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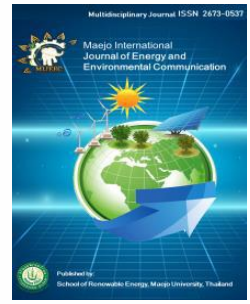

ARTICLE

Production of water-based mud for drilling operation application

Norida Ridzuan[1*], Fiona Ding[1], Victoria Mathew[1], Basem Elarbe[1]

[1]Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

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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 (SiO_2), and nickel (III) oxide (Ni_2O_3) 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 Ni_2O_3 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.

* Corresponding author.
E-mail address: norida@ump.edu.my (Norida Ridzuan)

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 carry 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 SiO_2 and Ni_2O_3 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 SiO_2 and Ni_2O_3, 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
SiO_2	Improving rheological properties, lubricity of drilling fluids, filtration characteristics (Ismail, Aftab, Ibupoto, & Zolkifile, 2016). Improving hole cleaning (Gbadamosi et al., 2018). Improving shale inhibition and wellbore stability (Yang, Shang, Liu, Cai, & Jiang, 2017).
Ni_2O_3	Mitigating pore pressure transmission Altering permeability (Ogolo, Olafuyi, & Onyekonwu, 2012). Enhancing oil recovery at low concentration (Giraldo, 2018).

2. Methodology

2.1 Materials

Bentonite, barite ($BaSO_4$), and soda ash (Na_2CO_3) were the chemicals used to formulate a basic mud were purchased from Sigma-Aldrich. Meanwhile, SABA copolymer, two nanoparticles which are silicon dioxide (SiO_2) and nickel (III) oxide (Ni_2O_3), 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 (SiO_2) 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 Ni_2O_3 nanoparticle solution. Equation 1 is used to calculate the volume of toluene that need to be added for new concentrations:

$$M_1V_1 = M_2V_2 \tag{1}$$

where M_1, V_1, M_2 and V_2 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 Na_2CO_3 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 $BaSO_4$ was added as a weighting agent, and the mixture was agitated for 40 minutes to produce a homogeneous sample.

Figure 1 Mud mixer for the mixing of WBDM.

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_2O_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_2O_3 nanofluid was added, some of the mud density increased, and some of it remained constant.

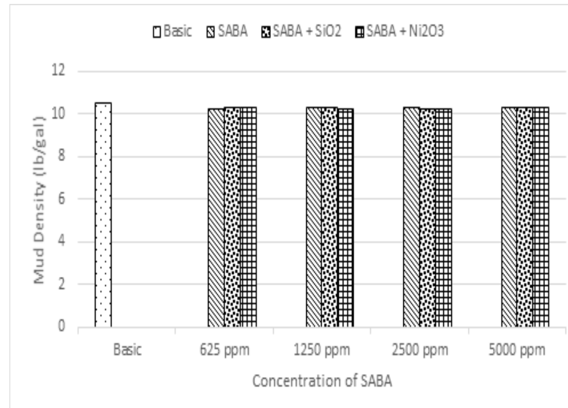

Figure 2 Mud density of drilling fluid with and without SABA copolymer and nanofluid.

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_2O_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).

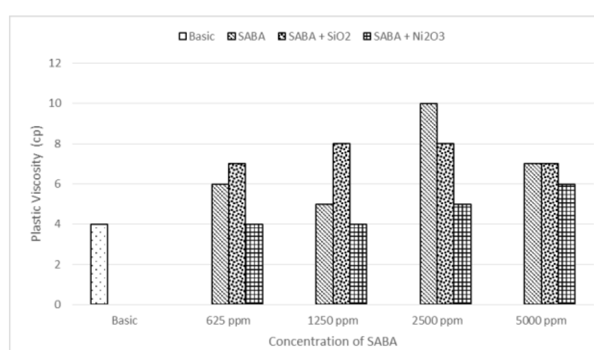

Figure 3 Plastic viscosity of WBDM with and without SABA copolymer and nanofluid.

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.

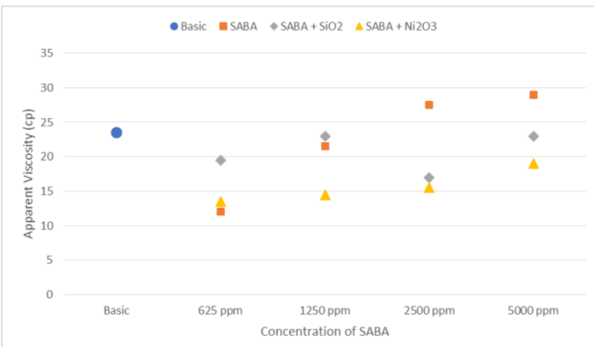

Figure 4 Apparent viscosities of WBDM with and without SABA copolymer and nanofluid.

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_2O_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).

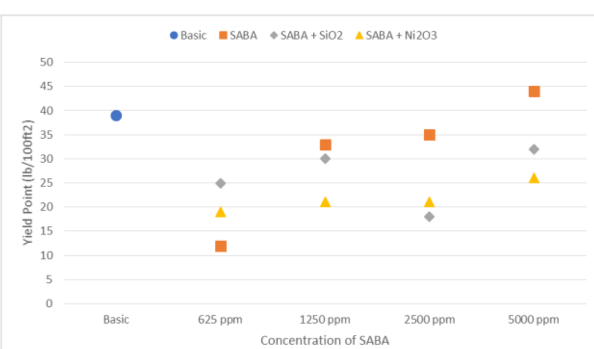

Figure 5 Yield point of WBDM with and without SABA copolymer and nanofluid.

The power of attraction forces in drilling fluid in a static state is gel strength. As illustrated in Figure 6, the SABA copolymer application results and both nanoparticles were inconsistent. These gels can be considered a progressive gel strength because the 10-minute strength was much higher than the 10 second strength. This indicated that the drilling mud gains strength as time processes.

Progressive gel strength is undesirable in drilling mud because it may require high pump pressure to resume circulation (Oseh et al., 2020).

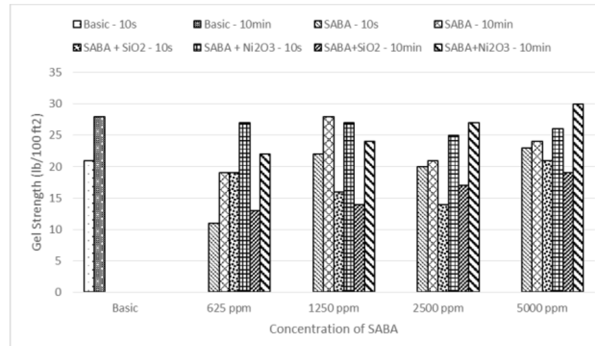

Figure 6 Gel strength of WBDM with and without SABA polymer and nanofluid.

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_2O_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, caped 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_2O_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_2O_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_2O_3 nanofluid formulation showed the minimum filter cake thickness with superior filtration performance, such as less fluid volume.

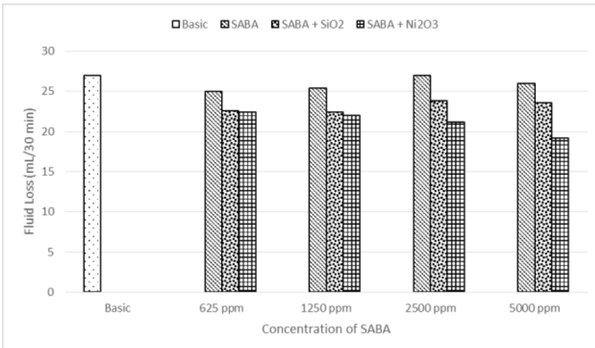

Figure 7 Fluid loss of WBDM with and without SABA polymer and nanofluid.

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).

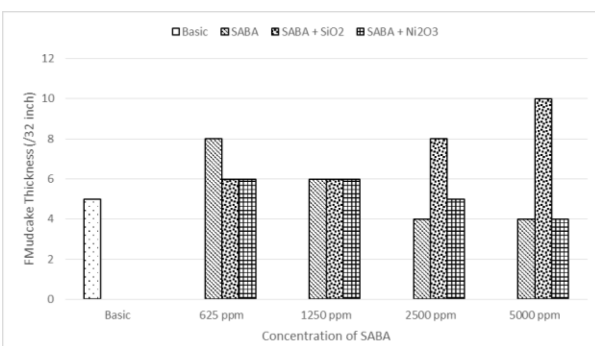

Figure 8 Mud cake thickness of WBDM with and without SABA polymer and nanofluid.

4. Conclusion

In this study, SABA polymer, SiO_2 and Ni_2O_3 nanofluid 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 Ni_2O_3 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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