An Investigation on The Effect of Silica Nanoparticle Concentration on Oil-based Mud Rheology and Fluid Loss Control Characteristic

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Abstract. Oil based mud (OBM) is well known in drilling operation for its good properties. However, under HPHT conditions, OBM might encounter thermal degradation, which will affect the performance of the mud leading to fluid loss and unstable rheology. Previous studies showed that implementation of nanoparticle as drilling mud additive can control the fluid loss into the formation thus preventing formation damage. In this research we evaluate the potential of using nanoparticle from silica as the fluid loss preventing agent. The OBM was used in this study and its performance at low and high temperature was evaluated after addition of nanosilica powder. The experiment was conducted at 275°F and 350°F with varying nanosilica concentration per amount of a commercial fluid loss control additive (gilsonite) between 30 to 70%, by total mud weight between 0 to 2 wt. %. Result of the study shows that the application of nanosilica in OBM results in better mud rheology and can effectively reduce fluid loss up to 50% concentration especially at HPHT conditions. The silica nanoparticles have the potential to enhance drilling fluid properties, which contributes to more efficient drilling operations with less formation damage. This finding would be economically beneficial to the industry as silica is an abundant earth element.

Keywords: fluid loss, HPHT, nanosilica, OBM, rheological properties.

Introduction

Proper control of drilling fluid properties is important to ensure successful drilling operation. Drilling fluids carry cuttings out of the well, minimize formation damage, secure permeable formation, preserve wellbore stabilities, cool and smear the drill bit and control the formation pressure. The oil based mud (OBM) is typically used for delicate formation to control reactivities with water and prevent clay swelling. OBM has several other advantages including good drilling rate, minor bit balling, minimal torque and drag of drill pipes, and low potential of differential sticking inside the wellbore [1].

Nevertheless there are some complications in cognition to the drilling fluid impairment and stability especially at high pressure and high temperature (HPHT) [2]. The rheology properties of the mud degrade as the mud keeps circulating in the wellbore resulting in poor performance of drilling operations such as decreasing rate of penetration (ROP), pipe sticking and higher torque and drag [3]. After some period of time fluid loss might happen, which possibly lead to kick or formation damage. Particles from drilling fluid penetrating the formation may lead to pore plugging that reduce its permeability [4]. Other possible problem includes wellbore instability due to exposure of drilling fluid
to shale and impairment of downhole tools and equipment while drilling. These problems may severely affect the wellbore productivity, causing loss of time and money.

To encounter this, nanotechnology has been introduced in oil and gas industry to produce a promising nanoparticle which is able to satisfy the requirements as a good additive; physically small, chemically and thermally stable to formulate a smart fluid. These nanoparticles such as nanosilica, carbon nanotube and graphene oxide are treated as alternative mud additives. A nano-based drilling fluid system is described as the fluid consisting of additives that have particles’ size of 1-100 nanometers [5]. These nanoparticles not only act as bridging agent in fluid which help to control loss of circulation [6], but also improve the thermal conductivity of drilling mud due to high surface area to volume ratio that can cool a drill bit efficiently, hence increasing its lifespan [7]. In fluid loss control, nanoparticles can easily inhibit shale-drilling fluid interactions by plugging the shale pore throat due to extremely fine particle size, which is way smaller than shale pore throat. Besides, high solid contents in drilling fluid can contribute to wellbore instability and tear of downhole tools. With the aid of an increased ROP, nano-based fluid can severely reduce the solid content of drilling fluid since it has higher surface to volume ratio thus reducing the kinetic energy impact of nanoparticles [5].

In this research we evaluated and analyzed the effect of different concentration of nanoparticle (nanosilica) on rheology properties and fluid loss control by conducting standard drilling mud tests such as density test, viscosity test, rheology test and filtrate analysis. We also investigated the potential of nanosilica to act as fluid loss control agent by comparing its performance with commercial fluid loss agent i.e gilsonite. The drilling mud performance was compared with established drilling mud without nanosilica at wellbore temperature.

**Methodology**

**Materials**

The chemicals used in this experiment includes Sarapar 147 as the base fluid and Calcium Chloride (CaCl₂) as the brine. CONFI-MULP and CONFI-MULS was used as the primary and secondary emulsifier respectively. CONFI-GELXHT acts as the viscosifier, DRILL-BAR as the weighting agent and lime was the alkalinity source. CONFI-TROLXHT together with nanosilica was used as the fluid loss agent. Table 1 shows the specification of nanosilica used in the experiment.

| **Product Name**          | Silicon Oxide Nanoparticles |
|---------------------------|----------------------------|
| **Form**                  | Nanopowder                 |
| **Features**              | Spherical, nonporous, amorphous |
| **True Density**          | 2.4 g/cm³                  |
| **Ultraviolet Reflectivity** | >75%                      |
| **Purity**                | 99.5+% trace metal basis  |
| **Color**                 | White                      |
| **Size**                  | 15 nm – 20 nm              |
Experimental Procedure

Preparation of OBM and enhanced OBM

Eight (8) samples were prepared by mixing OBM with nanosilica at different concentrations. The multi mixer (Hamilton Beach Mixer) was used to mix the combination thoroughly following by mud optimization to satisfy the API standard for further testing. The concentrations of added nanosilica were 0.48, 0.70, 0.81, 1.14, 1.16 and 1.64% by weight.

Table 2: Samples preparation for 275°F and 350°F system

| Samples | Type of Mud | Nanosilica additives | Temperature |
|---------|-------------|----------------------|-------------|
| Sample 1 | OBM base    | x                    | 275°F       |
| Sample 2 | OBM         | ✓                    | 275°F       |
| Sample 3 | OBM         | ✓                    | 275°F       |
| Sample 4 | OBM         | ✓                    | 275°F       |
| Sample 5 | OBM base    | x                    | 350°F       |
| Sample 6 | OBM         | ✓                    | 350°F       |
| Sample 7 | OBM         | ✓                    | 350°F       |
| Sample 8 | OBM         | ✓                    | 350°F       |

Rheology Test

All of the samples were tested for their initial rheology properties which are plastic viscosity, yield point, gel strength by using a couette-type viscometer (Grace M3600) and electrical stability using electrical stability tester (Model 23D) at room temperature. The measurements were obtained at fixed speeds of 600, 300, 200, 100, 6, 3 rpm before transferring the samples into aging cell containers and pressurized for measurement at elevated temperatures. The aging cells were then placed in a roller oven (Model RORC-8E) and hot rolled at designated temperature which were 275°F and 350°F for 16 hours. Final rheology test were done for all samples after being hot rolled. All of the testing procedures and equipment for rheology test followed American Petroleum Institute Recommended Practice (API RP) 13B-2 [8].

High pressure high temperature (HPHT) filtration test.

The filtration properties of the samples were investigated using HTHP filter press (Fann Series 387), HTHP filtration cells (500 ml), heating jacket (500ml), filter paper (diameter 2.5-in), high pressure nitrogen supply, stopwatch and a measuring cylinder. Preparation of the samples was carried out following API RP 13B-2 standard. The sample was placed in a cell covered with a heating jacket during test. A differential pressure of 100 to 600 psi and temperature of 275°F were applied to the sample. The filtrate volume was collected after 30 minutes and the thickness of filter cakes formed on the filter paper was measured using a filter cake ruler (Fann Ruler).
Result and Discussions

Rheological Analysis

Mud rheological tests i.e Plastic Viscosity (PV), Yield Point (YP) and 10 seconds/minutes gel strength tests were performed on the OBM with different concentrations of nanosilica at temperature of 275°F and 350°F (Table 3). Two measuring points were taken; Before Hot Rolled (BHR) and After Hot Rolled (AHR). The HTHP filtration test data was taken only at AHR. Plastic Viscosity, $\mu_p$ is the resistance of fluid to stream caused by mechanical friction of the particles and is in centipoises (cp) which can be calculated using equation (1)

$$\text{Plastic Viscosity (PV)} = \text{Reading at 600 rpm} - \text{Reading at 300 rpm}$$

(1)

Yield point (YP) which is the attractive force that exist between colloidal particles in drilling fluid is utilized to assess the ability of drilling fluid to remove drill cuttings out of the well and to the surface. YP can be calculated using equation (2).

$$\text{Yield Point (YP)} = \text{Reading at 300 rpm} - \text{Plastic Viscosity (PV)}$$

(2)

Figure 1 and Figure 2 show the PV and YP performance of both mud systems at BHR and AHR.

Fig. 1: Plastic Viscosity and Yield Point at 275°F system
Experimental results (Figure 1 and 2) showed that an increase in the concentration of nanosilica results in a more stable viscosity at higher temperatures which is an indication of the ability of nanoparticles to suppress viscosity reduction [9]. The addition of nanoparticles created a slight alteration in rheological properties supports the theory that nanoparticle behavior is controlled by nanoparticle grain boundary and its surface area. The enhanced mud for both systems showed relatively lower PV values compared to the base mud proving that nanosilica dissolve well in the mud making it less viscous. Higher nanosilica concentration also reduces barite in the mud formulation. The reduction of solid content causes the mud to have lesser solid particles, which reduce the interaction of clay mineral between it.

In this study, the specific range for yield point after ageing process is 15 – 35 cp and 22-34 cp for 275°F and 350°F mud systems respectively. All the samples satisfied the specific range given except for mud samples with 70% nanosilica at 275°F and 350°F. It can be concluded that nanosilica gives stable value of yield point especially when exposed to HPHT condition (350°F) but the mud’s performance decrease for both systems with addition of the highest concentration of nanosilica which is 70%. This may be due to nanosilica particles exceeding their optimum concentration. The decreased yield point value after aging indicates a loss of gel structure. However overall result showed that the YP values obtained did not suffer significant fluctuation. The higher yield point achieved when adding nanosilica will ensure better suspension of drill cuttings, thus increasing hole-cleaning capacity while drilling.

Figure 3 and Figure 4 show gel strength comparisons for both mud systems. Gel strength is the shear stress of drilling mud that is measured at low shear rate after the drilling mud is static for a certain period of time, normally measured at 10-second and 10-minute. It is an important property in drilling fluid to represent the ability of the drilling mud to suspend drill solid and weighting material when circulation ceased.
The gel strength of 10 seconds and 10 minutes for enhanced mud of both mud system show higher gel strength value compared to the base muds. Generally, addition of nanosilica increases the gel strength of the mud which is good for suspension of drill cuttings at static condition. Drilling muds exhibiting high gel strength will create high pump pressure in order to break circulation after the mud is static for a long time. The gel strength of all mud samples after hot rolled for both systems are within the operational limit as shown in Table 3.

Table 3: Criterion results for OBM at 275°F and 350°F mud systems

| Mud Properties               | Values         |
|------------------------------|----------------|
| Static Age Temperature, °F   | 275            |
| Gel Strength (10 seconds), lb/100 sqft | 8 - 18        |
| Gel Strength (10 minutes), lb/100 sqft | 15 - 30        |
Electrical Stability

Fig. 5: Electrical Stability at 275°F system

Fig. 6: Electrical Stability at 350°F system

Electrical stability (ES), measured in volts is the quality of emulsion and oil wetting qualities of solids in a mud sample. Nanoparticles can replace polymeric surfactants as a water-in-oil emulsion stabilizers and can also be hydrophobic, hydrophilic or amphiphilic [7]. They can exhibit a large free energy of adsorption and attach themselves to the oil water interface, especially for particles of intermediate wettability [7]. The acceptable range of values for emulsion stability is above 500 volts. For all samples, the electrical stability is above 500 (Figure 5 and 6), indicating good emulsion and oil wetting properties in the drilling mud. This exhibited that silica nanoparticles are quite effective in maintaining the emulsion stability of oil based mud especially when exposed to high temperatures.

HPHT Filtrate Analysis

Figure 7 and Figure 8 show the results on the HTHP filtration for both mud systems.
Mud cake thickness and filtrate loss of enhanced mud is reduced compared to the base muds. During spurt loss period (<7.5 minutes), mud particles attempted to flow with the filtrate through the filter paper. Nanoparticles bridge across pore throats to form the external mud cake immediately subsequently lowering the spurt loss. The incorporation of silica nanoparticles in oil-based mud contributed to the formation of a low permeability and integrated mud cake. The well dispersed mud cakes demonstrate their high potential for reducing drilling and production problems. The implementation of nanoparticles in the mud also reduced the fluid loss substantially due to their ability to block small pores and their ability to interact with clay particles [5]. Thus, it indicated that the silica nanoparticle additives are useful as a fluid loss agent because for effectively reducing permeability of mud cakes by plugging holes in the mud cakes and subsequently reducing fluid loss of the mud into the formation. However, an optimum range of combination should be studied for better formulation in order to obtain lower filtrate volume. It was observed that at 50% concentration of nanosilica to gilsonite, the filtrate volume and mud cake thickness were decreased after being exposed to 275°F and 350°F temperature. On the other hand, filtrate loss and mud cake thickness for mud with 70% of concentration of nanosilica at 350°F was not significantly reduce. This exhibits that the nanosilica particles had exceeded its optimum concentration thus causing no effect towards the mud. Therefore, a (1:2) ratio of nanosilica to gilsonite could be the optimum range of combination to achieve lower filtrate volume and mud cake thickness.

For future work, it is highly recommended to use various types of nanomaterial such as nanographene or nanocarbon which might produce different or better results. It can also be suggested to
use smaller size of nanosilica, ranging between 5-15 nm and at different concentration of nanosilica such as 20%, 40%, 60% and 80% in order to achieve optimum results.

Conclusion

The result of this study shows that silica nanoparticles have a high potential as an additive in OBM to improve rheological properties and filtration characteristics of the drilling fluid with the following conclusions;

1. Nanosilica is more efficient at lower concentration for filtration loss at HTHP condition (350°F). Maximum reduction of filtration loss was achieved upon the addition of 30% nanosilica concentration. However, at LTLP condition (275°F), higher fluid loss reduction occurred at higher concentrations of nanosilica. On the contrary, addition of nanosilica at different concentration to OBM system affected the filtration characteristics adversely for both HTHP and LTLP conditions.

2. Rheological measurements at 275°F and 350°F showed stable rheology in term of PV, YP, gel strength and ES for all the concentrations of nanosilica used compared to the base fluid.

3. Nanosilica is proven to be a very credible fluid loss agent up until 50% concentration and a functional rheology modifier due to the fact that under its usage, the rheology is stable after aging process. Nanosilica alone can effectively plug the pore to prevent the fluid loss during drilling at LTLP and HTHP conditions. As the fluid losses during drilling reduce, the cost and time of the operation can be reduced which is beneficial for well operators.

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