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Investigating and Enhancing Mud Cake Reduction Using Smart Nano Clay Based WBM

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Abstract

Mud cake is the solid particles deposited on the pores of the formation creating a form of barrier when the drilling fluid is forced against the formation under an applied pressure. The mud cake formed along the open hole formation may cause differential pipe sticking and increases torque and drag forces of the drill pipe. This causes drilling operator to stop drilling and perform frequent tripping or over pull to release the stuck pipe. This event may lead to Non-Productive Time (NPT) and increases the operational cost.

The aim of this research is to investigate the relationship between Nano Clay based water based mud (WBM) with mud cake thickness and comparing it with the conventional clay based mud (WBM). In this research study, we could only managed to get nano clay between 90 nm to 100 nm. Mud cake thickness, filtrate volume and rheology of the drilling fluids parameters are studied. It was found that the mud cake thickness of Nano-WBM using Nano Clay is half compared to base mud using conventional clay. However, the filtrate collected and the rheological properties show an adverse impact of the drilling fluid performance.

Keywords: Mud cake; Nano-clay; Water base mud (WBM); Borehole problems

Introduction

In the subject of nanotechnology, there are many applications in the oil and gas industry offering many significant benefits especially in the drilling operations. Nanotechnology thus becomes a more sustainable and cost effective solution when it comes to the challenges commonly faced by the oil and gas companies. Problems arising from drilling operations can be minimized by the introduction of an ultra-fine particle in drilling fluids. It has been well documented in the literature that nano-sized particles possessed a much better physical and chemical properties due to its molecular advantages when they are added into the drilling fluid as an additive. However, there is not much studies carried out when nanoparticles especially Nano Clay is being used as the main composition of the drilling fluid.

This paper discusses about the properties of clay, overview of mud cake formation with its associated issues, recent works and papers published by the experts in the oil and gas industry related to the application of nanotechnology in drilling fluids, methodology to be performed to achieve the targeted objectives as well as the results gathered from the laboratory experiments.

Literature Review

Properties of Clay: Clay consists of traces of minerals in which the major constituent is made up of montmorillonite. Montmorillonites consist of two tetrahedral layers pressing one octahedral layer in the middle as shown in Figure 1. Based on CETCO [1], the vertex of oxide anions of the two tetrahedral layers are pointing in the inward direction towards the octahedral layer where iron, aluminum and magnesium cat-ions are formed. In this configuration, there is bonding between the anion tetrahedral and cat-ion octahedral which holds the clay structure. The negative charges are counter-balanced by the exchangeable cat-ions which exist between the layers.

Nasser et al. [2] highlights that bentonite exhibit a swelling characteristic when it is exposed to fresh water. Bentonite becomes a gelling agent when it reacts chemically with various organic materials, thus exhibit non-Newtonian fluid characteristics.

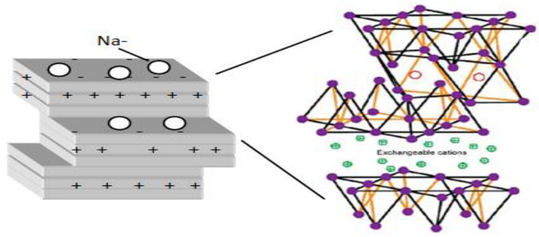

Figure 1: Sodium montmorillonite crystalline structure with inter-lamellar water layer [1].

The swelling ability of sodium bentonite is due to the bonding between bentonite and water molecules. Excess electrons, facilitate the formation water layer in between the layers. After forming one water layer, the bonds in the water layer continues to form another three to four water layers and the process continues to multiply. The increase of number in water layers decreases the strength of structure orientation, as increasing water molecules makes the structure less rigid, and resulting in increase of bentonite surface [1].

Overview of mud cake formation: The process where the differential pressure between the higher wellbore pressure and the

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lower formation pressure which causes the liquid phases in the drilling fluid seeped into the permeable formation is called filtration. The solid particles which have been filtered out from the drilling fluid builds up on the wall of the permeable formation, is called filter cake. As drilling fluid is circulating, the liquid component in the drilling fluid, also known as mud filtrate or spurt, continues to seeped pass into the formation until sufficient pores are blocked by the mud cake. This mud cake that builds up clogs the formation pores and decreases the permeability of filtrate invading into the formation [3,4].

Based on Figure 2, the solid residue deposited on the top of the formation forms the external filter cake. The second layer inside the formation, which is the internal filter are mainly invaded by mud filtrate through spurt loss.

Issues associated with mud cake formation in drilling operations: With increasing differential pressure in the wellbore as drilling gets deeper, mud cake continues to build up in the wall of the formation. Without careful selection of drilling fluid and proper controlling of drilling fluid filtration, many undesirable drilling issues may arise. For instance, filtrate invasion, excessive mud cake and poor mud cake quality will occur.

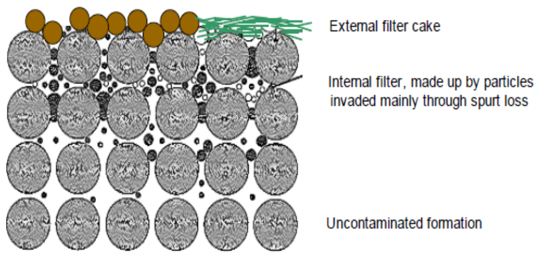

Figure 2: Filtration characteristics [4].

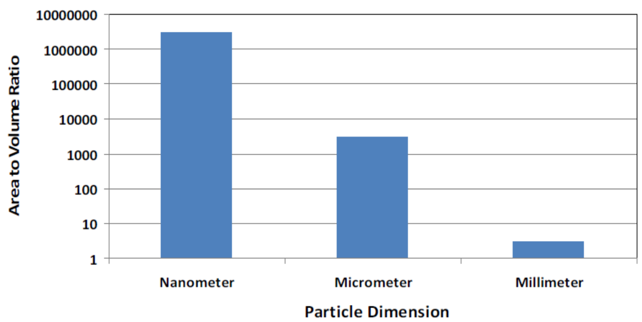

Figure 3: Surface area to volume ratio of same volume of materials [8].

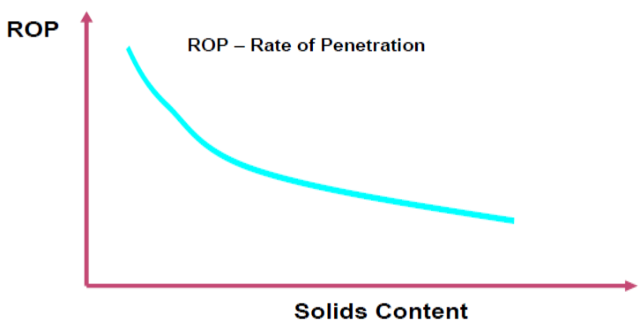

Figure 4: Mud solids content and its effect on ROP [8].

Time (Minutes)	Degree of Friction	
	Normal WBM	Nano-WBM
40 min	8	3
60 min	12	7

Table 1: Friction measurement for mud cake of normal mud and nano mud [2].

Component	Trial			
	1	2	3	4
Water	1 bbl	1 bbl	1 bbl	1 bbl
Clay	25 ppb	30 ppb	35 ppb	40 ppb

Note:
1)1 bbl is equivalent to 350 ml.
2) 1 ppb is equivalent to 1 g per 350 ml.

Table 2: Base mud formulation.

Component	Trial			
	1	2	3	4
Water	1 bbl	1 bbl	1 bbl	1 bbl
Nano Clay	25 ppb	30 ppb	35 ppb	40 ppb

Table 3: Nano-WBM formulation.

Recent works using nanoparticles: Over the last decade, there has been many experiments performed and literature studied by experts and engineers of the oil and gas industry incorporating the development of nanotechnology. For instance, Wahid et al. [5] showed that the introduction of nanosilica particles into synthetic based mud (SBM) offers a stable rheological results, thinner mud cake and 40% lesser filtrate volume up to 350.

Paper published by Al-Baghli et al. [6] presented the first successfully drilled well on high angled well in Kuwait. Al-Baghli introduced nano-sized polymer to substitute for the conventional oil based mud (OBM). Using a specially synthesized nanoparticles combining with graphite, the experiments conducted by Contreras et al. [7] demonstrates the possibility of wellbore strengthening in sandstone formation, which is similar to the literature presented by Al-Baghli et al. [6]. The molecular size of nanoparticles exhibits significantly high surface area to volume ratio. Figure 3 shows the huge differences between surface areas to volume ratio of the same material using different sizes [8].

It is worth noting that the concentration of mud solids plays an important factor in the drilling fluid system. The solid content present in the drilling fluid affects the rate of penetration (ROP) of the drill bit. Figure 4 shows that with increasing solid content, the ROP decreases gradually. By using smaller solid concentration, Amanullah et al., Jung et al. and Contreras et al. [7,9-11] agrees that the application of nanotechnology in drilling fluids can minimize cost, adhering to the strict environmental regulations as well as eco-friendly. In the aspect of mud cake, many researchers stress the importance of a good mud cake characteristics. Poor quality mud cake can be described as soft, thick, porous and highly permeable characteristics. A good mud cake is the exact opposite of the bad mud cake. A good mud cake exhibits thin, compact, homogenous, low permeability [12]. In every drilling situation, low filtrate loss, almost zero-spurt loss, ultra-compact and thin mud cake is desirable [9].

Many key parameters can be evaluated in the filter cake. Nasser et al. [2] highlights that mud cakes formed using mixed nanographite and nanosilicon also exhibit much lesser degree of roughness compared to conventional mud. Table 1 shows that the friction measurement of nano mud is lower compared to normal mud.

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Experimental Methodology

Drilling fluid formulation

The formulation for base mud using conventional clay is shown in Table 2. The formulation for Nano-WBM is the similar to base mud, but using Nano-Clay, as shown in Table 3.

Preparation of drilling fluid

Both base mud and Nano-WBM samples are prepared based on the same procedures. The ingredients are mixed using Multi-Mixer Model -9B spinning at a rate of 11,500 rpm with a single sine-wave impeller mixer spindle of 25 mm diameter for 30 minutes. In this research study, we could only manage to get the size of nano clay between 90 nm to 100 nm. The pH for all the samples are then adjusted to between 9.5 to 10.0. They are then hydrated in a sealed container for 24 hours before ready for testing.

Test experiments

Rheological properties: The rheological properties of all samples are measured using Viscometer FANN 35SA at standard conditions. The speed tested are 600, 300, 200, 100, 6 and 3 rpm. Both the plastic viscosity (PV) and yield point (YP) is calculated. The gel strength of all the samples are tested for 10 seconds and 10 minutes. The first highest dial reading is taken to be the gel strength. The filtration test is conducted using OFITE API Filter Press for low pressure and low temperature (LPLT). The test is operated under room temperature and an applied pressure of 100 psi using Nitrogen gas. The mud cake thickness is measured using a MITUTOYO Vernier Caliper and recorded in inch.

Results and Discussion

Mud cake thickness

Based on Figure 5, both the mud cake thickness for base mud and Nano-WBM samples shows an increasing trend of thickness for every addition of 5 ppb weight concentration. It is also noticeable that the mud cake thickness ratio of base mud to Nano-WBM reduces by half for every weight concentration. The ratio for mud cake thickness of base mud to Nano-WBM for 25 ppb, 30 ppb, 35 ppb and 40 ppb is 0.58, 0.63, 0.62 and 0.42 respectively. Averaging the ratio gives a value of 0.5625 (value in percentage is 56.25%). Thus, it is concluded that the Nano-WBM provides a thinner mud cake compared to the base mud samples. The total numbers of 8 different sample are prepared for both conventional and Nano fluids combined (Table 4).

The main objective of this investigative research is to enhance which means reduction in the mud cake thickness to minimize the borehole

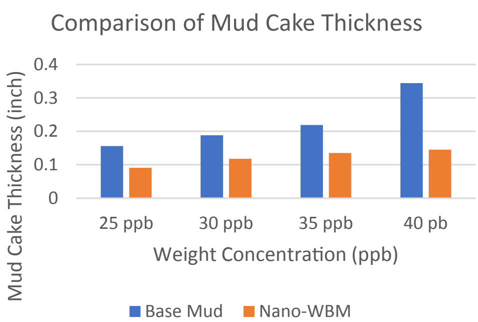

Figure 5: Comparison of mud cake thickness between Base mud and Nano-WBM.

Clay Concentration (ppb)	Mud Cake Thickness		
	Base Fluid (Inch)	Nano Fluid (Inch)	Reduction (%)
25	0.156	0.091	58.33%
30	0.188	0.118	62.77%
35	0.219	0.135	61.64%
40	0.344	0.145	42.15%

Table 4: Comparison of the mud cake thickness between conventional and nano fluid samples.

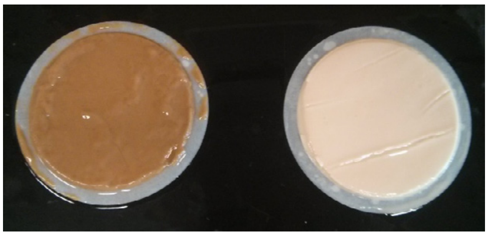

Figure 6: Mud cake of Base mud (Left) and Nano-WBM (Right).

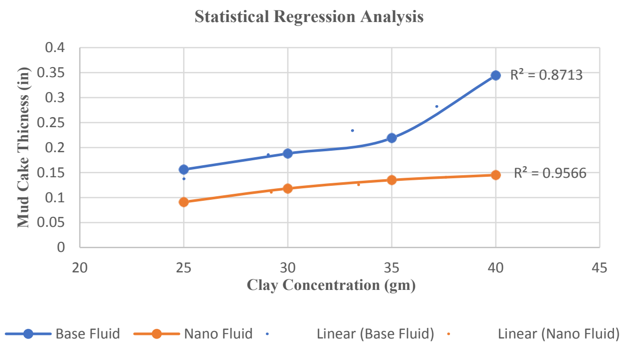

Figure 7: Statistical regression analysis.

problem, which is achieved well by using nano clay water based drilling fluid system. But, in terms of filtrate loss into the formation, there is adverse effect in the wellbore. The statistical analysis of this research study involve determinant coefficients, standard deviation from the mean and ratio of the enhancement of the results between two systems, which can help us to understand the comparison between conventional clay based and Nano based drilling fluid (Figure 6).

The statistical regression graph is given in Figure 7 and the statistical parameters are given in Table 5. The determinant coefficient value for the base conventional fluid is 0.8713, which means about 87% of the points are close to the best fitted, blue dotted line in Figure 7 and for the Nano fluid is 0.9566, about 96% of the points are close to the best fitted, red dotted line shown in Figure 7. The mean (average) value of base fluid and nano fluid are 0.23675 and 0.12225 inches respectively. The standard deviation values of base fluid is 0.08229, which means about 82% data points of the base fluid are deviating from the average value and for the nano fluid the value is 0.02363, which means about 82% data points of the base fluid are deviating from the average value (Figure 8).

Filtrate volume

The filtrate volume collected for both the base mud and Nano-WBM in Figure 9 shows a decreasing trend of filtrate loss for every addition of 5 ppb weight concentration. However, it is noticeable that the filtrate volume collected for Nano-WBM is roughly double

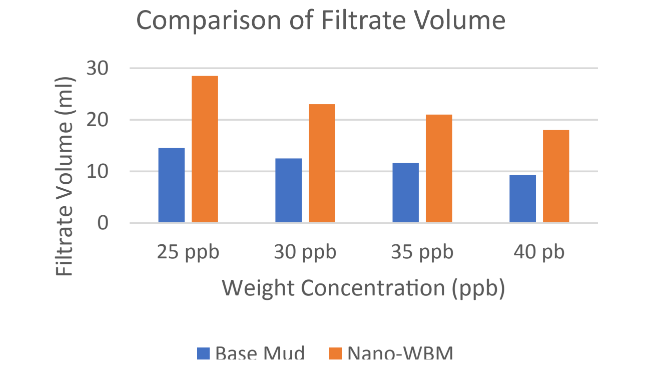

Figure 8: Comparison of filtrate volume between Base mud and Nano-WBM.

Figure 9: Filtrate volume (left: Base mud, Right: Nano-WBM).

Variables	Base fluid	Nano fluid
Determinant co-efficient	0.87130	0.95660
Mean	0.22675	0.12225
Standard deviation	0.08229	0.02363

Table 5: Statistical regressional parameters.

the volume of filtrate collected for base mud samples for all weight concentration. The ratio of filtrate volume for base mud to Nano-WBM for 25 ppb, 30 ppb, 35 ppb and 40 ppb is 1.97, 1.84, 1.81 and 1.94 respectively. Averaging these ratios gives a value of 1.89. This means the filtrate loss for Nano-WBM is 89% more than conventional clay. Based on the API specification for bentonite in WBM, the maximum filtrate collected should not exceed 13.5 ml. In this case, all the Nano-WBM fails to meet the API requirement.

From Figure 9, it can be observed that the filtrate collected for base mud (on the left) is crystal clear, whereas the filtrate collected from Nano-WBM is cloudy. This proves that the Nano Clay particles are small enough to pass through the pores of the filter paper, whereas the conventional clay particles are too big to pass through the filter paper.

The properties of the filter paper used in this experiment are OFITE Filter Press, Grade #50 Whatman, high quality cotton linter material, 150 mm diameter, thickness of 0.12115 μm with pore size of 2.7 μm (particle retention). It can be observed that the pore size of 2.7 μm is considered large enough for Nano Clay to pass through, but not conventional clay. This filter paper of Grade #50 Whatman having the smallest pore size is the best filter paper available in the market.

Conclusions

From the results and discussion presented, a number of conclusions have been deduced and they are listed as below:

a. The mud cake thickness of the drilling fluid has been reduced by 56.25% using Nano Clay compared to conventional clay. But, the filtrate volume collected using Nano Clay has been increased by 89% than the filtrate volume collected for conventional clay which is unexpected.

b. The determinant coefficient values for both base fluid and Nano fluid are 0.8713 (87%) and 0.9566 (96%) respectively close to the best fitted lines. The mean (average) values of base fluid and Nano fluid are 0.23675 and 0.12225 inches respectively. The standard deviation values of base fluid is 0.08229, which means about 82% data points of the base fluid are deviating from the average value and for the Nano fluid the value is 0.02363, which means about 82% data points of the base fluid are deviating from the average value.

c. The rheological properties, gel strength and filtrate volume for Nano Clay shows an adverse impact on the drilling fluid performance compared to conventional clay and does not meet the API specification. An increasing trend in value for PV, YP, gel strength of 10 seconds and 10 minutes and mud cake thickness can be observed, whereas the filtrate volume collected shows a decreasing trend for every addition of 5 ppb weight concentration from 25 ppb until 40 ppb.

d. This discovery matches the objective of this project, which is to reduce the mud cake thickness by using Nano Clay, compared to conventional clay. Also, the relationship between Nano Clay and mud cake thickness has been studied, which is related to the objective. Thus, Nano Clay enhances the mud cake reduction by almost half compared to conventional clay.

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