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Experimental Investigation of Effect of SiO_2, CuO, and ZnO Nanoparticles on Filtration Properties of Drilling Fluid as Functions of Pressure and Temperature

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Highlights

- Investigation of the effect of nanomaterial such as nono-SiO_2, nano-Cu, and nano-Zn on filtration properties of drilling fluid under both high pressure/high temperature (HP/HT) and low pressure/low temperature (LP/LT) conditions;
- Investigating the effect of nanomaterials on the reduction of filtration and loss of drilling fluid in high- and low-temperature conditions;
- Investigating the thickness of the mud cake due to the presence of nanoparticles;
- Experimental study of nano-drilling fluid based on nanotechnology.

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Abstract

Among the different operating parameters that must be carefully controlled during the drilling operation, penetration of drilling mud into the permeable zone of formations is one of the essential ones that can have a destructive effect on the productive zone. Thus, the current investigation concentrates on investigating the effects of different nanoparticles (NPs), namely SiO_2, CuO, and ZnO, considering their size, type, and concentration (0.2 to 2 wt % for each nanoparticle) on the properties of the drilling fluid, including rheology and high- and low-temperature filtration. NPs can improve the rheological properties of the mud by changing the friction coefficient favorably. Moreover, the effects of temperature and pressure as two critical thermodynamic parameters are examined. The results show that it is possible to enhance the rheological properties (viscosity) of the drilling mud to a maximum value of about 20 % if NPs with a concentration of 2 wt % are added to the drilling fluid. Extreme gel strength will lead to high pump initiation pressure to break circulation after the mud is in a static condition for some time. The results reveal that reducing the gelation properties of the drilling mud is possible using low concentrations of NPs. Moreover, the results reveal that SiO_2 and ZnO exhibit a lower filtration rate than CuO. Finally, the effects of temperature and pressure were investigated, which revealed that regardless of the reductive effect of NPs (reducing the filtration rate from 17.7 to about 10 cm^3), increasing the pressure and temperature lead to an increase in the filtration rate (reducing the filtration rate from 67 to 35 cm^3). Further, the rheological properties of the mud remain relatively constant.

Keywords: Copper oxide, Drilling mud, Filtration, Nanoparticles, Silicon oxide, Zinc oxide

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1. Introduction

One of the most effective ways to tune the formation pressure through drilling areas is utilizing a mixture of freshwater and drilling particles created during the subsurface formation drilling process. This pressure is crucial since it directly correlates with the fluid penetration into the formation or making of cakes. On the other hand, one of the effective methods for controlling well stability is reducing and controlling the permeability (i.e., changing pore size distribution) and chemical composition of the drilling fluid. It is well established that microscopic open pores comprise most of the penetrable zone of formations and can let the mud particles move into the formation under the effects of both differential pressure of the drilling fluid column and formation and the quality of the precipitated bottom cake on the formation. Larger open pores require lower differential pressure to be invaded with mud and mud filtrate.

On the other hand, it is approved that it is possible to control instability through hydrated shale or interactions between drilling mud compositions and the well wall by controlling the volume of drilling fluid and the filtration amount of formation fluids (Darley and Gray, 1988; Xuan et al., 2014). Further, drilling fluids produced with poor quality or thick filter cake can cause the wells to be tightened, the pipes stuck during the process, poor quality cement, and the well pipe drainage. These problems can be solved by changing the particle size distribution and chemical composition of the mud. Therefore, researchers have always tried to improve the drilling mud filtration properties.

One of the most common methods for this enhancement is the utilization of polymers and gums in drilling mud to modify the viscosity of the fluid, which can have a reverse effect on filtration drop or water loss in the drilling mud. Unfortunately, although increasing viscosity is one of the effective methods, it can directly affect the pressure drop and introduce a high load of pressure on the equipment. In this way, it appears that nanomaterials can be a novel method since they can reduce filtration by permeable cavitation. In detail, nanoparticles (NPs) can be advantageous since they can reduce filtration penetration by bridging the openings of the mud cake cavities due to their small particle size. Among the first attempts, it has been proven that using NPs with different sizes and surface charges can affect the diffusion of bentonite clay particles, consequently changing the filtration and rheology of drilling mud (Srivatsa, 2012). In addition, Yang et al. (2014) utilized graphite NPs particles in the aqueous drilling mud and reported that reducing the filtration capability with a maximum value of about 40% was possible. The performance of fluid-loss control was evaluated through API filtration tests and compared with several commonly used fluid-loss-control additives. The results show that nanographite oxide performance is much better than the additives for comparison at relatively low concentrations due to the well-aqueous dispersion of nanosheets. In addition, it is found that nanographite oxide exhibits a remarkable effect on controlling fluid loss even in the absence of bentonite, which is a significant advantage over traditional polymer additives. Srivatsa et al. (2012) examined the influence of NPs on the reduction of drilling filtration in surfactant-and-polymeric-base muds. Their results demonstrated that NPs could enhance surfactant stability and reduce filtration in drilling mud.

Moreover, Barid et al. (2007) reported that it would be possible to increase the stability of colloidal suspensions such as bentonite using NPs. Kim et al. (2014) produced two hybrid adobe–NPs hybrids, namely aluminum silica oxide–NPs (ASCH) and iron oxide–NPs (ICH), and examined their possible impacts on bentonite drilling mud rheological properties. They found that using NPs with a concentration of about 0.05 % w/w could improve yield and viscosity compared with the base mud since the presence of NPs could modify and develop the existing cross-links between particles. It was also reported that the ASCH binding of ASCH to clay platelets that existed in bentonite-based drilling fluid had a profound correlation to the pH value. In detail, for high pH values, ASCH presence could reduce the viscosity and gelatinous spot of the mud, while a reduction in pH value changes the behavior of the properties similar to ICH.

Furthermore, Aramendiz et al. (2020) evaluated the potential of using silica nanoparticles and graphene nanoparticles as drilling fluid additives in a single formulation to improve shale inhibition and the long-term stability of water-based mud (WBM) against temperature effects. Their results showed that these additives acted synergistically with other additives to improve the filtration characteristics of the WBM, with only minor effects on the rheological properties. Zakaria et al. (2012) utilized NPs to find if it was possible to modify the filtration properties of an oil-based mud. Vryzas et al. (2015) also selected iron oxide and silica NPs to examine the performance of bentonite-based drilling fluids. They claimed that it was possible to improve the filtration properties using iron oxide NPs with an optimum concentration of 0.5 wt %, while silica NPs manipulated the fluid loss characteristics.

Unfortunately, although several investigations have been performed to find the effect of NPs on different properties of the drilling and drilling process, a limited number of investigations exist on the NPs influence on mud lubrication. Further, an investigation performed by Abdo and Hanief (2013) revealed that it was possible to modify the lubricative effect of drilling fluids using Ligorstic NPs (10–20 nm). Moreover, Wrobel (2016) examined the possible effect of several NPs, including MoS_2, TiO_2, and TiN, in lubrication properties using bentonite-based drilling fluids. Fakoya et al. (2013) observed that silica NPs coated with polyethylene glycol (PEG) significantly inhibited clay swelling as electrolytes existed in the media. Thus, they act as clay stabilizers to retain the clay platelets in position by controlling the charge and electrolytic characteristics of the treatment fluid. Their findings revealed that enhancing the NPs concentration in the clay scattering resulted in the aggregation of particles.

In this regard, the current investigation aims to find the effect of different nanomaterials at different concentrations on the drilling filtration properties at high and low temperatures since they can reduce fluid penetration by causing bridging at the entrance of mud cake or mud cavity, thereby controlling formation damage. The changes in the base fluid drop and overall filtration at high and low temperatures will be reported and compared, and even the thickness of the mud cake will be measured. The results of this study can markedly enhance this process due to the lower cost of NPs if they are mixed with the base fluid, especially the bentonite type. Since Iran has rich resources for producing SiO_2, CuO, and ZnO, domestically produced materials are economical and can be used.

2. Experimental procedures

2.1. Materials

The sample drilling fluid was prepared by mixing bentonite with different types of NPs, including SiO_2, CuO, and ZnO, at different concentrations. After that, the filtration rate and the mud cake thickness were measured. Moreover, scanning electron microscopy (SEM) was utilized to find the deposition of NPs on the mud cake surface.

3. Results ad discussion

3.1. Effect of NPs on rheological properties of drilling mud

This section studies the effect of NPs on the rheological properties of water-based mud. We used WBM because oil-based muds are mostly made of oil and are incompatible with NPs. Firstly, water-based fluid comprised of water and salt was prepared using well mixing. Then, the variations in the fluid properties due to adding NPs to the mud were investigated (see Table 1). The results illustrate that the prepared mud has a yield stress and gelatin content of 5.58 Pa with an apparent viscosity of 28.5 cP. Further, the plastic viscosity was 25 cP with the strength of the base fluid yield of 7 lb/100ft^2.

Table 1

The rheological data of the base fluid.

Base fluid (water + 10 wt % bentonite + 3.5 wt % NaCl)			
rpm	Theta	SR	SS
3	11	5.109	5.58
6	12	10.21	6.09
100	22.5	170.3	11.41
200	28	340.6	14.21
300	32	510.9	16.24
600	57	1021.8	28.92

After that, the NPs were added to the base fluid, and the rheological data of the modified solutions were measured (Tables 2–4). In the first step, the effect of ZnO particles was investigated on the rheological properties of the prepared drilling mud (see Table 2 and Figure 1).

Table 2

The rheological properties of 10 wt % bentonite + 3.5 wt % NaCl after adding different concentrations of SM1-ZnO.

	0.2 wt % Nano-ZnO			0.4 wt % Nano-ZnO			0.6 wt % Nano-ZnO			0.8 wt % Nano-ZnO		
rpm	Theta	SR	SS	Theta	SR	SS	Theta	SR	SS	Theta	SR	SS
3.0	6.1	5.1	3.1	6.3	5.1	3.2	6.5	5.1	3.3	6.8	5.1	3.5
6.0	10.6	10.2	5.4	10.7	10.2	5.4	11.0	10.2	5.6	11.6	10.2	5.9
100.0	20.0	170.3	10.2	21.0	170.3	10.7	24.0	170.3	12.2	25.1	170.3	12.7
200.0	26.0	340.6	13.2	27.5	340.6	14.0	29.0	340.6	14.7	31.0	340.6	15.7
300.0	34.0	510.9	17.3	35.0	510.9	17.8	39.5	510.9	20.0	42.5	510.9	21.6
600.0	50.0	1021.8	25.4	52.0	1021.8	26.4	55.0	1021.8	27.9	58.0	1021.8	29.4

1 wt % Nano-ZnO			1.5 wt % Nano-ZnO			2 wt % Nano-ZnO		
Theta	SR	SS	Theta	SR	SS	Theta	SR	SS
7.1	5.1	3.6	7.5	5.1	3.8	8.3	5.1	4.2
12.2	10.2	6.2	12.8	10.2	6.5	13.5	10.2	6.9

26.0	170.3	13.2	28.2	170.3	14.3	29.0	170.3	14.7
32.5	340.6	16.5	34.5	340.6	17.5	38.5	340.6	19.5
40.3	510.9	20.5	45.5	510.9	23.1	49.0	510.9	24.9
62.8	1021.8	31.9	66.0	1021.8	33.5	72.0	1021.8	36.5
62.8	1021.8	31.9	66.0	1021.8	33.5	72.0	1021.8	36.5

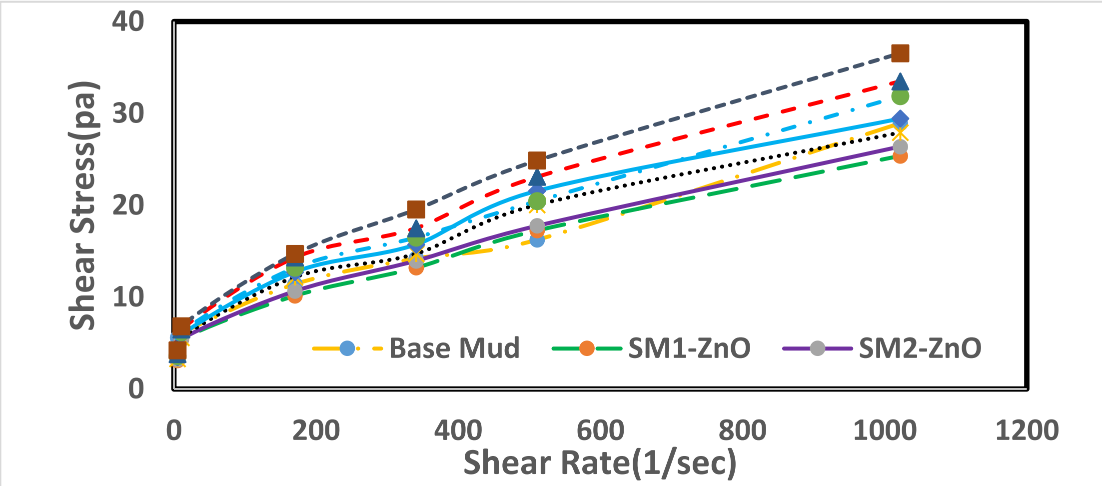

Figure 1

The rheology of the drilling mud containing zinc oxide NPs at different concentrations.

A closer look into the results tabulated in Table 2 shows a significant change in the rheological properties of the base mud containing ZnO NPs if concentrations change between 0.2 and 2 wt %. In each step, the optimized mud measurement with different NPs is numbered SM1 to SM7: SM1 representing a mud containing 0.02 wt % of NPs and SM7 a mud containing 2 wt % of NPs. As shown, increasing the concentration of ZnO NPs in the base fluid to a value of 0.6 wt % initially reduces the rheological properties such as yield stress and gelatinization, while a further increase in the concentration of the NPs moves the trend to the increasing one. The observed trend can be because NPs have a surface charge that interacts with the surface charge of the clay particles, spreading the clay and thus reducing the properties mentioned. On the other hand, adding the NPs to the fluid at a high concentration can enhance rheological properties since they are solid particles arranged between fluid particles.

Further, closer examination in Figure 1 reveals that the Herschel Buckley model is the best model that can justify the rheological behavior of the examined solutions. As the graph shows, for low concentrations of ZnO NPs (SM1 to SM3), the rheology diagram is lower than the base fluid. Nevertheless, this diagram is above the base fluid for higher concentrations, which indicates improved rheological properties at high concentrations.

After that, the effect of SiO_2 and CuO NPs on the rheological behaviors of the drilling mud was investigated (see Tables 3 and 4 and Figures 2 and 3). The results revealed that SiO_2 NPs similar to ZnO NPs could reduce the rheological properties of the mud at low concentrations, although this reduction was less than that of the mud containing ZnO NPs. As a result, it can cause a difference in the drop rate of the filter drilling mud. Similarly, CuO NPs, similar to other NPs, reduced the rheological properties at low concentrations although this reduction was more significant than the other NPs examined in the current investigation. Moreover, a glance into Figures 2 and 3 revealed that the rheological model of this type of fluids (containing SiO_2 and CuO NPs) was similar to that of the Herschel Buckley model similar to the previous NPs examined. The results depicted the shear stress in terms of the shear rate; for low concentrations of ZnO NPs (SM1 to SM3), the rheology diagram was lower than the base fluid as in the previous sample; however, at higher concentrations of the nanoparticles, this diagram was higher than the base fluid, implying an improvement in the rheological properties of the mud.

Table 3
The rheological properties of 10 wt % bentonite + 3.5 wt % NaCl after the addition of different concentrations of nanosilica

0.2 wt % Nano-Silica				**0.4 wt % Nano-Silica**			**0.6 wt % Nano-Silica**			**0.8 wt % Nano-Silica**		
rpm	Theta	SR	SS	Tet	SR	SS	Theta	SR	SS	Theta	SR	SS
3.0	9.5	5.1	4.8	8.5	5.1	4.3	8.0	5.1	4.1	8.1	5.1	4.1
6.0	10.5	10.2	5.3	10.0	10.2	5.1	9.0	10.2	4.6	9.5	10.2	4.8
100.0	20.0	170.3	10.2	20.5	170.3	10.4	21.0	170.3	10.7	21.5	170.3	10.9
200.0	25.0	340.6	12.7	26.0	340.6	13.2	26.4	340.6	13.4	27.0	340.6	13.7
300.0	29.0	510.9	14.7	31.5	510.9	16.0	32.0	510.9	16.2	32.5	510.9	16.5
600.0	52.0	1021.8	26.4	53.5	1021.8	27.2	55.0	1021.8	27.9	56.0	1021.8	28.4
		1 wt % Nano-Silica			1.5 wt % Nano-Silica			2 wt % Nano-Silica				
		Theta	SR	SS	Theta	SR	SS	Theta	SR	SS		
		8.5	5.1	4.3	9.5	5.1	4.8	11.0	5.1	5.6		
		10.0	10.2	5.1	11.0	10.2	5.6	12.5	10.2	6.3		
		22.5	170.3	11.4	23.5	170.3	11.9	24.0	170.3	12.2		
		28.0	340.6	14.2	29.0	340.6	14.7	29.5	340.6	15.0		
		32.5	510.9	16.5	34.0	510.9	17.3	36.5	510.9	18.5		
		57.0	1021.8	28.9	60.0	1021.8	30.5	62.0	1021.8	31.5		

Table 4
The rheological properties of 10 wt % bentonite + 3.5 wt % NaCl after the addition of different concentrations of nano-CuO

0.2 wt % Nano-CuO				0.4 wt % Nano-CuO			0.6 wt % Nano-CuO			0.8 wt % Nano-CuO		
rpm	Theta	SR	SS	Tet	SR	SS	Theta	SR	SS	Theta	SR	SS
3.0	5.8	5.1	2.9	5.5	5.1	2.8	5.8	5.1	2.9	6.4	5.1	3.2
6.0	10.2	10.2	5.2	9.5	10.2	4.8	10.2	10.2	5.2	10.5	10.2	5.3
100.0	19.0	170.3	9.6	19.5	170.3	9.9	19.0	170.3	9.6	20.4	170.3	10.4
200.0	25.0	340.6	12.7	25.5	340.6	12.9	25.0	340.6	12.7	27.2	340.6	13.8
300.0	31.5	510.9	16.0	30.3	510.9	15.4	32.4	510.9	16.4	35.0	510.9	17.8
600.0	48.0	1021.8	24.4	47.0	1021.8	23.9	50.3	1021.8	25.5	53.5	1021.8	27.2
		1 wt % Nano-CuO			1.5 wt % Nano-CuO			2 wt % Nano-CuO				
		Theta	SR	SS	Theta	SR	SS	Theta	SR	SS		

7.0	5.1	3.6	7.3	5.1	3.7	8.0	5.1	4.1
11.0	10.2	5.6	12.5	10.2	6.3	13.0	10.2	6.6
21.2	170.3	10.8	24.0	170.3	12.2	27.0	170.3	13.7
28.0	340.6	14.2	33.0	340.6	16.7	36.0	340.6	18.3
37.2	510.9	18.9	43.0	510.9	21.8	48.0	510.9	24.4
55.2	1021.8	28.0	61.2	1021.8	31.1	65.0	1021.8	33.0

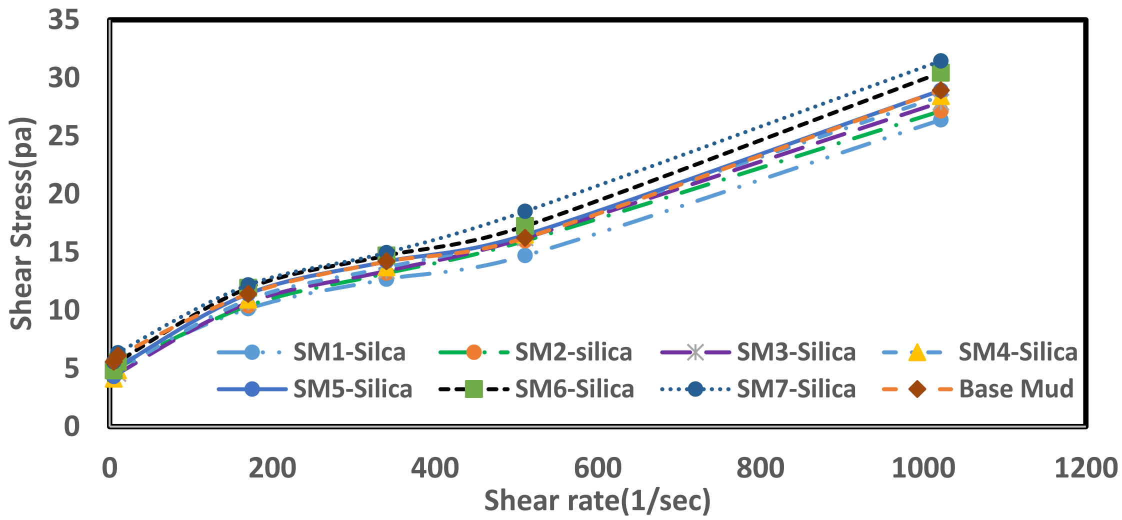

Figure 2

The rheology of the drilling mud containing silicon oxide nanoparticles at different concentrations.

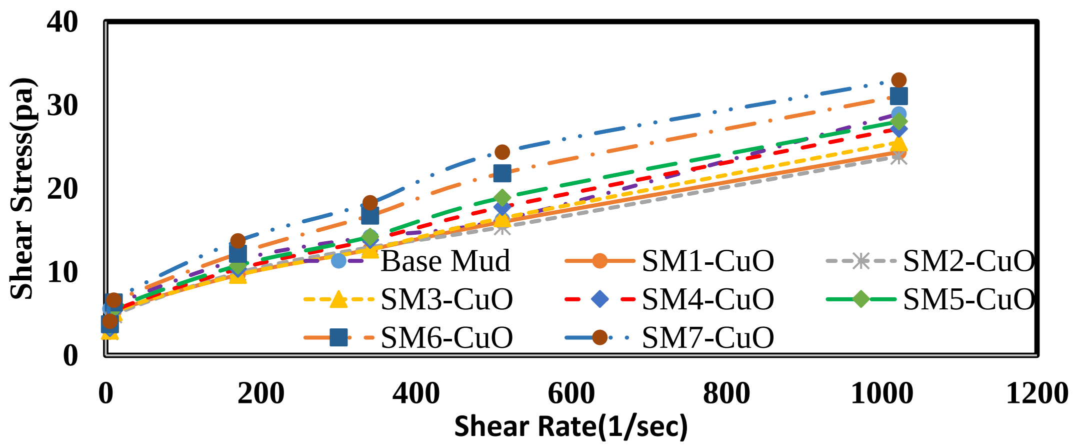

Figure 3

The rheological diagram of the drilling mud containing copper oxide nanoparticles at different concentrations.

3.2. Effect of nanoparticles on filtration properties under different pressures and temperatures

In the last phase, the values of drilling fluid filtration under low pressure–low temperature (LP–LT) and high temperature–high pressure (HP–HT) conditions were measured. To extend the usage of an additive to both LP–LT and HP–HT conditions, we should also check the stability of the additive at high pressures and temperatures. The rheological properties of the drilling mud were measured since the influence of each additive for each purpose on the other properties must always be measured. However, as the viscosity of the drilling mud increases, the rate of the fluid filter decreases. Considering this limiting factor, this high viscosity value increases the frictional pressure drop in the drilling track. As aforementioned, the rheological properties decrease at low concentrations of NPs and then improve at high concentrations (see Table 5 and Figures 4–6). The results in Table 5 show the amount of drilling mud loss volume in the LP–LT device over 30 min for the drilling mud containing SiO_2 nanoparticles. As can be seen, the drop rate at all concentrations of the NPs is lower than the drop rate at the base fluid without the NPs, due to the decrease in mud cake permeability. At the concentrations of 0.2 and 0.4 wt %, the rate of drilling mud loss does not change much; therefore, those data are not mentioned. The measurements revealed that the thickness of the mud cake was 4.5 mm for the base fluid; in contrast, for the base fluid with a concentration of 2 wt % NPs with the lowest fluid drop (10.1 cc), the thickness of the mud cake was 1.8 mm. Figure 4 shows the cumulative volume change of the drilling mud drop in terms of the second root of time, which shows that these changes are linear. With increasing the concentration of NPs, the slope of the diagrams decreases, which indicates improved filtration properties of the drilling mud.

Table 5

The fluid loss properties (filtrate loss) of the drilling mud at different concentrations of NPs.

Time (min)	Base mud	SM 3	SM 5	SM 6	SM 7	SM 3	SM 5	SM 6	SM 7	SM 3	SM 5	SM 6	SM 7
		Nanosilica				Nano-ZnO				Nano-CuO			
1	2.6	2.5	2.3	2	1.8	2.5	2.3	2	1.8	2.5	2.3	2	1.8
3	5.1	4.8	4.5	3.8	3.5	4.8	4.5	3.8	3.5	4.8	4.5	3.8	3.5
5	6.7	6.3	5.8	4.8	4.2	6.3	5.8	4.8	4.2	6.3	5.8	4.8	4.2
7.5	8.4	7.9	7.4	6	5	7.9	7.4	6	5	7.9	7.4	6	5
10	9.6	9	8.5	7.2	6	9	8.5	7.2	6	9	8.5	7.2	6
15	12.1	11.5	10.5	9.1	7.5	11.5	10.5	9.1	7.5	11.5	10.5	9.1	7.5
20	14.4	13.5	12.2	10.2	8.7	13.5	12.2	10.2	8.7	13.5	12.2	10.2	8.7
25	15.8	15	13.6	11.5	9.5	15	13.6	11.5	9.5	15	13.6	11.5	9.5
30	17.7	16.2	14.5	12.5	10.1	16.2	14.5	12.5	10.1	16.2	14.5	12.5	10.1

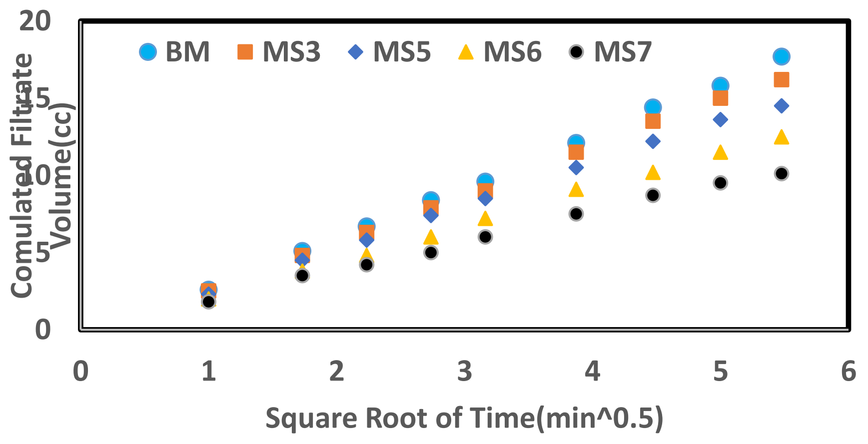

Figure 4

The filter graph loss changes in the drilling mud at different concentrations of silica oxide nanoparticles.

Similar to SiO_2 NPs, the data in Table 5 reveal that the volume of the drilling fluid loss in the LP–LT device over 30 min for the drilling mud containing CuO NPs is lower than the drop rate of the drilling fluid loss of the base fluid without the NPs, due to the decrease in mud cake permeability. At the concentrations of 0.2 and 0.4 wt %, the amount of drilling fluid loss experienced no change; therefore, its data were not mentioned. Moreover, Figure 5 shows the rate of change in the cumulative drop volume of drilling mud loss in terms of the square root of time. It demonstrates that these changes are linear, and the rate of drilling mud loss decreases with the concentration of CuO NPs in the drilling mud; the slope of the diagram has a decreasing trend, which indicates improving the filtration properties of the drilling mud. However, the rate of drilling fluid loss drops, and the slope of the changing trend of the drilling mud loss diagrams is lower compared to the fluids containing SiO_2 NPs, which implies the lower controlling ability of drilling mud filtration with CuO NPs than SiO_2 NPs.

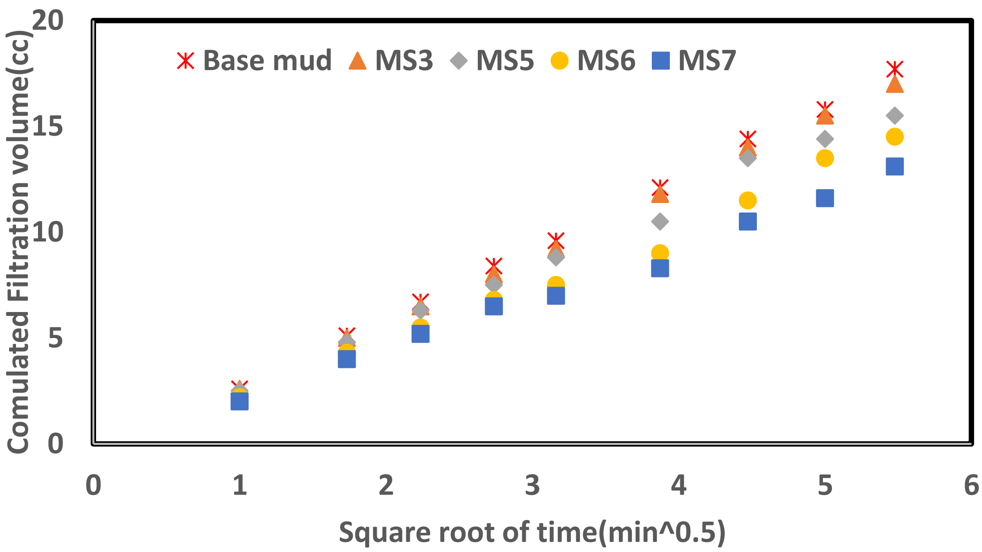

Figure 5

The changes in the filter graph loss of the drilling mud at different concentrations of CuO NPs.

Similar to CuO and SiO_2 NPs (see Table 5), the drop rate at all NP concentrations is lower than the drop rate of the base fluid without the NPs because of the decrease in mud cake permeability. At the concentrations of 0.2 and 0.4 wt %, the amount of drilling fluid loss experiences no significant change; therefore, its data are not mentioned. The thickness of the mud cake for the base fluid was 4.5 mm, while it was 2 mm at a nanoparticle concentration of 2 wt %, showing the lowest fluid filter drop rate for this type of NPs (11.1 cc). Moreover, Figure 6 reveals that these changes are linear, and the rate of drilling mud loss decreases with increasing the concentration of ZnO NPs in the drilling mud, which indicates an improvement in the filtration properties of the drilling mud. However, the rate of drilling fluid loss drops, and the slope of the changing trend of the drilling mud loss diagrams is higher compared to the fluid containing CuO NPs. This implies a better controlling ability of the filtration of the drilling mud with ZnO NPs than with CuO NPs.

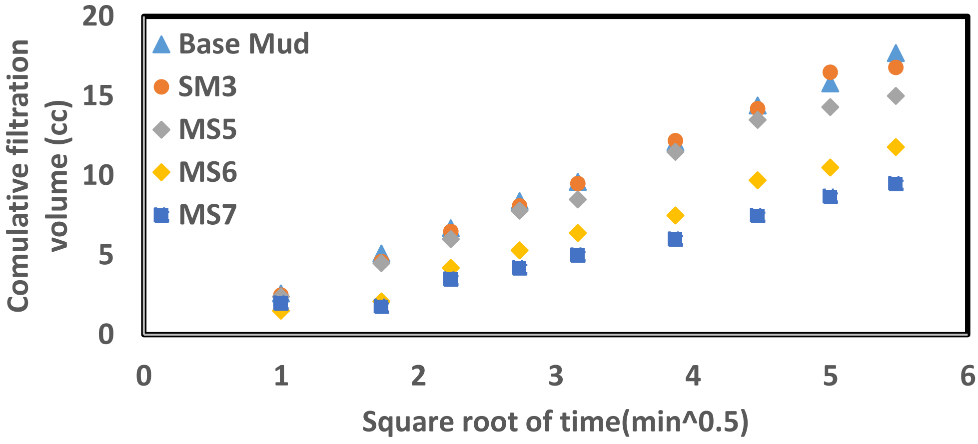

Figure 6

The changes in the filter graph loss of the drilling mud at different concentrations of ZnO NPs.

Furthermore, Figure 7 shows the final drilling fluid loss volume under low-temperature–low-pressure conditions for the drilling mud containing different NPs at different concentrations. Not only can all the used NPs introduce reasonable control over the fluid filtration behavior, but their controlling capability can also be enhanced by increasing the concentration of NPs. The results reveal the better performance of SiO_2 NPs than the other NPs for all the examined concentrations, probably due to the surface charge, type, or size of silica nanoparticles. In contrast, Figure 8 shows the filtration rate of the drilling mud containing different NPs under high-temperature–high-pressure conditions. At a pressure drop of 500 psi and a temperature of 90 °C, the overall drop rate of the drilling mud loss is much higher than the low-pressure–low-temperature conditions, which indicates the better controlling capability of NPs under the HP–HT conditions. The other important point is that under HP–HT conditions and a low concentration of 0.6 wt %, CuO NPs show low and poor performance, and the overall drop of the drilling mud loss of drilling mud is more significant than the base fluid.

Further, under HP–HT conditions, silicon oxide NPs perform the best. Finally, the SEM images of the mud cake surface for the base mud and mud containing different NPs are captured and analyzed. The mud containing SiO_2 NPs and ZnO have a higher surface bonding than the base fluid and the mud containing CuO, indicating that the SiO_2 nanoparticles can modify the bentonite clay plates, which can directly boost the reduction in the mud cake permeability, consequently declining the drop of the drilling mud loss rate.

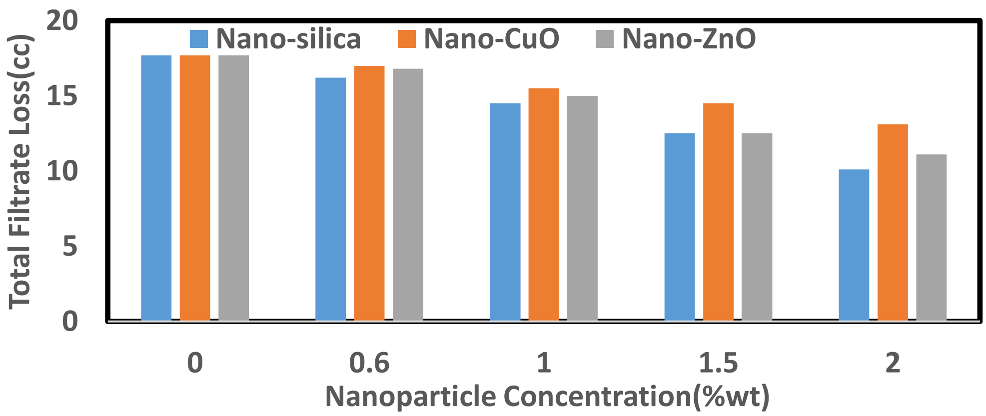

Figure 7

Comparing the smooth drop of the drilling fluid under low-temperature–low-pressure conditions for zinc oxide, copper oxide, and silicon oxide nanoparticles at different concentrations.

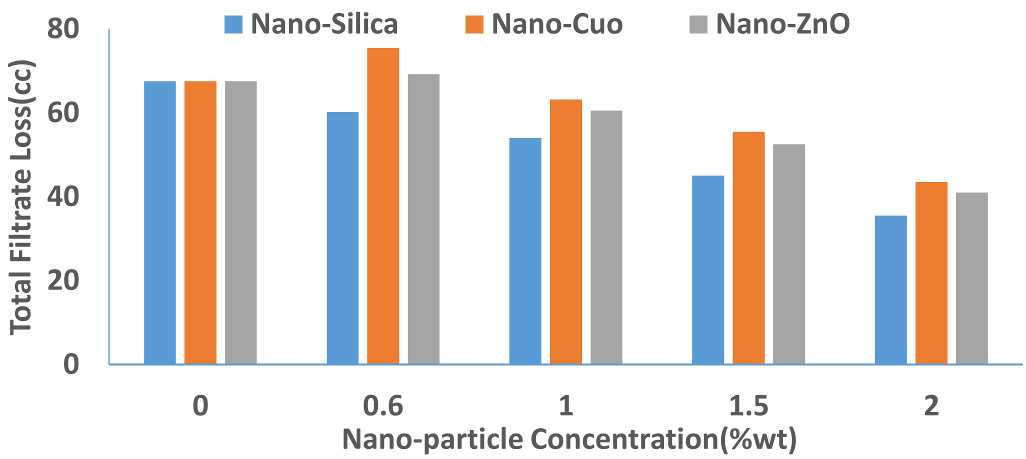

Figure 8

Comparing the smooth drop of the drilling fluid under high-pressure–high-temperature conditions for zinc oxide, copper oxide, and silicon oxide nanoparticles at different concentrations.

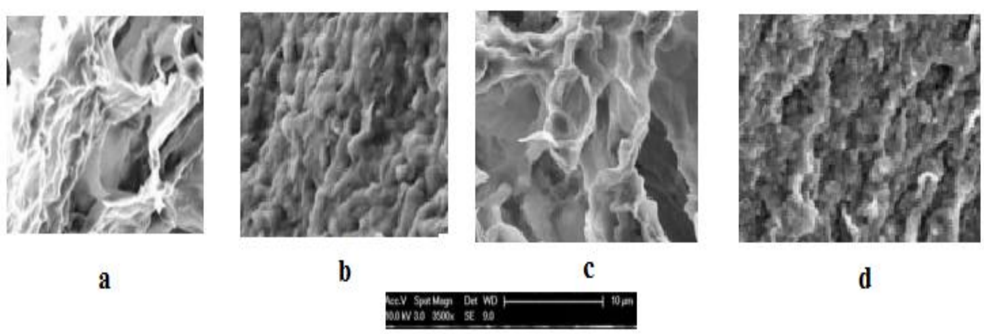

Figure 9

The SEM images of the surface of the drilling mud cake for (a) the base mud, (b) ZnO NPs, (c) CuO NPs, and (d) SiO_2 NPs.

4. Conclusions

The current work investigated the effects of different parameters of nanoparticles, including size, charge, concentration, and type, on the properties of drilling fluid, such as rheology, at high- and low-temperature filtration. The performed experiments and measurements revealed that:

- Using NPs with a concentration of about 2 wt % could increase the rheological properties of the drilling mud, such as viscosity, up to 20%.;
- The gelatinization properties of the drilling mud decreased at low concentrations of NPs might be due to the interaction of the surface charges of the clay plates with the NPs;
- The performance of SiO_2 and ZnO nanoparticles was higher in reducing the filtration rate compared to the CuO NPs;
- The rate of drilling mud loss drop under LT–LP conditions decreased from about 17.7 to 10 cm^3 for the mud containing silicon oxide NPs; in contrast, under high-pressure–high-temperature conditions, the drop rate of the drilling mud loss decreased from about 67 to

35 cm^3, indicating a sharp decrease in filter drop under high-pressure conditions without a significant effect on the mud rheology;

- Using 0.6 wt % of CuO NPs led to a more significant drop rate of the drilling fluid loss under HP–HT conditions.
- The SEM images of the cake filter surface revealed greater surface integrity of the mud cake in the presence of SiO_2 NPs.
- Using SiO_2 NPs with a concentration of 2 wt % could significantly reduce the thickness of the mud cake from 4.5 to 1.8 mm.

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