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ENHANCING LUBRICITY OF DRILLING FLUID USING NANOMATERIAL ADDITIVES

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Abstract

Poor lubricity and high friction between the drill string and wellbore/casing in directional and horizontal wells causes excessive torque and drag which is one of the most important issues in the drilling stage of oil wells. An important function of drilling fluids is the reduction of frictional forces between the drill string and wellbore/casing. In this research, the enhancement of the lubrication behaviour of a KCl polymer mud is fundamentally examined by adding different amounts of xanthan gum nanoparticles (XC polymer NPs), barite NPs, and lignite NPs.

The lubricity, rheology and filtration properties of the KCl polymer mud are measured at room temperature. KCl polymer mud with the best concentration, that yielded good results in improving coefficient of friction (COF), of XC polymer NPs, barite NPs, and lignite NPs was tested at two different temperatures 75°C, 100°C, and for 6 hours to investigate the effect of aging at high temperature towards KCl polymer mud with nanomaterials.

The nanomaterials show a reasonable reduction in the coefficient of friction. The coefficient of friction reduction percentage is increased with increasing nanomaterial weight, and the maximum value of the coefficient of friction reduction (more than 60%) is attained by adding 4 gm XC polymer NPs. Also, adding 4gm lignite NPs to KCl polymer mud caused 51.49% reduction in COF. While barite NPs has a limited friction reduction. Also, the results show an increase in the rheological properties (average viscosity, yield point, plastic viscosity, and gel strength) with increasing nanomaterial amounts except for the lignite NPs (mud thinner). By adding the best concentration of XC polymer NPs, and lignite NPs to KCl polymer mud, lubrication behavior was maintained unchanged after aging at 100°C, and for 6 hours.

Keywords*: KCl drilling fluid; lubricity; nanomaterials; thermal agent.*

1. Introduction

In the process of drilling, the friction, high torque, and drag, which result from the drill string and wellbore/casing interactions, causes over pullsin trip-outs, pipe stuck and even well loss. Furthermore, inside the casing, the energy that is formed from metal-metal surface contact between the drill string and casing causes casing wear [1].

When the contact surfaces have been immersed in a fluid, such as the drilling fluid, the force required to move the surfaces is usually reduced. Thus, the drilling fluid lubricates the drill string.

The coefficient of friction (CoF) provides a measure of the frictional forces encountered during the drilling stage of a well; a reduction in the CoF obtained by the drilling fluid is a function of the fluid composition [2].

Oil-based and synthetic-based drilling fluids generally produce lower friction and torque values than do water-based drilling fluids. However, these oil-based and synthetic-based drilling fluids are severely limited because of high costs and environmental concerns. As a solution, it appears that it would be advantageous to identify a water-based drilling fluid system with added lubricants that are environmentally friendly, cost-effective and lubricious similar to oil-based and synthetic-based drilling fluids [1].

Researchers have shown that using nanomaterials in drilling fluids enhanced the lubricity of the water-based drilling fluid system. Jahns investigated titanium and silica nanoparticles, which effectively reduced the friction factor of drilling fluids [3]. Taha & Lee studied the improvement in drilling fluid performance by using nanographene, and they reported an 80% torque reduction using 5% by volume of an engineered nano graphene product [4]. Krishnan *et al*. improved the lubricity of water-based drilling fluid by using a boron-based-nanomaterial-enhanced additive (PQCB), and they showed that the addition of 5% by volume of this additive resulted in an 80% torque reduction [5]. Caldarola *et al*. studied the effect of barite nanoparticles on the lubricity of a water-based drilling fluid, and they indicated a reduction in the coefficient of friction of more than 34 % with a concentration of 3% by weight of the chemically generated barite nanoparticles and a reduction of more than 15% with the mechanically generated nanoparticles [6]. Abdo & Al-Sharji showed the effect of using nano-sepiolite (NSP) on the lubricity of drilling fluids, and they determined that the friction was reduced by approximately 34 % at high-temperature high-pressure HTHP when a concentration of 4% by weight of NSP was used in a water-based lignosulfonate drilling fluid [7]. Al-Ogaili & Suripis evaluated the effect of the addition of TiO_2 nanoparticles on the rheology, filtration and lubricity characteristics of drilling fluid, and they reported an average torque reduction of 24% for amounts lower than 1g of TiO_2 in water-based mud [8]. Dhiman investigated the impact of different nanoparticles on various drilling fluid properties, including rheology, filtration, and lubricity [9]. Belayneh *et al*. showed the effect of titanium nitride (TiN), MoS_2 and graphene nanoparticles on the properties and performance of water-based drilling fluid [10-11].

A few researchers investigated the effect of nanoparticles on the lubricity behaviour of drilling fluid and more study should be conducted in this field. In this paper, experimental work has been conducted to minimize the lubricity coefficient of a KCl polymer mud using XC polymer nanoparticles, barite nanoparticles, and lignite nanoparticles.

2. Experimental work

2.1. Materials

2.1.1. Raw materials

The materials used in the preparation of the KCl polymer mud are bentonite, potassium chloride (KCl), caustic potash (KOH), low viscous polyanionic cellulose (PAC-LV), xanthan gum (XC-polymer), and barite. All the above materials were supplied from Oren Hydrocarbons Middle East Inc.

2.1.2. Nanomaterials

The nanomaterials used in this study are XC polymer, barite, and lignite with particle size 10-400, 112 and 63 nm, respectively.

2.2. Experiments

The effects of nanomaterials of different types and different amounts are explored in the KCl polymer mud, and the formulation of the KCl polymer mud is shown in Table 1.

Table 1. Formulation of drilling fluids

Material	Concentration	Primary function
Distilled water, mL	350	Liquid phase
Bentonite, gm/350 mL	8	Viscosity and filter cake
KCl, gm/350 mL	10	Potassium source
KOH, gm/350 mL	0.5	pH and potassium
PAC polymer, gm/350 mL	2	Fluid-loss control and encapsulation
XC polymer, gm/350 mL	1	Low-shear viscosity
Barite, gm/350 mL	100	Density

A blank sample of the KCl polymer mud is prepared by mixing the bentonite with distilled water for 20 minutes, and the suspension is aged in a sealed container for 16 hours. Then, the KCl, KOH, PAC polymer, XC polymer, and barite are added to the bentonite suspension, and each material is left to mix with the suspension for 2 minutes to ensure the dispersion of particles into the drilling fluid matrix. Finally, the whole mixture is mixed for 10 minutes. The nanomaterials with amounts of (0.2, 0.5, 1, 2 and 4 gm) are added to the blank sample of the KCl polymer mud and mixed for 10 minutes using a Hamilton Beach mixer. Then, the samples are further mixed using an ultrasonic bath for 10 minutes to ensure good dispersion of nanomaterials in the drilling fluid samples.

Before any testing, the drilling fluid samples are remixed for a period ranging from 5 to 15 minutes. The lubricating and rheological properties of the drilling fluid samples are determined at room temperature using an OFITE EP lubricity tester and Model 900 viscometer, respectively. The filtration properties are measured under conditions of 100 psi and room temperature using an OFITE filter press.

Finally, the stability of the KCl polymer mud under the conditions of temperature and circulation with the optimum amount of each type of nanomaterial is investigated using an OFITE roller oven. All experiments were repeated three times, and the average had been taken to ensure the accuracy of the results

3. Results and discussion

3.1. Clay characterization analysis

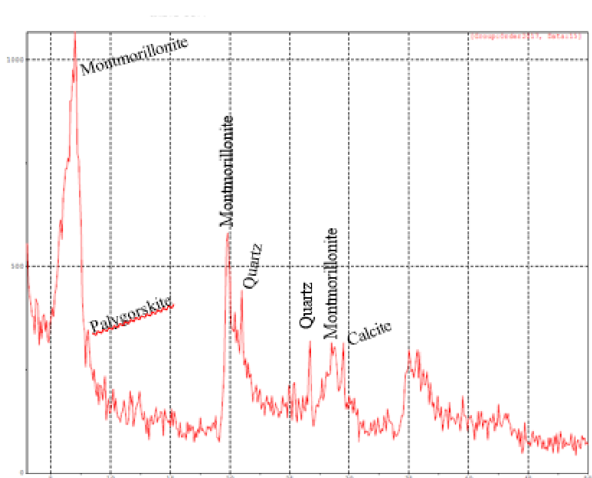
3.1.1. X-Ray Fluorescence (XRF)

The X-Ray fluorescence (XRF) analysis of the bentonite that is used in the preparation of KCl polymer mud is shown in Table 2. The XRF analysis of bentonite showed a significant percentage of silicon oxide (SiO_2) and aluminum oxide (Al_2O_3), and a low percentage of potassium oxide (K_2O) which means that bentonite is composed of mostly montmorillonite.

Table 2. XRF analysis of bentonite

SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	SO3 %	LOI %	P_2O_5 %	Na_2O %	K_2O %
49.98	10	17.5	4.4	4.9	0.16	8.49	0.62	2.24	0.12

3.1.2. X-Ray diffraction (XRD)



The X-Ray diffraction (XRD) analysis of the commercial bentonite is shown in Figure 1. As discussed in the previous section, the major component of bentonite is montmorillonite and quartz. The minor components are palygorskite and calcite.

Figure 1. XRD Analysis of bentonite

3.1.3. Particle size distribution

The particle size distribution of bentonite, lignite NPs and barite NPs are shown in Figures 2-5. The results of particle size distribution analysis show that the average size of bentonite is 238 nm, lignite NPs is 63 nm, and barite NPs is 112 nm. While the size of XC polymer NPs ranging from 10.6 to 5. The 8 nm to 339.68 nm.

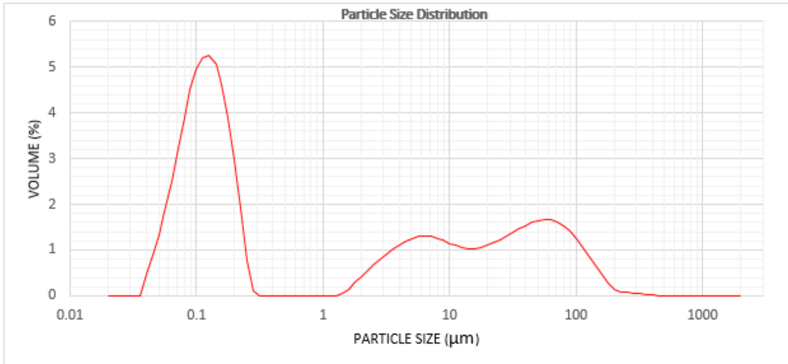


Figure 2. Particle size distribution of bentonite

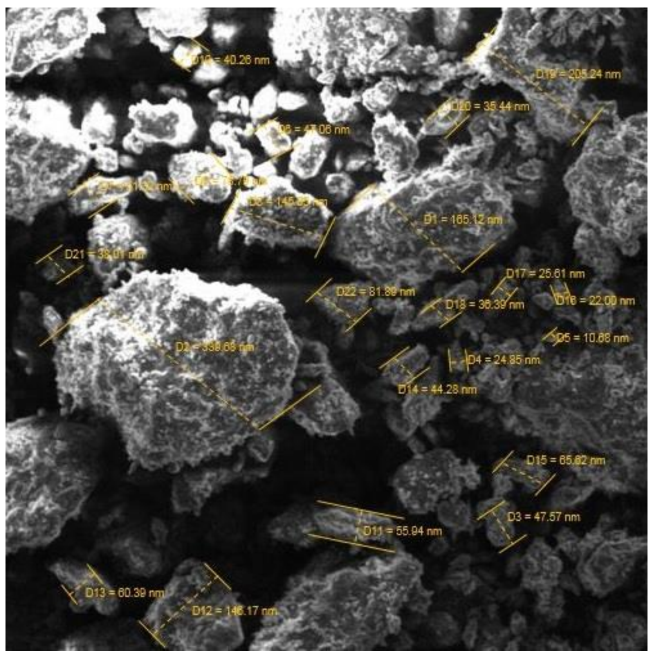


Figure 3. SEM image of XC polymer NPs

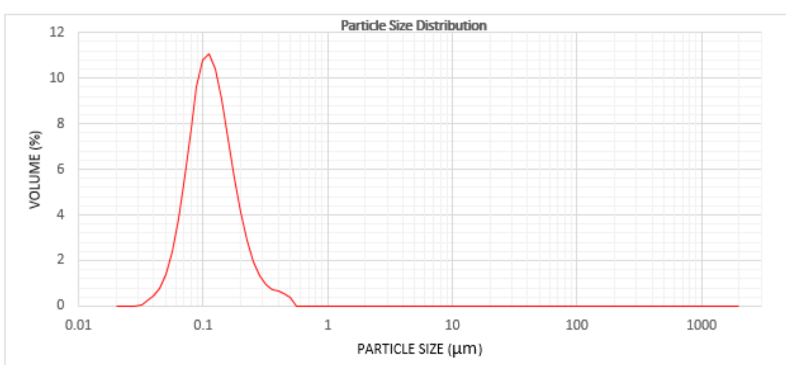


Figure 4. Particle size distribution of barite NPs

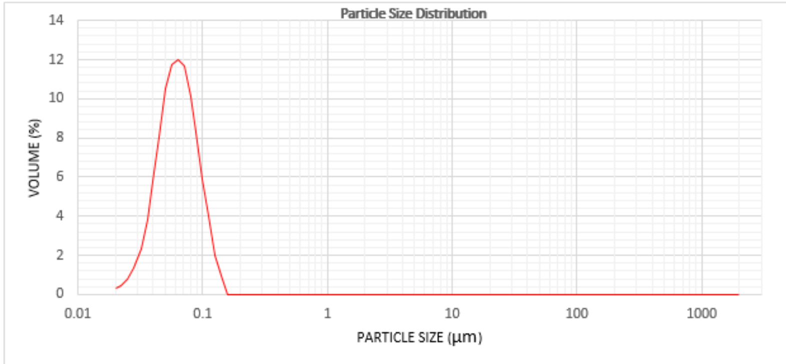


Figure 5. Particle size distribution of lignite NPs

3.2. Lubrication behaviour

To study the effects of nanomaterials on the lubricating properties of a water-based drilling fluid system, XC polymer NPs, barite NPs, and lignite NPs are added at different amounts to blank samples of the KCl polymer mud. The results are presented in Table 3.

Table 3. CoF and CoF reduction % of KCl polymer mud with nanomaterials

W_t, g	$\%W_t$	CoF	CoF reduction %	W_t, g	$\%W_t$	CoF	CoF reduction %
Blank	-	0.367	-	Blank	-	0.367	-
Blank + XC Polymer NPs				Blank + Barite NPs			
0.2	0.04	0.349	4.9	0.2	0.04	0.323	11.98
0.5	0.1	0.312	14.98	0.5	0.1	0.315	14.16
1	0.2	0.329	10.35	1	0.2	0.308	16.07
2	0.4	0.268	26.97	2	0.4	0.332	9.53
4	0.8	0.139	62.12	4	0.8	0.357	2.72
Blank + Lignite NPs				0.2	0.04	0.323	11.98
0.2	0.04	0.288	21.52				
0.5	0.1	0.226	38.41				
1	0.2	0.215	41.41				
2	0.4	0.185	49.59				
4	0.8	0.178	51.49				

3.2.1. Effect of XC polymer nanoparticles

The Table 3 visualize the obtained CoF values of KCl polymer muds with different amounts of the XC polymer NPs .-The highest CoF reduction (62.12 %) is generated with a weight of 4 gm. As the amount of the XC polymer NPs increases, the CoF value of the KCl polymer mud decreases.

XC polymer NPs show a mixed lubrication regime [13], which means it acts as a boundary lubricant and establishes a high-strength thin film at the contacting surfaces when the speed is too low, and the load is too high. When the load is decreased, and the speed is increased, the XC polymer NPs act as a hydrodynamic or elastohydrodynamic lubricant and form a wedge-shaped film between the contacting surfaces. In both situations, the result is a complete separation of the contacting surfaces, reducing the frictional forces between them.

3.2.2. Effect of barite nanoparticles

Table 3 show that the addition of barite NPs to the KCl polymer mud causes a reduction in the CoF value, and better lubrication results are observed with low amounts (≤ 1gm), where the maximum reduction in the CoF (16 %) is gained using the weight of 1 gm. At high amounts (more than 1 gm), the general trend is inverted, where the CoF is increased with increasing barite NP amount. However, this value remains less than the CoF value of the blank sample.

Barite is a soft, lamellar, crystalline material and as a result of these properties and structure, it can act as a lubricant due to its ability to form a low shear strength film on the contacting surfaces and thus reducing the CoF [14-15].

At an amount of 1 gm, a maximum reduction in the CoF is observed due to the formation of a complete low shear strength film, which explains why the CoF increases with an increasing barite NP amount above the amount of 1 gm.

3.2.3. Effect of lignite nanoparticles

The CoF values of the KCl polymer mud with different amounts of lignite NPs are illustrated in Table 3. The CoF values of the KCl polymer mud with different amounts of lignite NPs are illustrated in Table 4. According to the results, the KCl polymer mud with an amount of 4 gm shows a 51.49 % reduction in the CoF. As the amount of lignite NPs increases, the CoF value of the KCl polymer mud decreases. According to the XRD study, lignite has a random layer lattice structure (graphite-like structure) [16]. For this reason, lignite may act as graphite (self-lubricating solid material) and form a film between the contacting surfaces. As a result of the film formation, the friction between the contacting surfaces could be reduced.

3.3. Rheological properties

After the addition of nanomaterials to the drilling fluids, the rheological properties may change. Therefore, it is essential to investigate the effects of these nanomaterials on rheological behaviour. The rheological properties (including PV, YP, AV, gel strength), KCl polymer mud with different concentrations of nanomaterials, are illustrated in Table 4.

Table 4. Rheological properties of KCl polymer mud with different concentrations of nanomaterials

Wt (g)	% Wt	PV (cP)	YP (lb/100 ft²)	AV (cP)	YP/PV (lb/100 ft²/cP)	10 sec gel	10 min gel
Blank	----	14.6	27.9	27.85	1.91	6.4	19.2
Blank + XC Polymer NPs							
0.2	0.04	17	48.7	39.95	2.864	17.4	38.3
0.5	0.1	18.8	60.5	49.05	3.218	33.1	42.4
1	0.2	18.2	68.2	50.3	3.747	39	44.7
2	0.4	22.6	82.7	61.45	3.659	35.8	57.4
4	0.8	27.4	125.7	86.4	4.587	71.4	87.8
Blank + Barite NPs							
0.2	0.04	17.7	27.2	31.3	1.536	6.6	24.4
0.5	0.1	17.8	30.3	32.05	1.702	8.1	24.2
1	0.2	17.8	30.9	32.1	1.735	8.1	23.5
2	0.4	16.9	32.5	32.25	1.923	8.2	22.3
4	0.8	16.8	34.1	32.9	2.029	8.6	24
Blank + Lignite NPs							
0.2	0.04	17.5	35.1	35.05	2.005	11.5	38.7
0.5	0.1	20.4	34.3	36.55	1.681	8.8	24.8
1	0.2	22.2	33	37.4	1.486	6.8	17.6
2	0.4	25.6	27.4	38.4	1.070	6.7	17
4	0.8	22.4	26.8	34.5	1.196	5.8	16.6

3.3.1. Effect of nanomaterials on plastic viscosity

The results in Table 4 show that the addition of nanomaterials causes an increase in plastic viscosity compared with that of the blank sample. However, the plastic viscosity increases as XC polymer NPs amount increase while increasing amounts of the barite NPs above the amount of 0.2 gm do not show any effects on the plastic viscosity value.

Plastic viscosity is part of the resistance to flow caused by mechanical friction. An increase in the number of solids, a reduction in the size of the solid particles, and an increase in the total surface area of solids exposed will all increase the plastic viscosity. Nanomaterials have a large surface area per volume, which increases the interaction of nanomaterials with the drilling fluid matrix. The nanomaterials may then link or bond directly, through an intermediate chemical linkage, with the drilling fluid matrix, causing an increase in plastic viscosity. On the other hand, the reduction of the plastic viscosity is due to a repulsive force between nanomaterials and the drilling fluid matrix.

3.3.2. Effect of nanomaterials on the yield point

The yield point of the KCl polymer mud with different amounts of nanomaterials. The results show that the addition of nanomaterials causes an increase in the yield point compared with the blank sample, and the greatest increase in yield point value is obtained using the XC polymer NPs (125.7 lb/100 ft² at an amount of 4 gm).

The yield point is a measurement of the attractive forces (resulting from negative and positive charges located on or near the particle surfaces) in a drilling fluid under flow conditions. The yield point is increased with the addition of nanomaterials (as that with the addition of XC polymer NPs and barite NPs), and this may be due to the more effective dispersion ability of nanomaterials on the surface of bentonite, increasing the attractive force between them. Sometimes, the yield point decreases upon the addition of nanomaterials (as that with the addition of lignite NPs with high amounts), and this may be due to a repulsive force that occurs between the nanomaterials, water molecules, and bentonite particles [19].

3.3.3. Effect of nanomaterials on apparent viscosity

The results in Table 4 show that the addition of nanomaterials causes an increase in the apparent viscosity compared with that of the blank sample, and the greatest increase in apparent viscosity is recorded using the XC polymer NPs (86.4 cP ft² at a weight of 4 gm).

While the trends of the barite NPs and lignite NPs slightly increase with the increasing amount, an exception is that of the lignite NPs with an amount of 4 gm, causing a decrease in the apparent viscosity.

3.4. Filtration properties

The filtration properties of the KCl polymer mud with different amounts of nanomaterials are presented in Table 5.

Table 5. Filtration properties of KCl polymer mud with different concentrations of nanomaterials

Wt (g)	% Wt	Density (ppg)	PH meter	PH paper	Stability %	V7.5 (ml)	V30 (ml)	Mud cake thickness, (mm)
Blank	----	10	10.75	12	100	4	8	0.622
Blank + XC Polymer NPs								
0.2	0.04	10	10.17	12	100	4.2	8.4	0.488
0.5	0.1	10	10.06	10	100	4.4	8.8	0.488
1	0.2	10.1	9.89	10	100	3.8	7.6	0.586
2	0.4	10.12	9.74	10	100	3.4	6.8	0.672
4	0.8	10.15	8.94	9	100	3.6	7.2	0.572
Blank + Barite NPs								
0.2	0.04	10	10.65	12	100	3.8	7.6	0.368
0.5	0.1	10.1	10.58	12	100	4	8	0.448
1	0.2	10.12	10.55	12	100	4.2	8.4	0.458
2	0.4	10.15	10.53	12	100	4.2	8.4	0.554
4	0.8	10.2	10.42	12	100	4.2	8.4	0.778
Blank + Lignite NPs								
0.2	0.04	10	9.69	10	100	3.4	6.8	0.49
0.5	0.1	10.2	9.34	10	100	3.4	6.8	0.478
1	0.2	9.9	9.18	10	100	3.4	6.8	0.444
2	0.4	8.6	9.20	10	99	3.6	7.2	0.396
4	0.8	8.3	9.16	10	98	4	8	0.356

The Table 5 shows–barite NPs have no effect on the filtrate loss volume. The XC polymer NPs at low amounts (≤ 0.5 gm) cause a slight increase in the filtrate loss volume, while high amounts (≥ 1 gm) cause slight decreases in filtrate loss volume. The lignite NPs cause slight decreases in filtrate loss volume, and this trend increases with increasing the amount. The lowest value of filtrate loss volume (3.4 ml, 51% reduction in filtrate loss volume) is generated by using 2 gm XC polymer NPs and 0.2 to 1 gm lignite NPs.

The Table 6 shows that a decrease in mud cake thickness is obtained with the use of the XC polymer NPs, barite NPs, and lignite NPs.

Additionally, the XC Polymer NPs shows irregular increasing and decreasing behaviours in mud cake thickness as the weight increases, while increasing the barite NP weight increases the mud cake thickness. This thickness decreases with increasing lignite NP amounts, and the lowest value of mud cake thickness (0.356 mm, 42.76% reduction in mud cake thickness) is obtained with the use of 4 gm lignite NPs.

The addition of nanomaterials to the drilling fluid causes an increase in the filtrate loss volume, and this may be explained due to the solid accumulation that makes the mud less stable; this means an impermeable and low porosity mud cake cannot be obtained, and more filtrate can pass through the mud cake. On the other hand, nanomaterials may cause a decrease in the filtrate loss volume, and this may be explained due to the ability of nanomaterials to seal the nanopore throats of the wellbore formation and prevent water infiltration [20-21]. The results indicate that the role of nanomaterials in improving the drilling fluid performance is dependent on the type and the amount of nonmaterial used.

3.5. Effect of temperature on lubrication behaviour and rheological properties of KCl polymer mud with nanomaterials

The effect of temperature and circulation on KCl polymer mud with an optimum concentration of each type of nanomaterials is shown in Table 6.

Table 6. Effect of temperature and aging on KCl polymer mud with nanomaterials

T (°C)	CoF	PV (cP)	YP (lb/100 ft²)	AV (cP)	YP/PV (lb/100 ft²/cP)	10 sec gel	10 min gel
Blank							
35	0.367	14.6	27.9	27.85	1.91	6.4	19.2
75	0.399	33.7	63.5	63.4	1.88	27.1	28.5
100	0.279	22.7	61.7	51.8	2.71	28.8	39.5
Blank+ 4 gm XC Polymer NPs							
35	0.139	27.4	125.7	86.4	4.587	71.4	87.8
75	0.148	25.1	148.7	95	5.924	88.2	100.8
100	0.138	20.9	126.7	80.3	6.06	73.3	81.9
Blank+ 1 gm Barite NPs							
35	0.308	17.8	30.9	32.1	1.735	8.1	23.5
75	0.288	17.2	69.3	50	4.029	32.4	37.4
100	0.172	17.5	79	54.7	4.51	37.8	43.5
Blank + 4 gm Lignite NPs							
35	0.178	22.4	26.8	34.5	1.196	5.8	16.6
75	0.179	24.3	24.5	36.05	1.01	6.4	17.5
100	0.18	23.7	33.9	39.85	1.43	7.9	24

The increasing the temperature to 75°C causes an increase in the CoF values of the blank sample and with XC polymer NPs. At a temperature of 100°C, the CoF values of these samples are either equal to or less than their values at 35°C, while the CoF values of the barite NP samples decrease with increasing temperature. Increasing the temperature has no effect on the CoF values of the KCl polymer mud with the lignite NPs.

The increasing the temperature to 75°C causes an increase in the PV, YP and AV values of the blank sample and the sample with lignite NPs; at a temperature of 100°C, the PV values of these samples are less than the values at 75°C. These values slightly decrease with increasing temperatures of the XC polymer NPs. Increasing the temperature has no effect on the PV value of the KCl polymer mud with the barite NPs.

4. Conclusions

Nanomaterials promise a reduction in the coefficient of friction of KCl polymer drilling fluid. The addition of barite NPs, with amounts up to 1 gm, to the KCl polymer drilling fluid, can reduce the CoF up to 16%. XC polymer NPs with amounts up to 4 gm can reduce the CoF up to 60%in the KCl polymer mud.

Generally, nanomaterials (XC polymer NPs and barite NPs) increased rheological properties (PV, YP, AV, and gel strength), except lignite NPs which is a mud thinner. XC Polymer NPs with the best concentration (weight of 4gm) improved filtration properties of KCl polymer mud. The reduction percentages in filtrate volume and mud cake thickness were 10% and 8% respectively. Nanomaterials (XC polymer NPs and lignite NPs) with the best concentration-maintained lubrication behavior of KCl polymer mud after aging at 100°C for 6 hours.

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