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The Effect of Nano-Silicon Dioxide (SIO_2) on Properties and Performance of LV-CMC/XANthan Gum Polymer/Salt Treated Bentonite Drilling Fluid

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Abstract

In this paper the perforamnce of nano Silicon dioxide (SiO_2) on polymers and KCl salt treated bentonite drilling fluid systems has been studied at room temperature.

The results show that the effect of nano SiO_2 in bentonite mud system depends on its concentration and the types of salt and polymer systems used. From the considered spectrum of nano particle additives, the 0.048wt % SiO_2 was found out to be an optimum concentration, which exhibits positive impact on rheology and filrate control of the drilling fluid systems. The effect is more pronounced on the Yield strength than the plastic viscosity. The selected optimum nano SiO_2 treated system shows good cutting transport efficiency.

1. INTRODUCTION

In rotary drilling operation, drilling fluids main functions among others are to maintain well pressure, transport cuttings, cool well & drill bit and formation of filter cake deposition around the borehole. Good quality of filter cake (i.e thin and tough) reduce fluid loss, prevents drill string stickling and increase well strength.

Oil based mud system solve swelling problem. In susceptible drilling environment, the common practice is to use ‘’an inhibitive’’ water based drilling fluid. However, in terms of swelling issue, water based mud system doesn’t completely solve the problem.

Through chemical and/or physical processes, nanomaterials (1nm -100 nm) create materials with improved properties. Comparing with the micro/micro particles, the surface to volume ratio of nano particle is very high [Amanulah et al, [1]. Nanoparticles form a tough, dense mud cake and sealing micro cracks in shale (Riley et al, 2012)[2]. The positive impact of nano 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]).

Several papers have documented that SiO_2 improve the mechanical and petrophysical properties of cement. In this paper, we have selected SiO_2 to study its effect in LC-CMC /Xanthan Gum XC polymer/salt-bentonite drilling fluid system. The formulated nano treated drilling fluid evaluated through rheology, viscoelastic, and API filtrate loss measurement. The performance of the drilling fluid systems were analyzed through cutting transport simulation study.

2. EXPERIMENTAL INVESTIGATION

This section presents the material descriptions used for the formulation of nano based drilling , drilling fluid test matrix and the measured test results.

2.1 Materials characterization

2.1.1 Nano-silicon dioxide

A commercial Nano-silicon dioxide SiO_2 particle was purchased from a Chinese company [9]. The size and elemental analysis of the particles has been characterized using Elemental Dispersive Spectroscopy (EDS, Figure 1b) and Scanning Electron Microscopy (SEM) (Figure 1a). The average size of the particle was found out to be 15nm. The EDS element analysis shows the purrity of the nano- SiO_2. However, the presence of the palladium (pd) is not part of the nano particle. It was used for SEM analysis.

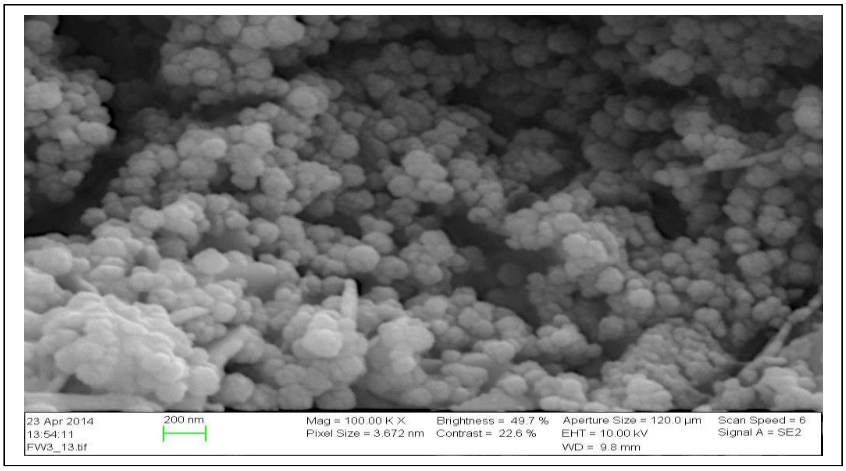

Figure 1a: SEM picture of nano- 15nm-SiO_2.

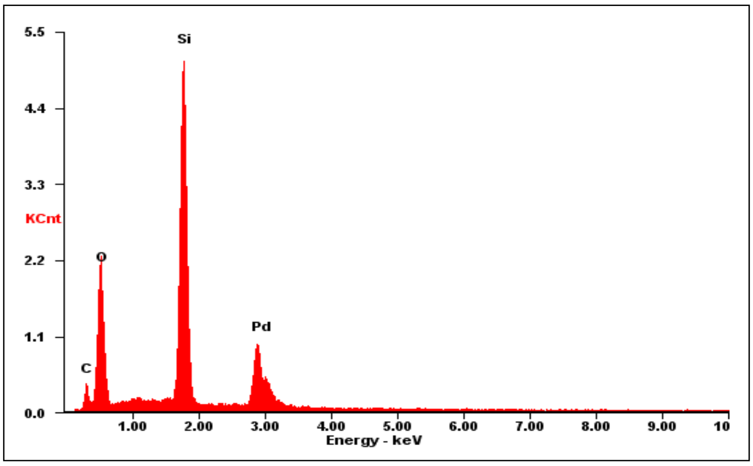

Figure 1b: Element analysis of nano- SiO_2.

2.1.2 Bentonite

Bentonite is used as viscosifier additive in water based drilling fluids. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the main factor to determine their properties. A single platelet of clay consists of an octahedral sheet and one or two silica tetrahedral sheets. Oxygen atoms tie the sheets together by covalent bonds as shown in Figure 2.

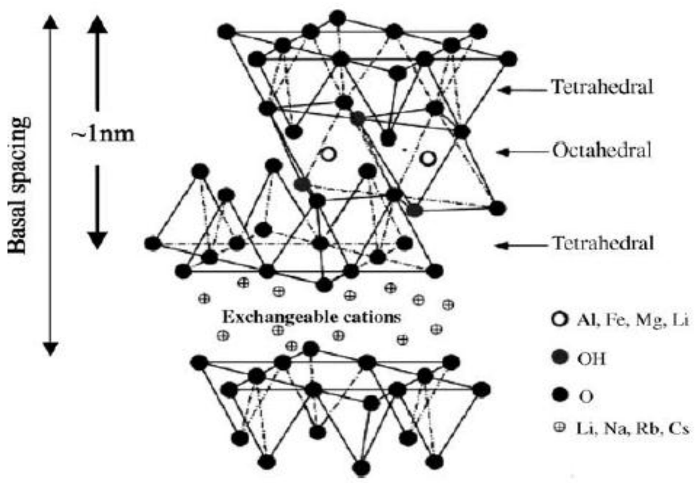

Figure 2: Idealized structure of a montmorillonite layer (2:1 type) [10].

2.1.3 Polymers

In this paper, two polymer types were used for analysis namely; Low viscous (LV) CMC and Xanthan gum. These polymers are used in drilling fluids to control fluid loss and to increase the viscosity of the fluid.

2.1.3.1 Poly-anionic Cellulose

Poly-anionic Cellulose, PACs have the same structure as CMCs but the difference is in their ability of substitution. They have higher degree of substitution with regards to CMCs and provide a good filter loss control for the drilling fluids. [11]. The chemical structure is shown in figure 3.

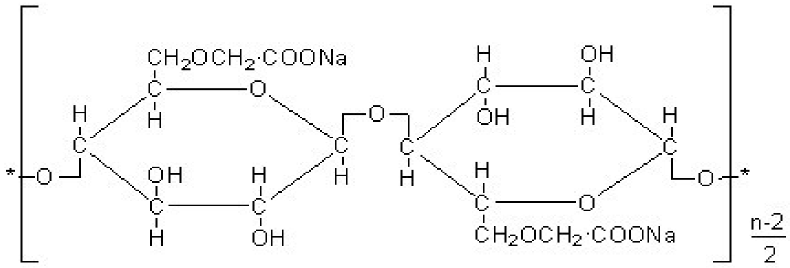

Figure 3: Structure of Sodium CMC [11].

2.1.3.2 Xanthan gum

Xanthan gum is a naturally occurring biopolymer and water soluble. It is often used in the oil industry to viscosify water based drilling. Figure 4 shows Xanthan gum, which 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 branching structure gives Xanthan gum thixotropic properties. [12]

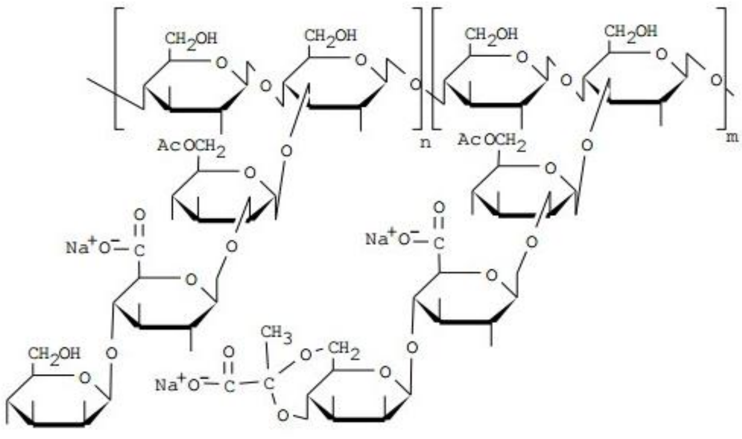

Figure 4: Structure of Xanthan gum [11].

2.1.4 KCL Salt

The K^+ ions attach to clay surfaces and the size can fit the plates of clay. Potassium based fluids exhibits shale-inhibition properties [13].

2.2 Nano-SiO_2 treated drilling fluid formulation and Characterization

The ingredients of 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 [15] standard.

From several screening tests, the mixture of 2.5gm KCL/NaCl with 25gm Bentonite and 500gm H_2O was found out to be a good system, which is less viscous to flow. Therefore, the rest of nano SiO_2 effect tests were carried out on this selected composition. Table 1 shows the composition of four drilling fluids formulation. The reference system was formulated by mixing 0.2gm low viscous (LV) CMC and 0.3gm Xanthan gum polymers in 25gm bentonite/500gmH_2O with 2.5gm KCl.

Table 1: Test matrix of nano-SiO_2 in LV-CMC and Xanthan gum polymers.

Mud system/ additives	**Bentonite (gm)**	**H_2O (gm)**	**LV CMC (gm)**	**Xanthan gum (gm)**	**KCl (gm)**	**Nano SiO_2 (gm)**
Reference (Ref)	25	500	0.2	0.3	2.5	0.00
Ref + 0.2gm SiO_2	25	500	0.2	0.3	2.5	0.20
Ref+ 0.25gm SiO_2	25	500	0.2	0.3	2.5	0.25
Ref + 0.3gm SiO_2	25	500	0.2	0.3	2.5	0.30

3.2.1 Rheology and filrate loss evaluation

Figure 5 displays the measured viscometer data of the formulated fluid systems. As can be shown, the addition of nano increases the viscometer response values. However, it is also observed that as the nano SiO_2 concentration increases from 0.25gm to 0.3gm, the system becomes thinning and reduces viscometer reading. This observation indicates that there exists a certain optimum concentration of nano SiO_2 that gives higher viscometer values. The structure of fluid system disintegrated as the concentration of nano increases in the considered polymer and brine systems.

The rheological parameters that describe the behavior of the drilling fluid were computed from the measured viscometer data. These are plastic viscosity (PV), yield stress (YS), consistency index (k) and flow index (n). In addition, the measured filtrate losses along with the mentioned parameter are plotted in figure 6~~.~~

Plastic viscosity and yield strength of a drilling fluid determines the hydraulics and the hole cleaning efficiency of the drilling fluid. In laminar flow, the annular cutting concentration is lower for higher YS/PV ratio for any well inclination Slavomir et al, [16]. Plastic viscosity of drilling fluid is caused by the mechanical friction between particles, and between particles and liquid phase. Cutting transport phenomenon and the well pressure hydraulics are a function of these parameters. As can be seen in figure 6, the plastic viscosity of the nano-free is almost the same as the nano treated mud system. This shows that the fluid system internal structures are unaffected by the added nano- SiO_2 at measured temperature condition i.e. (72°F)

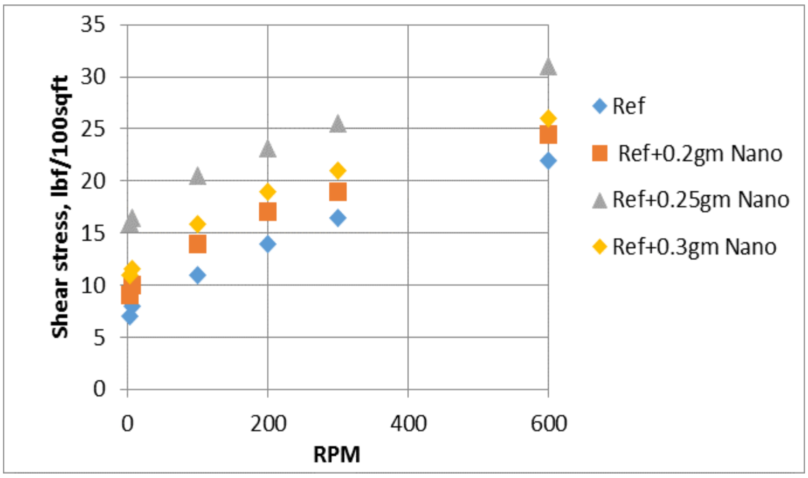

Figure 5: Viscometer measurement of Table 1

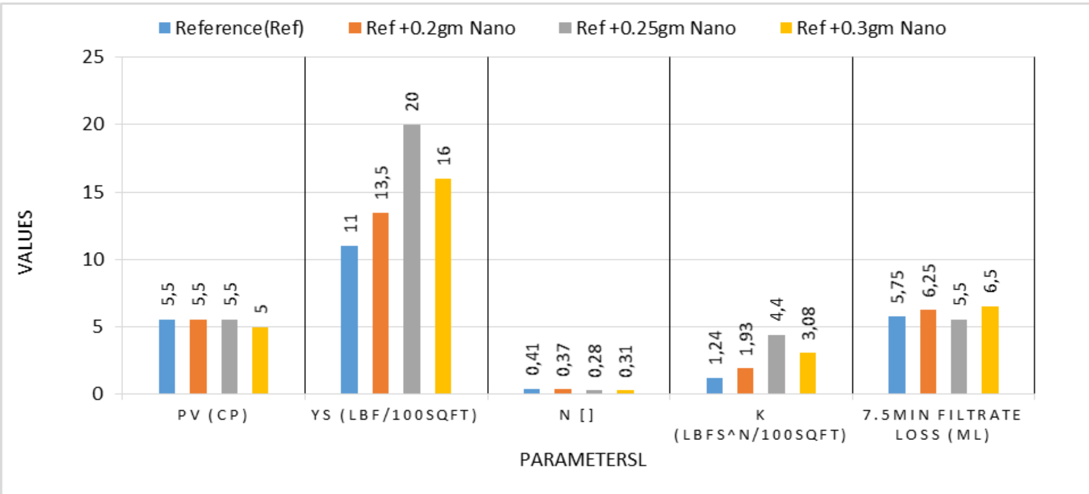

Figure 6: Calculated parameters and measured filtrate loss.

Yield stress of a drilling fluid describes part of the viscosity, which is caused by electrostatic forces between particles. As shown in figure 6, the addition of 0.25gm nano-SiO_2 increases the yield strength by 81.8% as compared with the nano free fluid system. This indicates that the nano system at this particular condition might have created a flocculated system.

Table 2 shows the measured API filtrate loss of nano treated and nano untreated (Reference) drilling fluid. As shown, the addition of 0.25gm reduces the filtrate loss by 4.5% as compared with the reference system. Similarly, it can also be observed that the addition of 0.2gm and 0.3gm nano increase the filtrate loss by 8.7% and 13.0%, respectively. This illustrates that there exist an optimum nano-SiO_2 concentration, which creates a good filtrate loss control in bentonite fluid system. The results also indicate that the effect of nano concentration on the internal structure of the fluid system, and hence on the filter cake quality.

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

Mud systems/ Parameters	**Ref.**	**Ref + 0.2gm Nano** SiO_2	**Ref + 0.25gm Nano** SiO_2	**Ref + 0.3gm Nano** SiO_2
7.5 min Filtrate [ml]	5.75	6.25	5.5	6.5
% Filtrate change		8.7	-4.3	13.0

2.2.2 Viscoelasticity evaluation

Drilling fluid exhibits a viscous and an elasticity, which is called viscoelasticity. In order to evaluate the effect of nano on the internal structure of the fluid systems, advanced test equipment, Anton-Paar was used [17].

For the viscoelasricity analysis, the best systems (i.e 0.25gm nano SiO_2) was selected based on the filtrate loss reduction behavior. Table 3 shows the comparisons of the Nano- additives with Nano free mud systems (Ref) the measured data. The comparions is based on yield strength value obtained from Anton-Paar and Fann-77 viscometer equipments. The comparison here is not to judge which one is correct, but to show the respoences of the two equipments. Comparing drilling fluid 1 (Ref) and drilling fluid 2, the nano additive increases the yield strength by 141.8%. Both of the fluids exhibited structural stability since in the elastic dominate region, the storage modulus (G') is higher than the loss modulus (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)
Conventional/Reference, (Ref) = 25gm Bentonite/500H_2O + 2.5gm KCl + 0.5gm (LV-CMC +Xanthan gum)	0.55	5.27
Nano-based drilling fluid = **Ref** + 0.25gm nano- SiO_2	1,33	9,58
% Change =	141.8 %	81.8%

3 Performance analysis of the formulated drilling fluids

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

3.3 Hole cleaning

The cutting transport efficiency of the fluid systems presented in Table 3 are also compared through simulation study. Using Landmark/Wellplan™ software [18], simulation was performed in 8.5in well to determine the minimum flow rate to clean out cutting from the hole without bed deposits. In this simulation, the well is inclined from vertical to horizontal. When the flow rate is less than the minimum requirement, particles will begin to settle in the annulus. Table 4 shows the operational and cutting simulation parameters.The simulation results show that the fluid containing 0.25g nano silica requires a lower flow rate to transport cuttings (see figure 7). On the other hand the nano free system requires a higher flow rate.

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

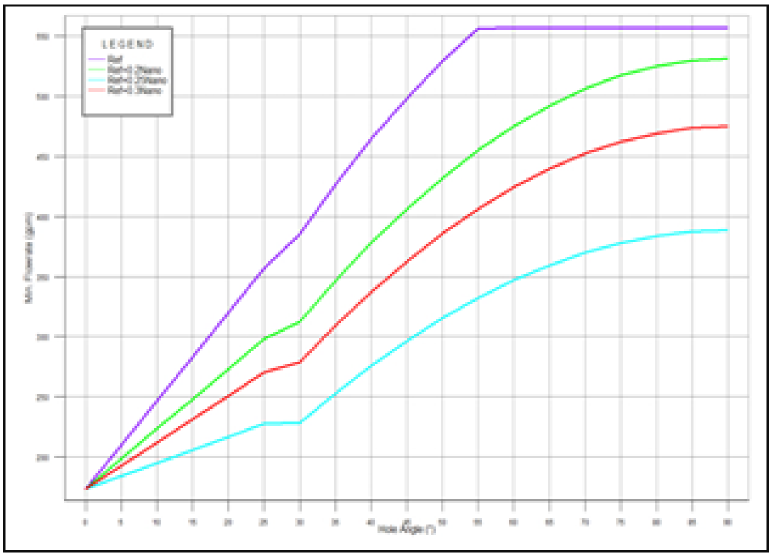

Figure 7: Comparison of minimum flow rate of fluids.

The cutting bed deposition of the the drilling fluids have been simulated in a deviated well (Figure 8, left). The operational and cutting parameters are shown in Table 4. The drilling fluids have been circulated in the well at a rate of 500gpm. As displayed on the right side of Figure 8, the considered flow rate is able to completely clean the cutting out of well when injecting the 0.25gm nano treated fluid system. On the other hand, the injecting the nano free system shows an average of 4.5in cutting bed in the wellbore.

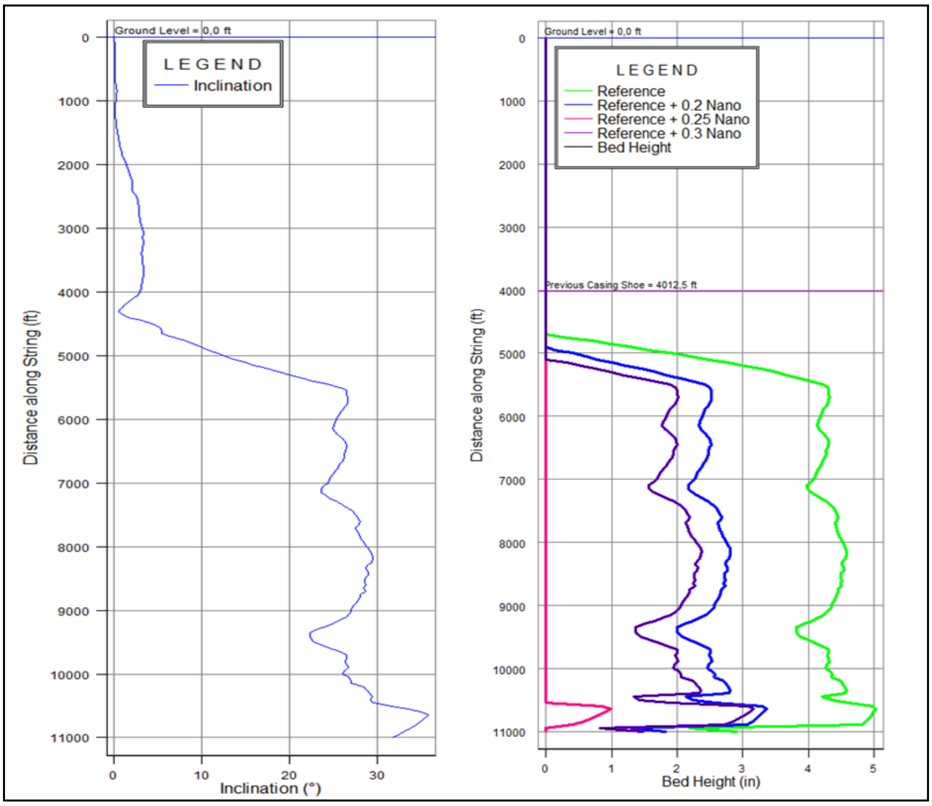

Figure 8: Well inclination (left) and simulated bed height (right)

4 SUMMARY

In this paper, the effect of nano- SiO_2 in 25gm bentonite /500 gm H_2O treated with polymers and salts has been tested. The test results at 72°F show that the addition of about 0.048wt% nano- SiO_2 in the considered fluid system influences the rheology and filtrate properties of the reference mud 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 result, it is observed that for a given system there exists an optimum concentration that works best in fluid system.

Based on the reviewed literatures and the present work, nano-fluids may have the potential to reduce drilling related problems. From the test and simulation results, the selected optimized nano- SiO_2 shows positive impact on rheology parameters, reduced filtrate loss, good cutting transport performance.

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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