulation, are caused by poor drilling fluid design, which is directly or indirectly related to the drilling fluid's hydraulic, rheological, and filtration properties (Golsefatan & Shahbazi, 2020). Fluid loss and suspension actions are two problems that have often been associated with WBM. Fluid loss occurs as filtrates reach the water-absorbing formation, leaving a dense, heavy mud cake on the borehole wall, which may lead to pipe sticking. Another essential property is suspension, which is needed to prevent solids from settling during tripping operations, which affects cutting circulation and borehole cleaning ability. When colloidal clays cannot provide the desired properties, polymers are an excellent option to be used as additives in drilling muds to improve rheological properties and increase penetration rate, as suggested by previous studies. Polymer mud was created to increase drilling efficiency.

By the arrival of nanotechnology, the unique properties have made them potential additives in various fields of science, allowing them to eliminate, reduce, or solve problems and enhance the characteristics of a substance or a process since the advent of nanotechnology (Golsefatan & Shahbazi, 2020). The use of nanoparticles reduced lost circulation by increasing carrying capacity to cuttings efficiently and maintain drilling fluid density and pressure under various operating situations. Nanomaterials are selected to be used in this experiment to study the use of nanoparticles in drilling fluids to improve operational performance, stability, and adaptability as one of the most promising prospects. Table 1 summarises the recent progress in using SiO2 and Ni3O4 nanoparticles as additives in drilling fluids to improve the drilling parameters.

For this research, the main objective is to study the effect of SABA copolymer and two nanoparticles which are SiO2 and Ni3O4, individually and in combination on the properties of WBDM to improve the rheological and filtration properties.

Table 1 Application of nanoparticles in drilling fluids

| Types of Nanoparticles | Improved Parameters                                                                 |
|------------------------|--------------------------------------------------------------------------------------|
| SiO2                   | Improving rheological properties, lubricity of drilling fluids, filtration characteristics (Ismail, Aftab, Ibupoto, & Zolkifile, 2016). Improving hole cleaning (Gbadamosoi et al., 2018). Improving shale inhibition and wellbore stability (Yang, Shang, Liu, Cai, & Jiang, 2017). Mitigating pore pressure transmission. |
| Ni3O4                  | Enhancing oil recovery at low concentration (Giraldo, 2018).                         |

2. Methodology

2.1 Materials

Bentonite, barite (BaSO4), and soda ash (Na2CO3) were the chemicals used to formulate a basic mud were purchased from Sigma-Aldrich. Meanwhile, SABA copolymer, two nanoparticles which are silicon dioxide (SiO2) and nickel (III) oxide (Ni3O4), caustic soda and toluene were available in UMP’s laboratory.

2.2 Methods

2.2.1. Preparation of SABA and nanoparticles solution

SABA copolymer solution was prepared by dissolving 0.5 g of SABA copolymer with toluene (solvent) in a 250 mL volumetric flask to form 5000 ppm of the stock solution. The solution was constantly stirred at 500 rpm for 60 minutes with a magnetic stirrer to form a steady and homogeneous solution. Then, the solution of 5000 ppm of SABA copolymer (stock solution) was diluted to 2500, 1250 and 625 ppm by adding toluene for every concentration in a 25 mL volumetric flask with volume 12.5, 6.25 and 3.125 mL, respectively. To prepare the nanoparticle solution, 0.08 g of nano-silica (SiO2) particle was mixed with 100 mL of stock solution to yield 800 ppm. The solution was then heated at 80°C on the heating mantle for 60 minutes while agitated at 500 rpm on the magnetic stirrer. After being produced, the stock solution was treated with ultrasound in an ultrasonic bath for 30 minutes at 40°C after being produced. For lower concentrations of nanoparticles solutions, toluene was added to the stock solution to make 400, 200, and 100 ppm concentrations (Elarbe et al., 2021; Sandhya et al., 2020). This process was also repeated to produce a Ni3O4 nanoparticle solution. Equation 1 is used to calculate the volume of toluene that need to be added for new concentrations:

\[ M_1V_1 = M_2V_2 \]  \hspace{1cm} (1)

where M1, V1, M2 and V2 refer to the concentration of the stock solution, the volume of stock solution, new concentration and the volume from the stock solution that needs to be taken, respectively.

2.2.2. Preparation of basic mud

First, 350 mL of distilled water was measured. Then, the WBDM was prepared by mixing 0.35 g of Na2CO3 using a mud mixer (as shown in Fig. 1) for 5 minutes for calcium ion contamination treatment and the same quantity of caustic soda to keep the drilling fluid’s pH in an acceptable range. A 8.5 to 10. 14 g of bentonite was added to the mixture and stirred again for 5 minutes to enhance the slurry’s viscosity and filtering qualities. Finally, 112 g of BaSO4 was added as a weighting agent, and the mixture was agitated for 40 minutes to produce a homogeneous sample.
2.2.3. Preparation of mud sample with the addition of SABA copolymer and nanoparticles

The WBDM properties were tested by varying the polymer concentrations between 625–5000 ppm while the nanoparticle concentrations were between 100–800 ppm. According to the various concentrations, the SABA polymer solution and SABA polymer-nanofluid were mixed into the WBDM. To conduct rheological studies, all formulation/dispersions were pre-sheared using the mud mixer for 5 minutes.

3. Results and Discussion

3.1 Effect of SABA copolymer and nanoparticles on WBDM properties.

The addition of SABA copolymer and nanoparticles into the mud sample becomes one of the most significant factors to be analyzed in this experiment. At various concentrations of SABA copolymer and nanoparticles, the characteristics of WBDM were studied. It started with a WBDM basic solution, then SABA copolymer and nanoparticles loaded with each, as presented in Table 2. The addition of SABA with SiO$_2$ and Ni$_2$O$_3$ nanoparticles has given different results as copolymers and nanoparticles.

Table 2 Drilling fluid containing different formulations of SABA copolymer and nanoparticles.

| Type | Sample                        |
|------|-------------------------------|
| A    | Basic drilling fluid          |
| B    | 625 ppm SABA                  |
| C    | 1250 ppm SABA                 |
| D    | 2500 ppm SABA                 |
| E    | 5000 ppm SABA                 |
| F    | 625 ppm SABA + 100 ppm nanofluid |
| G    | 1250 ppm SABA+200 ppm nanofluid |
| H    | 2500 ppm SABA+400 ppm nanofluid |
| I    | 5000 ppm SABA+800 ppm nanofluid |

3.2 Mud density measurement

The mud density was determined at an ambient condition. As seen in Figure 2, a basic drilling fluid initially has a high mud density with a 10.5 lb/gal value. After SABA copolymer was added, the density showed a decrement in value with the lowest concentration of 10.2 lb/gal. However, when SiO$_2$ and Ni$_2$O$_3$ nanofluid was added, some of the mud density increased, and some of it remained constant.

3.3 Drilling fluid rheological properties studies

Figure 3 to Figure 5 illustrates the comparison of plastic viscosity, apparent viscosity, yield point, and gel strength of the WBDM after adding SABA copolymer and two different types of nanoparticles, respectively. As illustrated in Figure 3, the plastic viscosity increased following the addition of SABA copolymer, although the readings were inconsistent. However, with the addition of nanoparticles, SiO$_2$ nanoparticles had recorded a higher result than Ni$_2$O$_3$ nanoparticles. The rise in plastic viscosity, driven by mechanical friction, was expected. Plastic viscosity rises as the concentration of solids in the drilling mud rises. Nanoparticles may give superior plastic viscosity due to flow resistance caused by friction between nanoplatelets, micro additives, and the mud’s liquid medium. Furthermore, the increase in plastic viscosity is exacerbated by reducing particles size (Aftab et al., 2017; Sandhya et al., 2022).
Figure 4 shows that increasing the concentrations of SABA copolymer significantly increased the apparent viscosity value. However, a basic drilling fluid has a higher apparent viscosity value than the sample with the lowest concentration of SABA.

Both nanoparticles also show an increasing trend except that the concentration of 2500 ppm SABA and 400 ppm SiO$_2$ nanofluid dropped. Thus, the application of polymer and nanoparticles has an important role in the apparent mud viscosity.

![Figure 4 Apparent viscosities of WBDM with and without SABA copolymer and nanofluid.](image1)

In Figure 5, the yield point of a drilling fluid increase as the SABA copolymer concentration increase. The highest concentration gave a higher value than the basic drilling fluid. Besides, the yield point of SiO$_2$ nanofluid efficiently increased except at a concentration of 400 ppm. The same goes for Ni$_2$O$_3$ nanofluid, which efficiently increased, although it has a lower yield point than SiO$_2$ nanofluid. The rise in yield point was attributable to an increase in solid particle amount and complicated interactions between nanoparticles and other additives. Under static conditions, drilling fluids are anticipated to suspend drill cutting and other weighting agents. This is made possible by the presence of a yield point, and this characteristic shows the drilling fluid's potential for hole cleaning and preventing barite sag (Power & Zamora, 2003).

![Figure 5 Yield point of WBDM with and without SABA copolymer and nanofluid.](image2)

Figure 6 Gel strength of WBDM with and without SABA copolymer and nanofluid.

When the gel strength is too high, the drilling fluid tends to solidify in static circumstances. Therefore, this is risky because getting the drilling fluid moving again may necessitate extremely high pump pressure. High pressures may create a frac-out, resulting in drilling fluid leakage into the subsurface.

### 3.4 Drilling fluid filtration studies

The loss of drilling fluid into the formations has been one of the most severe problems in the drilling process. The fluid loss and mud cake thickness measurements were done after 30 minutes using a low-pressure low temperature (LPLT) filter press and measured the thickness of the filter cake to the nearest 1/32 in. Figure 7 and Figure 8 represents the fluid loss values and mud cake thickness of all the samples. As illustrated in Fig. 7, a higher concentration of SABA copolymer significantly improved the filtration properties by minimizing the fluid loss of the mud and forming a thin mud cake. When nanoparticles were added to the system, the fluid loss decreased as the concentration increased. Compared to the fluid loss of the basic mud, addition of SABA polymer and nanoparticles showed a positive effect on WBDM. However, Ni$_2$O$_3$ nanofluid has shown a better result with reducing the fluid loss as the concentration increased. As the nanoparticle's concentration grows, the decline in imbibition amount becomes more noticeable. The roughness of the mud grows as the duration is increased because increasing pressure leads to more fluid loss and hence increased roughness. It is likely that nanoscale additions with improved structures, such as nanoplatelets and nanotubes, capped the wellbore formation's nanopore throats, preventing water intrusion.

As seen in Figure 8, WBDM with only SABA copolymer and the one with SABA polymer and Ni$_2$O$_3$ nanofluid showed a more significant change to its mud cake thickness than the WBDM containing SABA polymer and SiO$_2$ nanofluid. This showed that when a high concentration SABA copolymer was added to the system, the mud cake thickness decreased by 50%. It is better when Ni$_2$O$_3$ nanofluid is added to the system. It shows a greater result in forming a thinner and more impermeable mud cake, while SiO$_2$ nanofluid showed an adverse effect in WBDM. In summary, the filter cake using SABA copolymer and Ni$_2$O$_3$ nanofluid indicated that the drilling mud gains strength as time processes.
formulation showed the minimum filter cake thickness with superior filtration performance, such as less fluid volume.

Figure 7 Fluid loss of WBDM with and without SABA polymer and nanofluid.

Preparing different concentrations of copolymer and nanoparticles are expected to stop fluid from escaping through porous, permeable, and fractured formations. In smaller formations, the polymer does not affect the weight of the drilling mud. They have a covering on them that reduces their contact with one another and the possibility of agglomeration (Ghasemi et al., 2018). A lower fluid loss rate leads to better cake formation, which is preferred in drilling operations (Dehghani, Kalantariasl, Saboori, Sabbaghi, & Peyvandi, 2019). Due to the common possibility of pipe sticking issues, the thinner cake is recommended for well drilling operation (Saboori et al., 2018).

Figure 8 Mud cake thickness of WBDM with and without SABA polymer and nanofluid.

4. Conclusion

In this study, SABA polymer, SiO₂ and Ni₂O₃ nanoparticles were formulated and then used as an additive in the WBDM. The fluid samples were characterized in terms of rheological properties, fluid flow behaviour and filtration properties with and without the addition of SABA polymer and nanoparticles. It was observed that the results from the rheological and filtration properties indicate that SABA polymer could enhance drilling fluid performance. The addition of nanoparticles also gave better maintenance of rheological and filtration properties on WBDM. SABA polymer with 5000 ppm concentration and 800 ppm of Ni₂O₃ nanoparticles shows the best performance due to the best drilling fluid performance compared to basic drilling fluid. Overall, SABA polymer shows excellent potential application. The addition of nanoparticles shows that nanotechnology can enhance the properties of drilling fluids and lead the drilling industry to great cost savings.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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References

Aftab, A., Ismail, A., & Ibupoto, Z. (2017). Enhancing the rheological properties and shale inhibition behavior of water-based mud using nanosilica, multi-walled carbon nanotube, and graphene nanoplatelet. *Egyptian Journal of Petroleum*, 26(2), 291-299.

Aggrey, W. N., Asiedu, N. Y., Adenutsi, C. D., & Anumah, P. (2019). A novel non-ionic surfactant extract derived from Chromolaena odarata as shale inhibitor in water based drilling mud. *Heliyon*, 5(5), e01697.

Akinade, A. E., Wilfred, O. C., & Akin-Taylor, A. (2018). Improving the rheological properties of drilling mud using local based materials. *Am. J. Eng. Res.(AJER)*, 7, 58-63.

Dehghani, F., Kalantariasl, A., Saboori, R., Sabbaghi, S., & Peyvandi, K. (2019). Performance of carbonate calcium nanoparticles as filtration loss control agent of water-based drilling fluid. *SN Applied Sciences*, 1(11), 1-8.

Elarbe, B., Elganidi, I., Ridzuwan, N., Yusoh, K., Abdullah, N., & Vijaya Kumar, S. (2021). Application of full factorial design to screen the factors influencing the wax deposition of Malaysian crude oil. *Journal of Petroleum Exploration and Production Technology*, 1-11.

Gbadamosi, A. O., Junin, R., Oseh, J. O., Agi, A., Yekeen, N., Abdalla, Y., . . . Yusuff, A. S. (2018). Improving hole cleaning efficiency using nanosilica in water-based drilling mud. Paper presented at the SPE Nigeria annual international conference and exhibition.

Ghasemi, N., Mirzaee, M., Aghayari, R., & Maddah, H. (2018). Investigating created properties of nanoparticles based drilling mud. *Heat and Mass Transfer*, 54(5), 1381-1393.

Giraldo, L. J. (2018). *Janus nanoparticles for enhanced oil recovery EOR: reduction of interfacial tension*. Paper presented at the SPE annual technical conference and exhibition.

Golsefatan, A., & Shahbazi, K. (2020). A comprehensive modeling in predicting the effect of various nanoparticles on...
filtration volume of water-based drilling fluids. *Journal of Petroleum Exploration and Production Technology, 10*(3), 859-870.

Hasan, M. L., Abidin, N. A. Z., & Singh, A. (2018). The rheological performance of guar gum and castor oil as additives in water-based drilling fluid. *Materials Today: Proceedings, 5*(10), 21810-21817.

Ismail, A., Aftab, A., Ibupoto, Z., & Zolkifile, N. (2016). The novel approach for the enhancement of rheological properties of water-based drilling fluids by using multi-walled carbon nanotube, nanosilica and glass beads. *Journal of Petroleum Science and Engineering, 139*, 264-275.

Ji, M., Liu, S., & Xiao, H. (2018). Impacts of glyceride additive on tribological properties of water-based drilling mud for steel–steel contact. *Tribology Letters, 66*(4), 1-11.

Nwaiche, J. (2015). Selection and application of drilling fluids. *Teesside University.

Ogolo, N., Olafuyi, O., & Onyekonwu, M. (2012). *Enhanced oil recovery using nanoparticles*. Paper presented at the SPE Saudi Arabia section technical symposium and exhibition.

Oseh, J. O., Norddin, M. M., Ismail, I., Gbadamosi, A. O., Agi, A., & Ismail, A. R. (2020). Experimental investigation of cuttings transportation in deviated and horizontal wellbores using polypropylene-nanosilica composite drilling mud. *Journal of Petroleum Science and Engineering, 189*, 106958.

Power, D., & Zamora, M. (2003). *Drilling fluid yield stress: measurement techniques for improved understanding of critical drilling fluid parameters*. Paper presented at the AADE Technical Conference, Houston.

Saboori, R., Sabbaghi, S., Kalantariasl, A., & Mowl, D. (2018). Improvement in filtration properties of water-based drilling fluid by nanocarboxymethyl cellulose/polystyrene core–shell nanocomposite. *Journal of Petroleum Exploration and Production Technology, 8*(2), 445-454.

Sandhya, M., Ramasamy, D., Kadirkama, K., Harun, W. S. W., & Saidur, R. (2022). Experimental study on properties of hybrid stable & surfactant-free nanofluids GNP/CNCs (Graphene nanoplatelets/cellulose nanocrystal) in water/ethylen glycol mixture for heat transfer application. *Journal of Molecular Liquids, 348*, 118019.

Sandhya, M., Ramasamy, D., ahmad Khilji, I., Kumar, A., Chandramouli, S., & Kumar, G. V. (2020). Optimization of process parameters in machining of nimonic superalloy on EDM using genetic algorithm. *Maejo International Journal of Energy and Environmental Communication, 2*(1), 35-44.

Suliman, A. A. M., Isha, R., Seman, M. N. A., & Ahmad, A. L. (2020). Synthesis and characterization of TiO2 and palm oil fiber ash hybrid photocatalysts for seawater pretreatment. *Maejo International Journal of Energy and Environmental Communication, 2*(3), 11-20.

Yang, X., Shang, Z., Liu, H., Cai, J., & Jiang, G. (2017). Environmental-friendly salt water mud with nano-SiO2 in horizontal drilling for shale gas. *Journal of Petroleum Science and Engineering, 156*, 408-418.

Zhang, F., Sun, J., Dai, Z., Chang, X., Huang, X., Liu, J., . . . Lv, K. (2020). Organosilicate polymer as high temperature Resistant inhibitor for water-based drilling fluids. *Journal of Polymer Research, 27*(5), 1-13.