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Research Paper

Investigation of Effect of Aluminium Oxides Nanoparticles on Some Rheological Properties of Water Based Mud

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Abstract: The success of well-drilling operations is heavily dependent on the drilling fluid because, it cools down and lubricates the drill bit, remove cuttings, prevent formation damage, suspend cuttings and cake off the permeable formation, thus retarding the passage of fluid into the formation. Drilling through subsurface formations with induced and natural fractures attracts huge drilling fluid losses that lead to higher operational expenses. It is therefore vital to design the drilling fluid in such a way that minimizes the mud invasion into formation to prevent lost circulation. This research investigates the effects of a nano base fluid as additives on the rheological properties of water base mud. Baravis and polyanionic cellulose (PAC) were also used as additives and added to fresh water-based mud. The nano base fluid was obtained from aluminium oxide nanoparticles (Al_2O_3 NPs) and its effects on rheological properties of water-based mud were compared with water based mud mixed with baravis and polyanionic cellulose. The laboratory measurements included measuring filtrate losses and some rheological properties as well as filtration properties of water-based nano mud and local additives drilling fluids under static conditions. The lowest filtrate loss value of 14.4ml occurred for an addition of 1.0g of aluminium oxide nanoparticles without any additional materials or additives, and this result was obtained when Al_2O_3 NPs was acting as the loss circulation materials. More than 70% reduction in fluid loss was achieved in the presence of 0.5-2.0 grams of Al_2O_3 NPs. These results have also shown that the filter cake developed during the nano and local additives-based drilling fluid filtration was thin, which implies high potential for reducing the differential pressure sticking problem, formation damage and torque and drag problems while drilling. Nano-based drilling fluid with specific characteristics is thus expected to play a promising role in solving the circulation loss and other technical challenges faced with commercial drilling fluid during oil and gas drilling operation in any subsurface formation.

Keywords: *Aluminum Oxide Nanoparticle, Water Based Mud, Baravis, Polyanionic Cellulose, Rheological Properties,*

Introduction

The production of hydrocarbon fluids from subsurface formations requires drilling and completing a well into the reservoir. The drilling operation of a well involves the application of drilling fluid, which may be water, oil, air or synthetic base fluid. The importance of drilling fluids in drilling a well or hole cannot be overemphasized and its application in recent times has necessitated further study in getting appropriate

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drilling fluid properties that bring about improve process of drilling a well through various hole conditions or materials present at different depths. Anyanwu and Unubi (2016) studied the impact of aluminium oxide nanoparticles size distribution on filtration lost in drilling fluid. The application of drilling fluid in drilling an oil and gas wells is very key to the sustainability of the important role played by the drilling fluid during borehole construction. Nanoparticles can also be applied as fluid loss additives in a surfactant polymer-based drilling fluid (Srivatsa & Ziaja 2011). The drilling fluids used when drilling subsurface formations must keep the hole clean by removing cuttings and other debris, suspend the cuttings when the need arises, cool the drill bits, maintain the needed hydrostatic pressure to prevent the flow of reservoir fluids into the bottom of the well. The type of drilling fluid adopted is a function of the subsurface location, because different formations have different interactions with the constituents of the drilling fluids, and this led to loss circulation and filtration loss as well as other related issues associated with drilling fluids in subsurface formations.

The challenges from drilling fluids in deep waters, harsh formation associated with high pressure and high temperature will always attracts more research into better ways of drilling and into high performance drilling fluids appropriate for different subsurface formations, and these operations in deep waters has attracted advancing technologies (Smith et al., 2018). The growing demand for more oil and gas reserves has necessitated the drilling of more wells (Smith, 2001) in unconventional locations (Xu et al., 2017), and the need for high performing drilling fluids is on the increase. Often, oil-based muds are applied in deep waters because of the high pressure and high temperature (HPHT) associated with it, and has a better performance in HPHT environment when compared to water-based muds. However, the high costs associated with the use of oil based muds, and the environmental concerns of such oil base fluids are the major drawbacks why operators seek for alternative drilling fluids in drilling through the reservoir location in recent time. Amarfio and Abdulkadir (2016) and Aybar *et al*., (2015) focused on the thermal stability of water-based mud with added aluminium oxide NPs, while (Bybee 2001; Elward-Barry and Thomas 1994) looked at the application of nanotechnology in oil and gas deep-water drilling and ultra-deep formations.

This work focusses on the investigation of the formulation of potential application of nano-fluid obtained from the mixture of aluminium oxides nanoparticles and water based mud in HPHT reservoir conditions as well as low pressure and low temperature. Smith *et al*., (2018) stated that offshore exploration drilling and appraisal wells are among the highest capital costs, it cost as high as 60% in the development of an oil field. Adding nano materials to drilling fluids is aimed at increasing wellbore stability and drilling efficiency by enhancing the rheological properties of the drilling fluid at low pressure and low temperature, which reduces drilling cost (Mao *et al*., 2015; Shaughnessy *et al*., 2003). This is achieved through reduced filtration of drilling fluids (reduced filter cake thickness) which can prevent differential sticking, improved rheological properties that affect the transport of cuttings to the surface, reduced friction and hence lower torque and drag on the drill pipes, and reduced wear during horizontal and directional drilling operations. Drilling problems were reduced by using synthesized nanoclays in drilling fluids formulation (Abdo and Haneef, 2013). Furthermore, nanoparticles can improve heat transfer properties of drilling fluids which will reduce thermal degradation of down-hole equipment. Lower drilling costs through the use of nanoparticles instead of expensive additives would then allow drilling operations to become economically viable.

Materials and Methods

This research focused on the use of aluminium oxides nanoparticles (Al_2O_3 NPs) in the formulation of different concentrations of mud samples, other materials include baravis and polyanionic cellulose (PAC) and both materials were used as additives to fresh water-based mud. The powder form and scanning electron microscope (SEM) image as shown in figure 1 (Hawraa *et. al*. 2020; Smith *et al*., 2018), represent aluminium oxide nanoparticles and have hydrophilic surfaces; it is chemically inert, non-toxic, hard and tough, it has been widely used in high performance materials as fillers to increase toughness, ductility scratch resistance and also as an absorbent material for thermocouples (Ogolo and Onyekonwu, 2022). Furthermore, Al_2O_3 NPs have exceptional physico-chemical and structural features such as resistance to wear chemicals and mechanical stresses. They also have optical properties, low-cost preparation and easy handling and it is thermally stable, ductile, and is not flammable (Ogolo & Onyekonwu, 2022). It constitutes a good abrasive, adsorbent, low friction, composite and blasting material, presented in figure 1. It is a high-temperature component for heat resistance, a desiccant for drying gases, and is used as an electrical insulator, a catalyst carrier and adsorbent in the petroleum and chemical industries (Ogolo & Onyekonwu, 2022). The methodological concept applied and executed in this study is based on sample preparation of both water and nano based mud samples. These samples were subjected to several static periods and temperatures, and the rheological properties of these subjected mud samples were measured based on temperature and stability. The data used were local content materials easily manufactured and manipulated in the laboratory. These experimental procedures designed and adopted in this research is to help investigate standard procedural concepts to aid in the understanding and examining the data generated from laboratory condition. Water based drilling fluid samples were prepared based on the typical formulation currently used in drilling operations. Table 1 shows the water-based fluid (WBF) formulation with concentrations of aluminium oxide NPs with concentrations ranging from 0.5 wt% up to 2.0 wt%.

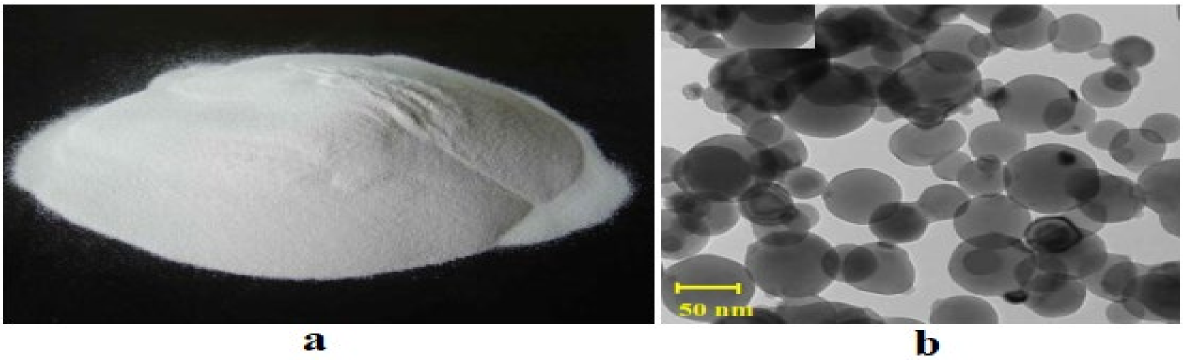

Figure 1. Aluminum Oxide Nanoparticles Al_2O_3 (**a**) Powder (**b**) SEM Image (Hawraa *et. al*. 2020; Smith *et al*., 2018)

Experimental Procedures

Fresh water-based mud was prepared, and the sample preparation procedure involves stirring and mixing after adding each component (water, bentonite, barite) for 15 minutes (Smith *et al*., 2017). To improve the rheological properties of water-based fluids typically baravis and polyanionic cellulose (PAC) were added. Baravis and polyanionic cellulose added to the fresh water-based mud were in the concentration of 0.5g, 1.0g and 2.0g. Then modified samples with addition of Al_2O_3 NPs were prepared and their rheological (apparent viscosity, plastic viscosity, yield point, 10sec gel-strength and 10min gel-strength) and filtration properties were tested. The rheological properties of water-based mud sample were tested, before adding nanoparticles, and the concentration of nanoparticles that was used in formulating drilling fluid samples are 0.5g, 1.0g, and 2.0g and these measurements were done at room temperature. Metal oxides dispersed in distilled water are used for water based. Basic rheological properties were carried out such as mud weight, plastic viscosity, yield point, gel strength, filter cake thickness and filtrate loss. The application of filter press to investigate the filtration properties of these different water-based mud samples were done for normal pressure and normal temperature as well as that of high pressure and high temperature, taking into consideration the API standard for filtration test. The fresh water-based mud prepared was the reference sample, while three samples each from baravis, polyanionic cellulose and aluminium oxide nanoparticles where formulated, making it a total of ten samples of mud used in the investigation.

Rheological Model Applications

The approach for this research requires the determination of some of the rheological properties of the different samples prepared and these samples include fresh WBM, fresh WBM containing baravis as additives, fresh WBM containing polyanionic cellulose additives and fresh WBM containing Al_2O_3 NPs. Some properties measured in laboratory conditions were used to determine the apparent viscosity (AV), plastic viscosity (PV) and yield point (YP). Equations 1 to 4 were used to generate the rheological properties as presented in table 1.

$$\beta = \frac{RPM_{600}}{2} \quad (1)$$

$$\alpha = RPM_{600} - RPM_{300} \quad (2)$$

$$\sigma = RPM_{300} - PV \quad (3)$$

$$\tau = k\gamma^{n} \quad (4)$$

Where β is the apparent viscosity (AV), α is the plastic viscosity (PV), σ is the yield point (YP), while RPM_{300} and RPM_{600} are the revolutions per minute at 300 and 600 respectively. Also, τ is the shear stress ($1bf/100ft^2$), k is the consistency index ($Pa\text{-}S^n$), γ is the shear rate (S^{-1}) and n is the flow behave index (dimensionless). The apparent viscosity was calculated based on the experimental effects of the measured 600 revolutions per minute (RPM_{600}) for the different samples of water base mud, while the PV were calculated based on the 600 revolutions per minute (RPM_{600}) and 300 revolutions per minute (RPM_{300}), also from the mud samples already prepared. Furthermore, YP were calculated based on the 300 revolutions per minute (RPM_{600}) together with already calculated value for PV. While equation 4 is referred to as the power law model, lower values of 'n' are an indication of a more non-Newtonian behaviour or a shear thinning fluid and Increasing values of the consistency index (k) imply an increased annular viscosity, and thereby an increased hole-cleaning capacity (William *et al*., 2014).

Results and Discussions

The results obtained as presented here in table 1 are some of the rheological properties for the different samples, which include the plastic viscosity, apparent viscosity, yield point, gel strength as well as the corresponding power law data for each of the properties measured and calculated. The charts presented in figure 1 to 6 described the influence of the different concentration of the Al_2O_3 NPs on the apparent viscosity and the plastic viscosity as well as on the yield point, including samples of fresh mud, fresh mud with additives such as polyanionic cellulose (PAC), baravis and Al_2O_3 NPs. After a careful survey of some research questions during the study, the data had to been filtered out and presented in a proper landscape for easier identification and explanation. And to fully fulfil the demands of this research, some laid down outlines would be followed through, these outlines best demonstrate the focus of this study. The experimental results of fresh muds and muds formulated using aqua gel (baroid) bentonite clay with Al_2O_3 nanoparticles additives and PAC and baravis is as given below in table 1. The results were compared with a base case drilling fluid with no nanomaterial, and they showed that there is an optimum concentration for aluminium oxide nanoparticles that can be used to improve the rheological and filtration properties of drilling fluids. These results demonstrated that nano-enhanced drilling fluids have an improved thermal stability at heightened temperatures and can withstand the harsh conditions in advanced drilling operations while they impose a lower environmental impact and capital costs.

Table 1. Rheological Properties of the Different Water Based Mud Samples

Mud Rheological Properties	Samples									
	Fresh Mud (Control)	Mud + PAC			Mud + BARAVIS			Mud + Al_2O_3		
		0.5g	1.0g	2.0g	0.5g	1.0g	2.0g	0.5g	1.0g	2.0g
pH	7	6.5	6.5	6.5	6	6	6	5	5	5
600 rpm	23	151	245	>300	115	90	163	120	137	147
300 rpm	12	110	184	>300	101	62	76	80	120	102
200 rpm	9	93	159	286	67	47	60	70	114	74
100 rpm	5	69	123	245	46	32	43	56	103	64
6 rpm	1	31	60	141	17	14	25	40	41	34
3 rpm	0.5	28	54	131	15	13	23	40	34	23
10 sec Gel (lb/100ft^2)	2	38	58	123	38	28	41	34	31	31
10 min Gel (lb/100ft^2)	11	80	113	162	77	38	72	54	47	39
P.V.	11	41	61	69	14	28	87	40	17	45
A.V.	11.5	75.5	122.5	150	57.5	52	81.5	60	68.5	73.5
Y.P.	1	69	123	73.00	87.00	34	21	40	103	57
Power law (n)	0.94	0.46	0.41	-	0.19	0.54	1.1	0.58	0.19	0.53
Consistency (k)	0.17	31.85	73.07	-	157.52	10.9	0.48	11.0	187.6	19.1

The effect of different mud samples with nanoparticles of different concentration on some rheological properties are presented below. These behaviours help in understanding the responses associated to increase or reduction of the nanoparticles concentration, and the composition of the muds in terms of the additives is also shown in figure 2 to 8.

Plastic Viscosity

The result shows that the plastic viscosity of water-based drilling fluid reduces after exposed to 250°F. Figure 2 shows that the trend of mud sample decreases when the concentration Al_2O_3 NPs increases. However, the plastic viscosity of water-based drilling fluid with aluminum oxide nanoparticles was found to be 23 centipoises (cp), which is slightly higher than the controlled sample (fresh mud) without nanoparticles.

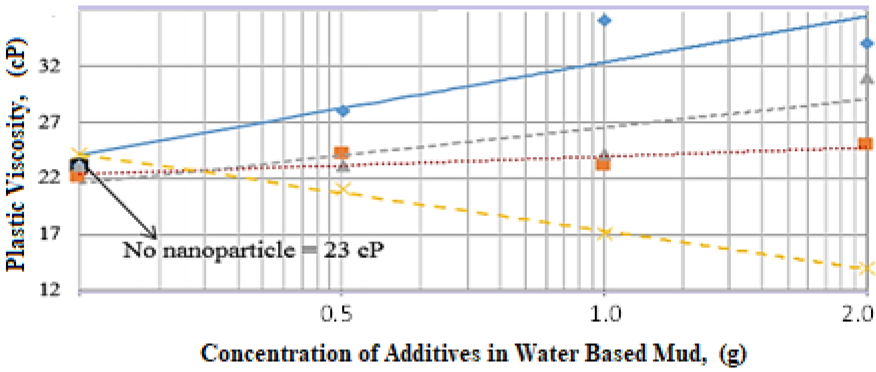

Figure 2. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentration on Plastic Viscosity

Nanoparticles consist of large surface areas per volume, and it will increase the interaction of the nanoparticles with the matrix and surrounding water-based drilling fluid. This surface area may serve as sites for bonding with functional groups can influence chain entanglement and thus can generate a variety of properties in the matrix. Thus, the nanoparticles and base fluid may be linked or bonded together directly or through certain intermediate chemical linkages to improve the plastic viscosity of water-based drilling fluid.

However, repulsive force occurs between aluminium oxides nanoparticle and water molecular, thus is caused the plastic viscosity to reduce as concentration increase due to greater repulsive force occur. In drilling fluid, it will maintain viscosity of drilling fluid at high pressure and high temperature. Then, the rheological behaviour may depend on the particle type, size, and concentration and interparticle distance of nanoparticles with the fluid because of the large surface area of nanoparticles compared to micron-sized and larger particles. For example, only about 1 lb/gal of nanoparticles may do the job of 10 lb/gal of other materials. The reduced solid volumes with increased surface area would thus help maintain equivalent viscosities of drilling fluids.

Yield Point

Figure 3 shows the effect of nanoparticle concentration on yield point in water-based drilling fluid. The yield point of aluminium oxide increases as nanoparticle concentration increases. The higher yield point of the nano-based fluid will provide better dynamic suspension of drilling cuttings and efficient cleaning of the wellbore while drilling.

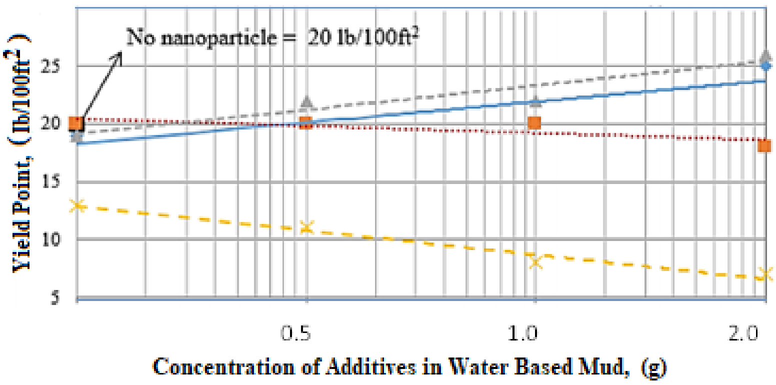

Figure 3. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentrations on Yield Point

Gel Strength

The results in figures 4 and 5 show the effect of aluminium oxide nanoparticles on gel strength at different concentrations at 10 seconds and 10 minutes respectively. aluminium oxide shows an increasing trend as concentration increased. This phenomenon occurs due to the electrostatic force between the nanoparticles that the attractive force causes the nanoparticles link together with base fluid within 10 sec and 10 min period to form a rigid structure, thus it will increase the gelling effect. This trend, however, was not followed by other drilling fluid samples where gel strength was found to reduce gradually as concentration increased.

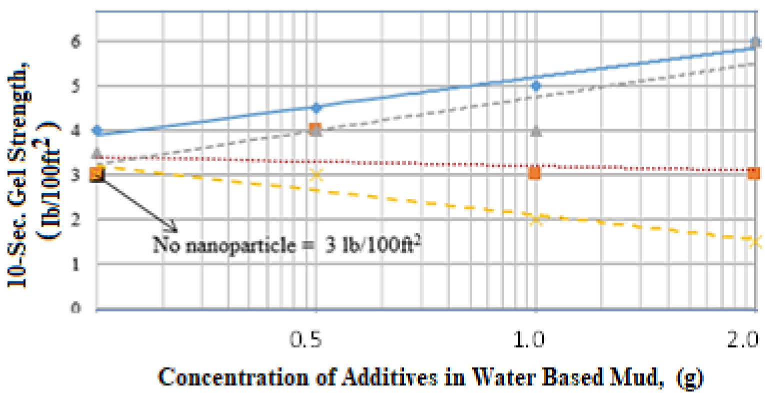

Figure 4. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentrations on Gel-Strength (10-sec)

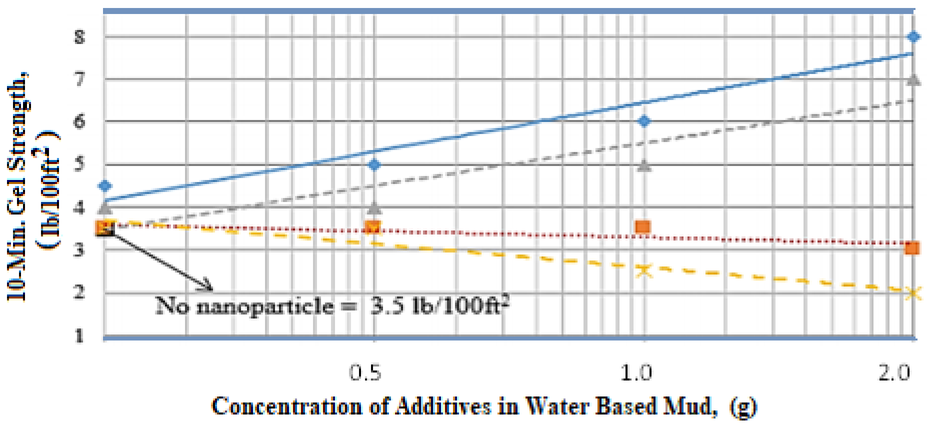

Figure 5. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentrations on Gel-Strength (10-min)

Apparent Viscosity

The one half of the dial reading of the RMP_{600} is presented in table 1, the results showed that there is a corresponding increase in the apparent viscosity as the concentration of aluminium oxide nanoparticles increases as presented in figure 6, and this is also observed when baravis and polyanionic cellulose were added to the fresh water-based mud. This trend is like what was obtained in other rheological properties. This is connected to the ability of the based fluid to enhance intermolecular forces in the nano fluid, and this leads to high and effective resistance to flow and the high surface area lead to an increase interactions with water based mud. The polyanionic cellulose has faster impacts on the apparent viscosity when compared with other two mud samples gotten from the Al_2O_3 NPs and baravis. Furthermore, water-based mud containing baravis has the tendency to increase apparent viscosity with higher concentration of baravis additives

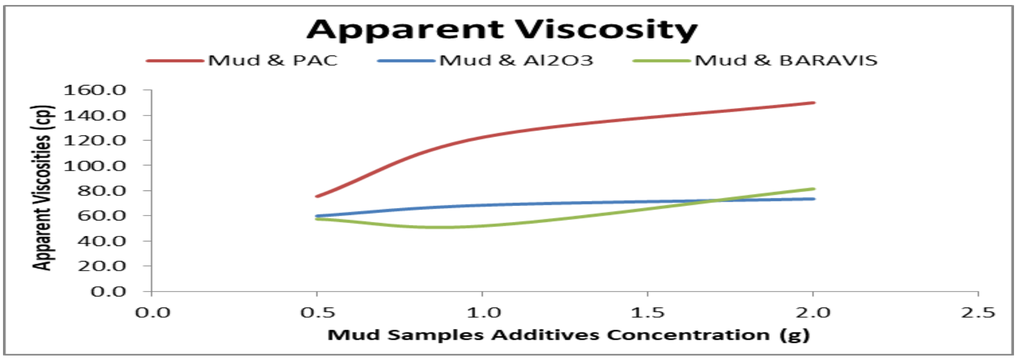

Figure 6. Apparent Viscosity of the three Mud Samples

High Pressure High Temperature Filtration Loss

The comparison of the HPHT fluid loss behaviour of the water base drilling fluid with different concentration of aluminium oxide nanoparticles is illustrated in Figure 7. An increased in nanoparticle concentration for mud sample gave lower filtration loss that shows a very good result. The dispersed mud sample acted as plaster between each particle, and consequently, seals the permeable filter cake at high temperature to reduce the filtration loss. The addition of metal oxide nanoparticles (aluminium oxide) is only good until 0.01 g and then increases after that value. Filtrate loss must be low enough to prevent excessive filter cake thickness and reduce the change of different pressure sticking.

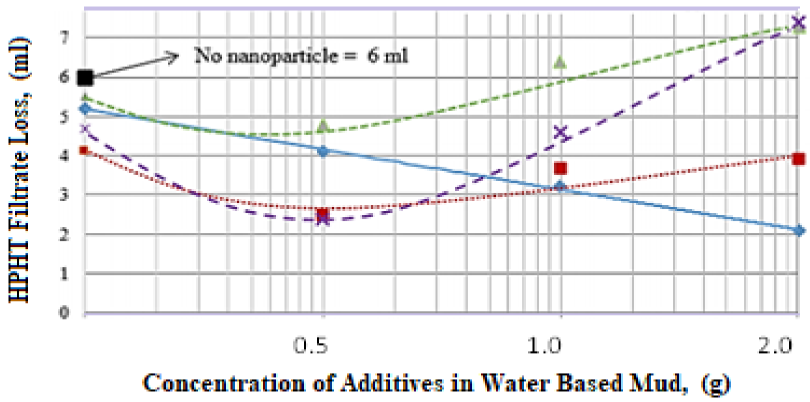

Figure 7. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentrations on HPHT Filtration Loss

Filter Cake Thickness

Figure 8 illustrated the results of filter cake thickness of different water-based drilling fluid samples against the different concentration of aluminium oxides nanoparticles. Mud sample showed a decreasing trend where the filter cake thickness decreases when the concentration of mud sample increases. However, aluminium oxide showed similar trend where they reached the optimum value of 0.1 g and then increased sharply as the concentration increases.

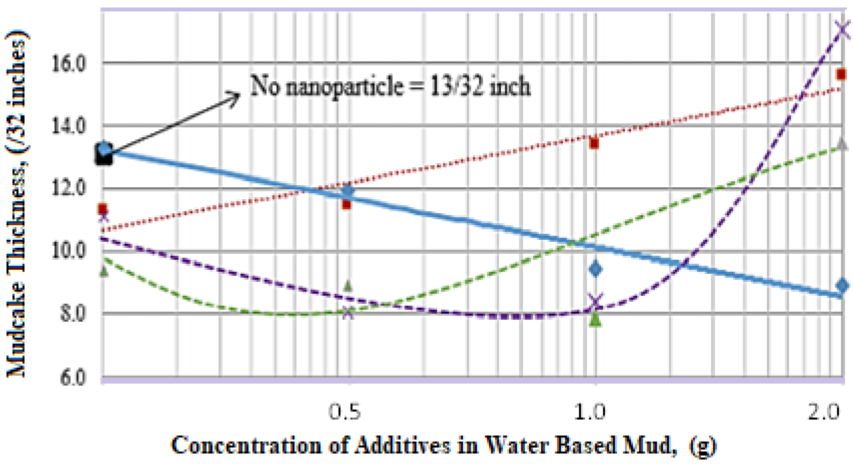

Figure 8. Effect of Baravis, Polyanionic Cellulose and Al_2O_3 NPs Concentrations on Filter Cake Thickness

Conclusion

This study has been able to show the effects of aluminium oxide nanoparticles on water-based mud and also when the baravis and polyanionic cellulose are added to act as anti-filtration loss materials. The determined rheological properties showed that the concentration of the different nano-fluids affect the properties of water based mud both at reservoir and laboratory conditions. The nano samples have favourable characteristics to hold cuttings under dynamic suspension and, aluminium oxide shows an increasing trend as concentration increased during the gel strength investigation for both 10 seconds and 10 minutes. This gel like structural behaviour will help the nano-based drilling fluid to prevent settling of cuttings and other solids from settling down during static periods. Furthermore, increasing the concentration of aluminium oxide nanoparticles leads to a reduction in filtration loss volume, and this filtration volume were also observed with the presence of baravis and polyanionic cellulose in fresh water-based mud. This behaviour of the nanofluid is connected to the high surface area of aluminium oxide nanoparticles because the viscosity of the nanofluid WBM is different from a fresh WBM. The thermal stability of the water based mud increased as a result of the addition of aluminium oxide nanoparticles when compared with reference samples. This was shown from the results presented in table 1 and in figure 1 through 6, the high pressure high temperature filtration outcome for the sample with aluminium oxide NPs had a reduced filtrate volume than the reference sample, and with this sample also showing some level of increase in shear stress for the sample with aluminium oxide NPs compared to the base sample (fresh water-based mud) during the rheological properties investigation. The following conclusion can be seen from this research study.

1. The lowest filtrate loss value of 14.4ml occurred for an addition of 1.0g of aluminium oxide nanoparticles and leads to a 70% reduction, suggesting that aluminium oxide nanoparticles can be used to reduce filtration loss of drilling fluids in subsurface or reservoir formation.
2. The addition of aluminium oxide nanoparticles and baravis and polyanionic cellulose in fresh water-based mud develop thin filter cake.
3. The rheological properties (apparent viscosity, plastic viscosity and yield point) and gel strength have direct relationship with aluminium oxide nanoparticles concentration.
4. Aluminium oxide nanoparticles have the tendencies to reduce filtration loss at high pressure high temperature and also at low pressure and low temperature.

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Compliance with Ethical Standards *Ethical responsibilities of Authors: The authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors".*

Conflict of Interest: *The authors declare that they do not have any conflict of interest.*

Change of Authorship*: The authors have read, understood, and complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.*

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