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The Effect Of Titanium Nitride(TiN) Nanoparticle On The Properties & Performance Bentonite Drilling Fluid

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Abstract

In recent years, the application of nanomaterials is attracting the oil and gas industry. Nanomaterials research results show an improving performance of cement, drilling fluid and Enhanced Oil Recovery.

In this paper, the effect of nano Titanium Nitride (TiN) on polymer (CMC) and salt (KCL) treated bentonite drilling fluid systems has been studied at 22-, 50- and 70^{o}C temperatures.

The results show that the addition of 0.0095 wt % TiN reduced the friction coefficient of the conventional nano-free drilling fluid by an average of -46 %. In addition, the yield stress and plastic viscosity increased significantly by +122 % and +by 17%, respectively. The API filtrate loss decreased by -7.1%. The torque and drag simulation results show that the friction coefficient reduction increased the drilling depth by +31% compared to the nano-free system.

1 INTRODUCTION

Properly designed drilling fluid, among others, is a key for a successful drilling operation. The rheology and lubricity of drilling fluids control the hydraulics, hole cleaning and the mechanical friction between string and wellbore.

During the well planning phase, an evaluation of drilling fluids is an essential part of drilling oil and gas wells. In rotary drilling operations, drilling fluid is used, among others: to maintain well pressure;- transport cuttings, cool well and drill bit;- and formation of filter cake around the borehole. Properly designed drilling fluid reduces fluid loss by forming good mud cake and increase well strength. The quality of the filter cake depends on its packing and mechanical properties. A typical conventional drilling fluid contains viscosity, density, and fluid-loss control additives. However, a conventional water based drilling fluid does not completely solve drilling related problems such as shale swelling and formation damage. Higher torque and drag limits drilling a longer offset due to higher friction between drill string and formation/casing.

Oil based drilling fluids are better than the water based drilling fluid. However, oil-based mud (OBM) is expensive and not environmentally friendly. It is, therefore, important to develop a water-based mud (WBM), which has good performance in terms of lubricity and shale inhibition property. This paper is going to look at the possibilities with nano based drilling fluid.

Nanotechnology (1nm – 100 nm) has utilized to solve complex biomedicine and electronics engineering problems. This technology may have the potential of solving technical challenges of the conventional technology in the oil and gas industry. Through chemical and physical processes, researchers have shown an ability to create nanomaterials with improved thermal, mechanical, electrical, and rheological properties. The surface area to volume ratio of the nano-system is significantly higher than the micro/macro sized particles systems (Amanullah et al, 2009) [1]. The positive effects of different types of nanoparticles on the properties of drilling fluids is documented by Sharma et al, (2012) [2], Riley et al, (2012)[3], Hareland, et al (2012) [4], Li et al, (2012) [5], Nwaoji, et al (2013) [6], Abdo et al (2013) [7], Fakoya et al. (2013) [8], Sadeghalvaad, et al. (2015) [9], Krishnan et al, 2016[10]. Similarly, the effect of nanoparticles on the conventional cement slurry with regards to fluid loss reduction and improved cement properties are also documented(Ruhal et al,2012 [11], Ershadi, et al(2011)[12], Jeremiah et al.(2012)[13], Vipulanandan,et al(2015) [14].

The performance of a nano-system in water based drilling fluid has shown promising potential in shale formations stability. The main mechanism through which the nano-system reduces the shale permeability is by physically plugging of the nanometer sized pores (Katherine et al, 2012) [15]. The right sized nanoparticles in combination with the correct fluid loss system can minimize the fluid-rock interaction.

This paper evaluates the impact of nano Titanium Nitride (TiN) particles on the conventional water based drilling fluid. The formulated drilling fluids will be evaluated through experimental and performance simulation studies.

2 EXPERIMENTAL INVESTIGATION

Ahmed et al [16] have reviewed about 200 water based drilling fluids used in the field. Their study showed that the amount of bentonite used in drilling mud varies between 0 and 14% of the slurry. However, the average was 6% bentonite. The average was found to be 5%. From the study, we found that 0.5g CMC was suitable in the considered 5%wt bentonite system. In this paper, several screening tests were performed to obtain a fluid system, which can easily flow.

For the experimental investigation, a conventional nano-free water based drilling fluid was formulated as a reference. The impact of nano-TiN particles on the reference system has been studied by adding a 0.06-0.08 wt % spectrum of TiN nanoparticles.

2.1 Materials characterization

2.1.1 Titanium nitride (TiN)

Titanium nitride (TiN) nanoparticles have a high melting point (2950 °C), high hardness, high-temperature chemical stability, and excellent thermal conductivity properties. Because of these properties TiN nanoparticle is an excellent ceramic material for high intensity scenarios. **Figure 1** shows a scanning electron microscope (SEM) photograph of titanium nitride, which has a spherical morphology. The particle has been purchased from *EPRUI Nanoparticles and Microspheres Co. Ltd* [17]. **Table 1** provides the typical properties of TiN.

Purity	> 97%
Average Nanoparticle Size	20 nm
Specific Surface Area	48 m^2/g
Melting Point	2950 °C
Density, true	5.22 g/cm3

Table 1: Properties of TiN

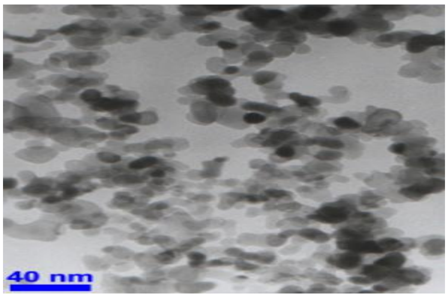

Figure 1 SEM picture of TiN particle

2.1.2 Bentonite

Bentonite is used as viscosifier additive in water-based mud. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the prime factors that determine their properties. Most clay has a mica-type structure, with flakes composed of tiny crystal platelets as shown in **Figure 2a**. A single platelet, called a unit layer, consists of an octahedral sheet and one or two silica tetrahedral sheets. Oxygen atoms tie the sheets together by covalent bonds. **Figure 2b** shows an **i**llustration of Bentonite aggregations, which is related to the rheology and filtrate loss properties of drilling fluid [19]. The addition of nanoparticles may play a role in the network of the aggregated bentonite system and will be studied later.

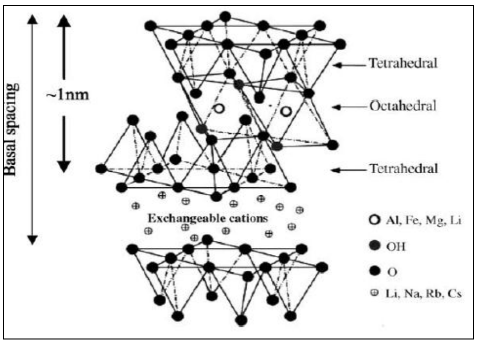

Figure 2a: (2:1 type)-Montmorillonite [18]

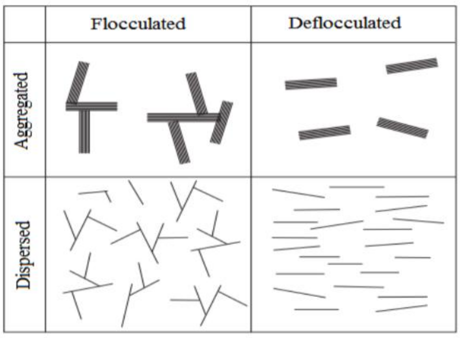

Figure 2b: Illustration of Bentonite aggregations [19]

2.1.3 CMC Polymer

Carboxymethyl cellulose (CMC) is derived from cellulose, which is carboxymethyl groups (-CH_2-COOH) bound to some of the hydroxyl groups. CMC has linear structure and is a polyelectrolyte. It is formed by the reaction of sodium salt of monochloroacetic acid ($ClCH_2COONa$) with cellulose. In drilling fluids where bentonite is a component, CMC can be used to increase the viscosity, control the fluid loss and maintain adequate flow properties at high temperatures [20].

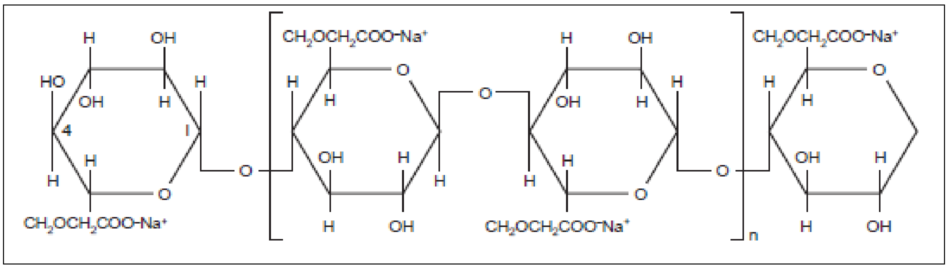

Figure 3: Structure of Sodium CMC [20].

2.1.4 Salts-KCl

For water sensitive shale formation, the potassium- and water-based drilling fluids are the most widely used. Potassium chloride is more effective in reducing swelling than other salts such as sodium chloride (NaCl) at the same concentration [21]. The K^+ ions attach to clay surfaces and the size can fit the plates of clay.

3.2 TiN Nanoparticle treated drilling fluid formulation and Characterization

The conventional drilling fluids system has been formulated by mixing 500g fresh water (H_2O), 2g salt (KCl), 0.5g polymer (CMC), and 25g bentonite. This was considered as the reference – nano free – fluid (**Ref**). Nano-based drilling fluids have been prepared by adding Nano-TiN particles to the reference fluid. The drilling fluids were mixed with a Hamilton beach mixer, and were aged for 48 hours in order for the bentonite to swell. All the tests were carried-out according to API RP 13B-1 [22] standard. Table 2 shows the test matrix. The formulation of the fluids was as follows:

- Reference fluid (1) = 500gm H_2O + 2gm KCl + 0.5gm CMC + 25gm Bentonite
- Nano-treated fluids (2-5) = Reference fluid (1) + (0.05-0.2)gm TiN

Ingredient	Fluid 1 Ref	Fluid 2 Ref + 0.05gm TiN	Fluid 3 Ref + 0.10gm TiN	Fluid 4 Ref + 0.15gm TiN	Fluid 5 Ref + 0.20gm TiN
H_2O[g]m	500	500	500	500	500
Nano - TiN[gm]	0	0.05	0.10	0.15	0.20
CMC[gm]	0.5	0.5	0.5	0.5	0.5
KCl[gm]	2.5	2.5	2.5	2.5	2.5
Bentonite[gm]	25	25	25	25	25

Table 2: Test matrix of nano-TiN CMC polymers.

2.2.1 Rheology and filtrate loss evaluation

Figure 4 shows the measured viscometer responses for the formulated mud systems provided in **Table 2**. As can be shown on the figure, the performance of nano-TiN in CMC behaves non-linearly as the concentration varies. For all nano-TiN additive systems, the measured rheology values are higher than the nano-free system. The responses of the 0.05gm and 0.1gm are nearly the same and are higher than the rest of the drilling fluids.

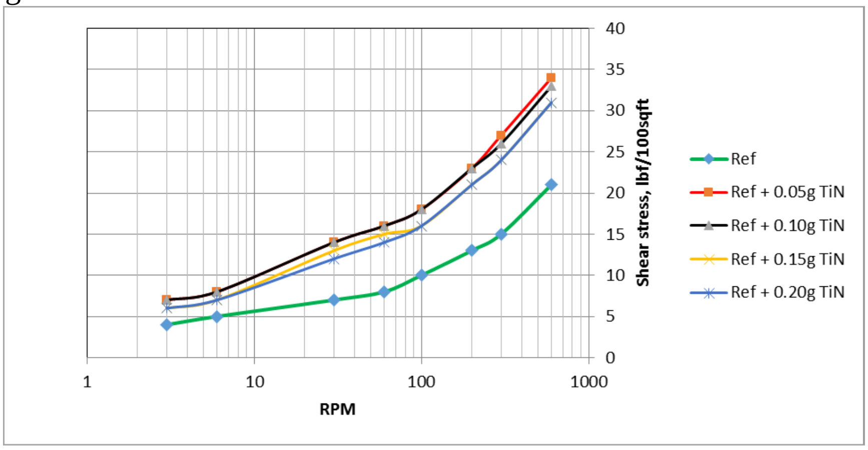

Figure 4: Viscometer measurement of test matrix –Table 1.

Figure 5 shows the computed Bingham parameters (yield strength (YS), plastic viscosity (PV)) and the lower shear yield stress (LSYS). The results show that the addition of 0.05gm TiN increases the yield strength by 122 %. For the higher concentration (i.e 0.2gm), the yield strength increases by 89 %. For the considered whole spectrum of the nano additives, the PV and LSYS increased by +17 % and +55%, respectively. Scott et al [23] have indicated that a LSYS value between 7-15lbf /100sqft is good for controlling barite sagging. As can be seen from the analysis, the impact of TiN on the various drilling fluid parameters, is significant, especially on the yield strengths. This can be interpreted as the TiN might have increased the attractive force of attraction between the clay plates.

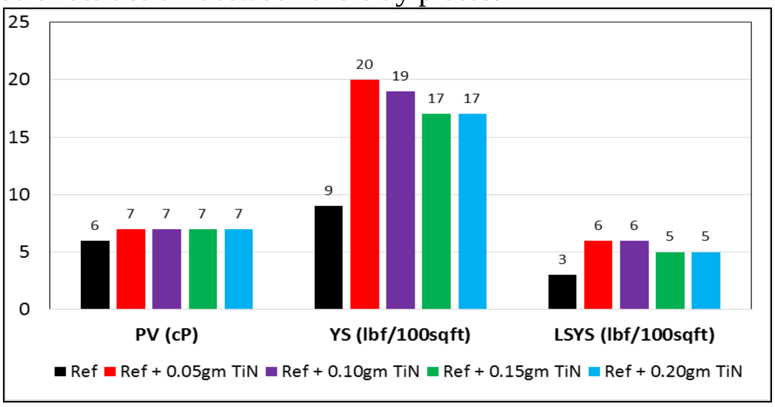

Figure 5 Calculated Yield strength, Plastic viscosity (PV) and lower shear yield strength (LSYS)

Figure 6 displays the computed consistency index (k) and flow index (n) Power law parameters. These parameters impact the hole cleaning and hydraulics performance of the drilling fluid. As shown in the figure, the addition of 0.05gm and 0.2gm TiN increase the consistency index from 0.7 to 3.4lbfs^n/100sqft and 2.4lbf.s^n/100sqft respectively. Converting into percentages, the nano additives increase the k-value by +386 and +284%, respectively. On the other hand, the 0.05gm and 0.2gm TiN decrease the flow index (n) by -40% and -20% respectively.

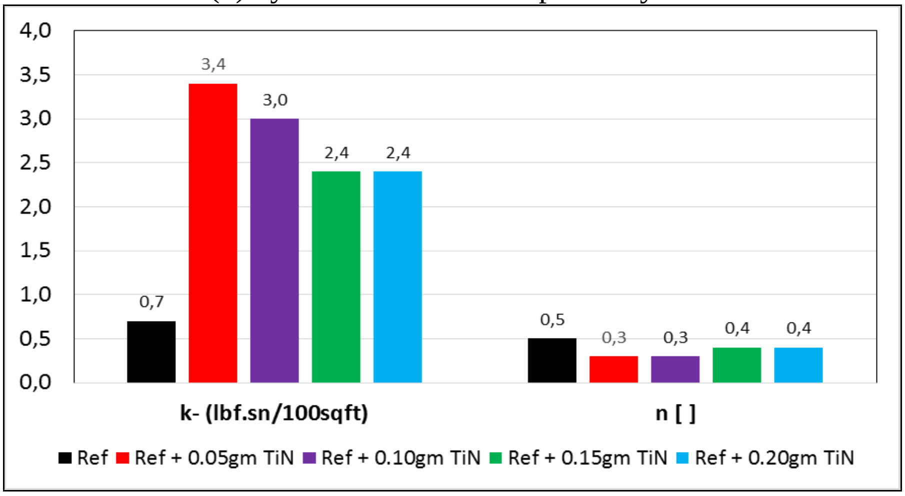

Figure 6: Computed consistency index(k) and consistency flow index n-value

Table 3 shows the 7.5 minutes static filtrate loss measured with an API filter press. As shown, the concentration 0.05g (0.0095 wt%) of TiN nanoparticles decreases the filtrate loss by -7.14%. One can observe the non-linear filtrate loss as the nano-concentration increases higher than the 0.05gm.

The 0.05gm TiN drilling fluid system increases the plastic viscosity, yield and gel strength. But the decrease in filtrate loss may have been caused by the dispersed and flocculated nature of the system.

Parameters	**Ref.**	**Ref + 0.05g TiN**	**Ref + 0.10g TiN**	**Ref + 0.15g TiN**	**Ref + 0.20g TiN**
Filtrate (ml)	7	6.5	7	7.5	7.2
% Change		-7.14	0.00	7.14	2.86

Table 3: Filtrate loss after 7.5 minutes.

2.2.2 Coefficient of friction evaluation

A Ball-plaste CSM tribometer [24] was used to measure the lubricity of the drilling fluids. The measurement was on ball and plate surface contact in the presence of the drilling fluid. The steel ball is an alloy of 6-chromium and 6mm diameter. At first, several tests were carried out in order to calibrate the test machine and get reliable results. The lubricity of the formulated drilling fluids has been measured at 20, 50 and 70 deg centigrade. For each testing, repetitive tests have been performed with the objective of obtaining representative average values.

Figure 7 shows the test results of the nano free and the 0.05gm TiN additive fluid system. The test results of the fluids systems (2-5) were measured between the one shown on the figure. Therefore, we only displayed the best system result. One clear observation is that the lubricity is a non-linear function of nano-TiN concentration. One of the possible explanations is that the lubricity is associated with the internal structure of the fluid component association, which also influences the rheology and the filtrate performances. Table 4 shows the measured mean values and the % average deviation from the reference drilling fluid. As shown, the addition of the 0.05gm TiN and 0.1gm TiN reduce the coefficient of friction by -43% and -23%, respectively.

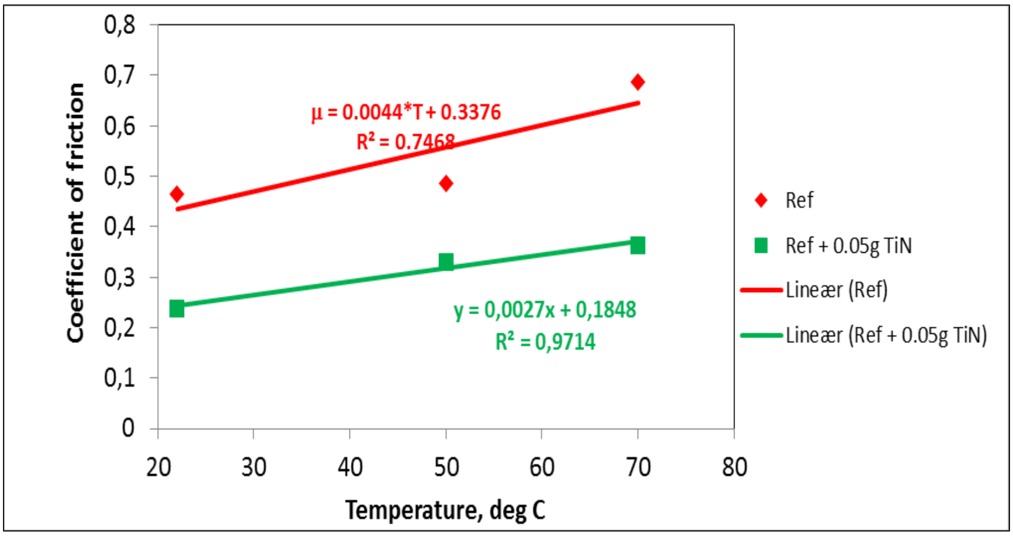

Figure 7: Mean Friction Coefficients vs temperature

3 NANO-FLIUIDS DRILLING PERFORMANCE SIMULATION

Using Landmark/WellplanTM software [25], drill string torque and drag in the considered well trajectory have been evaluated to investigate the impact of the lubricity of the nano treated drilling fluid. The well is a typical drilling trajectory with a maximum inclination of 36deg, with various azimuth variations. During simulation, the tripping in/out speeds and drill string rotation were 60 ft/min and 40 RPM, respectively. A 5'' OD size of E-75 grade drill string was used for the simulation. The drilling fluids have been pumped in the simulation well at the rate of 500gpm. The coefficient of friction between the drill string and the casing, drill string and the open hole was assumed to be constant.

The drilling fluids used for the evaluation are the reference and the 0.05gm TiN nano additives (Fluid 2). The coefficient of friction of these drilling fluids are displayed in **Figure 7**. For the simulation, the average of the three temperature measured coefficient of friction values were used. The mean values are given in Table 4 as 0.546 and 0.311, respectively.

The primary objective of this simulation was to evaluate how far one can drill with the considered drilling fluids. The maximum drilling length was obtained by simulating the torque, drag and the Von-Mises stresses of the drill strings provided that they are in a safe operational window. Among the three simulations, the torque was found to be reaching to the torque makeup limit, and, hence, will only be presented.

Figure 8 shows the simulation results obtained from the reference drilling fluid. As displayed on the figure, for the 10 332ft drillling depth, the torque reaches the limit even though the drag and Von-mises are far more within the safe operational window. Under the given simulation's operational parameters, one can not drill exeeding this depth. Similarly, **Figure 9** shows the simulation results obtaind from the 0.05gm TiN treated drilling fluid. Due to the lower coefficient of friction, the torques are within the safe operational window until the maxmum drilling depth is 13 523ft.

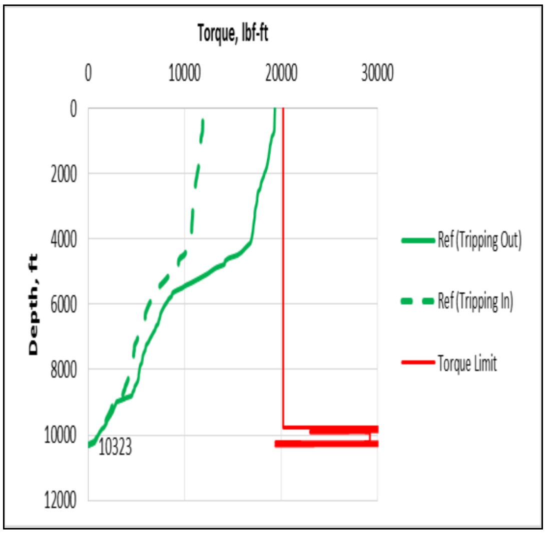

Figure 8: Maximum length drilling with the **reference fluid** (Nano-Free) without exceeding the torque limit.

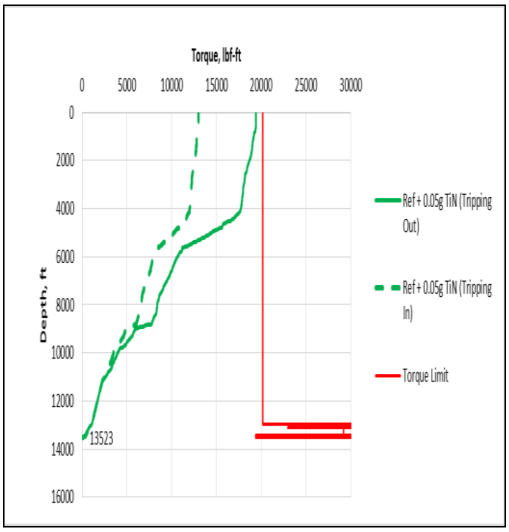

Figure 9: Maximum length drilling **with the 0.05g TiN nanopowder** treated fluid

Table 4 sumarize and compares the maximum drilling depths when drilling with the two drilling fluid types. As shown, the addition of 0.05TiN allows to drill 3200 ft longer than the nano-free drilling fluid. This mean that the drilling length is increased by about 31% due to the reduction of the coefficient of friction by 46%. The results presented here illlstrate the huge potential of nano technology in improving drilling performance.

	Ref	Ref + 0.05g TiN	Ref + 0.10g TiN
Maximum drilling depth, ft	10 323	13 523	11 523
% drilling depth elongation	-	31.00	11.62

Table 4: Maximum lengths drilling with the considered drilling fluids, and the percentage deviation from the reference fluid.

4 SUMMARY

In this paper, the effect of TiN nanoparticle in 25gm bentonite/500 gm H_2O treated with CMC polymer and salt has been tested. The rheology and the lubricity of the drilling fluids have been measured. The results show that the addition of about 0.05gm nano-TiN (i.e. 0.0095wt %) influences behavior of the nano-free reference mud system.

One clear observation is that the performance of nano-TiN is a non-linear effect as the concentration increases. From the overall test results, the performance of the selected optimized 0.095wt% nano-TiN treated drilling fluid system is summarized as follows:

- The nano-TiN additives have the following effects:
    a. Reduces the filtrate by -7.1 %
    b. Increases the yield strength by +122 %
    c. Increases the plastic viscosity by +17 %
    d. Reduces the coefficient of friction by -43 %

- The reduced coefficient of friction allows a +31 % longer drill path than the nano-free drilling fluid.

Please note that this analysis and the summary are based on the performance of nano-TiN in the formulated water-based composition and concentration. Changing the composition and concentration may produce different behavior.

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