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Application of SiO_2 and Al_2O_3 Nanoparticles to Improve Filtration and Rheological Properties of Water-Based Drilling Fluid

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Abstract:
There are many studies which reported the nanoparticles could enhance the rheological behavior and the properties of filtration for water-based drilling fluids. Different types of nanoparticles were used in the experiment including silicon oxide and aluminum oxide, which were evaluated at three concentrations (1g, 2g, and 3g), also shows the development and comparison of a new drilling fluid utilizing a biopolymer (xanthan gum)/ nanoparticle (Al2O3 and SiO2) mixture to optimize the properties of a water-based mud (WBM) preparation. In this research, the main objective is to compare the influence of changing the amounts of Al2O3 and SiO2 nanoparticle on the rheological properties and filtration rate of water drilling fluid at low-temperature 30˚ C and low pressure 150 psi (LPLT). In addition, the 10 seconds gel was decreased by aluminum oxide while it was increased by silicon oxide. A rotational viscometer (model 3500) was utilized to measure the rheological properties of drilling muds. The filtration process was conducted with Fan high-pressure and high-temperature (HPHT) static filter press. In terms of hole cleaning and filtration rate, properly engineered Nanofluids showed more effective performance than conventional water-based muds.

Keywords: Rheological properties; Filtration; Nano-enhanced water-based mud.

1. Introduction

The based drilling fluid or commonly named (drilling mud), is one of the most significant compounds of well construction process. Drilling fluid plays a very important role in the drilling operation [1], [2]. Any problem in drilling fluid can significantly impact the functioning of the operation. Accordingly, it is important to comprehend the performance of drilling mud in the well. Drilling mud has chemical and physical properties. These properties must be enhanced or optimized to minimize the well problems and later costs. Consequently, the poorly designed mud leads to major problems in the well such as stuck pipe, shale swelling, bit balling, mud circulation loss, torque and drag, inadequate hydraulics system, reservoir damage, formation sloughing [3]. Drilling fluid (drilling mud) is a viscous fluid that results from mixing liquid or gas with suspended soil. In the past, water has been used as drilling fluid then the development of drilling fluid science was started to use water and plastic material as drilling fluid which successfully to make a good wall around the hole [4]. There are three basic types of drilling fluids; water-based, oil-based and gaseous–based drilling fluid. The usages of drilling mud in oil industry cover several areas from cooling and lubricating the drill tool, cleaning by moving the rock cuttings to the surface, creating hydrostatic pressure to prevent formation fluid from the entering in the wellbore, and deposit mud cake around the walls of wellbore [5], [6]. The experimental setup consists of viscometer (Fann-VG meter) for rheology, pressurized density mud balance, pH meter, constant speed mixer, electronic balance, atmospheric sensitometer for rheology at high-pressure and high-temperature (HPHT) filter press. Professional experts played an important role to conduct experiments. Two types of drilling muds, freshwater bentonite xanthan gum (FWB-XG) and (FWB-XG) with nanoparticles were prepared for this study. The aim of using these types of drilling muds is because they are the most popular types used in Iraq's southern fields. The samples were prepared according to API RP 13B (drilling fluids). Blank FWB mud can be easily prepared [7]. Pre-hydrated bentonite was prepared by mixing 25 gm of bentonite with 500 ml of distilled and retained the sample for 24 hours for hydration. Subsequently adding 1gm of xanthan gum. After that, two types of Nano-drilling muds were prepared by adding nanoparticles (SiO2 and FWB-XG) or (AL2O3 and FWB-XG) by 1 gm, 2 gm and 3 gm to blank mud at laboratory temperature (30˚C) and atmospheric pressure. For getting the behavior of water-base drilling fluids improved, different substances were added to these fluids to enhance the rheological properties such as plastic viscosity which measures of the friction between layers of the fluid, yield stress which measures of the attractive forces between particles, and gel strength that can be known as the measurement of shear stress which important to initiate flow of a stationary fluid for an interval of time [8], [9].

Nanomaterial’s had the viability to improve the environment through direct implementations of nanomaterials to detect, prohibit, and eliminate pollutants, as well as indirectly by using nanotechnology to create cleaner industrial processes and create environmentally responsible products. Nanoparticles are small particles with sizes less than 100 nm with different application areas, which been applied in the oil and gas section, including enhanced oil recovery, shale stabilization, fluid loss reductions, wellbore strengthening and formation damage reduction. On the other hand, biopolymers such as xanthan gum, are applied to create rheological filtration properties and to dilute borehole instability issues drilling fluid invasion controllers, and fluid loss reducers [10].

To the best of our knowledge, most studies are managed to deal with a single property, such as rheological or filtration properties. However, the drilling fluid has multiple functions in the drilling process, such as cooling and lubrication. Secondly, the effect of nanoparticles may add one nanoparticle to one property, but not to the other [11], [12]. Therefore, the main aim is to design formula of drilling properties that show acceptable capabilities both in static and dynamic conditions, which have not been taken into considerations in the last studies. The information needed to design a reliable predictive tool can be provided by considering the effects and mechanisms of nanoparticles to distinguish drilling purposes. Finally, the addition of nanoparticles can show a significant enhancement of the physical and mechanical properties of polymers because of the high-volume ratio/surface area resulting from nanoparticles [13]. The most studied polymers so far do not occur naturally. However, so far according to the knowledge in our hands, no systematic study has been accomplished on applying nanoparticles along with a natural biopolymer to improve the performance of water-based drilling fluid and lowering the impact on the environment. The objective of this work is to study the effect of two types of nanoparticles on water-based drilling mud rheology and filtration [14].

2. Materials and Methods

Experimental

2.1 Materials

In this study, the model drilling fluid used to contain the followings material:

1. Freshwater as the base fluid 0.5 L.
2. Bentonite 25g as viscosifier and filtration control material.

3. Xanthan gum (XG) as rheology control material with two different concentrations (0.04g).
4. Silicon oxide nanoparticles (SiO2, 99.5+%, p-type, porous) with different concentrations (0.1g, 2g, and 3g).
5. Aluminum oxide nanoparticles (Alumina, gamma-Al2O3, 99.9%, 20nm, white color) with different concentrations (0.1g, 2g, and 3g).

The components of the drilling fluid were freshwater with bentonite clay and xanthan gum, both added to increase the viscosity. All properties were described (chemical formula, molecular weight, and purpose of use) of materials used is shown in Table 1. This table is a summary of the product specification for SiO2 and Al2O3 nanomaterials used in the experiment.

Table. 1. Purpose of use and the properties of materials.

Materials	Chemical Formula	Purpose
Freshwater	H_2O	Main fluid
Wyoming bentonite	$Al_2O_3.4SiO_2.H_2$	Viscosifier
Xanthan gum	$C_{35}H_{49}O_{29}$	Viscosifier/dispersing agent

2.2 Equipment

Constant speed mixer and electronic balance were used for the components in the drilling fluid. The filtration loss was measured using fan high-pressure high-temperature filter press and pressurized density mud balance. Rheological properties were measured using the viscometer model-350. The pH meter was utilized to determine the pH value of drilling fluids during the study. All instruments were operated according to the user manual.

2.3 Sample Preparation

The drilling fluid samples were prepared by mixing 0.5 liter freshwater, 25 g bentonite clay, and 1 g xanthan gum. The mixture was stirred at ~900 rpm for 15 min by constant speed mixer, and then after 24 hours, xanthan gum was added to have a 0.2 wt% mixture. After that, the mixture was retained for 24 hours for hydration. Then, two types of Nano-drilling muds were prepared by adding nanoparticles (SiO2 and Al2O3) by (1, 2 or 3 g in 0.5 L) to blank mud at laboratory temperature (30˚C) and atmospheric pressure, see Table 2.

Table 2. Formulate the nano-fluid.

Nanoparticle	Size (nm)	Purity %
Aluminum oxide Al_2O_3	27-43	99
Sailic oxide SiO_2, P-type porous	15-20	99.5

Each type of Nano-drilling mud was blended for 30 minutes for each concentration. The Sample water-based, xanthan gum and SiO_2 or Al_2O_3 were prepared as illustrated in Table 3.

Table 3. Drilling fluid samples.

Sample	Nanoparticle	Concentration (WT%)	Xanthan Gum Concentration (WT%)
S_1	Al_2O_3	0.2	0.2
S_2	Al_2O_3	0.4	0.2
S_3	Al_2O_3	0.6	0.2
S_4	SiO_2	0.2	0.2
S_5	SiO_2	0.4	0.2
S_6	SiO_2	0.6	0.2

2.4 Measurements

1. Rheological Properties of Drilling Mud

The rheological properties of drilling fluid were measured as follows: Drilling mud sample was placed into the viscometer cell of 350 mL. The shear stress at different shear rates for FWB muds were measured at laboratory temperature. After this, the shear stress readings are taken at 20, 30, 60, 100, 200, 300 and 600 rpm. The viscometer kept 15 s for stabilization at each reading step.

For the initial and final gel strength parameters, the drilling mud sample was submitted at 600 rpm for one minute, the rotor was stopped for 10 seconds and rotor speed control was adjusted at 3 rpm. Rotor was operated, and the maximum torque value was listed to measure the initial gel strength. Rotor was ceased for 10 minutes at 3 rpm. Following this step, rotor was started, and the maximum torque value was recorded to measure the final gel strength.

Rheological properties were measured with the Model-350 Viscometer, yield point (Yp) measures of the attractive forces between particles that resulting from the presence of positive and negative charges near or on the surface of these particles, plastic viscosity (Pv) measures of the friction between particles and it's an index of the thickness of drilling fluid. It is necessary to keep plastic viscosity as low as possible for drilling muds because of the high concentration of solids leads to damage to the drilling pipes (wash problem). In addition, the gel strength is the measurement of shear stress which is essential to start the flow of a stationary fluid for a while.

2. Rheological Properties of Drilling Mud

Blank and Nano-drilling muds filtration was measured at laboratory temperature (30˚C) and pressure of 150 psi. The filtration of drilling mud was measured as follows: The sample was placed into Fann HPHT filter press, the device temperature and pressure were adjusted at desired values. After applying the pressure, the bottom valve was loosened till the premium drop falls in the graduated cylinder. Fluid loss was collected for 7.5 minutes.

The result values were gathered from the measurements because the filtration area of API standard being 7.1 in^2 (Yu and Xie, 2012). The following equations are used:

$$\mu_a = \frac{\phi_{600}}{2} \tag{1}$$

$$\mu_p = \phi_{600} - \phi_{300} \tag{2}$$

$$\mu_e = \frac{300\phi}{w} \tag{3}$$

$$Y_p = \phi_{300} - \mu_p \tag{4}$$

$$Shear\ Stress\ (\tau) = 1.065\phi \tag{5}$$

$$Shear\ Rate\ (\gamma) = 1.7023 * w \tag{6}$$

In the above equations, ϕ is dial reading (lb/100 ft^2) and w is speed of the rotor (RPM).

3. Results

This section presents all rheological properties and filtration results of drilling muds. A comparison between rheological properties of Blank muds and these of nano-drilling muds was established. Since the effect of NPs type on mud properties is to be tested at different temperatures regardless of the concentration. The first step taken was holding a comparison and discussion for the rheological properties of the conventional drilling fluids with Nano drilling fluids [15], [16].

Rheology test was performed at low temperatures to determine the use of the drilling fluids at low temperatures conditions. Plots of shear stress versus shear rate in log scale at 30° C are shown in Figure 1 and Figure 2 for SiO_2 and Al_2O_3 nanomaterial-drilling mud, respectively [17]. The observation for the results indicates that the viscosity of drilling mud slightly increases with 1g SiO_2 nanomaterials addition and sharply increase with 2g and 3g of SiO_2 additions, the increase behavior is normal because its work chain joiner points that post viscosity increase, as show Figure 1 While the Al_2O_3 with drilling fluid showed increase in their shear stress values with concentration long all shear rate at 30° C, as show in Figure 2.

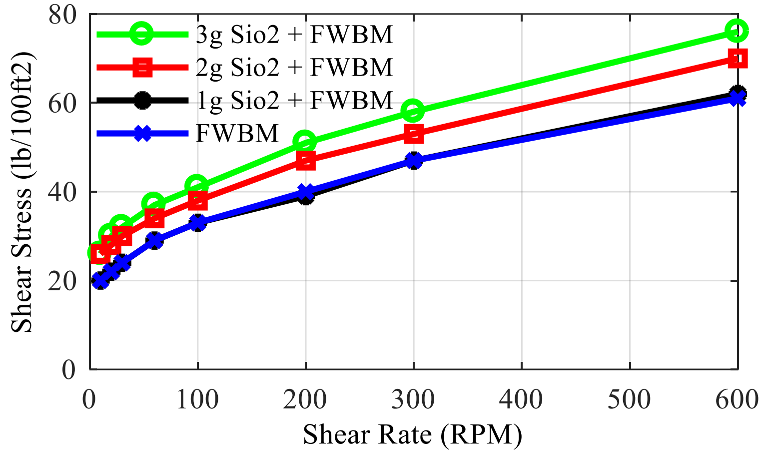

Figure 1. Shear stress and shear rate behavior of the drilling fluid with different concentrations of SiO2 nano-material.

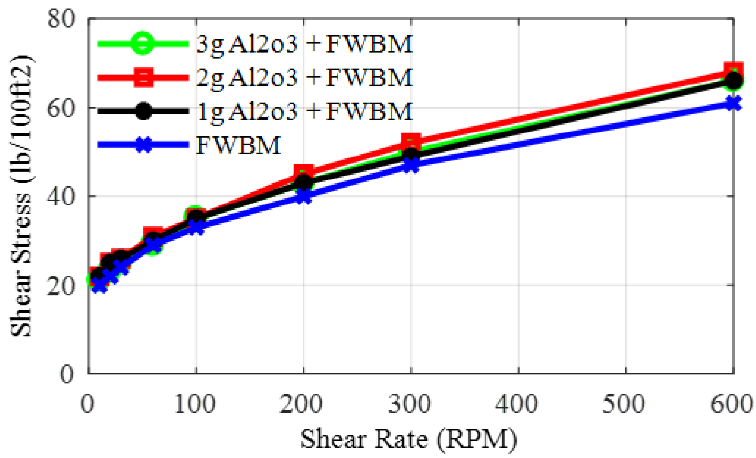

Figure 2. Shear stress and shear rate behavior of the drilling fluid with different concentrations of Al2O3 nano-material.

The results of PV, AV, YP, and gel strength as nanoparticle concentrations change at LTLP conditions (low temperatures low pressure) were also listed in tables. The filtrations loss properties of the sample at 150 psi and 30° C were compared and discussed as well as pH effect. Rheology tests were carried out at low temperatures with the purpose to determine the potential utilization of the drilling fluids at low-temperature conditions [18], [19]. The rheological properties for based drilling fluid analysis by measured values of PV, AV, YP, Gel 10s, and Gel 10min at 30° C for Al_2O_3 and SiO_2 nanoparticles –based drilling fluids, respectively, as shown in Figure 3–Figure 8.

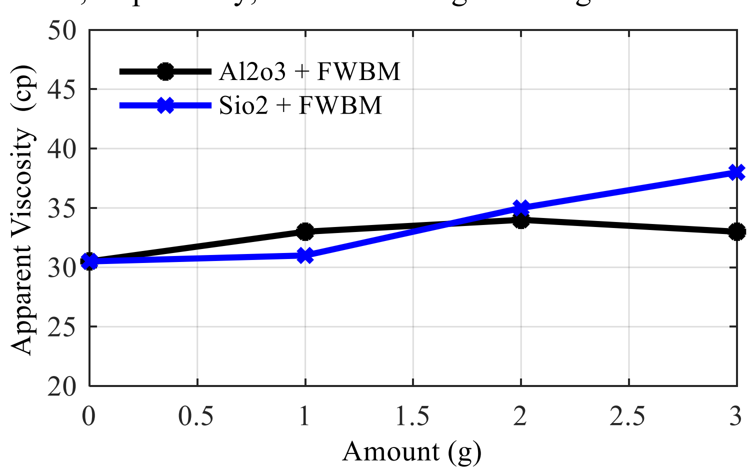

Figure 3. Apparent Viscosity (samples with different concentrations of nanomaterials).

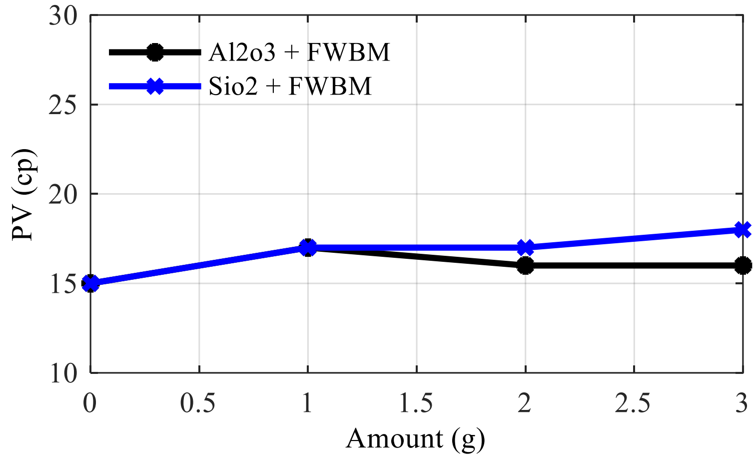

Figure 4. Plastic viscosity (samples with different concentrations of nanomaterials).

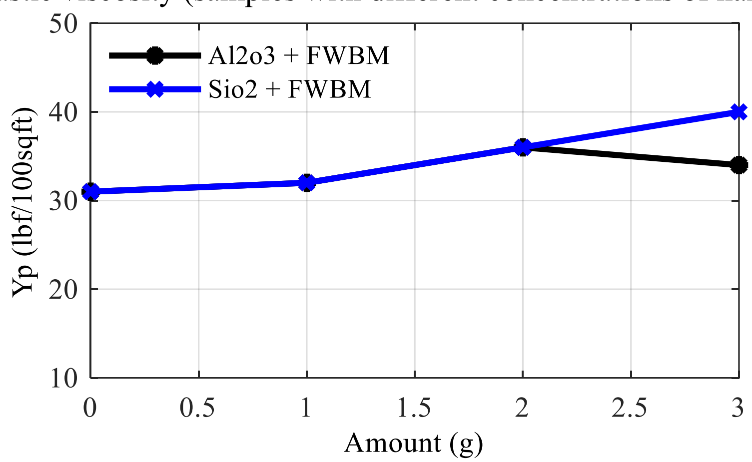

Figure 5. Yield point (samples with different concentrations of nanomaterials).

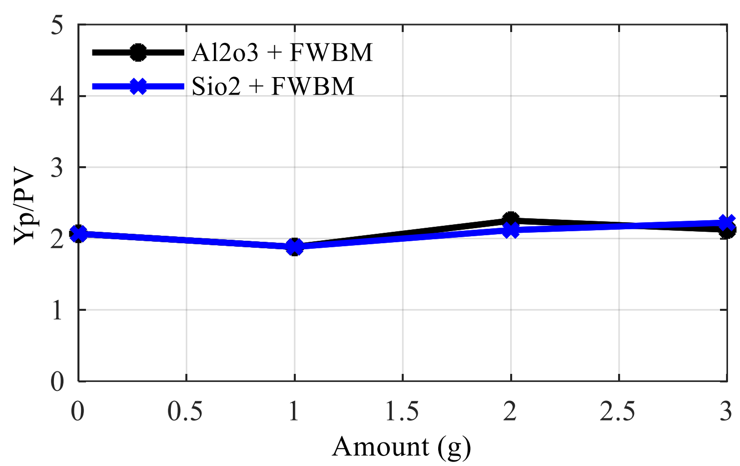

Figure 6. YP/PV ratio (samples with different concentrations of nanomaterials).

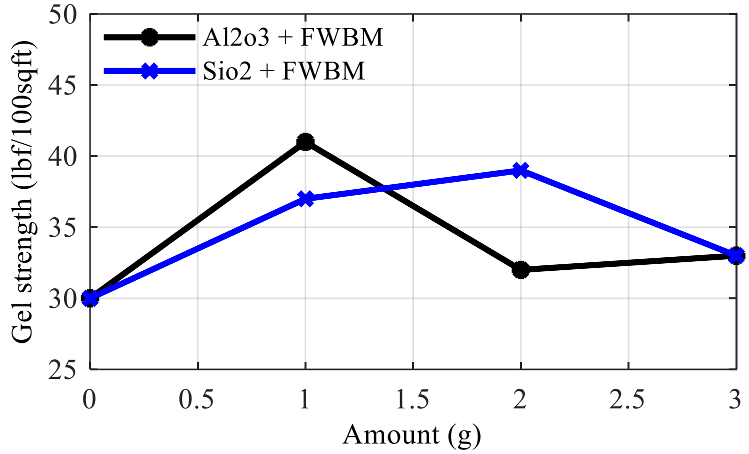

Figure 7. Gel strength for 10 min (samples with different concentrations of nanomaterials).

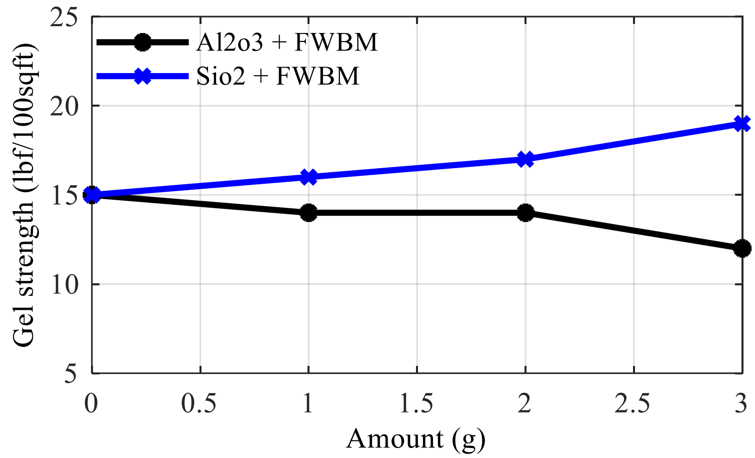

Figure 8. Gel strength for 10 sec (samples with different concentrations of nanomaterials).

Overall, for SiO_2 and Al_2O_3 nanoparticles, the other properties (PV, YP, and AV) increase with different concentrations. The gel strength is produced by particles that are electrically charged which will be attached to compose a solid structure in the fluid [20], [21], [22]. The gelation structure formed is a function of temperature, time, the amount and type of solids in suspension. On another hand, gel strength is the yield stress of the drilling fluid within static conditions. The 10s gel strength for water-based drilling fluid was 15 pa, and it's decreased with 1g, 2g, 3g of Al_2O_3 nanoparticles to 14 pa, 14pa, and 12 pa, respectively. Furthermore, it is increased with 1g, 2g, and 3g of SiO_2 nanoparticles to 16 pa, 17pa, and 19pa. The 10 min gel strength for water-drilling fluid was 30 pa, and it is increasing with different concentrations of Al_2O_3 and SiO_2.

In this study, Fan HPHT filter press was used and the experiment of filtration loss on Al_2O_3 and SiO_2 nanoparticles doped drilling fluid carried out at laboratory temperature (30˚C) and pressure of 150 psi and under static condition. Filtration is the process of allowing the fluids to pass through a permeable formation, whenever the formation exposed to mud at a pressure higher than formation pressure. The differential pressure causes to separate the drilling fluids liquid phase from the solid phase. The obtained results also showed that as the concentrations for nanoparticles is decreased, the thickness is increased since at higher concentrations more particles will be present in the fluids and thus thicker filter cake (Table 4 and Table 5). Stable suspended materials form dense and compact sediments, whereas flocculated suspended materials form more voluminous sediments and particles linked in the form of open networks or poor fabrics. Moreover, the water able to pass easily by the soft mud cake then increases the filtration loss. Also, this is because of the small size of nanoparticles that reduces the porosity of filter cake.

Table 4. Filtration properties (samples with a different concentration of SiO_2).

Amount of SiO_2 (g)	Filtration Volume (ml)	Mud Cake Thickness (mm)

0	9.6	1
1	8.8	1.25
2	8.6	1.25
3	8.4	1.25

Table 5. Filtration properties (samples with a different concentration of Al_2O_3).

Amount of Al_2O_3 (g)	Filtration Volume (ml)	Mud Cake Thickness (mm)
0	9.6	1
1	9.2	1.5
2	9.0	1.5
3	9.1	1.5

For the pH, it can be observed that both Al_2O_3 and SiO_2 did have any effect on the pH as shown in Table 6 and Table 7. It can also be determined that increasing the concentrations of both Al_2O_3 and SiO_2 reduced the pH slightly.

Table 6. pH (samples with a different concentration of Al_2O_3).

Amount of Al_2O_3 (g)	pH
0	9.3
1	9.2
2	9.1
3	9.0

Table 7. pH (samples with a different concentration of SiO_2).

Amount of SiO_2 (g)	pH
0	9.3
1	9.1
2	9.0
3	8.9

4. Conclusion

In this work, we formulate and evaluate the samples of water-based drilling fluids, which contained xanthan gum and SiO_2 nanoparticles or xanthan gum and Al_2O_3 nanoparticles, in order to compare and assess the drilling water fluid properties, also to study the effect of nanoparticles on the rheological properties of nanoparticles, the following conclusions were drawn:

1. The viscosity of drilling mud slightly increase with 1g SiO_2 nanoparticles addition and sharply increase with 2g and 3g, SiO_2 additions.
2. Overall, for SiO_2 and Al_2O_3 nanoparticles, the other properties (PV, YP, and AV) increase with different concentrations.
3. The 10gel strength decreased with different concentrations, while the 10 min gel strength increased with different concentrations.
4. The filtrate loss volume was reduced with prepared nano-fluid, while the thickness of filtrate cake is increase.
5. The PH of drilling fluid slightly decreased with different concentrations.

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