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Effectiveness of Alumina Nanoparticles in Improving the Rheological Properties of Water-Based Drilling Mud

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Highlights

- More than 90% of the well instability problems are caused by very low permeability properties, high pore pressure of clay minerals and high capacity of CEC (cationic exchange capacity).
- In this paper, the properties of rheological fluid and shale samples recovered by the alpha alumina and gamma alumina based drilling fluid were studied. Also to do the validation of filter cake and simulate the wellbore in this research, the CT scan has been used in the filter cake of the drilling fluid and took an image that this analysis has been done to simulate the stability of the wellbore for the sake of filter cake formation of Nano-drilling fluid system.
- Data of experimental in this study show that the rheological properties such as: YP, PV, and GEL have been kept constant without any changes. In filtration, the reduction of fluid loss in API condition in comparison with blank sample can be ignored. High pressure/high temperature fluid loss is less than the blank sample.

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Abstract

Wellbore stability is one of the challenges in the drilling industry. Shale formation is one of the most problematic rocks during drilling because the rock has very low permeability and tiny pores (nanometers). This study assesses the viability of the alumina nanoparticles (Al_2O_3) in water-based mud. The effectiveness of alumina nanoparticles as a mud additive in improving the rheological properties in water-based drilling mud is investigated. The alumina nanoparticles have specific chemical and physical properties, such as high compressive strength, high hardness, and high thermal conductivity. These properties improve the properties of water-based drilling mud, reduce filtration loss, and meet environmental regulations. The results of experimental data show that alumina nanoparticle improves rheological properties such as yield point gel strength (GEL 10 s, Gel 10 min) of water-based drilling that can be utilized to enhance the significant feature of drilling mud, particularly in rheology and filtration. Preliminary data demonstrated that alumina nanoparticles, a nano additive, possess proper properties like thermal stability, rheology enhancement, fluid loss control, and lubrication. It is likely to encounter shale formation plug and significant improvement formation pressure. In addition, alumina nanoparticles reduced 60% API/HPHT fluid loss by 60% compared to the blank sample. The most striking feature is that nanofluid improved shale integrity between 60% and 70% compared to the blank sample. Further, the experimental data of the CT scan show that the mud cakes formed by each of fluid samples, including nanoparticles containing alpha- and gamma-alumina base are more cohesive and cause an integrated filter cake on the well.

Keywords: Alumina Nanoparticle, CT Scan, Filtration Control, Rheological Properties, Water-based fluid.

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1. Introduction

Shale formations are known as minimum stability and maximum water susceptibleness, including clay and admixture of ions, and they are classified as mainly precarious drilling formations stone. Shale permeability can be neglected, and it contains tiny pores (on a nanometer scale) that do not significantly obstruct solid particles of drilling grains. Water absorption occurs when water-based drilling mud is disclosed to shale because the water activity of drilling fluid is not in equilibrium with the water activity of formation. Inhibitors like salts or other inhibitors could meet this requirement. Undeniably, clay swelling can be considered a consequence of tension and volume increment, and sequent formation tension is likely to diminish. Ultimately, it causes some problems like drill trapping and trapping of drilling pipe (Steve, 2011). Shales form approximately 75% of drilled formations. Central problems associated with good instability stem from low permeability properties, clay minerals' high pore pressure, and CEC's high capacity. Enlarged clay layers occur when they touch water. Eventually, wellbore instability can be caused, and the shale is broken into the well. Shale is sedimentary rocks when separated into thin layers. They are also rich in clay which can be shrilled, can be swollen, and absorb water. Some identified problems through drilling, such as instability of wellbore, washouts trapping of pipes, high temperature, and directional drilling, can happen.

Over 500 million dollars owing to shale instability incur, so guaranteeing well stability in shale by water-based mud is noticeable for the major environmental problem and oil-based mud expenses. Following up on this, shale sensitivity to water is the center of the matter. Shale hydration is directly related to resistance decrement and tiny particles. The majority of oil-based mud is utilized for shale drilling's main problems (Amanullah, Al-Tahini, 2009). Nanoparticles with high thermal stability and similarity to acidic gases like hydrogen sulfide and carbon dioxide are useful in deep drilling and geothermal drilling to solve technical problems in the environment caused by sour gas. Therefore, they are expected to be very economical and profitable by reducing the risks in the exploration and drilling of oil well reservoirs (Tookallo, 2018).

According to current studies, reducing shale swell and collapse can be regarded as porous surroundings entrance obstruction and shale permeability decrement by drilling mud, drilling fluid, and the reaction of shale. The nanoparticle reduction is due to particle size, ranging from 10 to 100 nm. In addition, essential costs incurred by maintenance and fluid transmission are decreased. In particular, these particle surfaces decrease the unbalance influence between fluids and solids; consequently, it results in suspension stability. When gas particle size dwindles, the thermal transmission surface becomes abundant, and floating particle thermal efficiency is raised by particle size reduction (Pour et al., 2012).

Drilling mud containing titanium oxide nanoparticles can block nano-sized pores in Chilean formations and decrease the permeability of shale, which reduces pressure transformation and improves well stability. Henceforth, the drilling mud containing nanoparticles makes a skinny and impermeable mud cake, which reduces the compression difference and torque and drag (Mijić et al., 2017). Nanoparticles can block the shale pores and inhibit water flow into the shale. Shale pores entrance is cut off, and drilling mud crossing is dampened. Drilling mud can be designed by adding nanoparticles to a nanofluid (Pham, Nguyen, 2014). With a combination of nanotechnology and drilling mud technology, nanomaterials can significantly increase heat resistance, control waste, have no environmental pollution, and better transport particles in the drilling mud system, improving drilling at high temperatures and pressures in special tanks. After adding nanoparticles, the basic fluid properties such as viscosity, smooth control, thermal stability, and lubrication can be designed to the optimal level, which raises the drilling mud properties (Kasiralvalad, 2014; Petar. Et al., 2019). The effective presence and the influence of adding nanoparticles to the water-based drilling mud and its impact on water penetration into stiff and soft shale indicate that water penetration into shale will be reduced mostly by nanoparticles (Jung et al., 2011). The characteristics of soft shales during drilling can be categorized as the adhesion of mud to the drill, mud rings, well narrowing, while hard shales cause scaling, shedding, and lubrication. Nanoparticles have been considered an alternative to polymer additives, and the nonmineral properties of nanoparticles are expected to stabilize drilling mud even at high temperatures and high pressures occurring in deep well conditions.

The experimental data on iron oxide nanoparticles investigation with bentonite fluid at high temperature and pressure showed the role of iron oxide nanoparticles in temperature stability in bentonite fluid. The addition of iron oxide nanoparticles increased viscosity and inversion point (YP) and reduced the amount of smoothness and its stability at high temperatures. Research shows that nanofluids have good properties for improving drilling fluids. These improvements include increased heat transfer, increased fluid stability, corrosion control, reduced friction, reduced pressure, reduced clogging in the flow path, decreased pump power consumption, and reduced overall device size (Amarfio, Abdulkadir 2016; Hosseini et al., 2016).

The multipurpose nano additives help the well stability and reduce the decrease in the water-based fluid of formations. It is estimated that millions of dollars are spent for the sake of well instability. Indeed, the mildew is exposed to shale formations. Silica nanoparticles are used as multi mud additives to reduce filter loss, lubricate the mud, prevent shale swelling, and stabilize the rheological properties. These nanoparticles in different concentrations obstruct shale pores (Alihosseini et al., 2016; Fazelabdolabadi et al., 2015). Laboratory information on viscosity, inversion point, thermal conductivity, and smoothing value was obtained, and thermal conductivity was measured based on time and the effects of temperature and the amount of carbon nanotubes (CNT) on the parameters. Moreover, at a temperature of 50 °C a significant improvement of 23.2% was achieved, and using oil-based fluid with CNT (1% by volume) at a temperature of 50 °C reached an improvement of 43.3%; the rheological results also improved (Andres et al., 2008).

The laboratory studies on the effects of Fe_4O_3 on the rheological properties of the water-based mud at various temperatures indicate that the viscosity and controlling water are kept during the operation. Accordingly, Fe_4O_3 nanoparticles can keep the tension shear of fluids more than the shear stress to some extent as the temperature (Nasser et al., 2013; Dehghani et al., 2019). The nanofluid retained all the desired rheological properties at high temperatures and pressures. Therefore, the possibility of using it in deep wells increased. High temperatures and pressures are quite common (Contreras et al., 2014; Bolis et al., 1998; Paglia et al., 2004). The multi-walled CNTs in water-based drilling mud are used to improve the rheological properties of the drilling mud and the shale stability. Research shows that these nanoparticles can help decrease fluid wasting. Therefore, they contribute to economizing costs. Using nanoparticles in drilling mud can improve performance and reduce drilling mud waste. The effect of nanoparticles on the drilling mud is to prevent wastage at low pressures and temperatures with a filter press. According to this research, these nanoparticles can reduce fluid waste and thus save costs (Mao et al., 2015).

Analyzing the effect of Al_2O_3 nanoparticles on the rheological properties of the water-based drilling mud illustrates that the presence of Al_2O_3 nanoparticles can stabilize the rheological properties at different temperatures. Al_2O_3 nanoparticles can keep the shear tension of the drilling mud when the temperature is increased (Contreras et al., 2014; Razavi et al., 2016). The distribution of aluminum oxide through the drilling mud can improve thermal stability (Kang et al., 2016; Smith et al., 2018). There are two major types of alumina groups called alpha and gamma. Nanoparticles can obstruct the shale pores and block the water flow into the shale. Nanoparticles can properly block the entrance of shale pores and prevent crossing the drilling mud. The alpha-alumina is stiffer, and its surface area is less known as corundum. Moreover, the alpha type holds a cubic structure. Thus, it includes fewer OH groups, and this factor causes their pH difference (Mahmoud et al., 2016; Hasanzadeh et al., 2020). The more porous alumina is known as gamma with a high surface area and thermal conduction. The gamma type holds a rhombohedra structure.

This study presents the properties of the rheological fluid and shale samples recovered by the alpha- and gamma-alumina-based drilling mud. Moreover, to validate the filter cake and simulate the wellbore, this work used the CT scan in the mud cake of the drilling mud and took an image so as to simulate the stability of the wellbore for the sake of filter cake formation of nano drilling mud systems.

2. Experimental procedures

2.1. Materials, methods, and equipment

Tables 1 and 2 indicate the required materials and equipment list and their percentage combination according to the standard; Sigma Company has provided the necessary chemicals.

Table 1

The analysis and the percentage combination of nano alumina.

Name of nanoparticle	Alpha-alumina	Gamma-alumina

Characteristics analysis		
Density	3.97 gr /m^3	3.89 gr/m^3
Purity	99.9%	99%
APS	30 nm	20 nm
SSA	>100 $m^{2/}$gr	< 200 m^2/gr
Appearance	White powder	White powder
Morphology	Nearly spherical	Nearly spherical

Table 2
The list of the required equipment.

Row	Company	Application	Device
1	Hamilton	Preparing the drilling muds	Five-blade stirrer
2	FANN 35	Measuring the amount of fluid viscosity	Viscometer
3	OFITE	Under the pressure of CO_2	Filtration of high pressure and high temperature
4	FANN	At room temperature and pressure of 100 psi	API high-pressure filtration device
5	3003 PTS	The detection analysis of components using X-ray	XRD
6	Zeiss DSM-960A	Spectrometry and 3D imaging from a delicate structure	SEM
7	Multi-slice CT scan	CT Scan simulator	CT Scan

2.2. Methodology

In the laboratory part, the effect of the common additives is on the micro-measurement of the rheological properties, wastefulness, and the strength of the shale sample. Then, these experiments have been done in the presence of alumina nanoparticles to specify the affectivity of these particles on drilling mud properties. Each component was stirred for 10 min in water as the base fluid at 11000 rpm. The nano additive was separately added to the fluid in a powder form. After final adding, the fluid was stirred at a high speed for 20 min so that a completely homogeneous combination was obtained. After measuring the properties, the fluids were put for 4 h in the hot roll at a temperature of 250 °C. Table 3 presents the formulations related to each of the water-based drilling muds.

Table 3
The formulations of the water-based drilling mud systems.

Additives	**Application/ description**	**Unit**	**Blank sample**	**MUD #1**	**MUD #2**	**MUD #3**	**MUD #4**
			Concentration	**Concentration**	**Concentration**	**Concentration**	**Concentration**
Drill Water	Base Fluid	cc	335.4	336.5	336.5	336.5	336.5
Nano-Alpha Alumina	Nano-additive	lb/bbl	-	0.35	0.7	-	-
Nano-Gama alumina	Nano-additive	lb/bbl	-	-	-	0.35	0.7

SODIUM CHLORIDE AC	Weighting agent	lb/bbl	25.2	25.2	25.1	25.2	25.1
KCL R-UPG	Weighting agent/Inhibitor	lb/bbl	0	0	0	0	0
CAUSTIC SODA	pH control agent	lb/bbl	pH 9.5–10	pH 9.5–10	pH 9.5–10	pH 9.5–10	pH 9.5–10
SODA ASH	Hardness control agent	lb/bbl	0.2	0.2	0.2	0.2	0.2
AMYLOSE B	Drilling starch/Fluid loss control agent	lb/bbl	5	5	5	5	5
PAC LV-TG	Fluid loss control agent	lb/bbl	1	1	1	1	1
BIO-XCD	XC-Polymer/Viscosifier	lb/bbl	1	1	1	1	1
BIOCIDE MP	Biocide/Bactericide	lb/bbl	a few	a few	a few	a few	a few

2.3. Analyzing the rheological properties

Viscometer FANN35 measured the rheological properties of each of the fluids, once after a four-hour rotation in the roller oven and once after that at a temperature of 120 °C in the final stage. Next, the numbers related to the apparent and plastic viscosity and the strain point were calculated.

$$AV = RPM600/2 \tag{1}$$
$$PV = RPM600 - RPM300 \tag{2}$$
$$YP = RPM300 - PV \tag{3}$$

where *AV* is the apparent viscosity, *PV* indicates the plastic viscosity, and *YP* denotes the yield point.

Table 4 tabulates the rheological properties of each water-based drilling mud (before and after being put in the roller oven).

Table 4
The rheological properties of each water-based drilling mud (before and after being put in the roller oven).

Measured parameters	**Unit**	**Blank sample**		**#1**		**#2**		**#3**		**#4**	
		BHR	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
		120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F
MW	PCF	64		63		63		64		64	
AV		15	11.5	15.5	19	16	19.5	17	11	15	11.5
RPM 600		30	23	31	38	32	39	34	22	30	23
RPM 300		21	18	23	26	24	28	23	16	21	17
PV	cP	9	5	8	12	8	11	11	8	9	5
YP	lb/(100 ft^2)	12	13	15	16	16	17	12	8	11	12

RPM 200		17	14	19	21	19	23	19	13	17	15
RPM 100		12	11	13	16	14	17	13	10	12	11
RPM 6		4	4	5	4	5	5	4	3	4	3
RPM 3		3	3	4	3	4	4	3	2	3	2
Gel 10 s	lb/(100 ft^2)	4	3	5	4	6	5	5	2	4	2
Gel 10 min	lb/(100 ft^2)	5	4	7	6	7	6	6	3	5	3
pH		9.8	8.4	9.8	9.2	9.6	9.3	9.8	8.2	9.7	8.2
API-FL	cc/(30 min)	-	5.8	-	5.6	-	5.5	-	5.2	-	5.6
Filter cake thickness	in/32	-	1	-	1	-	1	-	1	-	1
HPHT FL	cc/(30 min)	-	30	-	18	-	16	-	19.2	-	17.8
Filter cake thickness	in/32	-	1	-	2	-	2	-	2	-	2
Foam	cc	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Settlement	cc	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Shale recovery	%	-	67.1	-	31.7	-	26.3	-	64.7	-	72.1

2.4. Investigating filtration properties (API/HPHT)

The filtration properties of the designed fluids were measured in two different phases: API-FL, measuring the volume of filtrated water at room temperature and pressure of 1000 psi, based on the API13B standard, and HPHT-FL, measuring the volume of filtrated water at a temperature of 250 °F (the temperature of the roller oven) and pressure of 5000 psi (high-temperature high-pressure), based on the API13B standard B.

The experiments of both parts are performed within 30 min, and the volume of the water removed from the fluids affected by temperature and pressure is reported as the filtration loss. It should be pointed out that the volume of fluid exiting from the high-temperature and high-pressure filtration device should become two times more because the cross section of the paper is half of the paper of the API filtration device. Figure 1 shows the X-ray diffraction (XRD) and the high-pressure and high-temperature filtration device of OFITE (with a tank volume of 175 cc under the pressure of CO_2 and a 25-inch filter paper).

a) b)

Figure 1

a) The XRD and b) the high-pressure and high-temperature (HPHT) filtration device.

3. Results and discussion

3.1. The mineralogical results of shale

According to Figure 2, the analysis of XRD has been done on shale samples to measure the amount of leading minerals. X-ray diffraction is an essential tool for the mineralogical analysis of shales. It is an analytical technique primarily used for a crystalline material to identify its phase and provide unit cell dimensions. It is most widely used to identify unknown crystalline materials (e.g., minerals and inorganic compounds). XRD measures the intensities of a reflected area from a small area, and from the results obtained, the atomic-level spacing of the crystal can be calculated, helping in understanding the crystalline structure of substances. Table 5 demonstrates the quality and quantity analysis of the shale sample. It also indicates that the shale samples used in these experiments have included more than 60% of montmorillonite and are very active. Notably, they become hydrated in the drilling water pure from any preventing additive in less than a minute. The remaining 5% of the minerals include dolomite, calcite, and quartz.

Table 5

The qualitative and quantitative shale sample analysis.

The percentage of combination	Formulation	Phase formation
65	Ca0.2(Al,Mg)2Si4O10(OH)2, xH_2O	Mont (13-0135)
13	SiO_2	Quartz (33-1161)
12	SiO_2	Montmorillonite (39-1425)
5	$CaCO_3$	Calcite (05-0586)
4	$CaMg(CO_3)_2$	Velomite (36-0426)
1	$CaSO_4$, $2H_2O$	Gypsum (33-0311)

Figure 3 displays the scanning electron microscopy (SEM) analysis. The device has a very high separation limit of accessible solid samples because of using electrons, and it can take images from surfaces with a magnitude of 10 to 500000, equaling the separation power of less than 1 to 20 nm depending on the sample. These findings have been obtained from the (unrecovered) shale montmorillonite sample. As indicated, this image displays much porosity in the montmorillonite sample. In the SEM images of the rock samples such as shales, the porosity is indicated via a hollow black environment. Figure 3 presents the image of the shale samples containing black hollow areas, which confirms highly porous media.

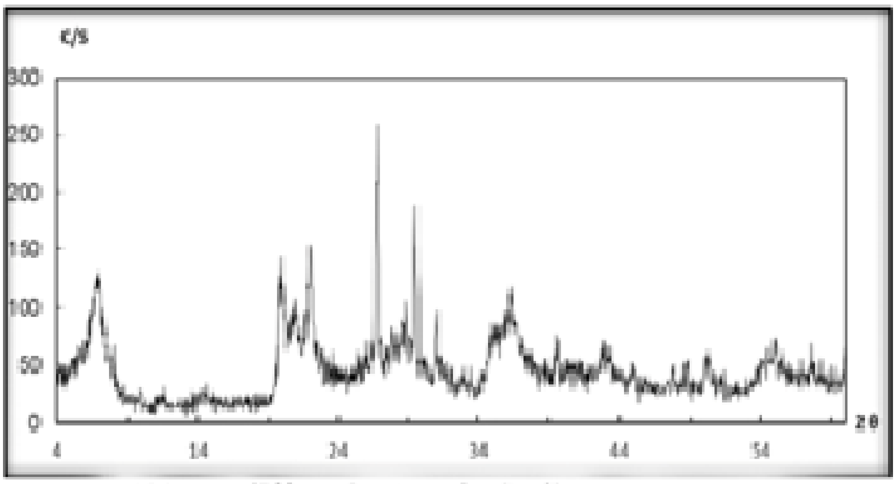

Figure 2
Analysis of the XRD of the shale sample.

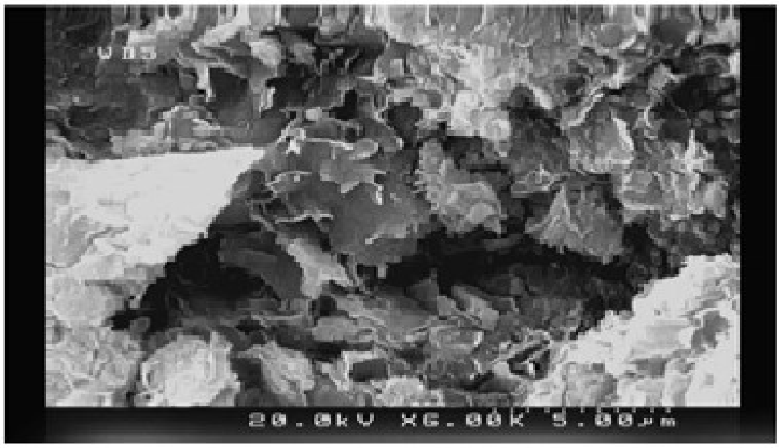

Figure 3

The SEM analysis of the shale montmorillonite sample.

3.2. The rheological properties of the water-based nano mud

Figures 4–6 present the comparison of rheological properties. Comparing the rheological properties of the water-based drilling mud (PV) in Figure 4 shows that the nano drilling mud system No. 4 (MUD#4), compared with the blank sample, has kept the PV constant. In another nano drilling mud system, it is observed that the PV has been more than that of the blank sample. It is noteworthy that the alpha-alumina sample increases the rheological properties compared to the blank sample, according to Table 2. The nano drilling mud system with gamma-alumina has kept the rheological properties instant. By comparing the pH, it can be concluded that the nano drilling mud system with an alumina base acts as a buffer and prevents the swift loss of pH.

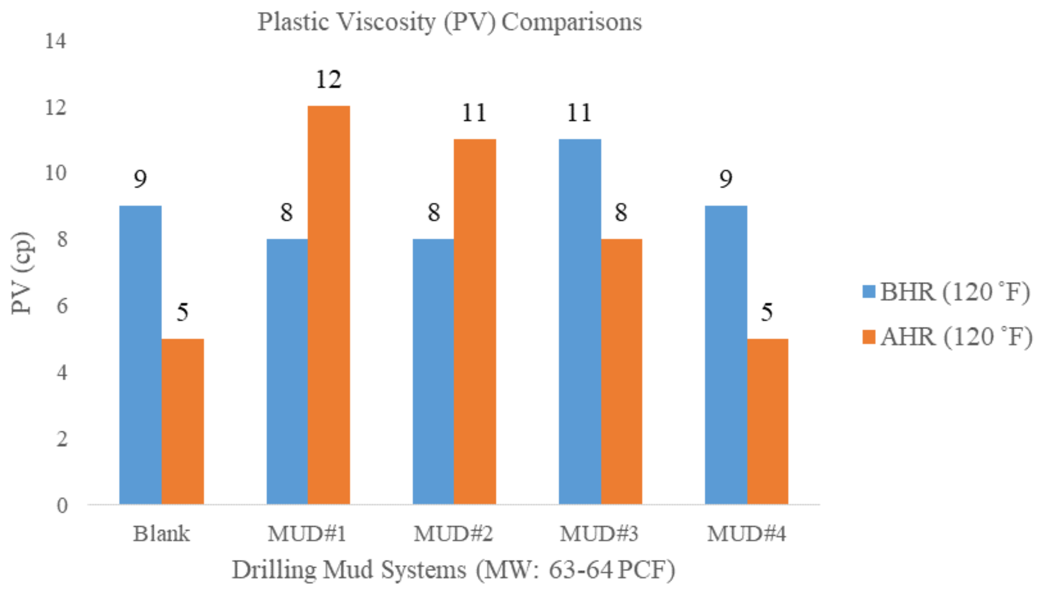

Figure 4
Plastic viscosity properties of the water-based drilling mud.

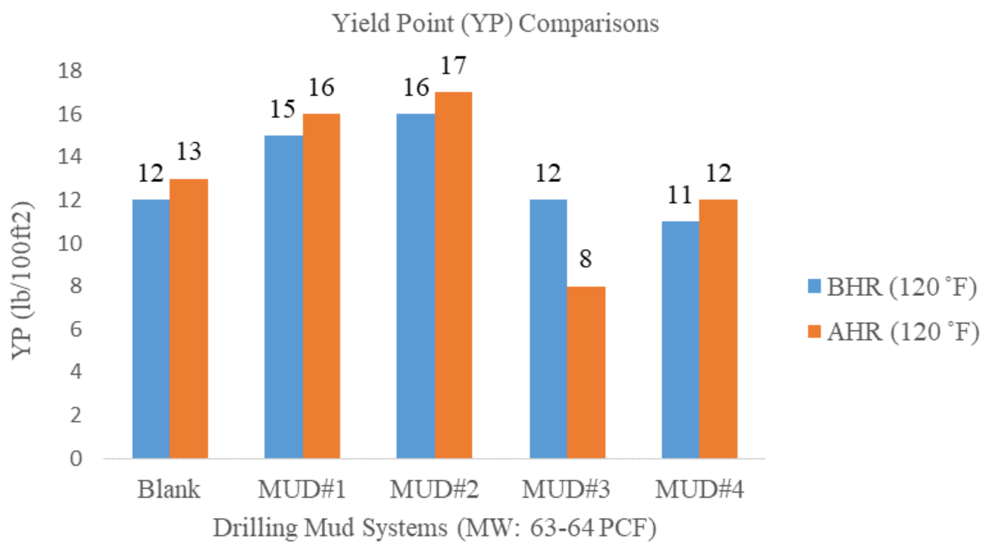

Figure 5
Rheological properties of the water-based drilling mud.

Comparing the rheological properties of the water-based drilling mud (RPM6) in Figure 6 reveals that the nano drilling mud system No. 4 (MUD#4) has been able to keep the amount of RPM6 constant. However, it should be evaluated in clay/shale formation for cleaning up the well. In the other nano drilling mud systems, it is observed that the amount of the RPM6 has been more than that of the blank sample. It is noteworthy that the nano drilling mud systems with an alpha-alumina base cause an increase in the rheological properties compared to the control sample, according to Table 4.

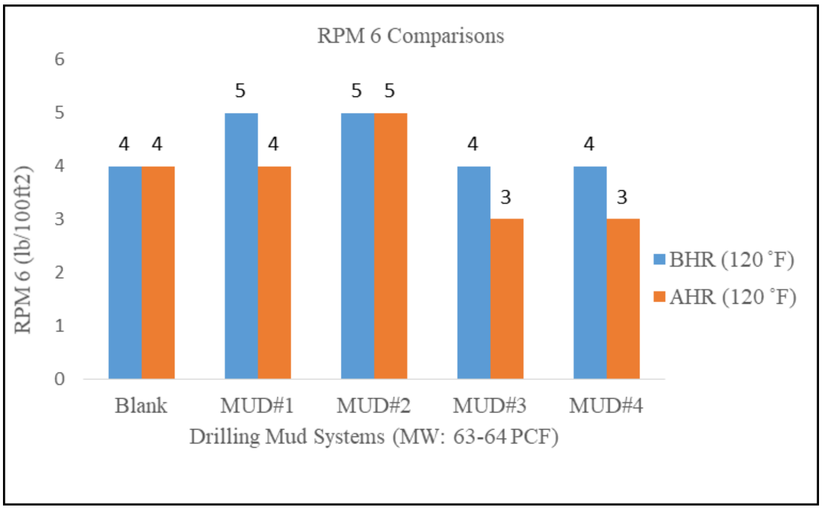

Figure 6

Comparing the rheological properties (RPM6) of the water-based drilling mud.

The nano drilling mud systems with a gamma-alumina base have kept the rheological properties intact. Comparing the rheological properties of the water-based drilling mud (Gel 10 s) in Figure 7 shows that nano drilling mud system No. 4 (MUD#4) has been able to keep the Gel 10 s parameter constant. In the other nano drilling mud systems, it is observed that the amount of the Gel 10 s has been more than that of the blank sample. It is noteworthy that the nano drilling mud systems with an alpha-alumina base cause an increase in rheological properties compared to the blank samples, according to the data in Table 3. The nano drilling mud system with a gamma-alumina base has kept the rheological properties constant. Comparing the rheological properties of the water-based drilling mud (Gel 10 min) in Figure 8 reveals that nano drilling mud systems fluid No. 4 (MUD#4) has been able to keep the amount of Gel 10 min constant. In the other nano drilling mud systems, it is observed that the amount of the Gel 10 min has been more than that of the blank sample. It should be noted that the nano drilling mud systems with an alpha alumina base increase the rheological properties according to the data in Table 3. The nano drilling mud systems with a gamma-alumina base have kept the rheological properties unchanged.

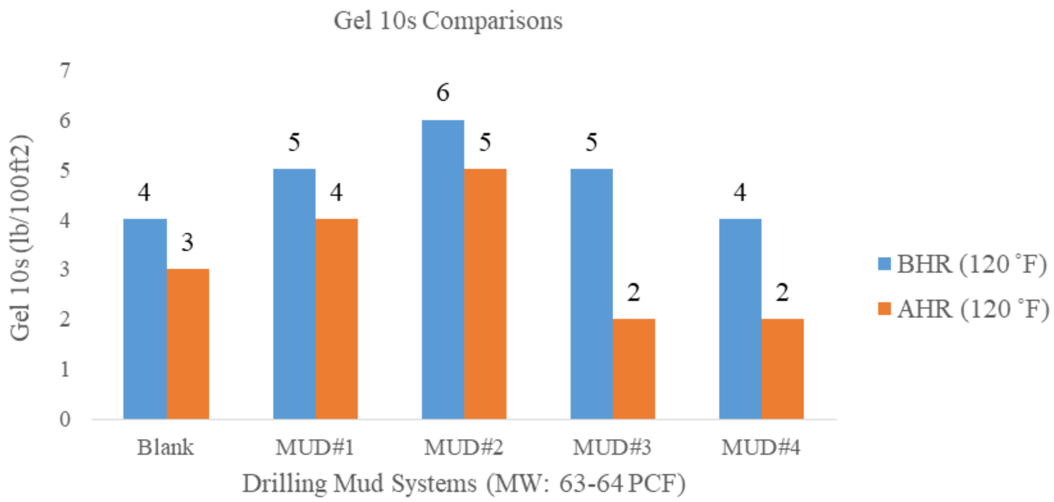

Figure 7

Comparing the rheological properties (Gel 10 s) of the water-based drilling mud.

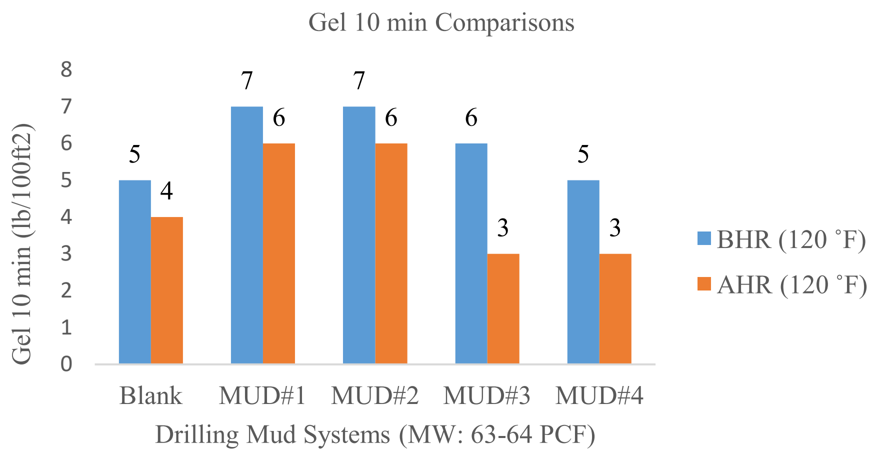

Figure 8

Comparing the rheological properties (Gel 10 min) of the water-based drilling mud.

Figure 9 depicts the filtration amount (API/HPHT). Table 3 and Figure 9 reveal that the reduction of filtrated water on API conditions can be ignored compared to the blank sample. Therefore, fluid loss at high temperatures and high pressures for the nano drilling mud systems is less than the blank sample.

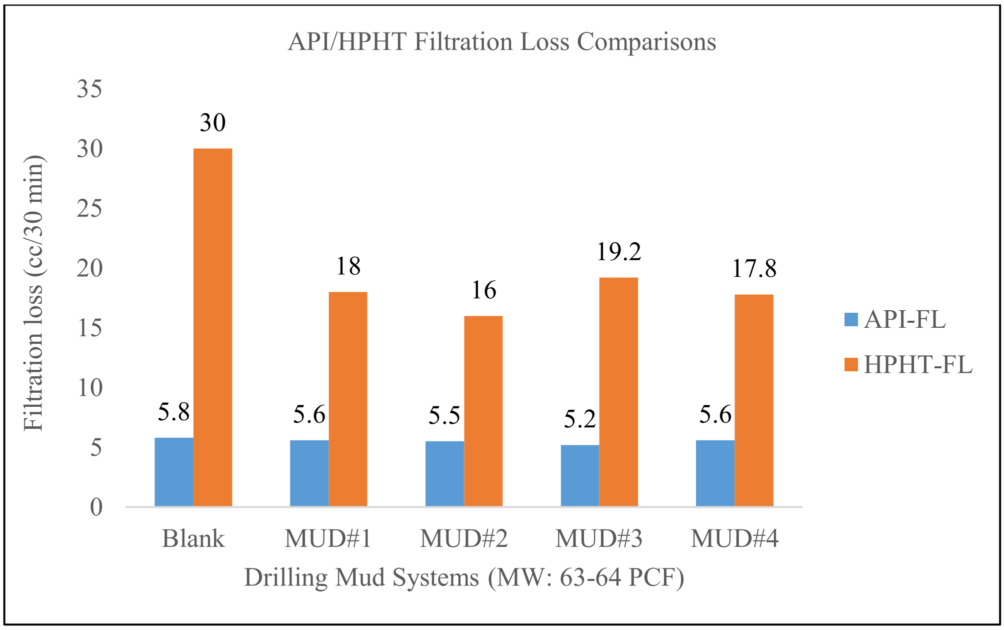

Figure 9

Comparing the filtrated water of the water-based drilling mud.

3.3. The CT scan simulator

In general, CT Scan is a type of SEM done within half an hour. In this type of radiology, X-ray and computer are used, and it takes a 300-degree schematic from the needed cross section; the CT scan images are exact. The CT scan has been used in the drilling mud cake filtration and took an image to validate the mud cake and simulate the wellbore in this research. This CT scan was provided by Imam Khomeini Hospital, Tehran, Iran (See Figure 10).

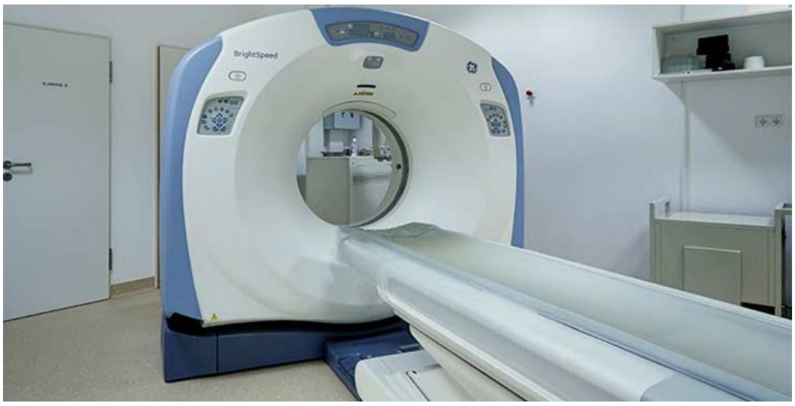

Figure 10

The CT scan of Imam Khomeini Hospital, Tehran, Iran.

3.4. The CT Scan Simulator Analysis for the investigation of the stability of the wall of the well

This analysis has been done to simulate the stability of the wellbore for the sake of mud filter cake formation of nano drilling mud systems. Figures 11–13 display the analysis of the CT scan from the mud filter cakes formed on the wellbore by each water-based drilling mud. Comparing Figures 11–13 reveals that the filter cakes formed by each nano drilling mud system with alpha-alumina and gamma-alumina has been more organized and stabilized than the blank sample and are subjected to forming a uniformed cake filter on the wellbore. Further, these filter cakes do not have shrinkage, collapse, or crumple.

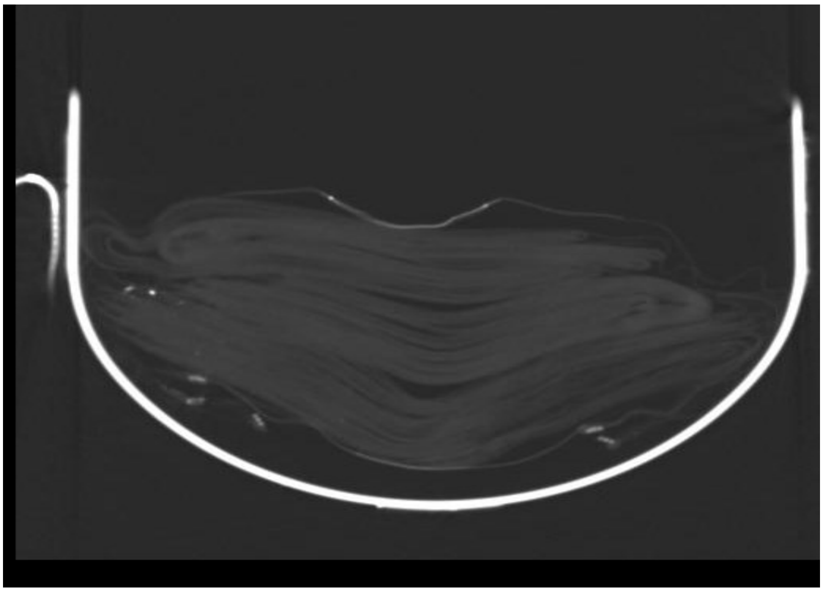

Figure 11

The CT scan image of a mud cake formed on the wall of the well by the water-based drilling nanofluid with a gamma-alumina base.

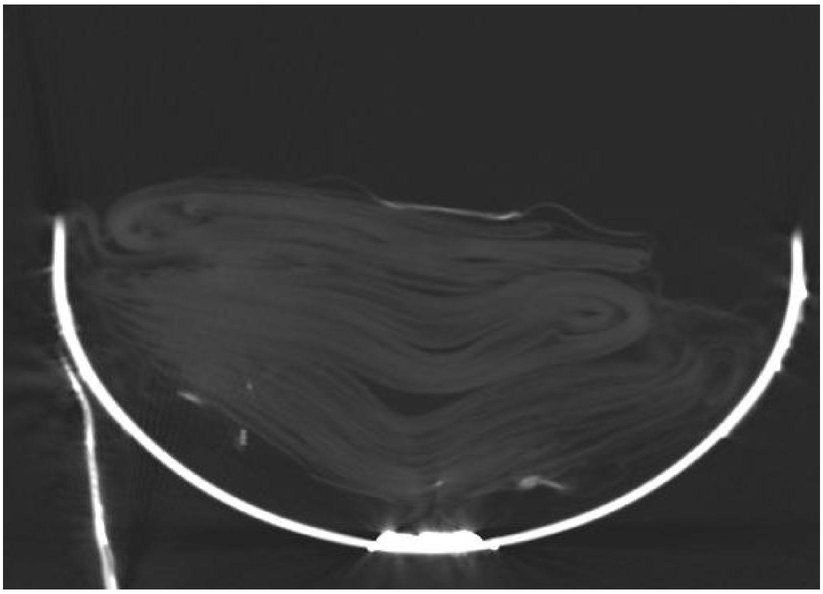

Figure 12

The CT scan image of a mud cake formed on the wall of the well by the water-based drilling nanofluid with an alpha-alumina base.

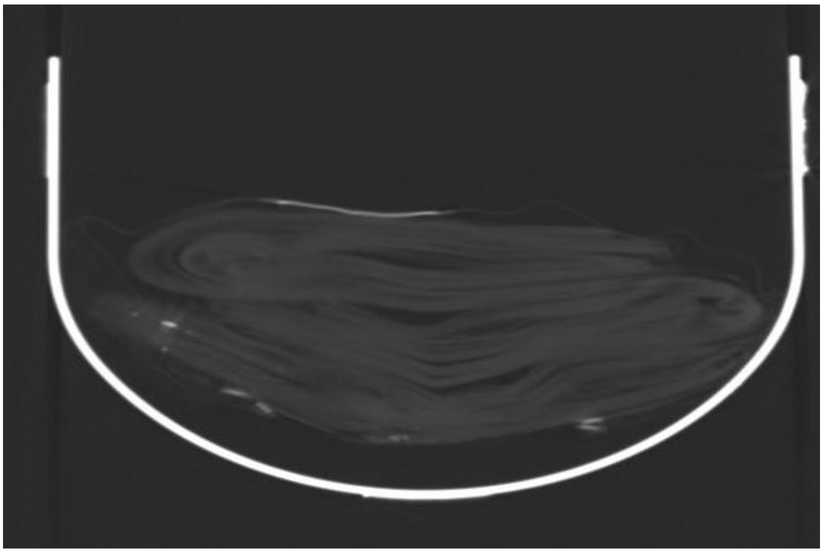

Figure 13

The CT scan image of a filter cake formed on the wall of the well by the control fluid sample.

4. Conclusions

This work investigated the effectiveness of alumina nanoparticles in improving the rheological properties of water-based drilling mud. The findings indicate that the nano drilling mud systems modified by alumina nanoparticles increase the PV compared to the blank sample. Alumina nanoparticles modify the nano drilling mud systems, improving the rheological properties of drilling nanofluids modified by gamma-alumina nanoparticles. Thus, the rheological properties such as the yield point, plastic viscosity, and GEL have been kept constant without any changes. In filtration, fluid loss reduction in API conditions compared to the blank sample can be ignored. High-pressure–high-temperature fluid loss is less than the blank sample. Indeed, it improves the AP/HPHT up to 60%. Moreover, the uniformity of shale has been improved by almost 60% to 70%. The CT scan analysis indicates that the mud cakes formed by nano drilling mud systems based on alpha- and gamma-alumina have better uniformity on the wellbore, and it is also more stabilized and organized than the blank sample.

According to the data obtained from the available analyses, the following results can be summarized:

- The use of nano alpha-alumina and nano gamma-alumina has filled the existing pores compared to the unrecovered shale rock sample, so the physical mechanism of pore plugging can be proved in the case of water-based drilling nanofluids with gamma-alumina and alpha-alumina.
- The use of nano alpha-alumina and nano gamma-alumina caused a surface coating on the shale rock compared to the control sample, so another physical mechanism called surface coating can be proved in the case of water-based drilling nanofluids with gamma-alumina and alpha-alumina.
- A sample of water-based drilling nanofluid with a gamma-alumina base with a concentration of 0.4 wt % (1.4 g) compared to nano-alpha alumina with the same percentage composition had a more significant effect on the inhibition of shale rock sample.
- The SEM analyses and images showed the presence of alpha-alumina and gamma-alumina nanoparticles as a layer on the surface of shale rock (surface coating).
- In addition to the physical mechanism of pore plugging, the XRD, CT scan, and SEM evaluation demonstrated another physical mechanism called surface coating for water-based drilling nanofluids with a gamma-alumina and alpha-alumina base as the shale barrier mechanisms.

Nomenclature

API	American Petroleum Institute
AV	Apparent viscosity
HTHP	High-temperature–high-pressure
PV	Plastic viscosity
SEM	Scanning electron microscopy
XRD	X-ray diffraction
YP	Yield point

References

Alihosseini, A., Hosseini, Sh., Ara Zadeh, Study of Compress Strength and Time Setting of Concrete by Additives of Silica Fume and Nanosilica, Asian Journal of Chemistry, Vol. 24, No. 2, 903 p., 2016.

Amanullah, M., Al-Tahini, A. M., Nano-technology-its Significance in Smart Fluid Development for Oil and Gas Field Application, in SPE Saudi Arabia Section Technical Symposium, Society of Petroleum Engineers,2009.

Amarfio, E. M., Abdulkadir, M., Effect of Al2o3 Nanoparticles on The Rheological Properties of Water-based Mud, Int. J. Sci. Eng. Appl, Vol.5, p.7–11, 2016.

Andres, M. Oleas, Collins, E., Martin, E., Mukul, M., Sharma, Entrance Pressure of Oil-based Mud into Shale: Effect of Shale, Water Activity, and Mud Properties, SPE 116364, Presentation at The SPE Annual Technical Conference and Exhibition, Denver, p.21–24, September 2008.

Bolis, V, Cerrato, G., Magnacca, G., Morterra, C., Surface Acidity of Metal Oxides, Combined Micro Calorimetric and IR-Spectroscopic Studies of Variously Dehydrated Systems, J. Therm. Acta, Vol.312, p.63–77,1998.

Contreras, O., Hareland, G., Husein, M., Nygaard, R., and Al-Saba, M., Application of In-house Prepared Nanoparticles as Filtration Control Additive to Reduce Formation Damage, in SPE International Symposium and Exhibition on Formation Damage Control, Society of Petroleum Engineers, 2014.

Contreras, O., Hareland, G., Husein, M., Nygaard, R., Al-Saba, M., Application of In-House Prepared Nanoparticles as Filtration Control Additive to Reduce Formation Damage, International Symposium and Exhibition on Formation Damage Control, Society of Petroleum Engineers, Louisiana, USA, 2014.

Dehghani, A.H., Pirouzfar, V., Alihosseini, A, Novel Nanocomposite Membranes-derived Poly (4-Methyl-1-Pentene)/Functionalized Titanium Dioxide to Improve The Gases Transport Properties and Separation Performance, Polymer Bulletin, p.1–23, 2019

Fazelabdolabadi, B., Khodadadi, A. A., and Sedaghatzadeh, M., Thermal and Rheological Properties Improvement of Drilling Mud Using Functionalized Carbon Nanotubes, Applied Nano Science, Vol.5, No. 6, p.651–659,2015.

Hassanzadeh, A, Alihosseini, A, Monajjemi, M, Sarm-Nazari, A., Nano-alumina based (Alpha and Gamma) Drilling fluid System to Stabilize High Reactive Shales, Petroleum Engineer Journal, Doi.Org/10.1016/J.Petlm .2020.07.003. 2020

Hosseini. S., Farahbod. F., Zargar. G., The Study of Effective of Added Aluminum Oxide Nanoparticles to The Drilling Mud: The Evaluation of Two Synthesis Methods, J Pet. Env. Bio., Vol.7, No.3., p.1–5, 2016.

Jung, Y., Barry, M., Lee, J. K., Tran, P., Soong, Y., Martello, D., and Chyu, M., April, Effect of Nanoparticle-Additives on The Rheological Properties of Clay-based Fluids at High Temperature and High Pressure, in AADE National Technical Conference and Exhibition, Houston, Tx: American Association of Drilling Engineers, p. 1–4, 2011.

Kang, Y., She. J., Zhang. H., You. L., Song. M., Strengthening Shale Wellbore with Silica Nanoparticles Drilling Mud, J. Pet., Vol.2, p.189–195, 2016.

Kasiralvalad, E., The Great Potential of Nanomaterials in Drilling and Drilling Mud Applications, International Journal of Nano Dimension, Vol.5, No.5, p.463, 2014

Mahmoud, O., Nasr-El-Din, H. A., Vryzas, Z., and Kelessidis, V. C., Nanoparticle-based Drilling Mud for Minimizing Formation Damage in HPHT Applications, in SPE International Conference and Exhibition on Formation Damage Control, Society of Petroleum Engineers, 2016,

Mao.H., Qiu Z., Shen. Z., Huang.W., Hydrophobic Associated Polymer-based Silica Nanoparticles Composite with Core-shell Structure as A Filtrate Reducer for Drilling Mud at Ultrahigh Temperature., J. Pet. Sci. Eng., Vol.129, p.1–14, 2015.

Mijić, P., Gaurina-Međimurec, N., and Pašić, B., The Influence of Sio2 and Tio2 Nanoparticles on The Properties of Water-based Mud, in ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering (p. V008t11a002-V008t11a002), American Society of Mechanical Engineers, 2017.

Nasser, J., Jesil, A., Mohiuddin, T., Al Ruqeshi, M., Devi, G., and Mohataram, S., Experimental Investigation of Drilling Mud Performance as Nanoparticles, World Journal of Nano Science and Engineering, Vol.3, 03, Vol.57, 2013.

Paglia, G., Buckley, C. E., Rohl, A. L., Hart. R.D., Winter, K., Studer, A. J., Hunte. B. A., Hanna. J.V., Boehmite Derived Γ-Alumina System. 1. Structural Evolution with Temperature, with The Identification and Structural Determination of a New Transition Phase, Γ'- Alumina, Chem. Mater, Vol. 16, p.220–236, 2004.

Petar, M., Nediljka, G.M., Borivoje, P., Igor, M., The Influence of Tio2 and Sio2 Nanoparticles on Filtration Properties of Drilling Muds, Mining-geology-Petroleum Engineering Bulletin, p.1–12, 2019.

Pham, H., Nguyen, Q. P., Effect of Silica Nanoparticles on Clay Swelling and Water Stability of Nanoparticle Dispersions, J. Of Nano Research, Vol.16, No. 1, p.2137, 2014.

Pour Faraj Qajari, M., Tabatabaeinejad, Sa, Emami, M., Experimental Investigation of The Effect of Nanoparticle Size and Concentration on The Shale Stability of an Iranian Reservoir, First International Oil Conference, Iran, (In Persian) 2012.

Razavi, O., Vajargah, A.K., Van Oort, E., Aldin, M., Govindarajan, S., Optimum Particle Size Distribution Design for Lost Circulation Control and Wellbore Strengthening, J. Nat. Gas Sci. Eng, Vol.35, p.836–850, 2016.

Smith, S. R., Rafati. R., Sharifi Haddad, A., Cooper, A., Hamidi, H., Application of Aluminum Oxide Nanoparticles to Enhance Rheological and Filtration Properties of Water-based Muds at HPHT Conditions, Colloids, and Surfaces A: Phys and Eng. Aspects., Vol. 537, p.361–371, 2018.

Steve Y., Graphene-based Material for Shale Stabilization and Method of Use. The U.S., Patent Application, No.13.877. 852, 2011.

Tookallo, K., Heidarian, J., Drilling Mud- Nano drilling Mud, Scholar Press,2018.