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Effect of Titanium Nitride (TiN) Nanoparticles on the Lubricity and Viscosity of Water-Based Drilling Fluid

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ABSTRACT

The effectiveness of the fluid's performance depends on the combined effect on its rheological, thermos-physical, chemical, and lubricity properties. In this paper, the effect of TiN nanoparticles on different properties of KCL-based water-based drilling fluid was evaluated. Results showed that the TiN nanoparticles among others increased the lubricity of the drilling fluid by 40% and reduced the filtrate loss by 9.8%. Moreover, the additive has shown an impact on the thermal, electrical conductivity, and rheological properties of the considered drilling fluid.

INTRODUCTION

The rheological and physical properties of drilling fluids influence the prediction of well pressure and cutting lift capacity. As the drilling depth increases, the temperature and pressure also vary. These increases affect the fluid properties. Therefore, formulation of thermal stability and prediction of the behavior of the fluids for the considered thermodynamic state is crucial to precisely predicting the pressure in the wellbore. When the fluid behaviors are not estimated, or the fluid properties are not designed to maintain their properties, the well pressure fluctuation may exceed the well stability window. As a result, the likely occurrence of well instability issues causes the well to fracture, hence lost circulation and well collapse, and also drill string sticking. Moreover, the fluid's rheological properties change may not maintain the cutting lifting performance, which, as a result, cutting accumulation may occur. The overall impacts are reflected in reduced drilling efficiency and increased operational and non-productive time costs.

Another issue is that during drilling, casing running, and well intervention, the mechanical friction between the strings and the wellbore/casing results in drag force against the motion. The higher the friction, the higher the torque, drag, and string/casing wear. These may reduce the reach of the desired target depth and cause casing or tubing integrity issues. Casing wear is a critical issue in oil well operation. In Gullfaks A-42, the measured casing wear indicated that about 35% of the wall thickness had been removed.[1] The casing wear was due to drill string connections, casing interaction, and hydrodynamic fluid flow. Production tubing's wear measurement also showed that about 47% of the wall thickness of the tubing had been reduced.[2] Finite element modeling results showed that local wear damage reduced the burst and collapse pressure rating significantly.[3-6] One of the best solutions to minimize wear damage and frictional force is to improve the lubricity of the well fluids. Therefore, the viscosity and tribology properties of the drilling fluids are the key to determining fluid behaviors, among other fields of study.

In recent years, the impact of nanoparticles (1–100 nm) on well cement performance, drilling fluid properties, and enhanced oil recovery potential has been studied experimentally in the laboratory. Compared with the micro-sized particles, the nanoparticle has a higher surface-area-to-volume ratio. Results on the effect of different nanoparticles on the conventional drilling fluids have shown that nanoparticles can be used to adjust rheological properties [7-10], decrease filtrate loss and filter cake thickness[7-12], decrease the permeability of shale[13-15], increase fluid lubricity[16-18], improve wellbore strengthening[19], increase electrical and thermal conductivites[20-24] and reduce shale swelling.[25-26]

The nanoparticle properties, such as its structure, size, concentration, and surface chemistry, determine the drilling fluid's properties, which is the overall interaction of the nanoparticle with the base fluid's chemical ingredients. Therefore, the effect of nanoparticles also varies in different base fluids formulated with various chemicals. Moreover, an analysis of the literature shows that a single nanoparticle does not enhance all the properties of the drilling fluid.

In terms of lubricity and shale swelling, the performance of oil-based mud is better than that of water-based drilling fluid. However, the treatment of oil-wet drill cuttings is expensive. Hence, it is common to use KCL-based water-based drilling fluid, especially on large top hole sections.

In this paper, it is presented experimentally evaluated effects of Titanium Nitride (TiN) nanoparticles on the properties of in-house formulated KCL-water-based drilling fluids. One of the reasons for testing Titanium Nitride is that the particles have the properties of a wear-resistant coating with high hardness, high scratch resistance, low friction coefficient, high-temperature chemical stability, and excellent thermal conductivity properties. [27-28]

MATERIALS AND METHODS

Materials

The drilling fluid is a laboratory model drilling fluid. The chemicals used for water-based drilling fluids synthesis, such as viscosifier (Xanthan Gum) and density control material (Barite), were obtained from MI-SWACO (Stavanger, Norway). Carbopol (carboxyl polyacrylate) is a family of polymers (viscosifier) that was purchased from Lubrizol company (Germany). Carbopol polymer is not commonly used in drilling fluids, especially in the North Sea. However, for the sake of stability of the base drilling fluid, about 0.019 wt.% of the drilling fluids has been used. Sigma Aldrich provided Anhydrous soda ash, which was used to control the pH of the drilling fluid. An inorganic titanium Nitride (TiN) 20 nm nanoparticle (NP) and 10 wt.% dispersed in water solution was purchased from US Research Nanomaterials, as shown in **Fig. 1**. The zeta potential of the TiN NP is -17.5 mV and has a bulk density of 5.22g/cm^3.

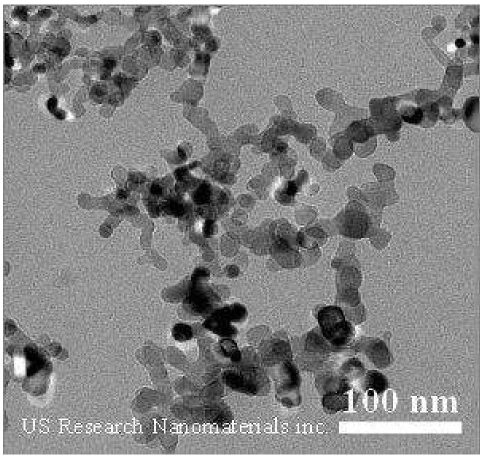


FIGURE 1: SEM picture of TiN nanoparticle.

Characterization and Analyses Methods

Viscosity Measurements

We measured the viscosity of the drilling fluids using the OFITE Model 800 viscometer (OFITE, Houston, USA) under atmospheric pressure and at 20ºC, 50ºC, and 80ºC. We utilized the OFITE Thermocup 130-38-25 for this purpose. The Viscosity response of the drilling fluids has been measured at the shear rates of 1022, 511, 340.7, 170.3, 102.2, 51.1, 10.2, and 5.1 1/s.

Anton Paar Rheometer

Viscoelastic properties can be used to increase the knowledge of the internal gel structure of the fluids including yield stress and gel formation. An Anton Paar MCR 302 (Anton Paar GmbH, GRAZ, AUSTRIA) was used to measure some dynamic responses of the drilling fluids at room temperature. An oscillatory amplitude sweep test was conducted on fluid samples between parallel plates that oscillate at a constant angular frequency of 10 rad/s and varying % strain in the 5×10^{-4} % to 1000% range.

API Filter Press

We used the Static API Filter Press (OFITE, Houston, USA) to measure the filtrate loss of the drilling fluids. The measurement was conducted at low pressure (100 psi) and temperature (room) for 7.5 min at room temperature.

CSM Tribometer

CSM Tribometer (CSM Instruments, Needham, Massachusetts, USA) was used to measure the lubricity of the fluids. The test was conducted on a steel ball-plate interface. The cup was filled with drilling fluid. The 13cr steel ball has a diameter of 6mm and rotates at the speed of 3 cm/s for 10 m by applying a 5 N load on the ball-plate interface. We conducted all measurements at 20 ^{0}C. The ball-plate interaction could potentially damage both surfaces. Therefore, several repeat tests were carried out by controlling and changing the damaged surfaces. The average values of the tests are reported.

Thermal Conductivity Analysis

A Tempos thermal properties analyzer meter (Decagon, Pullman, WA, USA) was used to characterize the thermal conductivity of the drilling fluid by immersing the probe into the sample. We took multiple readings and reported the average values.

Electrical Conductivity

An RS PRO Conductivity Meter (RS 1410-1002 model, Bad Hersfeld, Germany) was used to measure the electrical conductivity of the drilling fluid. We conducted measurements by immersing the probe in the fluid specimen.

Modelling and Viscosity Characterization

Herschel–Bulkley is a three-parameter non-Newtonian rheology model. The model is a modified yield power-law model that reads as Eq. 1[29].

$$\tau = \tau_y + k\dot{\gamma}^n \qquad (1)$$

where the shear stress (τ) are the measured values at the shear rate ($\dot{\gamma}$). The flow index (n) and the consistency index (k) are determined once the yield stress (τ_y) is estimated. In the drilling industry, the yield stress Eq. 2 is obtained from the lower viscometer reading data following Zamora and Power[30]:

$$\tau_y = 2\tau_3 - \tau_6 \tag{2}$$

where the subscript refers to the applied rotation rates of an oilfield standard viscometer. 3RPM gives the shear rate of 5.11 1/s and 6 RPM gives 10.22 1/s.

In the Herschel Bulkley model as presented in Eq. 1, the consistency parameter k is a function of the curvature index, n. Therefore, these parameters might not provide accurate comparisons of the drilling fluids' viscosities since different k and n values may describe nearly similar flow curves. This was recognized by Nelson and Ewoldt (Reference) who had to tabulate fluid properties for 3-D printing purposes. To similarly compare drilling fluid properties without interdependence, based on Nelson and Ewoldt's model, Saasen and Yttrehus presented the Herschel-Bulkley model using a dimensionless shear rate as shown in Eq. 3[31]

$$\tau = \tau_y + \tau_s \left(\frac{\dot{\gamma}}{\dot{\gamma}_s}\right)^n \tag{3}$$

where surplus stress, $\tau_s = \tau - \tau_y$ is a pre-determined value at the shear rate of $\dot{\gamma}_s$, and τ_y is the yield stress. In the following the yield stress approximation shown in Eq. 2 will be used.

After estimating the yield stress from the viscosity flow curve, the surplus stress τ_s is determined at a specified shear rate. Here, based on the typical for many drilling operations practices, a shear rate of $\dot{\gamma}_s$= 170.3 1/s will be selected[31]. On the conventional oil field viscometer, the 170.3 1/s shear rate is obtained at 100 RPM, and the corresponding shear stress, τ_{100} will also be measured. The surplus stress will then be estimated as [31]:

$$\tau_s = \tau_{100} - \tau_y \tag{4}$$

Finally, the curvature coefficient will be determined based on two possible cases where the shear rate, $\dot{\gamma} < \dot{\gamma}_s$ and $\dot{\gamma} > \dot{\gamma}_s$. As the example presented by Saasen and Ytrehus, the shear rates 30 RPM and 600 RPM were selected to determine the lower (nls) and the higher (nhs) shear exponents. In the following, we also applied this method [31] :

$$n_{ls} = \frac{ln\left(\frac{\tau_{30} - \tau_y}{\tau_s}\right)}{ln\left(\frac{\dot{\gamma}_{30}}{\dot{\gamma}_s}\right)} \tag{5}$$

$$n_{hs} = \frac{ln\left(\frac{\tau_{600} - \tau_y}{\tau_s}\right)}{ln\left(\frac{\dot{\gamma}_{600}}{\dot{\gamma}_s}\right)} \tag{6}$$

Including the shear yield stress, τ_y, computed with Eq. 2, the τ_s (EQ. 4) and n (EQ. 5, 6) parameters will be used to characterize the drilling fluids.

Drilling Fluid Formulation

The base drilling fluid, which is hereafter named reference (nanoparticle-free), is a laboratory KCL-based water-based drilling fluid, formulated by modifying the compositions presented by Torsvik et al.[32]. The impact of TiN nanoparticles (NP) in the range of 0.05 wt.% - 0.2 wt.% concentrations on the reference fluids has been evaluated. Table 1 shows the drilling fluids formulation. We mixed KCL and soda ash with water and stirred with a spoon during drilling fluid synthesis. The mixture was blended with Hamilton Beach for 2 min to make sure of solubility. Xanthan Gum was slowly mixed with the brine and then mixed for 5 min. Further, the mixture was mixed with Barite for 10 min. Finally, the Carbopol was added to the drilling fluid ex-situ and mixed for 3 min. From several attempts, the 0.1g Carbopol mixing improved the drilling fluid stability reducing the water-solid phase separation. The density of the drilling fluid was 1.33 sg. The pH of the base and the nano-blended drilling fluids were in the range of 9.20-9.30.

TABLE 1: Chemical ingredients of drilling fluid

Chemicals	Reference	Reference+ NP
Water, g	350	350
KCL, g	25	25
Xanthan Gum, g	1.5	1.5
Soda ash, g	0.5	0.5
Barite, g	143	143
Carbopol, g	0.1	0.1
TiN NP (g/wt.%)	-	0.05(0.010), 0.10(0.019), 0.15)(0.029), 0.20 (0.038)

RESULTS AND DISCUSSION

The viscosity response of both the control and the nano-blended drilling fluids was measured at 20°C, 50°C, and 80°C. **Fig. 2 - 4** display the dial readings. As shown in the figures, compared with the reference fluid, all the nanoparticle blended systems show slight increases in the dial reading for the higher and the lower rotational speeds. As the temperature increases, the reference fluids' viscosity response decreases for most of the nanofluids. However, the impact of nanoparticle concentration on the dial reading is non-linear. TiN is a non-polymeric additive. The possible explanation for the effect of TiN on the dial reading could be due to the surface chemistry that will interact with the chemical additive of the base fluid.

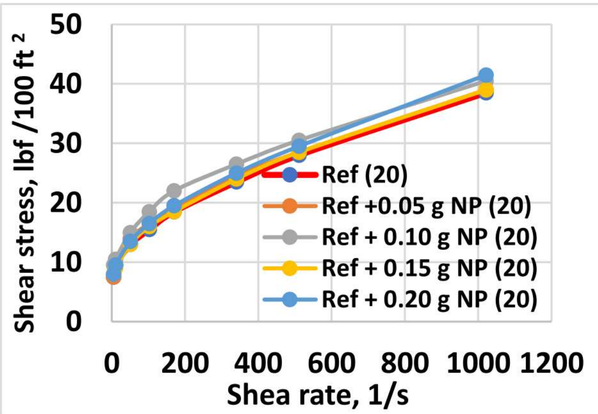


FIGURE 2a: Viscosity responses at 20°C.

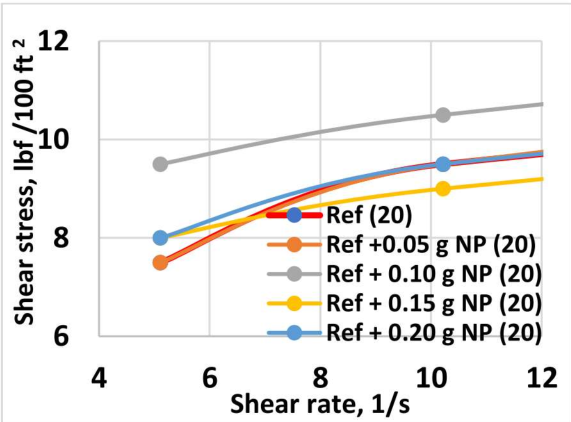


FIGURE 2b:5.1-10.2s^{-1}Viscosity responses at 20°C.

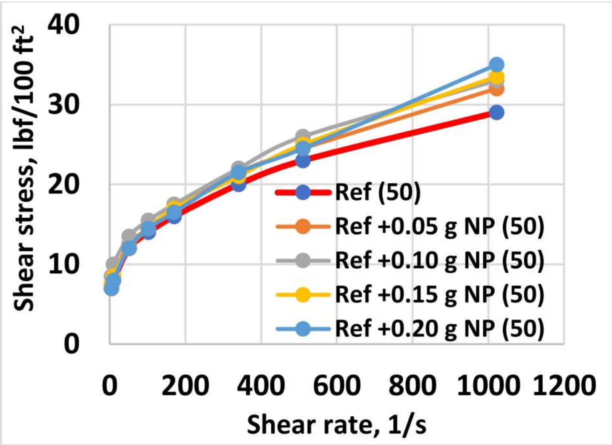


FIGURE 3a: Viscosity responses at 50°C.

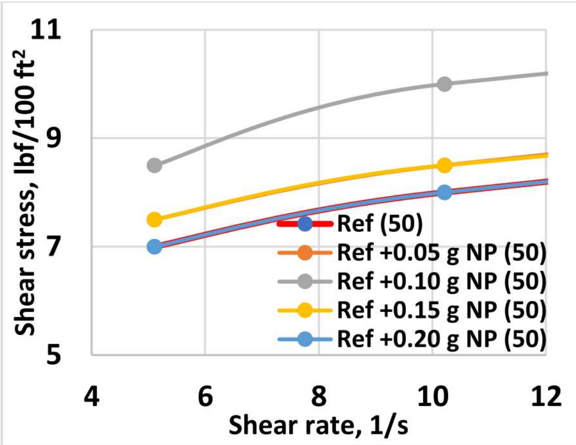


FIGURE 3b:5.1-10.2 s^{-1} Viscosity responses at 50°C.

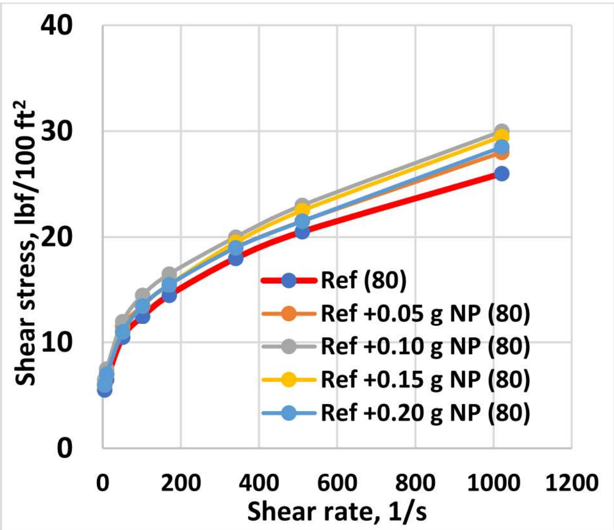


FIGURE 4a:Viscosity responses at 80°C.

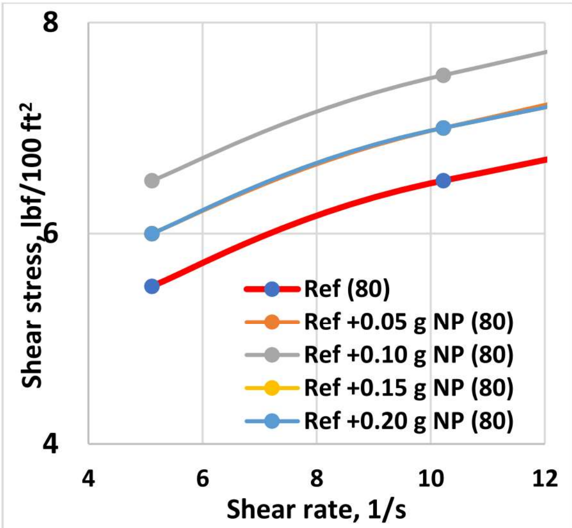


FIGURE 4b:5.1-10.2s^{-1}Viscosity responses at 80°C.

Effect of TiN and Temperatures on the viscosity parameters

Figs. 5-6 show the computed Herschel-Bulkley rheological parameters of the drilling fluids. The nanoparticle effects on the rheological parameters are compared with the reference nano-particle-free fluid. Results showed that for considered temperature, all the nanoparticle concentrations increased the shear yield strength of the base fluid. As shown in **Fig.4,** the impact of the 0.10 g TiN is relatively significant compared to the rest. We computed the flow index, as shown in **Fig.5,** from the whole shear rates (5.1-1022 1/s) by applying the curve fitting method. As shown, the impact of nanoparticles on the base fluid in general increases. However, at 50 and 80°C, the effect was insignificant. Further, the viscosity of the drilling data was computed with Eq. 4-6 and presented in **Fig. 6-8**. The lower and higher curvature index and the consistency index rheological parameters are displayed in **Fig.7 -8**, respectively. For most of the nanoparticles and three considered temperatures, the impact of nano increased the curvature values. As shown in both figures, the values are lower than the HB (n) (**Fig.5**) computed based on curve fitting for the entire shear rate (5.1-1022 1/s). However, the degree of the nanoparticles' impact on the curvature could be evaluated by applying the parameters to the hydraulics model.

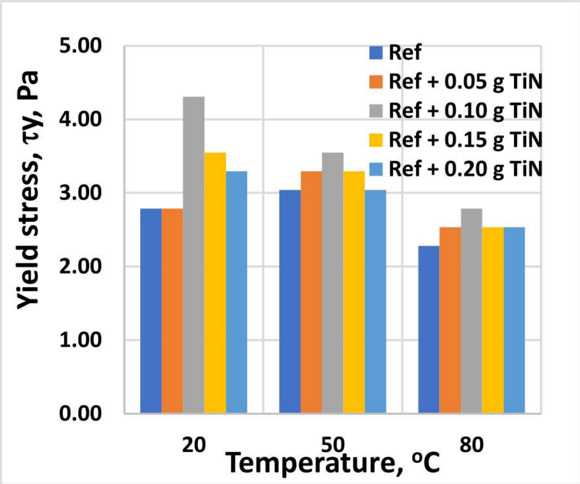
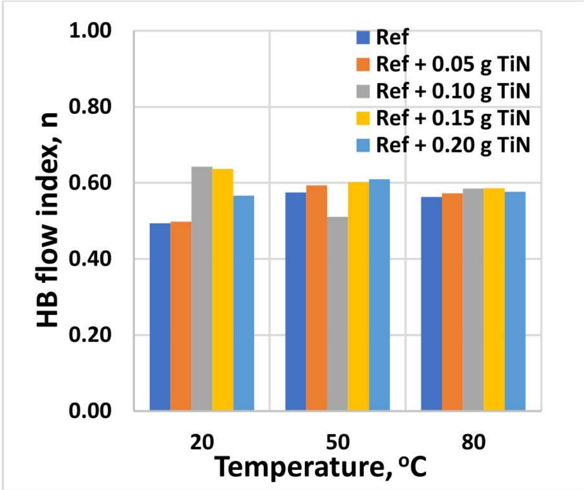


FIGURE 5: Effect of TiN on Herschel-Bulkley yield stress of Drilling fluids



.**FIGURE 6**: Effect of TiN on Herschel-Bulkley Flow index of Drilling fluids

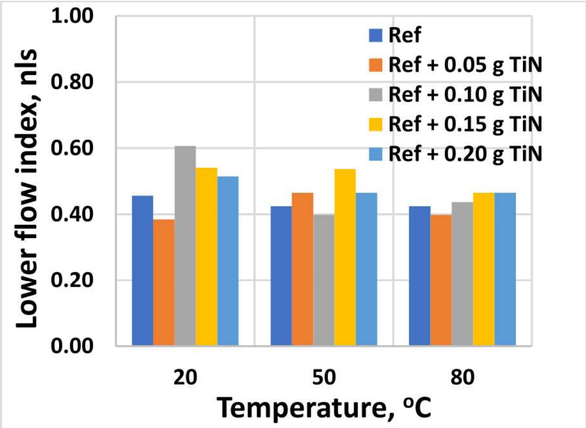


FIGURE 7: Effect of TiN on the lower curvature index (nls) of Drilling fluids

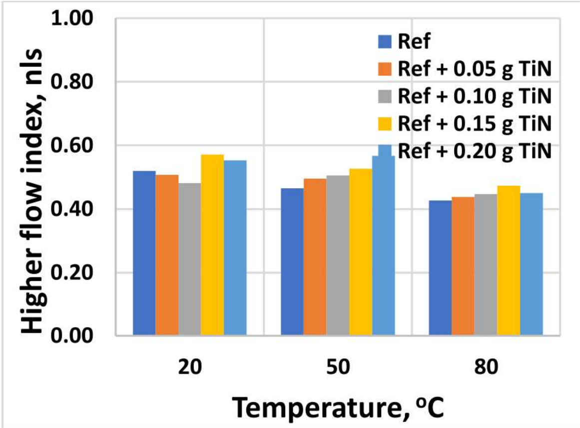


FIGURE 8: Effect of TiN on the higher curvature index (nhs) of Drilling fluids

Fig. 9 displays the surplus stress, which describes the combined effect of the consistency index and flow index parameter. The parameter here is computed with Eq. 5, and results showed that the nanoparticles-based fluid exhibited minor increment values.

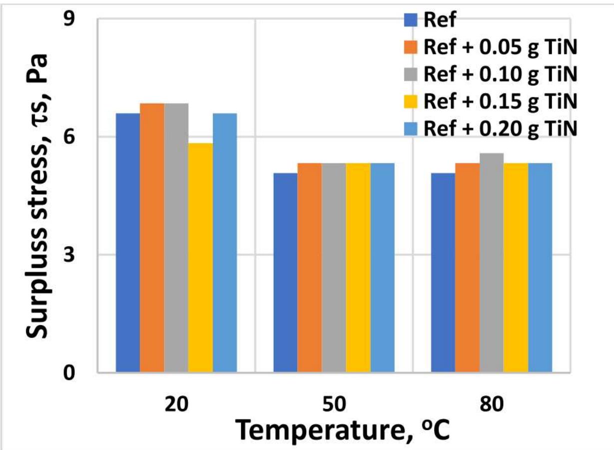


FIGURE 9: Effect of TiN on the surplus stress (t_s) of Drilling fluids.

Effect of TiN on the Lubricity of the KCL-based Drilling Fluid

The lubricity of drilling fluids minimizes the mechanical friction between the drilling string and casing/wellbore and reduces wear damage. The engineering implications are increasing the bit life and casing/drill string integrity and reducing torque and drag issues. Moreover, sufficient lubricity between the wellbore and BHA could mitigate torsional vibration (stick-slip) during drilling in an inclined well with an aggressive PDC bit.

Fig.10 displays the impact of TiN on the lubricity of the KCL-Water-based drilling fluid. The tribometer-logged data was measured over 10 min, and the results show an average of more than eight test datasets. The mean of the curves was calculated, and the results are displayed in **Fig. 11** along with the percentile changes compared with the nano-free reference drilling fluid.

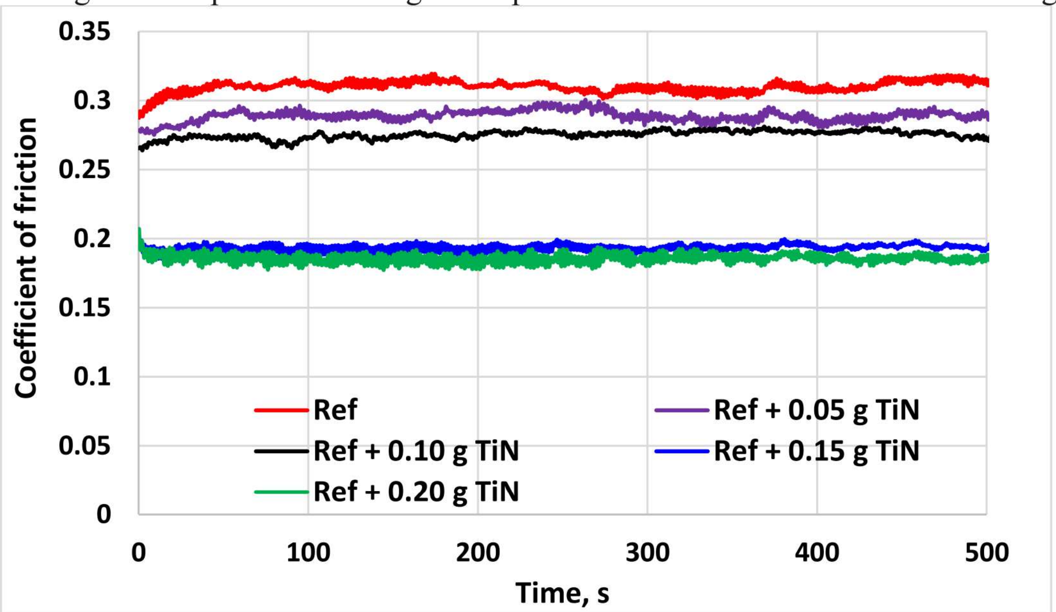


FIGURE 10: Effect of TiN on the lubricity of the KCL-based drilling fluid.

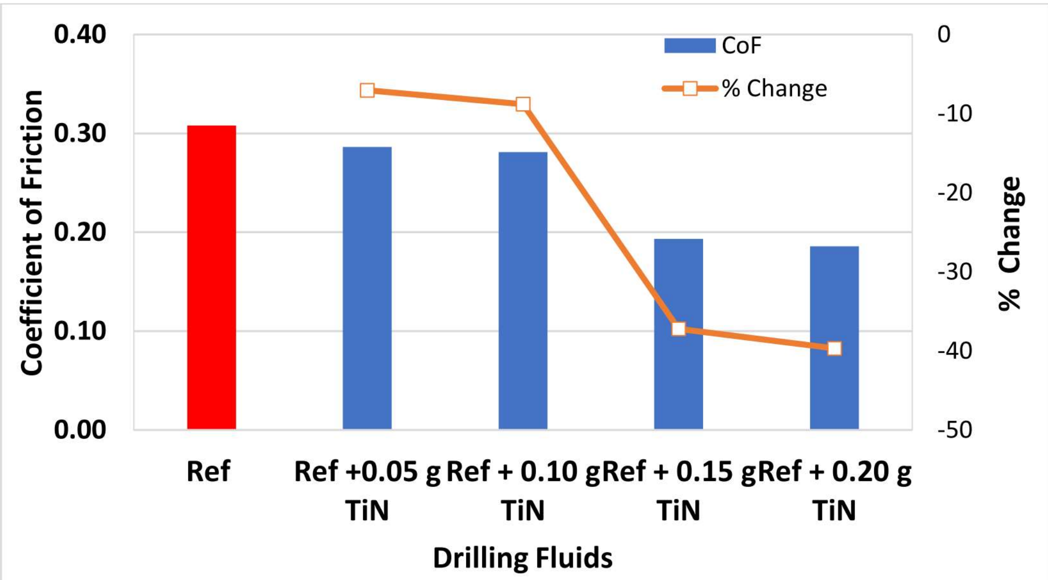


FIGURE 11: Effect of TiN nanoparticle on the lubricity of nanoparticle-free drilling fluid.

Results show that when the nanoparticle concentration increases, the lubricant behavior of the reference drilling fluids increases. The impacts for the lower concentration (0.05 g and 0.1 g TiN) were moderate, and dramatic effects were shown for 0.15 and 0.20 g TiN.

Results show that the addition of 0.05 g (0.01 wt%), 0.10 g (0.09 wt%), 0.15g (0.029wt%), and 0.2 g (0.038 wt.%) TiN reduced the coefficient friction of the base fluid by -7%, -9%, -37% and -40%, respectively.

As illustrated in **Fig.12**, a 5 N load was applied to the ball at a certain radius from the center of the cup during testing. The cup is rotating so that the ball's position will reciprocate, as illustrated in the broken red line. During testing, both the ball and the surfaces were scratched, as shown in **Fig.13**.

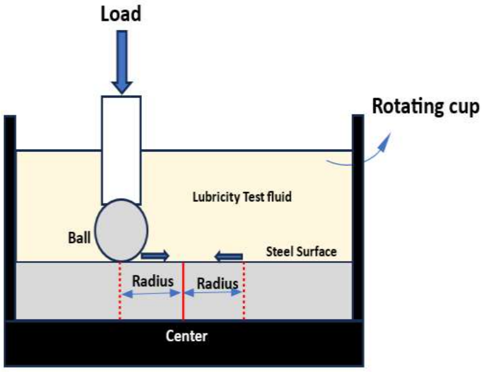


FIGURE 12: Friction testing illustration.

FIGURE 13: Photograph picture of ball-surface wear

Depending on the morphological /crystal structure of nanoparticles, the intermolecular force of the atoms, the binding force between interlayers, and their mechanical strength, the performance of the lubricity of systems will vary. For instance, MoS_2 has a weak interlayer binding force, and hence, the particle lubricity mechanism is caused by the interlayer slip mechanism, which reduces frictional resistance between surfaces.[33]. The lubricity mechanism of nanoparticle systems can be categorized as (1) rolling effect, (2) mending effect, (3) polishing effect, and (4) protective film formation effects[34-36].

Since the TiN nanoparticles have a high hardness, the particles may have intense structural interatomic bondage. So, unlike the MoS_2, the possible improved lubricity mechanisms of TiN Nanoparticle could be the "rolling bearing" effect. In addition, the nanoparticles deposit on the scratched surface and compensate for the loss of mass, which has been called a surface "mending/repair effect."

As illustrated in **Fig.14**, both the "rolling bearing" effect and surface "mending effect" are assumed to be the enhanced lubricity mechanism of TiN that allows surfaces to slide with less resistance and reduce the degree of mechanical wear.

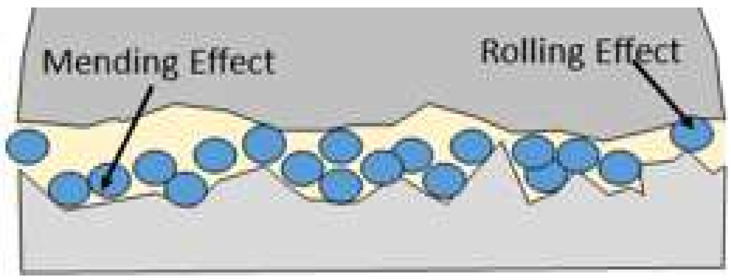


FIGURE 14: Schematic illustrations of the possible enhanced lubricity mechanisms of TiN Nanoparticles.

Effect of TiN on the Viscoelasticity of the KCL-based Drilling Fluid

Viscoelasticity describes fluid properties that are both viscous and elastic. Experiments have shown that most water-based drilling fluids are viscoelastic.[37] An Anton Paar Rheometer was used to characterize the viscoelasticity of the drilling fluids. During testing, at the loading/lower deformation, the drilling fluid behaves elastically/or solid-like, and more energy is stored than lost energy. At higher deformation, the deformation reaches the yield stress, and hence, the internal structure of the fluid begins loosening up, and the energy loss dominates. **Fig.15** displays the amplitude sweep responses of the base fluid and the nano-blended drilling fluids. As shown, the impact of the nanoparticles on the storage and loss moduli, as well as the shear stress and the factors, are insignificant.

Further, the dynamic yield stress was estimated from the amplitude sweep test shown in **Fig.16**. The drilling fluid's yield strength is obtained when the deformation deviates from the linear elastic part.[38] **Fig. 16** shows the flow point where the storage and loss moduli cross each other and describes how drilling fluid behaves as equal portions of elastic and viscous. **Fig. 16** shows the drilling fluids' estimated yield stress and flow point stress values. As shown, only the 0.05 and 0.15 g TiN increased both parameters, but the magnitude is insignificant. Regardless of the result, the non-linear effect of nanoparticles in the dynamics rheological parameter is not investigated at this level of research. However, by changing the base fluid, one may achieve different results.

For comparison purposes, the yield stress estimated from the dynamic measurement was compared with the yield strength computed from Fann viscometer data using Eq. 2.[30]. As shown in **Table 2**, the traditional Fann-based yield stress is higher than the dynamic estimated value. For oil-based drilling fluids, Strømø[49] also verified that there may be a huge difference between the dynamic viscosity-determined yield stresses and the Fann-based yield stresses.

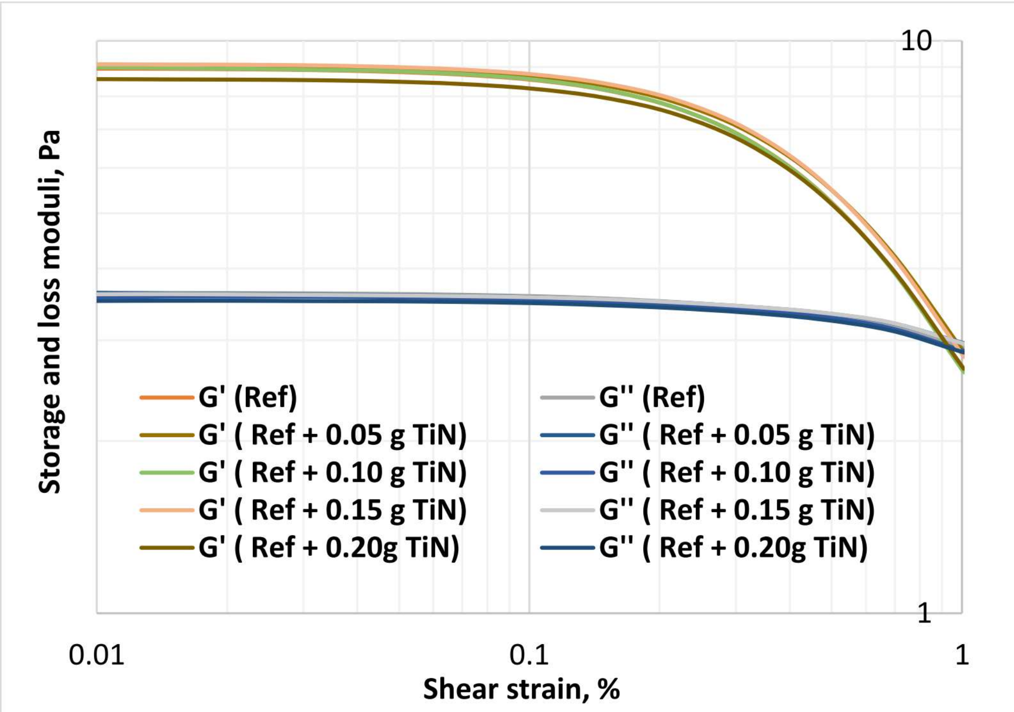


FIGURE 15: Effect of TiN on the dynamic amplitude tests of the KCL-based drilling fluid.

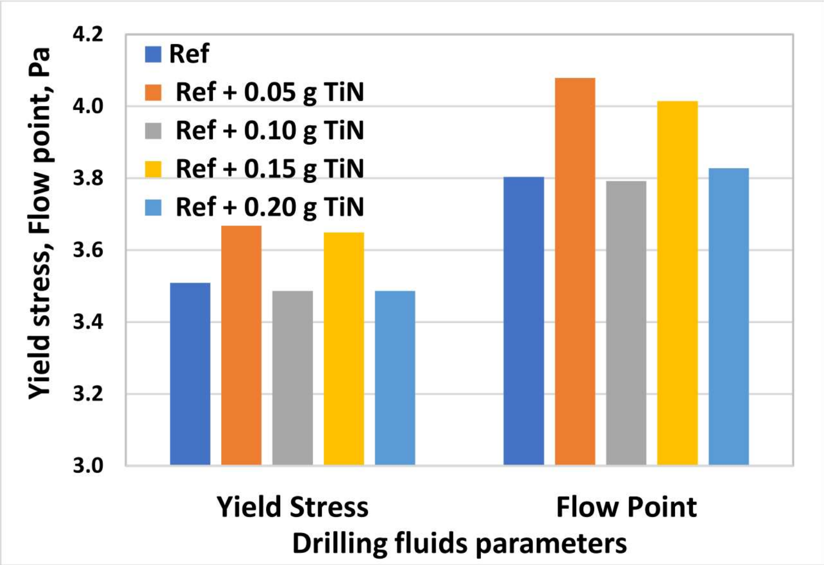


FIGURE 16: Effect of TiN on the dynamic yield stress and flow index of KCL-based drilling fluid

TABLE 2: Comparison between dynamic yield stresses and estimated yield stresses measured using viscometers made in accordance with API specifications.

Drilling fluid	Dynamic measurement Yield Stress, Pa	API equipment Yield Stress, Pa
Ref.	3.5	5.8
Ref. +0.05 g NP	3.7	5.8
Ref. + 0.10 g NP	3.5	9.0
Ref. + 0.15 g NP	3.6	7.4
Ref. + 0.20 g NP	3.5	6.9

Effect of TiN on the Filtrate Loss of the KCL-based Drilling Fluid

Drilling fluids that form good filter cake provide several operational advantages, such as less filtrate loss, reduced differential sticking, and increased wellbore strength. The quality of the filter cake depends on the chemical additives, such as polymers and the solid particles packed in the mud cake, that are responsible for the porosity/permeability of the cake. NP pore plugging shale reduced swelling phenomenon.[13-15]. **Fig. 17** shows the API filter press filtrate losses of the KCL water-based drilling fluid and TiN nanoparticles mixed with drilling fluids. As shown, the 0.05g (0.01wt%) TiN additives decrease the filtrate loss of the base fluid by 7.4 %. When the concentration increases, the reduction rate decreases.

By the visual inspection, the quality of the mud cakes is quite indistinguishable. Sometimes, it can happen depending on the mud cake property, and the filtrate may contain small solids and nanoparticles. A photograph was taken to evaluate the presence of particles in the filtrate, shown in **Fig.18**. All the filtrates are clear, and the bottom-settled particles are nearly similar. However, through ICP-OES filtrate analysis, the ionic concentration of the filtrate could be evaluated to gain more insight into the filtrate. Moreover, performing a Scanning Electron Microscope (SEM) may also allow us to assess the cake's structure.

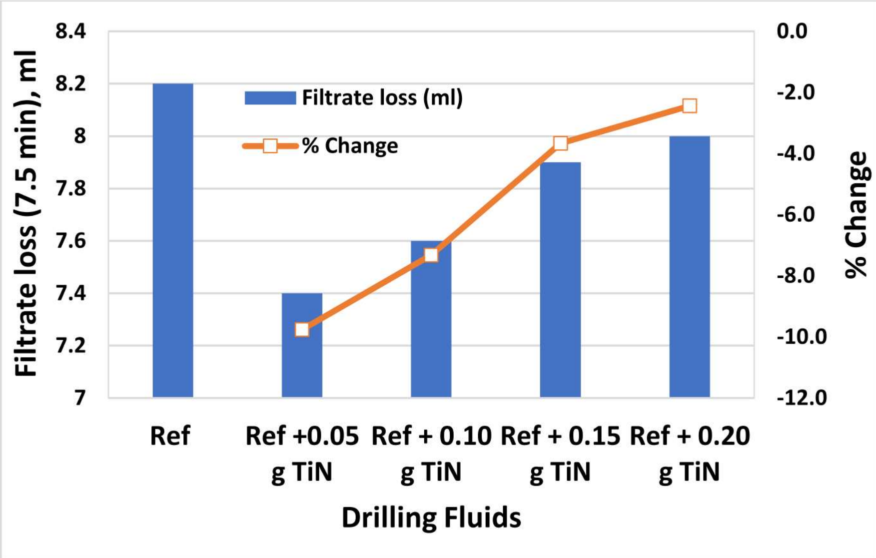


Figure 17: Effect of TiN on the filtrate loss of the KCL-based drilling fluid.

Figure 18: Effect of The 7.5 min filtrate loss volume

Effect of TiN on the Thermal Conductivity of the KCL-based Drilling Fluid

The mechanical interaction between the bit and the rock generates heat in the bit. To cool the bit during operation, it is vital to design a drilling fluid with sufficient heat transfer properties to inhibit drill bit overheating.

The nanoparticles' large surface area and mobility around the bit are dispersed and allow an increased heat transfer through the micro-convention of fluids.[39]

Several experimental studies have been conducted on the thermal behaviors of nanoparticle's effect on drilling fluids. Results were reported that the nanoparticles increase the thermal conductivity of the considered drilling fluid[20-24].

This paper measures the thermal conductivity of the nano-free and TiN-blended KCL drilling fluids with the KD2 apparatus at room temperature. Before measurement, the instrument was calibrated with a known calibration fluid. For each fluid specimen, several readings were taken, and the average value is reported in this paper.

Fig. 19 displays the test results. As shown, adding 0.01 wt %, 0.019 wt %, and 0.029 wt% increased the thermal conductivity by 0.2 %, 1.0% and 1.2%, respectively. On the other hand, the 0.039wt% (2.0 g) TiN decreased the thermal conductivity by 0.9%.

Among others, TiN has good thermal conductivity properties.[27-28] However, the impacts of the TiN solution used in the KCL-based drilling fluids were insignificant. The effect could be different if the TiN additive were in dry form.

Several mechanisms for the thermal conductivity enhancement of the nanoparticles are reported in the literature for instance due Brownian motion of nanoparticles[39-41], nanolayers at the solid-liquid interface act as 'thermal bridge'' [42-43], and nanoparticle aggregation and size effect [44-45] can be mentioned. As displayed in **Fig.19**, the thermal conductivity effect of TiN in KCL-based drilling fluid was non-linear in increments until the concentration reached 0.15 g and then decreased for 0.2 g TiN. The reason for this performance could be interpreted based on the above-mentioned mechanisms. However, for this, advanced characterization methods should be employed. Up to this level of research, the mechanisms are not presented, and future work will explore the possible mechanisms.

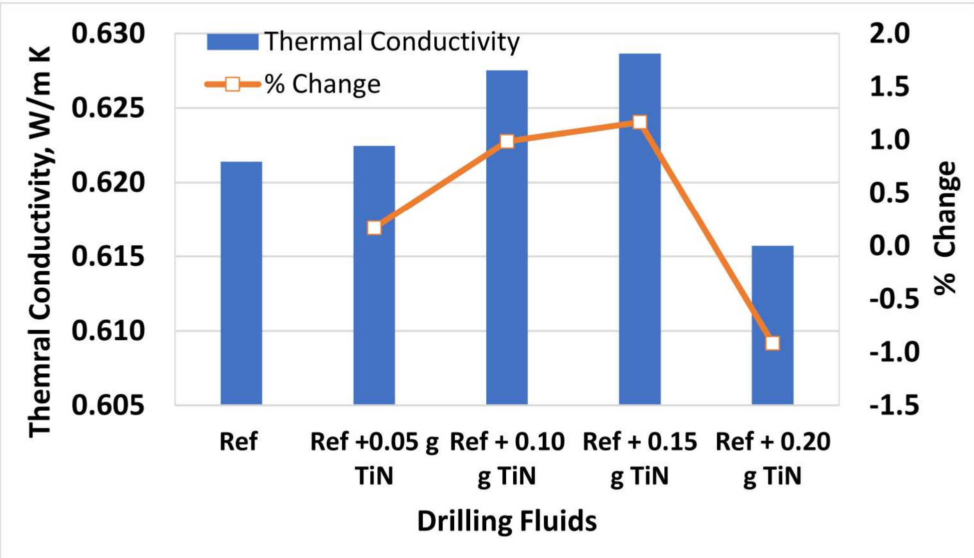


Figure 19: Effect of TiN NP on the thermal conductivity of the KCL-based drilling fluid

Effect of TiN on the Electrical Conductivity of the KCL-based Drilling Fluid

The electrical conductivity of the drilling fluid is an essential property for downhole data transfer, and the magnitude should be within the recommended range for electrical logging operations. A poor conductive fluid does not allow sufficient electrical penetration into the formation, resulting in poor wireline log data recording. Therefore, during operation, the electrical conductivity of the drilling fluids must be controlled and needs to be maintained to ensure an appropriate measurement without interruption.[46]

Fig.20 shows the effect of TiN on the Electrical conductivity of the KCL-Water-based drilling fluid. Results showed that as the TiN solution concertation increases, the conductivity increases until the 0.15g TiN decreases afterward. It is interesting to observe that the thermal conductivity also decreases for the 0.2 g TiN, as shown in **Fig. 19**. Among other properties, TiN exhibits electrical properties including metallic conductivity, high electron mobility, and low resistivity.[47-48] Therefore, these properties are highly attractive for application in microelectronics and nanoelectronics. However, when it comes to the TiN solution used in the paper the maximum impact on the KLC-based fluid reaches 1.8%. The reason could be due to the combined effect of chemicals of the KCL-base drilling fluid. Another possible reason for the performance associated with the 0.2 g TiN could be the concentration of the surfactants as compared with the lower concentration.

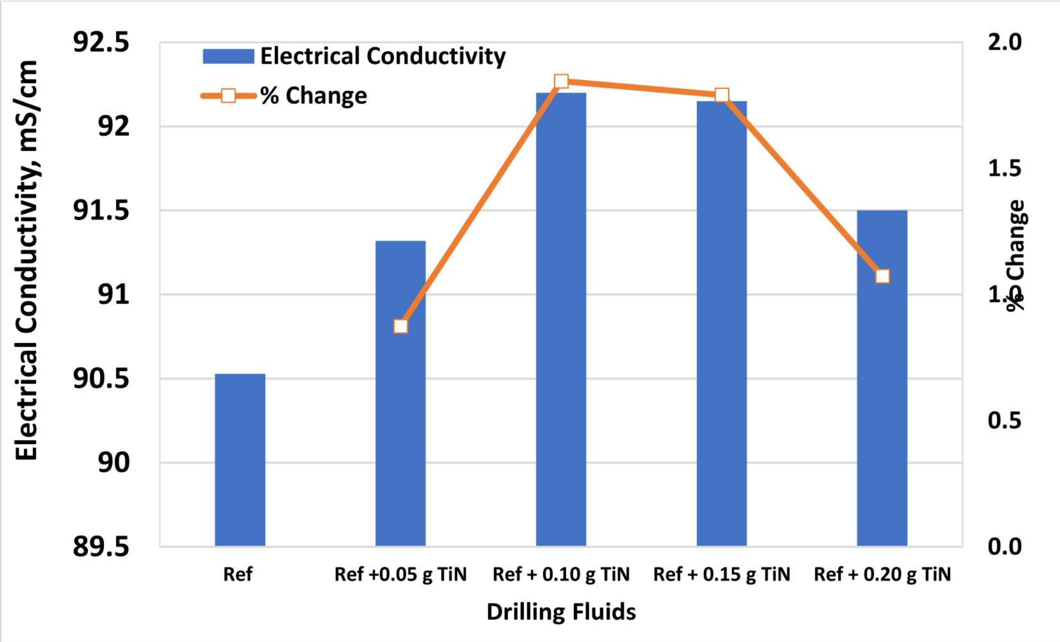


FIGURE 20: Effect of TiN NP on electrical conductivity

CONCLUDING REMARKS

In this paper, KCL-based drilling fluids have been synthesized, and the effect of nanoparticles on rheological, filtrate loss thermal, and lubricity. Results show TiN nanoparticles significantly impact the lubricity and filtrate loss reduction performance. Moreover, the additive has shown an effect on the considered drilling fluid. By changing the base drilling fluid, the effect of TiN may achieve different results. In drilling operations, the tubular surface damage increases the surface roughness and will increase the friction resistance of the motion. Increasing the lubricity of the well fluids allows a) decreasing wear rate and b) reducing torque and drag. As a result, it ensures that possible integrity issues arise, and the target depth is reached.

It is, therefore, imperative to design fluids with holistic desired properties (rheological, filtrate loss, pH, mud cake thickness/tough, lubricant, thermal and electrically conductive) that have a multi-tasking purpose. Further, ensuring that the selected additives in the drilling fluid will not impose formation damage in the pay zone is essential.

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