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The Impact of Nano-Silicon Dioxide (Sio_2) on Property and Performance of the CMC Polymer/Salttreated Bentonite Drilling Fluid Systems

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Abstract

In the petrolem industry, research results have shown that nanomaterials improve the properties and performances of cement, drilling fluid and Enhanced Oil Recovery.
This paper is trying to look at the effect of nano Silicon dioxide (SiO_2) on CMC polymer and KCL/NaCl salt blended water based bentonite drilling fluid system.
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 0.06wt % SiO_2 influences rheology, and filtrate loss of the drilling fluid systems. The simulation result of the selected best nano treated system has also shown impact on hole-cleaning and hydraulics performances.

1 INTRODUCTION

In rotary drilling operation, drilling fluid is circulated down the drillstring, through the bit and back to the surface through the annulus. Among many others, drilling fluids are used to maintain well pressure, transport cutting and cool well & drill bit and formation of filter cake. Good mud cake reduces fluid loss and increase mechanical strength of a wellbore. The quality filter cake depends on its thickness, porosity, permeability, and toughness. These properties are a function of the filter cake structural make up.

Conventional water based drilling fluids are formulated with fluid loss control additives, weight materials and viscosifiers. However, water based drilling fluids do not completely solve shale swelling problem.

Nanotechnology (1nm -100 nm) is believed to have solving potential problems of conventional technology. Nanomaterials improve material properties such as thermal, mechanical, electrical, and rheological through chemical and/or physical processes. The surface area to volume ratio of the nano-system is higher than the micro/macro sized particles systems (Amanullah et al, 2009) [1]. Nanoparticles form a tough, dense mud cake and sealing micro cracks in shale (Riley et al, 2012)[2]. The fluid loss reduction potential of nano-particles is 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]).

In this papers, SiO2 was selected to analyze its performances in CMC polymer/salt-bentonite drilling fluid system. The formulated drilling fluids evaluated through Fann-77 rheology, viscoelastic, and API filtrate loss measurement. The performance of the drilling fluid systems also analyzed through hydraulics and cutting transport simulation study.

2 EXPERIMENTAL INVESTIGATION

For the purpose of investigating the effect of nano SiO_2, a conventional drilling fluids has been formulated using CMC polymer, KCL salt and bentonite water based drilling fluids. This section presents the material descriptions, drilling fluid test matrix and the measured test results.

2.1 Materials characterization

2.1.1 Nano-silicon dioxide

The commercial nano particle purchased from EPRUI Nanoparticles and Microspheres Co. Ltd, China [9]. The structure and the element analysis of nano-SiO_2 particle have been characterized by using Scanning Electron Microscopy (SEM, Figure 1a) and Elemental Dispersive Spectroscopy (EDS, Figure 1b), respectively. 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.

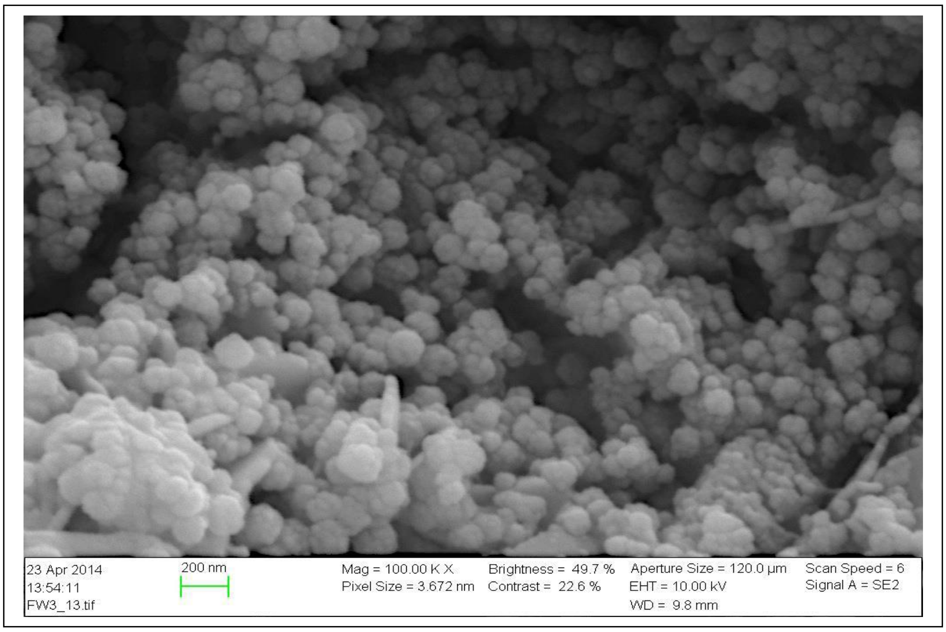


Figure 1a: SEM picture of nano- SiO_2.

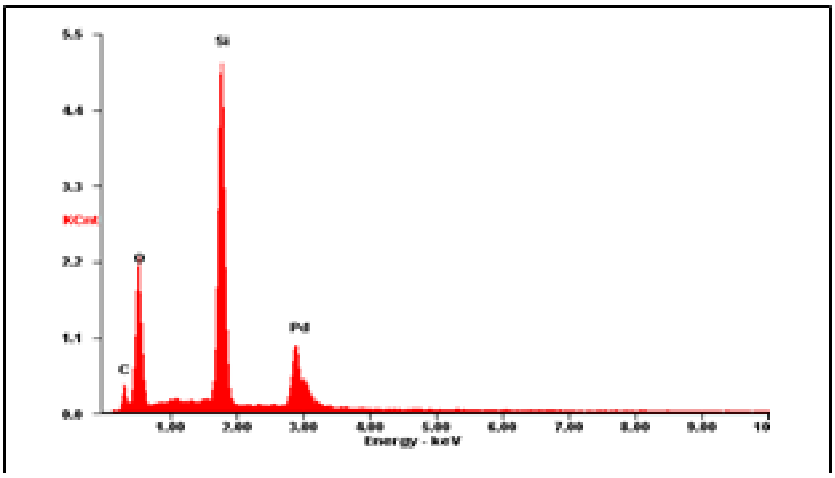


Figure 1b: Element analysis of nano- SiO_2.

2.1.2 Bentonite

Bentonite is a commonly used additive, which viscosify water based drilling fluid. The atomic structures of clay crystals are the key factor to determine their properties. Figure 2 is an idealized structure of a montmorillonite layer showing two tetrahedral-site sheets fused to an octahedral-site sheet (2:1 type) [10]. Oxygen atoms tie the sheets together by covalent bonds.

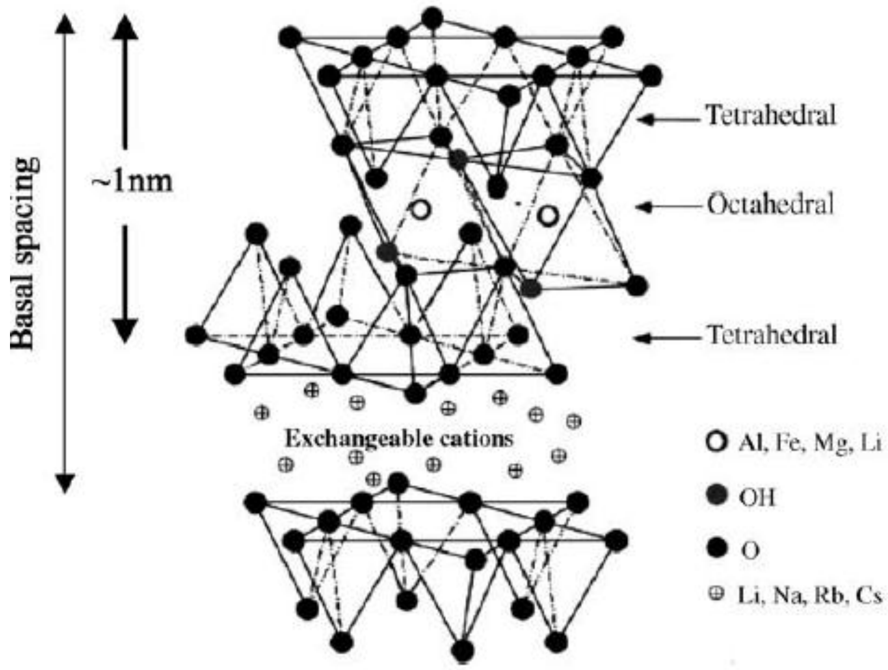


Figure 2: Structure of a montmorillonite layer [10].

2.1.3 Polymers Carboxymethyl Cellulose

CMC has linear structure and is a polyelectrolyte. As illustrated on Figure 3, the molecular formula is $[C_6H_7O_2(OH)_2CH_2COONa]n$. 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 [11, 12].

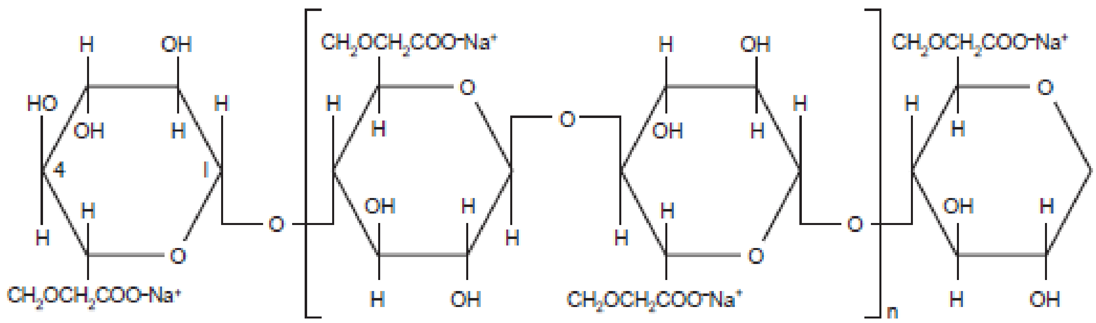


Figure 3: Structure of Sodium CMC [11].

2.1.4 Salts

2.1.4.1 KCl

Potassium chloride is the most widely salt in water fluid system for drilling water sensitive shales. The K^+ ions attach to clay surfaces and the size can fit the plates of clay. Potassium based fluids are superior to calcium fluids due to their shale-inhibition properties [13]. Potassium chloride is more effective in reducing swelling than other salts such as sodium chloride (NaCl) at the same concentration. [12]

2.1.4.2 NaCl

Sodium chloride is less used in drilling fluids than potassium chloride. Na^+ is not as good as the K^+ ion, but has other advantages such as reducing the invasion of filtrate into the clay [14].

2.2 Nano-SiO_2 treatead drilling fluid formulation and Characterization

A conventional nano free reference drilling fluid has been formulated from bentonite, CMC polymer, salts and water. The nano-based and the conventional drilling fluid systems were mixed with Hamilton-beach mixer and then aged for 48 hours at room temperature for the bentonite clay to swell. 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 [15] standard. Since the drilling fluids are not treated with weighing materials, the density of all fluid systems presented in this paper is 1.02sg.

After several screening tests, the mixture of 2.5gm KCL/NaCl with 25gm Bentonite and 500gm H_2O shows a nice system and less viscous to flow. Therefore, the rest of nano SiO_2 effect tests were carried out on this selected composition. Table 1 shows the formulated test matrix considered for the evaluation of nano-SiO_2.

Table 1: Test matrix of nano-SiO_2 treated water based drilling fluids

Additives /mud systems	**Reference (Ref)**	**Ref + 0.2gm Nano** SiO_2	**Ref + 0.3gm Nano** SiO_2	**Ref + 0.4gm Nano** SiO_2
Water (gm)	500	500	500	500
Bentonite (gm)	25	25	25	25
CMC (gm)	0.5	0.5	0.5	0.5
KCl (gm)	2.5	2.5	2.5	2.5
NaCl (gm)	2.5	2.5	2.5	2.5
SiO_2 (gm)	0.0	0.2	0.3	0.4

2.2.1 Rheology and filrate loss evaluation

Figure 4 shows the measured viscometer response data of the drilling fluid systems. As can be seen on the figure, the sloid line that follows the black triagle data are the nano-free reference drilling fluid. The addition of 0.2g and 0.3gm nano shift viscometer data downward with respect to the reference nano-free systems. On the other hand, the addition 0.4gm nano- SiO_2 shifts the measured viscometer data above the reference fluid system.

Figure 5 shows the computed Bingham and power law parameters as well as the 7.5min measured filtrate losses. As shown, the addition of 0.2gm and 0.3gm nano reduces the plastic viscosity by -36% and -29%, respectively. This is an indication that the nano-additives might have created a deflocculated system. The 0.4gm nano additive does not show any effect on the plastic viscosity. Another observation is that the addition of 0.2gm and 0.4 gm nano- SiO_2 increase the yield strength, whereas the 0.3gm nano reduces the yield strength of the drilling fluid.

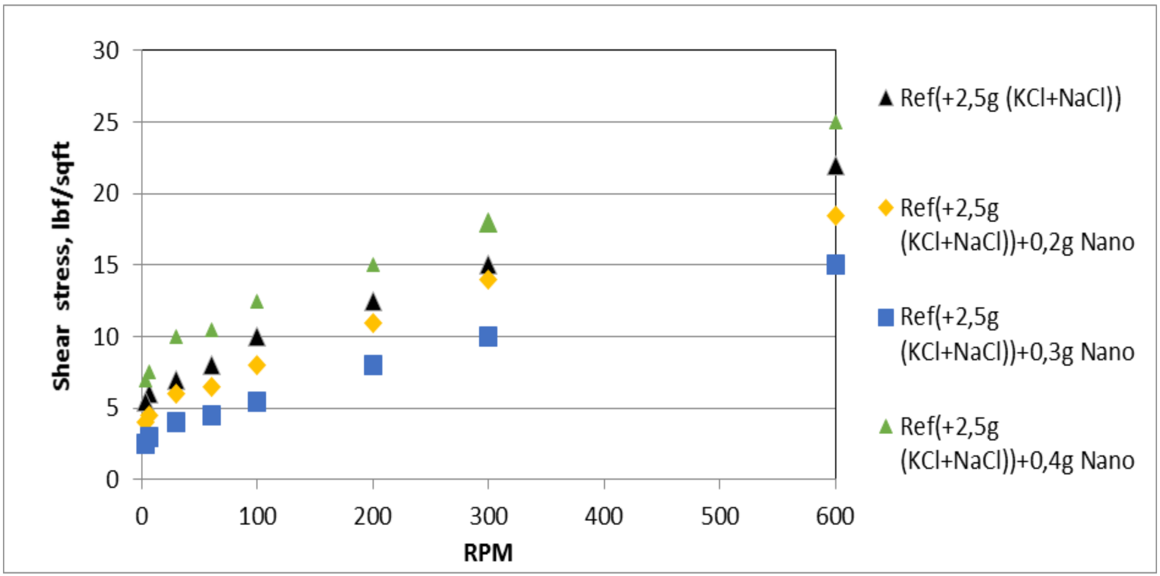


Figure 4: Viscometer measurement of Table 1

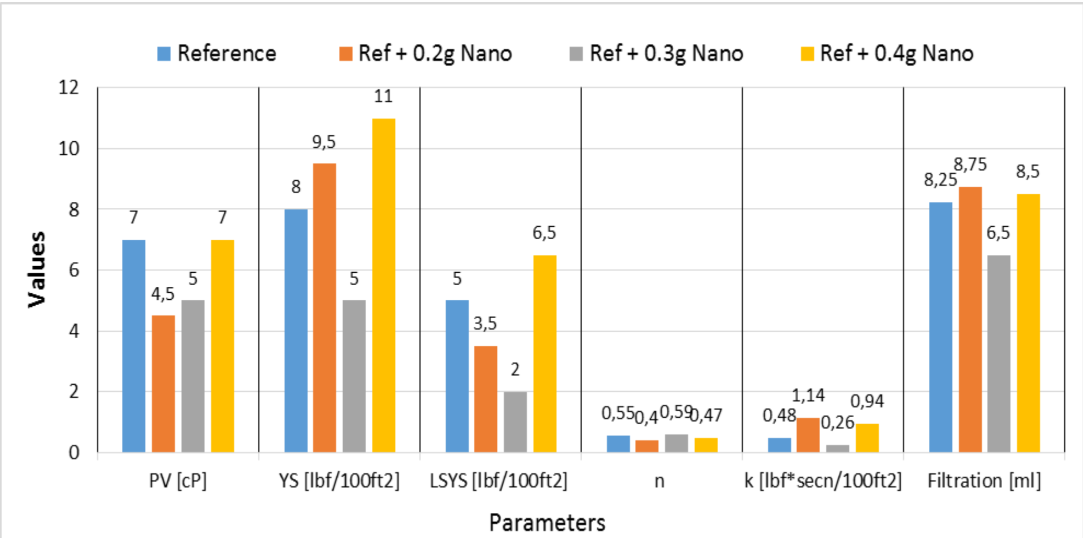


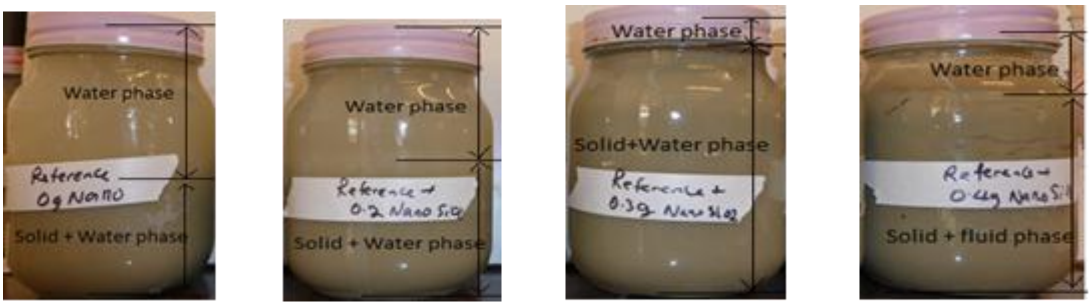
Figure 5: Calculated parameters and measured filtrate loss

As shown in Table 2, the addition of 0.3gm reduces the filtrate loss by 21.2%. Whereas, the addition of 0.2gm and 0.4gm increase the filtrate loss by 6.1% and 3.0% respectively. This illustrates that under the given fluid composition and testing condition, the 0.3gm nano- SiO_2 is an optimum value, which creates a good structure that controls filtrate loss. The others observation is that below or higher than 0.3gm shows a disintegrated structure, which allows fluid loss from the system.

Table 2: Comparisons of filtrate losses of nano-SiO_2 based fluids in Table 3 system.

Mud/ Parameters	**Reference (Ref.)**	**Ref + 0.2gm** SiO_2	**Ref + 0.3gm** SiO_2	**Ref + 0.4gm** SiO_2
7.5 min Filtrate [ml]	8.25	8.75	6.5	8.5
% Filtrate change		6.1	-21.2	3

As illustrated in figure 6, except picture (c), all other systems created two phases separating water from the bentonite. This indicates that nano additive might have undergone a chemical reaction with the surface charge of bentonite, salt and polymer.



[a] [b] [c] [d]

Figure 6: [a] Reference, [b] Ref.+0.2Nano, [c] Ref.+0.3Nano, [d] Ref.+0.4Nano.

2.2.2 Viscoelasticity evaluation

Drilling fluids exhibit both a viscous and an elasticity behaviors. Based on fluid loss and other rheology properties, the 0.3gm-nano additive systems is found out to be the best system. The dynamic response of the internal structures the 0.3gm-nano SiO_2 treated and the nano-untreatred drilling fluids have been analyzed by using Anton-Paar [16]. Table 3 shows the comparion of the yield strength value obtained from Anton-Paar and Fann-77 viscometer equipments. The comparion here is only to show the responces of the equipment. As shown, the nano system increases the yield strengths by 27.4%. In these two fluid systems, the storage modules (G') is also higher than the loss modulus (G''), which is structurally stable. On the other hand, the Fann-77 viscometer shows that the Bingham plastic parameter reduced by -38%.

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)
Conventional (Reference) (Ref) = 25gm Bentonite/500H_2O + 5gm (KCl +NaCl) +0.5gm CMC	0.310	4.088
Nano treated drilling fluid 4 = **Ref** + 0.3gm nano- SiO_2	0.395	2.555
% Change =	27.4 %	-37.6%

3 PERFORMANCE ANALYSIS OF THE FLUID SYSTEMS

This section presents the performance simulation studies of the selected drilling fluid system.

3.1 Hydraulics

The equivalent circulation density (ECD) of the drilling fluids were evaluated in a 12000ft vertical simulation well. The well has 8,5inch size, and the outer and inner diameters of the drill pipe were 5 inch and 4.8 inch respectively. The flow rate was varied from 100 gpm to 600gpm. Unified hydraulic model [17] was used to calculate the frictional pressure losses. Figure 7 shows the simulation results. As shown, the fluid containing 0.3gm nano- SiO_2 exhibits lower ECD for the considered flow rates. This fluid system was selected as best in terms of filtrate loss as presented in Table 4.

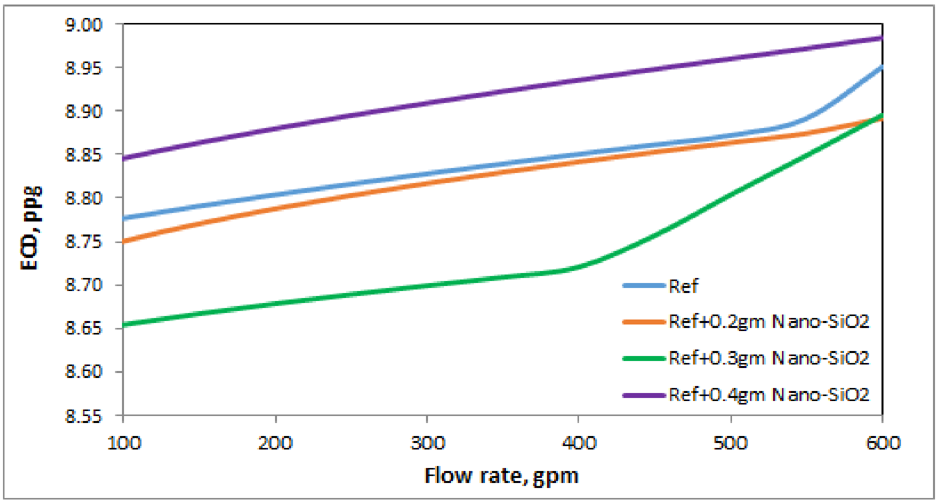


Figure 7: ECD calculation obtained from the Unified hydraulics model.

3.3 Hole cleaning

The cutting transport efficiency of the fluid systems are also compared through simulation study. Using Landmark/Wellplan^{TM} software [18], simulation was performed in 8.5 in well to determine the minimum flow rate to transport cutting from the hole without bed deposit. In this simulation, the well is inclined from vertical to horizontal. The simulation parameters are given in Table 4. When the flow rate is less than the minimum flow rate, particles will begin to deposit in the annulus. The results obtained from the simulation show that the fluid containing 0.3gm nano silica requires a lower flow rate to transport cuttings (see figure 8).

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

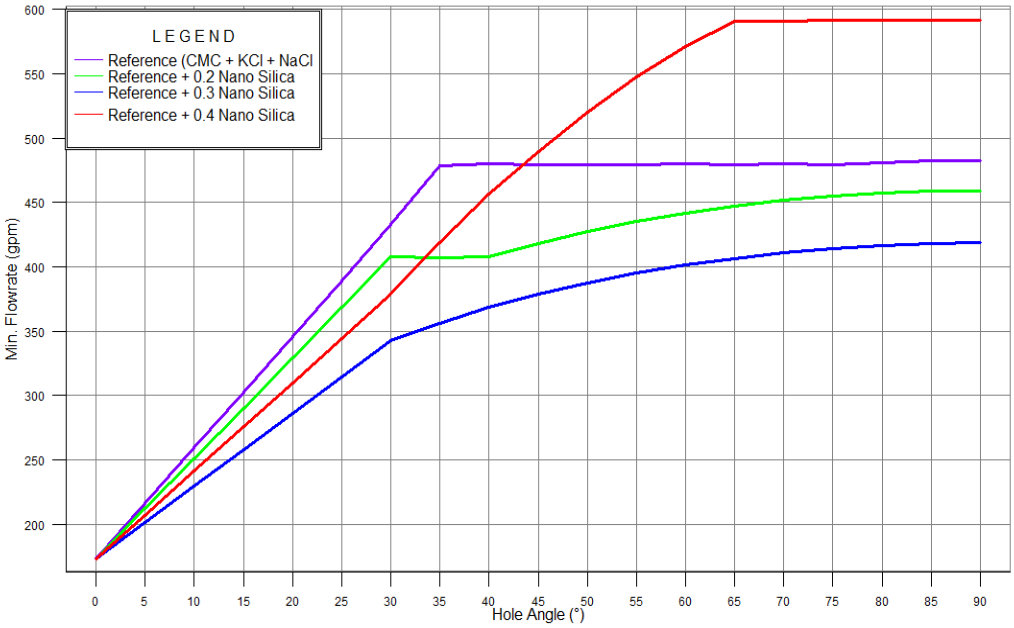


Figure 8: Comparison of minimum flow rate of fluids.

Similarly, the bed height simulations were carried out in a well deviated from vertical to about 36deg inclination (See Figure 9 left). The simulation results show that at the considered flow rate, the 0.3gm nano treated fluid system exhibits lower bed height deposition as compared with the other fluid systems (Figure 9, right).

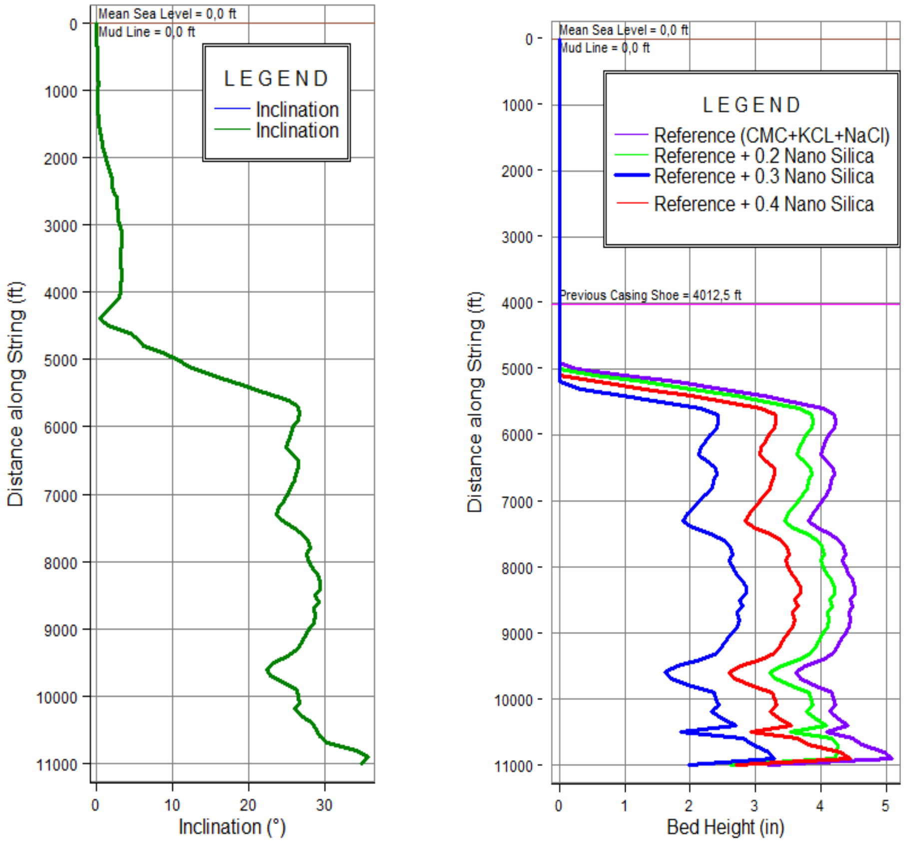


Figure 9: Well inclination (left) and simulated bed height (right).

4 SUMMARY

In this paper, the effect of nano- SiO_2 in 25gm bentonite /500 gm H_2O treated with CMC polymer and salts has been tested. The test results at 72°F show that the addition of about 0.06wt % nano- SiO_2 influences the rheology and filtrate properties, the hydraulics and hole cleaning performance of the conventional drilling fluid system.

One clear observation is that the performance of nano- SiO_2 depends on its concentration, types of polymer and salt system. From the test results, it is observed that there exists an optimum concentration that works best in considered fluid system. Although nano based drilling fluids are expensive than the conventional one, nano-fluids drilling fluids may have potential to reduce drilling related problems and improve 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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