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The Effect of Nano-Silicon Dioxide (Sio_2) on the Properties & Performance of Xanthan Polymer/Salt Treated Bentonite Drilling Fluid

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Abstract

Nanotechnology (1nm -100 nm) is a promising technology that could solve the technical challenges of conventional technology. In the recent years, the application of nanomaterial research in oil industy has shown good results in improving performance of cement, drilling fluid and Enhanced Oil Recovery.
In this paper, the impact of of nano Silicon dioxide (SiO_2) on Xanthan gum polymer and KCL salt based bentonite drilling fluid systems has been investigated.
The results show that the performance of nano SiO_2 in bentonite mud system depends on its concentration and the types of salt and polymer systems used. In the considered fluid systems, it is also observed that the addition of about 0.019% SiO_2 influences rheology, and filtrate loss of the drilling fluid systems. The hole cleaning performance simulation study also indicated that the nano treated drilling fluids exhibit a lower flow rate and lower bed deposition as compared with the nano free system.

INTRODUCTION

In rotary drilling operation, drilling fluids plays an important role. The main functions of drilling fluids among many others are to bring cutting to surface, to maintain well pressure, cool well & drill bit and formation of filter cake around on the face of the borehole. Properly designed drilling fluid provides good hydraulics & hole-cleaning performance, reduces formation damage by reducing fluid loss, prevents drill string sticking and increase well strength. The quality of filter cake is characterized by its thickness, porosity, permeability and mechanical properties.

Drilling fluids contain viscosity, density and fluid loss control additives. Polymers are used as an additive in drilling mud to control fluid losses and to provide higher viscosity. The application of polymers largely depend on parameters such as their molecular weight (length) and charge. The question to be addressed is how nano particle interact with the xanthan gum polymer and influences the fluid properties?

Through chemical and/or physical processes, nanomaterials have the ability to create materials with improved properties. These properties include such as thermal, mechanical, electrical, and rheological properties, which depend significantly on size and shape of nanoparticles. 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]. Due to the small size, nanoparticles form a tough, dense mud cake and sealing micro cracks in shale (Riley et al, 2012)[2]. Research results on the fluid loss reduction performance of nano-particles has been documented in drilling fluid (Zakaria et al,2012 [3], Charles et al, 2013 [4], Sharma et al, 2012 [5], Katherina et al [7], Gongrang et la [8]) and in cementing system (Ruhal et al, 2011 [6]).

This paper presents the effect of nano particle in polymer/salt-bentonite drilling fluid system. The formulated drilling fluids are evaluated through rheology, viscoelastic, and API filtrate loss measurements. The performance of the drilling fluid systems also analyzed through cutting transport simulation studies. These investigations motivate us to test commercial nano-SiO_2 in water based drilling fluids.

2. EXPERIMENTAL INVESTIGATION

Nano fluid has been formulated by treating 0.06-0.08 wt % SiO_2 in a conventional water based drilling fluid. The conventional drilling fluid was formulated by mixing water, Xanthan polymer and KCL salt. The description of the drilling fluid ingredients and the measured tests results are presented in this section.

2.1 Materials characterization

2.1.1 Nano-silicon dioxide

15nm sized SiO_2 was used for experimental investigation. The particle was purchased from EPRUI Nanoparticles and Microspheres Co. Ltd [9]. Since we have not received the detail specification of the particle, we have characterized the structure and the Elemental Dispersive Spectroscopy (EDS) for elemental identification using Scanning Electron Microscopy (SEM). Figure 1a and Figure 1b show the SEM image and EDS element analysis, respectively. Based on Figure 1b, one can observe the purity of the nano- SiO_2. Please note that the palladium (pd) is not part of the nano particle. It was used for SEM analysis.

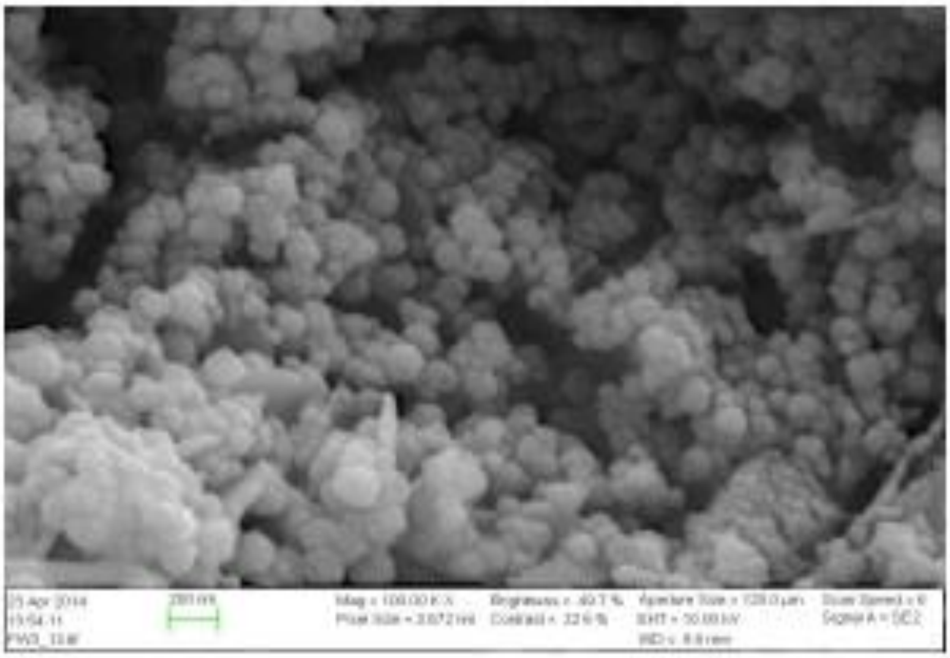

Figure 1a: SEM picture of nano- SiO_2.

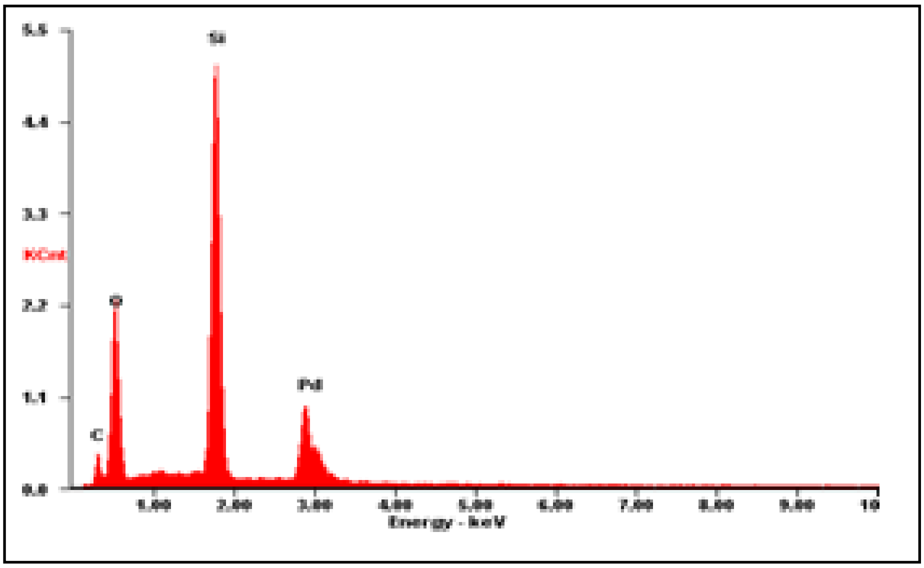

Figure 1b: Element analysis of nano- SiO_2.

2.1.2 Bentonite

In water-based muds (WBMs), bentonite is used as viscosifier additive. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the main factor to determine their properties. Figure 2 shown an idealized structure of a montmorillonite layers, which is composed an octahedral sheet and two silica tetrahedral sheets.

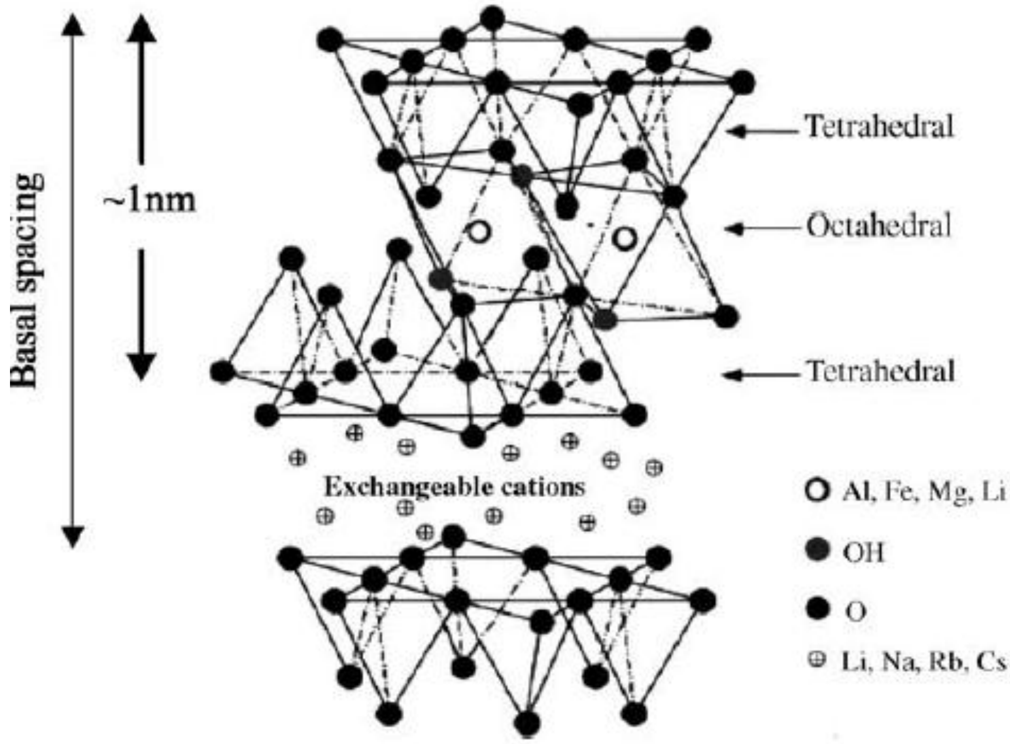

Figure 2: Idealized structure of a montmorillonite layers (2:1 type) [10].

2.1.3 Xanthan gum Polymer

Xanthan gum is a water soluble polymer. It is used to thicken water based drilling mud due to its viscous properties. As can be seen from Figure 3, Xanthan gum composes of a five-ring structure: A three-ring side chain with a two-ring backbone. Coupled to the side chain are different functional groups such as carbonyl and hydroxyl. This unique branching structure gives Xanthan gum thixotropic properties. The polymer branches will connect by hydrogen bonding. Since the hydrogen bondings are weak, they will break when shear is applied to the system. Under low shear rate conditions, the hydrogen bonding will again connect, and viscosity goes back to initial state. [12]

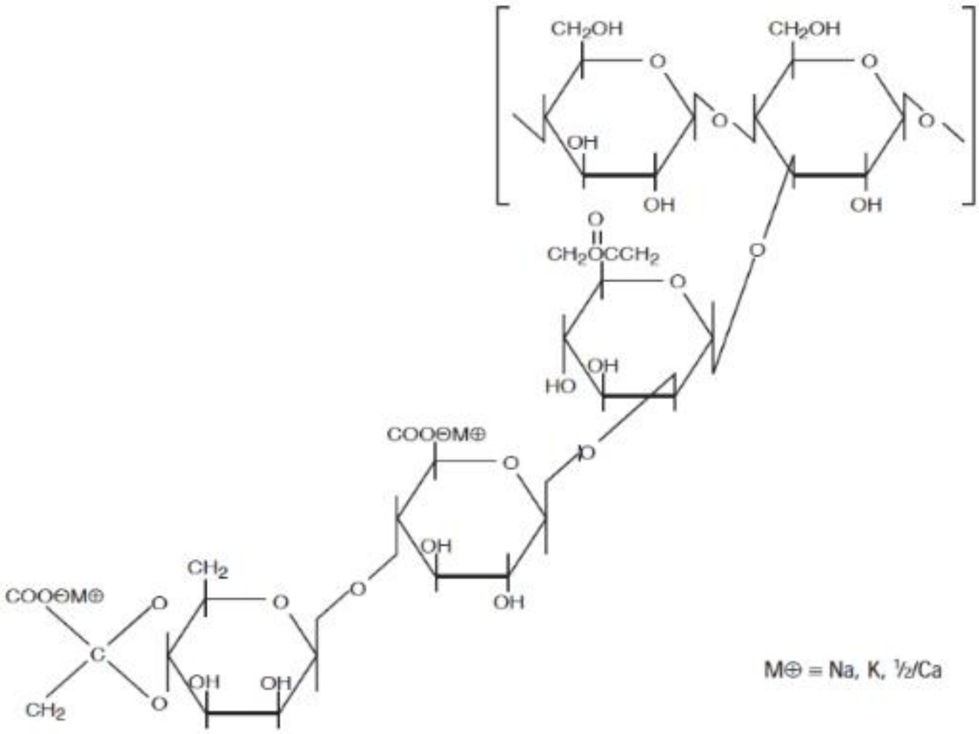

Figure 3: Structure of Xanthan gum [11].

2.1.4 KCLSalt

Potassium chloride salt is the most commonly used in water based drilling fluid system for drilling water sensitive shales. The K^+ ions attach to clay surfaces and the size can fit the plates of clay. Potassium is exchanged for sodium and calcium when drilling in shale that contains montmorillonite, resulting in a more stable fluid system and is less susceptible to hydration [13]. Potassium chloride is more effective in reducing swelling than other salts such as sodium chloride (NaCl) at the same concentration. [12]

2.2 Nano-SiO_2 treatead drilling fluid formulation and Characterization

For the investigation, a reference bentonite /polymer and salt treated water based mud system was considered. The drilling fluids were prepared by adding 25gm bentonite in 500gm water, polymer, salt and nano- SiO_2. The drilling fluid systems were mixed with Hamilton-beach mixer and were then aged for 48 hours at room temperature in order the bentonite clay to swell well. The nano particle free mud system here after is going to be named as reference, or (**Ref**). All testing were carried out according to the API RP 13B-1 [14] standard.

Several screening test was performance to obtain a soup like fluid system, which can easily flow. From the study, we have obtained 0.5gm Xanthan gum was suitable in the considered bentonite system. Therefore, a total six fluid system was formulated as shown on Table 1.

Table 1: Test matrix of nano-SiO_2 in KCl and Xanthan gum systems.

Mud/ additives	**Water (gm)**	**Bentonite (gm)**	**Xanthan gum (gm)**	**KCl (gm)**	**Nano** SiO_2 **(gm)**
Ref	**500**	**25**	**0.5**	**2.5**	**0.0**
Ref +0.1 SiO_2	500	25	0.5	2.5	0.1
Ref +0.2 SiO_2	500	25	0.5	2.5	0.2
Ref +0.3 SiO_2	500	25	0.5	2.5	0.3
Ref +0.4 SiO_2	500	25	0.5	2.5	0.4
Ref +0.5 SiO_2	500	25	0.5	2.5	0.5

2.2.1 Rheology and filrate loss evaluation

Figure 4 shows the measured viscometer responses for the formulated mud systems provided in Table 5. As can be shown on the figure, the performance of nano SiO_2 in Xanthan gum behaves non-linearly as the concentration varies, which is a similar phenomenon as observed in CMC systems.

For all nano SiO_2 additive systems, the measured rheology values are higher than the nano free systems. Comparing the 0.1 gm nano additive with the 0.5gm nano additive, the 0.1 shows higher yield strength than the 0.5gm nano system. Another observation is that the measured rheology data becomes closer to the nano free system as the nano concentration increases from 0.1 to 0.5g. One clear observation is that all of the nano treated systems increase the apparent viscosity of the fluid systems.

Figure 5 also shows the computed Bingham/Power law parameters and the 7.5min measured filtrate losses. As shown in the figure, the addition of 0.3gm and 0.4gm nano increase the plastic viscosity by 56% and 33% respectively. These additives increase the yield strength by 60% and 93% respectively.

The addition of 0.1gm and 0.2gm nano reduce the plastic viscosity by 11%, which is negligible. The yield strength is increased by 153.3% and 126.7%, respectively. This is also an indication that nano-additives might have created a deflocculated system. The 0.5gm nano- SiO_2 increases the yield strength by 60 %, but does not show any significant effect on the plastic viscosity.

The addition of 0.1gm and 0.2gm nano- SiO_2 reduce the plastic viscosity & filtrate loss and increase the yield strength & gel strength. This is an indication that the system became aggregated and flocculated. On the other hand, the addition of 0.3gm and 0.4gm nano- SiO_2 increase the plastic viscosity, yield & gel strength, but the decrease in filtrate loss was due to the system might have been dispersed and flocculated type.

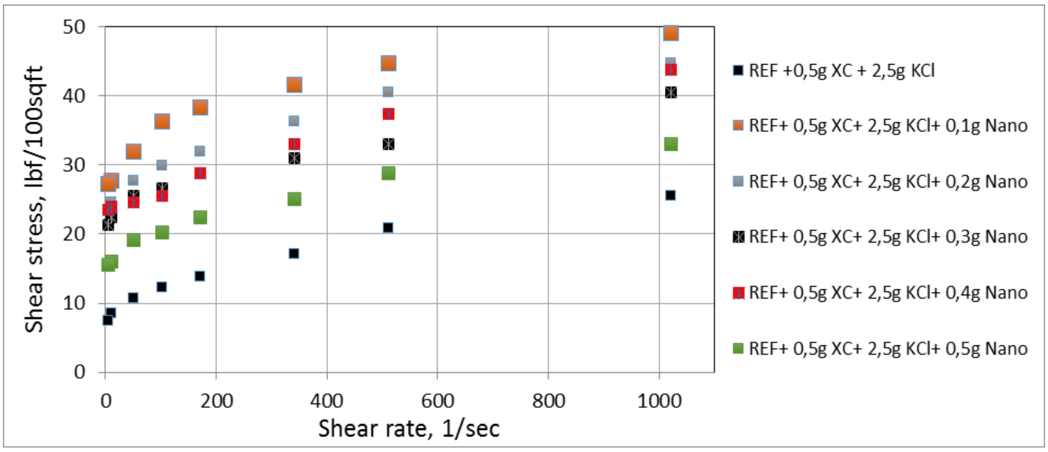

Figure 4: Viscometer measurement of Table 1.

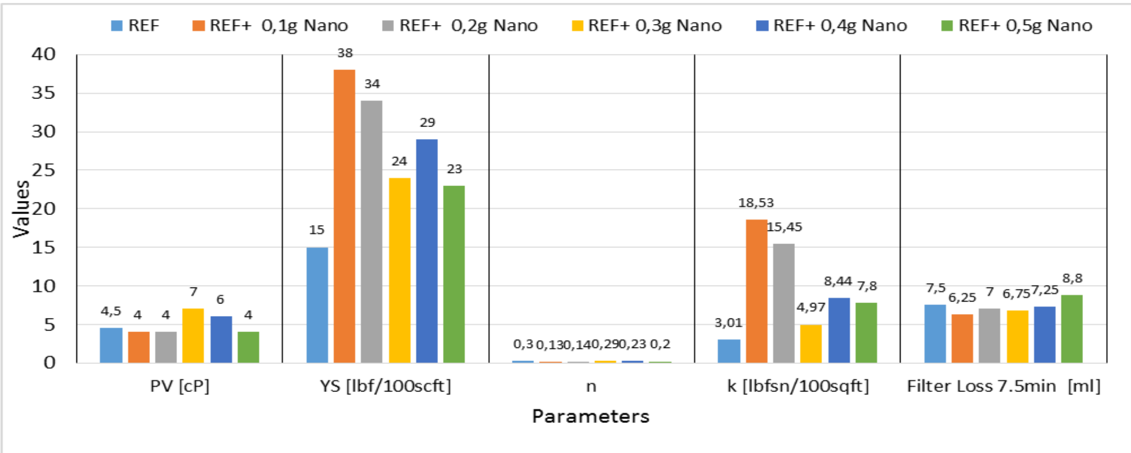

Figure 5: Calculated paramerter and measured filtrate loss.

The flow index (n) and consistency index (k) of a drilling fluid are also important input parameters for hydraulics and hole cleaning and ECD issues. As shown in figure 10, the consistency index of the fluid systems also highly influenced by the nano- SiO_2 than the flow index. As can be seen on the figure, the addition of 0.1gm nano- SiO_2 increases the k-value by 515.6%. The least effect observed by 0.3gm nano, which increase the k-value by 65.12%.

Table 2 shows the measured filtrate loss and percentage filtrate loss changes. The table shows that except the 0.5gm nano - SiO_2 additive, the rest concentrations reduce the filtrate loss as compared with the nano-free system.

Table 2: Comparisons of filtrate losses of SiO_2 based fluids in Table 1 system.

Mud/ Parameters	**Ref**	**Ref+ 0.1gm** SiO_2	**Ref+ 0.2gm** SiO_2	**Ref+ 0.3gm** SiO_2	**Ref+ 0.4gm** SiO_2	**Ref+ 0.5gm** SiO_2
7.5 min Filtrate [ml]	7.5	6.25	7.0	6.75	7.25	8.75
% Filtrate change		-16.7	-6.7	-10.0	-3.3	16.7

The 0.1gm nano-SiO_2 system reduced the filtrate loss by 16.7%. Whereas, the addition 0.5gm nano destabilized the internal structure of the fluid system and increased the filtrate loss by 16.7%.

2.2.2 Viscoelasticity evaluation

Drilling fluid behaves as a viscous and an elasticity, which is called viscoelasticity. The internal structure of the fluid systems best optimized nano fluid system has been evaluated using Anotn-Paar viscoelasticity measuring equipment [15].

The amplitude dymanic sweep respoences of the fluid specimens were studied in order to learn the structural stability, strength and dynamic yield point and flow points of the Nanoparticle treated with Nano free drilling fluids. Table 3 shows comparion of yield strength value obtained from Anton-Paar and API Fann-77 viscometer equipments. Comparing conventional drilling fluid (Ref) and nano treated drilling fluid, the Nano additive does not show any effect on the yield strengths. During testing, both of the fluid systems show almost the same storage and loss modulus (G'=G'').

Table 3: Comparisons of Yield strength of drilling fluids measured from Anton-Paar and Fann-77 viscometer.

Drilling fluid systems	**Anton-Paar** Yield point (pa)	**Fann -77** Bingham Yield strength (pa)
Reference/Conventional Drilling fluid (Ref) = 25gm Bentonite/500H_2O + 2.5gm KCl + 0.5gm Xanthan gum	0.7777	7.18
Nanotreated Drilling fluid = **Refe** + 0.1gm nano- SiO_2	0.7778	18.19
% Change =	0.01%	153.3%

4. HOLE CLEANING PERFORMANCE ANALYSIS OF THE FLUID SYSTEMS

This section presents the performance simulation studies of the selected drilling fluid system. As mentioned in the introduction part, cutting transport is one of the main function of drilling fluid. The cutting transport efficiency of the fluid systems depeneds on among others on its rheological properties. The fluid systems considered in Table 1 are also used to evaluate their cutting lifting capacity through simulation study. Using Landmark/Wellplan^{TM} software [16], simulation was performed in 8.5 in well to determine the minimum flow rate to clean out cutting from the hole without bed deposits. When the flow rate is less than the minimum requirement, particles will begin to settle in the annulus.

In this simulation, the well is inclined from vertical to horizontal. Tabe 4 provides the simulation parameters. As displayed on Figure 6, the results obtained from the simulation shows that the fluid containing 0.1g nano silica requires a lower flow rate and the reference requires a higher flow rate to transport cuttings.

Table 4: Cutting transport simulation parameters.

Parameters	Values
Cutting density [g/cc]	2.6
Cutting size [in]	0.25
Cutting porosity []	0.40
RPM []	100
ROP[ft/hr]	60
Drill bit size [in]	8.5
Drill string size [in]	5.0

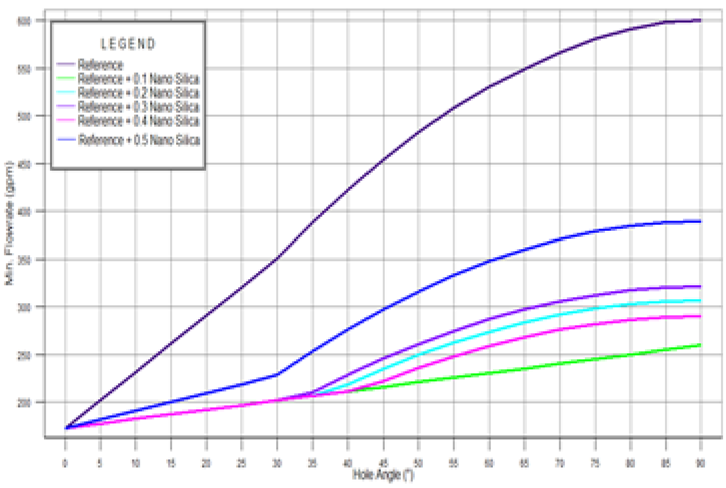

Figure 6: Comparison of minimum flow rate of fluids.

Similarly, the bed height simulations were carried out in a well deviated from vertical to about 36deg inclination (See Figure 7a). IFor this simulation, we have selected the 0.1gm and 0.5gm nano additive system along with the nano free reference system. The cutting transport circulation rate was 400 gpm. The cutting transport operational and cutting properties are the one provided in Tabe 4.

The simulation results on Figure 7b show that at the considered flow rate, the 0.1gm nano treated fluid system exhibits about 50% lower bed height deposition as compared with the reference nano free system.

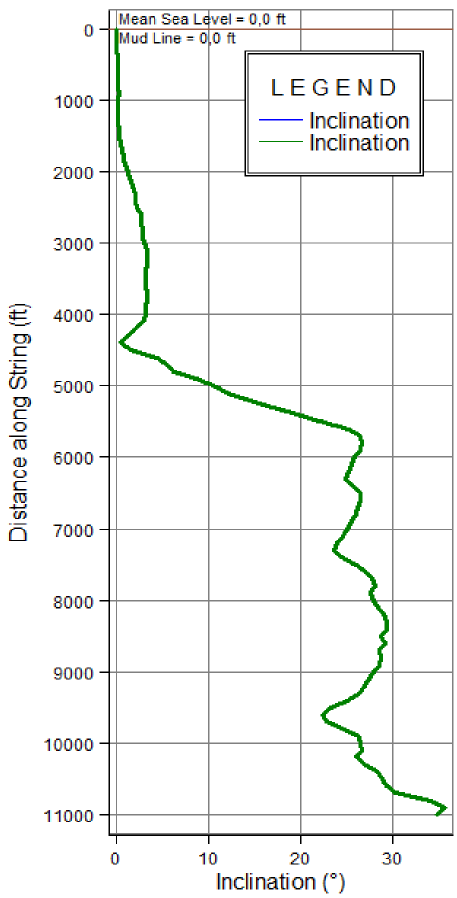

Figure 7a: Well inclination

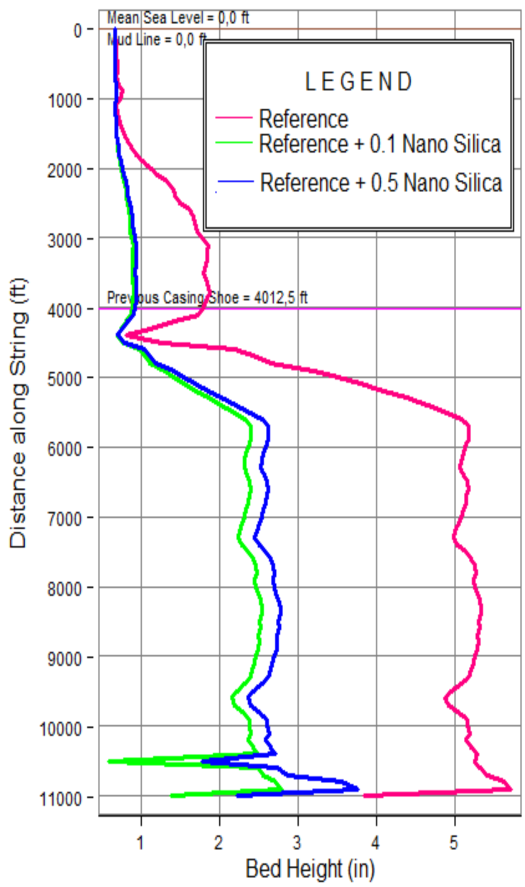

Figure 7b: Smulated bed height.

4 SUMMARY

In this paper, the effect of nano- SiO_2 in 25gm bentonite /500 gm H_2O treated with polymers and salts has been tested at 72°F. From the overall test results, the performance of the selected optimized 0.019wt % (i.e 0.1gm) nano- SiO_2 Xanthan gum system has shown an impact on the rheology parameters, reduced filtrate loss and good cutting transport performance.

One clear observation is that the performance of nano- SiO_2 depends on its concentration, types of polymer and salt system. From the test result, it is observed that for a given system there exists an optimum concentration that works best in fluid system. Although nano based drilling fluids can be more expensive than conventional one, nano-fluids drilling muds may have the potential to reduce drilling related problems and improves performances.

FUTURE WORK

The present work is limited to an evaluation of nano-SiO_2 in various polymer and salt systems. However, the knowledge of the performance mechanisms is very important. In future, the rock/fluid interaction, the chemo/thermo/electrical properties of the Nano fluid, the lubricating, particle stability at the mouth a fracture and well strengthen properties of the nano-SiO_2 based fluids will also be investigated.

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