



An approach to improve the cuttings carrying capacity of nanosilica based muds



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ABSTRACT

Rheological and filtration properties of water based muds play vital roles to have a good drilling efficiency in high pressure high temperature (HPHT) environments. However, there are many occasions where controlling the variation of mud properties due to disintegration of additives is barely possible, resulting in stuck pipe, kick incident or even loss of wells. Although there have been many studies in the past indicating the application of nanosilica in improving the filtration control of water base muds, there are almost no studies on the significant reduction of the yield point which may cause a huge decrease in cutting carrying capacity of muds and rate of penetrations. The aim of this study is to propose an approach to improve the filtration control of water based muds using nanosilica while maintaining the rheology by using a cationic surfactant.

The results obtained from zeta potential measurements indicated that bentonite and nanosilica particles are both negatively charged at different ranges of pH, which would result in reduction of the yield point of the mud samples containing nanosilica. This issue was resolved by employing a cationic surfactant and following certain procedures. Filtration tests conducted under LPLT and HPHT conditions indicated that adding modified nanosilica into the mud samples creates a thin and low permeability filter cake without having any negative impacts on the rheology.

1. Introduction

Water based muds (WBMs) are still the best option to drill through complicated geological formations, ranging from active shale formations to high pressure high temperature (HPHT) wellbore conditions, due to their environmental friendly and easy to modify characteristics. However, some extra modifications might be required when WBMs are used for HPHT conditions, perhaps due to degradation of bentonite, which may result in increasing the filtration loss and ineffective upward transportation of cuttings (Bourgoyne et al., 1986; Kelessidis et al., 2006). In a normal drilling condition, these issues can be resolved by using polymers, but these additives are thermal insulators with limited applications under extreme downhole conditions (Mahto and Sharma, 2004; Mao et al., 2015). An alternative method to improve the limitation of WBMs is to modify the surface charge of bentonite particles which may enhance the rheology and filtration control of drilling muds (Barry et al., 2015).

Nanoparticles have found their applications in the oil and gas industry and been successfully used in enhanced oil recovery (Zargartalebi et al., 2014), reservoir deliverability (Hoelscher et al., 2012) and drilling fluid design (Srivatsa and Ziaja, 2012; Sadeghalvaad and Sabbaghi, 2014; Barry et al., 2015). In fact, there have been many

studies reporting the integration of nanoparticles with drilling mud formulations in recent years. Although improvements of filtration loss have been indicated by many (Amanullah and Al-Tahini, 2009; Amanullah et al., 2011; Srivatsa and Ziaja, 2012; Zakaria et al., 2012; Sadeghalvaad and Sabbaghi, 2014; Barry et al., 2015; Ismail et al., 2016), there are concerns about the reduction of cutting carrying capacities of WBMs (Vryzas et al., 2015; Mahmoud et al., 2016) when nanoparticles are added. This is mainly because of the interaction between the negative surface charge of bentonite with that of the nanoparticles. In fact, bentonite has a negative surface charge because of the substitution of low valence atoms in its lattice (Luckham and Rossi, 1999; Missana and Adell, 2000). The stability of colloidal suspensions is, therefore, a function of the surface charge of bentonite and pH of the aqueous system (Hafshejani et al., 2016). As a result, in a HPHT environment, bentonite solutions aggregate and flocculate, resulting in decreasing the yield point of drilling muds and capacity to control the filtration loss. This situation may become far worse when nanoparticles with a negative surface charge are added to muds, due to domination of a strong electrostatic repulsive force (Missana and Adell, 2000; Yalcin et al., 2002; Ma et al., 2010). Vryzas et al. (2015) and Mahmoud et al. (2016) showed that as a result of this repulsive force, deflocculation occurs causing an increase in viscosity and reduction of

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the yield point, which is a crucial parameter to have a good cutting carrying capacity during drilling.

There have been only few studies providing strategies to improve both rheology and filtration loss of WBMs when nanoparticles such as nanosilica are added (e.g., Barry et al., 2015). In fact, most of studies carried out in recent years are providing discussions on changes observed either in rheological properties or filtration loss separately (e.g., Ahualli et al., 2011; Ghanbari and Naderifar, 2016; Sibel et al., 2012). This indicates the fact that the nature and interaction of bentonite with nanoparticles have not been fully addressed.

The aim of this study is to provide an approach to improve the rheology and filtration control of WBMs in HPHT conditions when nanosilica is added. In the next section, after a short introduction on the application of silicate based muds used in the industry, the interaction between nanosilica and WBMs was discussed by providing measurements of changes in rheology and filtration loss of muds when modified and unmodified nanosilica were used.

2. Silicate based muds

2.1. Applications

Sodium or potassium silicate based drilling fluids are known as successful approaches for drilling through reactive and low/high permeable formations because of their inhibitive and filtration control characteristics (McDonald et al., 2007). The mechanisms by which silicates are able to prevent mud filtration and water hydration are as follows:

- **Pore plugging:** This is perhaps the most important characteristics of a silicate based mud. Soluble silicate solutions start out as monosilicate, that partially polymerises to form negatively charged silicate oligomers. The process is halted at pH 11–12 due to mutual repulsion, leaving oligomers which can partially penetrate micro-pore structures. Filtrate containing these oligomers is given by hydraulic flow or diffusion into pore fabrics where:
 - I. Pore fluid (pH +/-7) dilutes the filtrate whereby the oligomers overcome their mutual repulsion and coagulate to form silicate gels.
 - II. Oligomers react with free polyvalent cations associated with clay surfaces (or edges) to form insoluble precipitates.
 - III. The gelled and/or precipitated silicates provide a physical barrier which prevent further filtrate invasion and pore penetration. The wellbore and formations are, thus, pressure isolated and filtration stops.
- **Osmotic dehydration:** The barrier of gelled/precipitated silicates also acts as a highly selective osmotic membrane through which the drilling fluid's water activity can be reduced. This generates an osmotic pressure driving osmotic flow of waters across the silicates membrane from formations to the drilling fluid. Although the amount of water involved is minimal, this process will dehydrate the near wellbores shale effectively: dehydration leads to larger near wellbore effective stresses and an increase in the shale strength, both of which are beneficial to stability (Alford et al., 2005).
- **Ion Exchange:** An additional advantageous of monovalent ions such as K^+ included in a silicate based mud is that they can be exchanged by Ca^{+2} and Mg^{+2} at the clay surface, making these ions available to precipitate. The high salinity will also lower silicate gelation times and increases the deposition of silicate gels (Fritz and Jarrett, 2012).

Silicate based muds are cheaper than synthetics, which are widely used for drilling through HPHT conditions, and can provide excellent wellbore stability, together with a good metal/shale and metal/sand-

stone lubricity (McDonald et al., 2007). They are also environmental friendly and less prone to bit balling which is required to have a high rate of penetration (ROP). However, attentions need to be taken on good hole cleaning practices when silicate based muds are used (Soric et al., 2004).

Nanosilica has been used for stabilizing invert emulsion drilling muds in HPHT operations with potential of inhibitive even in low concentrations (Amanullah and Al-Tahini, 2009). The nano scale size and high surface area of nanosilica makes it a strong and reactive additive for a drilling mud formulation (Alias et al., 2014). These nanoparticles also have a high thermal stability (higher than that of a conventional silicate), and are affinitive to acidic gases such as H_2S and CO_2 . In other words, nanosilica based muds can overcome many of limitations induced by the conventional silicate based mud while maintaining all of its advantageous. However, rheology and dispersion related issues of nanosilica based muds have not been properly addressed, which are raised and resolved in this paper.

2.2. Nanosilica based muds limitations

As mentioned earlier, there have been only few studies where unavoidable changes in the rheology of silicate based muds were presented (e.g., Barry et al., 2015). To further reveal this issue, an attempt was made to evaluate the surface charge of solutions having bentonite and nanosilica using a Zeta Potential (ZP) apparatus, which measures the colloidal stability of dispersed particles in an aqueous system (Hunter, 1988). To do this, nanosilica with a BET specific surface area of 170–200 m^2/g , spherical particle size of 15–20 nm and purity of 99.5% was used to prepare a 5 mg/L of nanosilica solution stirred with Silverson homogenizer for 10 min, having 0.1 M HCl and 0.1 M NaOH to vary pH from 1.0 to 10.0. A similar methodology was applied when ZP measurements were done to determine the surface charge of bentonite.

The results obtained indicated that at any ranges of pH, the surface of bentonite and nanosilica particles are negatively charged but the ZP decreases with increasing the pH of the aqueous system. At the pH of 8–9, the ZP of nanosilica shows a maximum negative charge which indicates the fact that at this state there is a sufficient and adequate hydroxyl group on the surface of nanosilica. Likewise, for the aqueous bentonite solution, which is also pH dependent, negative charges were observed which are responsible for the electrostatic repulsion effect between nanosilica and bentonite. Fig. 1 shows the relationship between the ZP and pH ranges of the aqueous systems containing bentonite and nanosilica.

These negative charges create a repulsive force between bentonite and nanosilica which can result in reduction of the yield point and issues linked to borehole cleanings including reduction of Rate of Penetration (ROP) and sticking of drilling string.

In the next section, a strategy was presented as to how the issue of adding nanosilica into WBMs can be resolved so that fluid loss can be reduced without disturbing the rheology.

2.3. Modification of nanosilica

For modifications, 2.5 wt% alkylbenzyltrimethylammonium chloride (ABDACl) as a cationic surfactant with a molecular weight of 284 $gmol^{-1}$ was dissolved into deionized water. Different concentrations of nanosilica (0.5 wt%, 1 wt% and 2 wt%) were then prepared and added to the solution while pH was adjusted in the range of 8.0–8.5 using 0.1 M NaOH. The solution was then completely mixed by the Silverson homogenizer for 15 min, followed by ultrasonification for 10 min in the temperature of 60 °C. Fig. 2 depicts the reaction taking place when nanosilica is modified by the ABDACl.

The pH of the aqueous solution and large surfaces of nanosilica plays important roles in this modification. The pH of 8–9 is appropriate for the modification to take place because at this pH, the negative

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