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Enhancement of Water-Based Mud Rheology and Lubricity Using Silica Nanoparticles

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Abstract

Nanotechnology has been widely used in the oil and gas sector in recent years, which has shown successful results at various stages of the oil field, such as exploration, drilling, completion, production, refining, and processing. In particular, the application of nanoparticles to enhance the properties of drilling fluids. The effect of the addition of silica nanoparticles to water-based mud on the properties of rheology, filtration, alkalinity, and lubrication was studied in this paper. Experimentally, different samples of water-based mud were formulated with different SiO_2 and MWCNT concentrations (10 nm in size) and tested with Modular Compact Rheometer (MCR), MCR tribometer, API filter press and pH meter for rheological, friction factor, filtration and alkalinity measurements, respectively. The rheological results showed an increase of the yield point by 20.1% at 0.013 wt% of SiO_2 and a decrease of the plastic viscosity by 14%. However, the lubricity results showed the highest reduction of the friction factor at 0.013 wt% of SiO_2 by 25% and by. Furthermore, the pH results showed a decrease in pH due to the addition of SiO_2 and a slight increase in filter loss. Finally, the addition of silica nanoparticles to the water-based mud showed a significant improvement in the rheological properties that help to solve hole cleaning problems. In addition to the lubrication enhancement by reducing the friction factor, which reduces the torque and drag problems during drilling, in particular at deviated wells and therefore increases the drilled length.

Keywords: *Drilling fluid; Water-Based Mud; Nanoparticles, Rheology; lubrication; filtration; friction factor.*

1. Introduction

Drilling fluid plays an important role in the drilling process as it serves as a conduit for the blood in our bodies. As any problem with drilling fluid can affect the performance of the drilling operation. It is therefore essential to maintain the functions and behavior of the drilling fluid in the well. As a result, fluid drilling is a focal point for many researchers to improve drilling fluid design and its properties. Nanotechnology has recently demonstrated its benefits in the oil and gas industry, especially in drilling fluids. Researchers are looking into the use of nanoparticles in drilling fluids due to its many advantages to drilling fluids. [1-4]. Several researchers reported the positive impact of nanoparticles on drilling fluids. For instance, Ziaja and Sirvatsa [5] investigated the effectiveness of bio polymer-surfactant fluid blends, like nanoparticles, as fluid loss additives, as they minimize filtrate losses in the formulation by creating a thin filter layer. They concluded with an increase in the concentration of nanomaterial the loss of fluid was decreased but restricted to the accumulation of nanoparticles in polymer fluid, which could contribute to an efficient filter cake. Al-Majed *et al.*[6] identified nanotechnology as the current trend and future challenges. Although Wilson [7] reported that silica nanoparticles can be used in drilling fluids to improve drilling operations.

Chenevert *et al.* [8] examined a new type of water-based drilling fluid that includes nanoparticles and assessed its contact with shales. They observed that the water penetration of the shale was minimized by physically plugging the shale pores and cracks with water-based drilling fluid with nanoparticles. Ragab and El-Diasty [9] have shown a study of the use of

Nanoparticles in the upstream sector of the oil and gas industry. They addressed the importance of using silica nanoparticles to improve the performance of drilling fluids and its effectiveness in enhancing the recovery of oil. Hareland *et al.* [10] examined the impact of using graphite nanoparticles in oil-based mud (OBM) on the enhancement of wellbore. They noticed an increase in fracturing pressure on the sandstone core using a hydraulic fracture test. The fracture tolerance was found to be increased by 65% hen calcium-based nanoparticles were used. While the use of iron-based nanoparticles improved by 39%. They also examined the filtration of mud in the ceramic plate under HPHT conditions. They found that the insulation of the tip resulting from the development of immobile mas was the reason for the increase in fracture strain. Salih *et al.* [11] studied the impact of the use of synthetic nanoparticles in water-based mud on rheological, filtration properties. The nanoparticles used were 5.7 nm colloidal silica dioxide. They observed an increase in rheological and filtration properties with a concentration of nanoparticles below 0.7% by weight. Nanoparticles produce fewer filtrate fluid volume thin mud cake, a decrease in equivalent circulating density (ECD) and a decrease in circulating pressure loss. Hafiz *et al.* [12] have produced water-soluble polymers and nanoparticles to enhance bentonite drilling fluid performance The nanoparticles used were carbon nanotubes and graphite nanotubes at different concentrations and temperatures. The result showed a decrease in the volume of filtrate fluid, thin mud cake and an increase in rheological properties. The addition of 0.25 wt.% of polymer and 0.25 wt.% of nanoparticles was found to be the optimum concentration to improve both filtration and rheological properties. Al Ruqeishi *et al.* [13] investigated the impact of using nanoparticles as drilling fluid rheological properties modifiers. The nanoparticles used were carbon nanoparticles (CNP) with a size of 50 nm and ZnO nanowires. The results showed an increase of 1-3 wt.% of drilling fluid density. A reduction of 1, 2 and 3 g of CNP were also obtained by 7.4.8 and 4 mL, respectively. in addition, the drilling fluid viscosity was improved by 24 % by the use of 2 g of ZnO nanowires. Jamal and Haneef [14] carried out experimental work using nanomaterial called ATR in the formulation of the drilling fluid. This ATR material has a chain structure with a large surface area. The rheological properties of nano-based drilling fluid were tested with traditional bentonite drilling fluid. Ten samples were tested using different sizes of nano. The first group consisted of four samples that were used to show the effect of nano size reduction, the first sample was fine-grained, the second sample was less than 63 µm, the third sample was less than 63 µm and the fourth sample was 20 nm. They conducted PV and YP measurements for all of these samples and found that there was no trend difference from sample one to sample three. On the other hand, nano-based sample four showed a different pattern, especially in gel strength, as it showed an increase of about 200 %, indicating its high performance in drilling cuttings.

Mahmoud *et al.* [15] analyzed the impact of the use of iron oxide and silica nanoparticles in water-based mud at filtration properties. thy found that the filtration loss decreased as the concentration of iron oxide increased, as demonstrated by CT scan measurements. The experimental study showed that the optimum concentration of iron oxide was 0.5 % (w / w). While above this concentration a new layer was formed in the filter cake, it adversely affected the filter cake and the loss of fluid properties.. Al-Saba *et al.* [16] had studied the impact of using nanoparticles on the rheological properties of water-based drilling fluids. In this study three different types of nanoparticles have been used as aluminum oxide, copper oxide and magnesium oxide at two different concentrations. The results showed that plastic viscosity was decreased by 50% while the yield was increased by 84%, 121 % and 231% for 0.5 % of vol copper oxide, aluminum oxide and magnesium oxide respectively. In contrast, the gel strength of 10 seconds was increased by up to 95%. A reduction in fluid loss to 30% was found at low-pressure low-temperature conditions. Lee and Taha [17] used nano-graphene nanoparticles to improve the performance of the drilling fluid. Nanoparticles were found to reduce the torque by 70-80 % on 10 lb./gal (ppg) of conventional salt polymer mud and to reduce the torque to 50 % in 13.5 ppg of water-based mud under high-pressure high-temperature conditions. All of these studies do not take into account measurements of the friction factor and their effect on torque reduction and drag. In this paper, the effect of adding SiO_2 of 15 nm nanoparticles on water-based mud was tested to investigate its effect on lubricity, rheological, filtration and alkalinity properties of the mud.

2. Material and methods

2.1. Silica nanoparticle

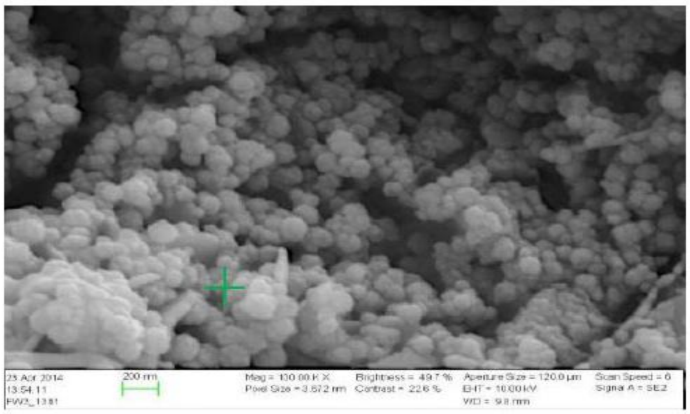

Fig.1. SEM picture of silica nanoparticles

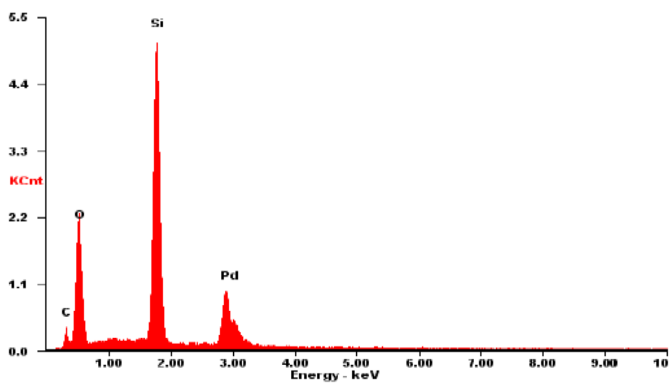

Fig.2. EDS analysis of nano-silica

Silicon dioxide nanoparticles (SiO_2) are chemically composed mainly of silicon and oxygen. These particles can also be called nanoparticles of silica or silica. These have low toxicity and can be tailored to different types of polymers. These particles are commonly used as an additive for rubber or plastic and are used to stabilize concrete due to their stable and non-toxic properties [18]. In this paper, scanning electron microscopy was used to determine the size of silica particles. From the SEM picture analysis the used silica has a size of 15 nm as shown in the SEM picture and density of 2.2 gm/cc.

In addition, the Elemental Dispersive Spectroscopy (EDS) analysis as shown in Figure 2 shows that the silica nanoparticles used are Si, O and small Pd, which were used only for the coating of the particles during the SEM analysis. Furthermore, Table 1 summarizes the properties of used Silica.

Table 1. SiO_2 properties

Specifications	Value
Purity	99.5 wt.%
Diameter	10-20nm
Density	2.2-2.6 gm/cm^3

2.2. Water based mud samples formulation

Six drilling fluid samples were designed to investigate the effect of nanoparticles on water-based mud, including the reference sample. The fluids have been developed in order to gain knowledge of the effects of nanoparticles, salt and polymer on each other. The drilling fluid sample consists mainly of water salt, xanthan gum polymer, nanoparticle and bentonite. Salt was added to the sample for stabilization purposes, xanthan gum polymer for control of viscosity and filtration, as well as bentonite.

No nanoparticles have been added to the base fluid, while other drilling fluid samples contain different concentrations of SiO_2 from 0.013 wt% to 0.53 wt%. In addition, all drilling fluid samples have the same amount of water, salt, XG polymer and bentonite. The water was added to the container to construct the drilling fluid sample, then salt was added to the water KCl salt has been used for all samples. After the salt was dissolved in the water the XG polymer was carefully added to the system to prevent the formation of lumps and mixed with the Hamilton beach mixer. After mixing, the fluid was allowed to swell properly for 48 hours to the age of enough time for bentonite. Finally Nanofluid is prepared using a two-step method as the nanopowder is added to the device and mixed with an ultrasonic homogenizer to ensure the mixing and homogenization of nanoparticles. Table 2 shows the composition of the samples.

Table 2. Water based mud samples composition

Material/Quantity	Reference	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Bentonite, pbb	18	18	18	18	18	18
Xanthan gum polymer, pbb	1	1	1	1	1	1
KCl salt, pbb	3	3	3	3	3	3
Water, pbb	1	1	1	1	1	1
Nanoparticle (SiO^2) (wt%)	0	0.013	0.03	0.04	0.053	0.53

2.3. Determination of water-based mud properties

2.3.1. Rheological properties

The MCR rheometer of Anton Paar is used to study the rheology of the nanofluid so that the accuracy of the experiment is strongly assured. The shear stress measured at different shear rates ranged from 100 RPM to 600 RPM. The Bingham plastic viscosity (PV), Yield point (YP) and Power-law model parameters flow behavior index (n) and Consistency index (k) were then determined using the following equations [19] ;

$$PV = \ominus 600 - \ominus 300 \quad (1)$$

$$YP = 2 \ominus 300 - \ominus 600 \quad (2)$$

$$n = 3.32\, log \left(\frac{\theta_{600}}{\theta_{300}}\right) \quad (3)$$

$$K = \left(\frac{\theta_{300}}{511^n}\right) \quad (4)$$

where: $\ominus 600$ Fann Reading at 600 rpm; $\ominus 300$ Fann Reading at 300 rpm.

2.3.2. Friction factor determination

The tribometer of the MCR is used to determine the friction factor of the samples. Measures the friction between the steel ball and the steel plate in the presence of three-ball drilling fluid on three plates The drilling fluid samples were examined by applying a constant normal force of 5N to calculate the friction factor through the following equation [20];

$$\mu = \frac{F_F}{F_N} \quad (5)$$

where: F_F Friction Force; F_N Normal Force.

2.3.3. Filtration and pH determination

The filtration volume of the water-based samples is determined through the API filter Press test standard for 30 minutes test [21]. In addition, the alkalinity of the samples is determined through the measurement of pH value using standard electrode pH meter. All tests carried out based on the API RP 13 B-1 procedures [22].

3. Results

3.1. Effect of silica nanoparticles on water-based mud rheology

Fig.3 shows the response of SiO_2 water-based mud samples with and without silica nanoparticles to the viscometer measurements. The rheological results showed an increase in the shear stress of SiO2 water-based mud samples relative to the reference fluid, except for sample 5 (0.53 wt %) with the largest reduction in shear stress. From these results, the optimum concentration for SiO_2 was 0.013%, which resulted in the greatest improvement in water-based mud rheology.

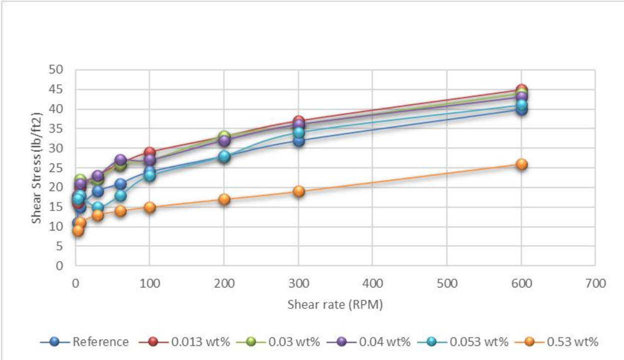

Fig. 3. Shear stress vs shear rate for different SiO_2 concentrations

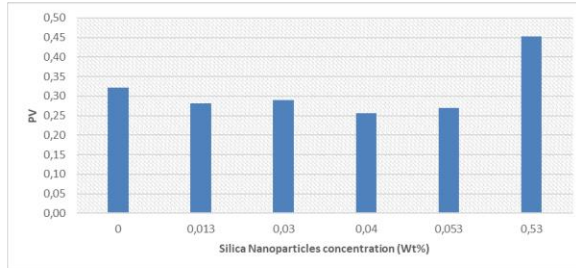

Figure 4. PV of water-based mud samples with different SiO_2 concentrations

As shown in figure 4, the addition of silica nanoparticles does not change the PV compared to the reference fluid at (0.013,0.03) wt% while with the addition of (0.04,0.053,0.53) wt% showed a reduction of PV by 12.5 % compared to the base fluid without nanoparticles.

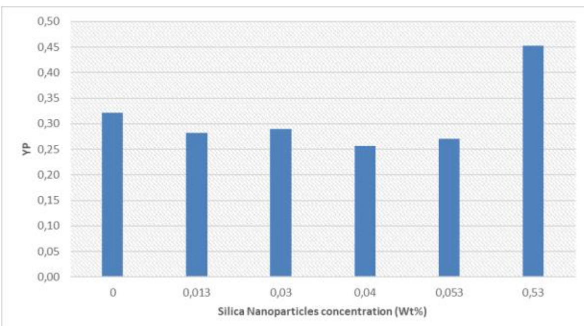

Figure 5. YP of Water-based mud samples with different SiO_2 concentrations

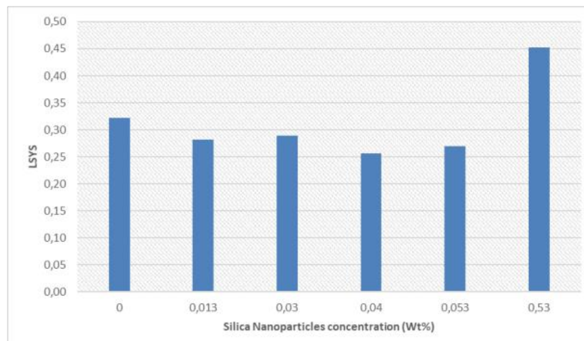

Figure 6. LSYS of water-based mud samples with different SiO_2 voncentrations

Figure 5 shows the effect of adding the SiO_2 at different concentrations to the water-based mud on Yield point. From the results, the YP for all nano drilling fluid samples was increased compared to the base fluid except at the highest concentration of 0.53 wt% of SiO_2 where it was decreased by about 50%. While the highest increase of YP was achieved at 0.053 wt% with 16 lb/100 ft^2 compared to 7 lb/100ft^2 for the base fluid. In addition, the Low Shear Yield Stress(LSYS) as shown in Figure 6 is showed an increase for all SiO_2 fluids compared to the base fluid except for 0.53 wt% of SiO_2 where it had the same value as the base fluid. The maximum increase of LSYS was achieved 0.053 wt% of SiO_2 by 129%. This enhancement of LSYS aided in the cleaning of the cuttings in the low side of the borehole in the annulus.

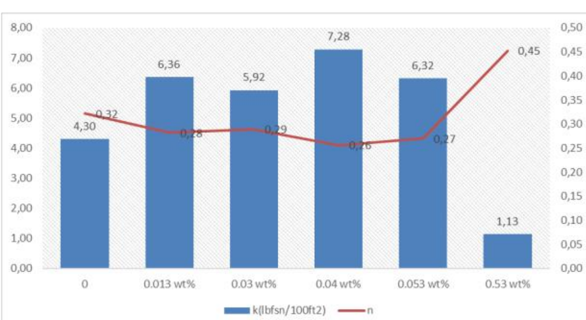

Figure 7. n,k of water-based mud samples with different SiO_2 concentrations

Figure 7 showed the consistency index was increased for all SiO_2 fluids in comparison with the base fluid without nanoparticles except for 0.53 wt% of SiO_2 where it was decreased to 74 %. While for other fluids sample the consistency, the index was increased varied from 37 to 70 % compared to the base fluid. Moreover, the flow index values decreased for low concentration SiO_2 fluids in comparison with base fluid and it was decreased to the most value for 0.04 wt% of SiO_2 to 0.26. While for the high concentration of SiO_2 fluid at 0.53 wt% the flow index was increased by 41% at 0.45. However, all SiO_2 fluids have n-value less than 1 which indicates the pseudoplastic behavior.

3.2. Effect of silica nanoparticles on water-based mud lubrication

In order to determine the lubricity effect of SiO_2 on water-based mud samples, the coefficient of friction was measured for all SiO_2 samples and the base fluid using the MCR tribology cell. Several tests were performed by applying a normal force of 5 N in order to determine the coefficient of friction.

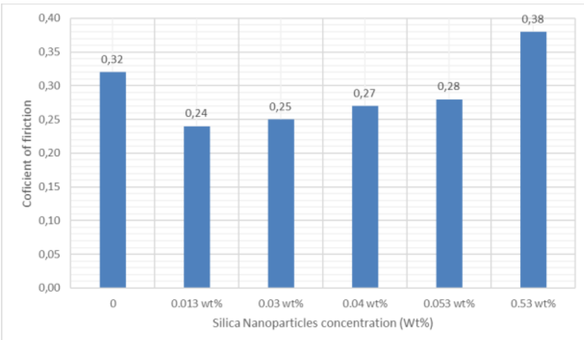

Figure 8. Coefficient of friction water-based mud samples with different SiO_2 concentrations

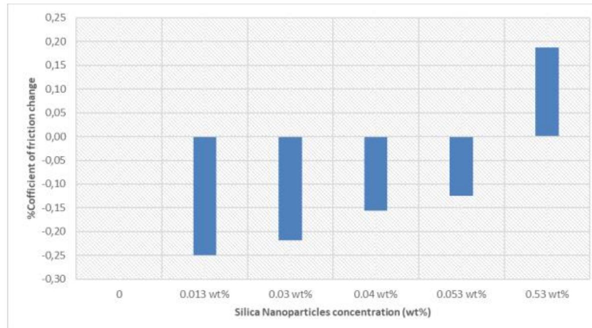

Figure 9. Percentage of friction factor change for water-based mud samples with different SiO_2 concentrations

Figure 8 showed the measurements of friction factor with different SiO_2 concentrations. From the results, the lowest value of the coefficient of friction was achieved by 0.013 wt% of SiO_2. However, as the concentration of SiO_2 increases greater than 0.013 wt% the coefficient of friction was increased, therefore this was the optimum concentration. Moreover, at a high concentration of SiO_2 at 0.53 wt%, the coefficient of friction was exceeded the base fluid's value.

Figure 9 showed the changes in the coefficient of friction in terms of percentage compared to the base fluid. The water-based mud sample with 0.013 wt% of SiO_2 had the highest decrease in friction by 25 % in comparison with base fluid. However, it increased to 19% for water-based mud samples with 0.53 wt% of SiO_2 which indicates that the higher concentration of SiO_2 increases the friction coefficient. This reduction of friction results in the reduction of the torque and drag that cause huge drilling problems especially in deviated wells.

3.3. Effect of silica nanoparticles on water-based mud on filtration

The filtration volume of the water-based mud sample was tested on all samples with and without SiO_2 nanoparticles on API filter Press. The samples allowed to filter through filter paper and the filtrate volume recording during 30 minutes of the test.

As shown in figure 10, the filtration volume was increased with the addition of SiO_2 nanoparticles with the highest increase of 19% at 0.013 wt%. In addition, the lowest filtration volume was with 0.03 wt% that had the same value as the base fluid. This indicates that silica nanoparticles do not control the filtration loss, therefore, filtration loss additive should be added to control the filtration with silica nanoparticles samples.

3.4. Effect of silica nanoparticles on water-based mud on alkalinity

The alkalinity of the drilling fluid samples is an important factor that should be tested in order to allow the reaction and functions of other additives in drilling fluid samples [14]. Therefore, the water-based mud samples with and without silica nanoparticles were measured through pH meter.

From pH measurements shown in Figure 11, the silica nanoparticles do not change the pH greatly. Although, there was a reduction of the pH value compared to the base fluid ranges from 0.6 % at 0.03 wt% to 6% at 0.53 wt% of SiO_2. Therefore, the pH of the drilling fluid samples with the addition of silica nanoparticles does not need the addition of other additives to control the alkalinity of the drilling fluid.

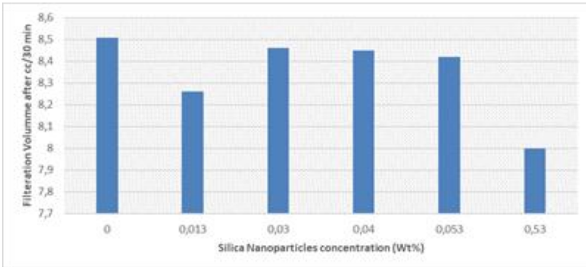

Figure 10. Filtration volume for water-based mud samples with different SiO_2 concentrations

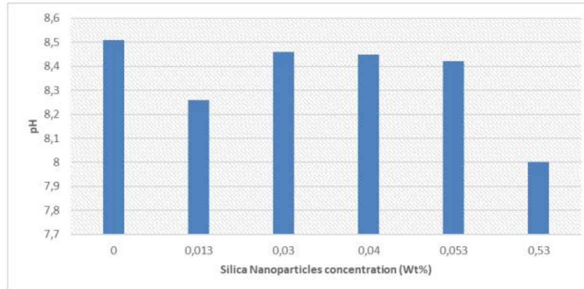

Figure 10. pH values for water-based mud samples with different SiO_2 concentrations

4. Conclusions

In this paper, the effect of SiO_2 nanoparticles in water-based mud samples was evaluated based on the laboratory work. The drilling fluid samples properties were examined according to rheology, lubricity, filtration and pH tests.

Addition of SiO_2 nanoparticles increase and enhance rheology of the water-based mud except for the high concentration at 0.53 wt% that decreases the rheology. The enhancement includes the increase of Yield stress and low shear yield stress that aid in cleaning the borehole while drilling especially in the deviated hole. The optimum concentration that showed the greatest enhancement was at 0.013wt% of SiO_2.

Moreover, the SiO_2 showed the greatest reduction of the friction factor at low concentration of silica nanoparticles at 0.013 wt% by 25% compared to the base drilling fluid. While it showed an increase in friction factor at high concentration with 0.53 wt% of SiO_2.

However, the silica nanoparticles increase the filtration loss by the highest increase of 19% at 0.013 wt% that needs the addition of fluid loss reducer additive. Also, the silica nanoparticles were decreased the pH slightly by a maximum value of 6% at 0.53 wt%.

The nanoparticles drilling fluids showed a trend future in the enhancement of the drilling fluid properties that improve the drilling performance and mitigate several drilling problems. Accordingly, the enhancement of rheology led to the reduction of the cutting bed heigh and enhancement of the overall hole cleaning especially at the harsh condition of the deviated wells. Moreover, the reduction of friction factor is a very significant feature that will reduce the torque and drag that appear in deviated wells and is increased the maximum drilling length of the wells.

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