CSCanada
Advances in Petroleum Exploration and Development
Vol. 17, No. 1, 2019, pp. 100-104
DOI:10.3968/11130

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

Performance Evaluation of a Biomaterial in an Aqueous-Based Drilling Mud at High Pressure High Temperature

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Received 28 February 2019; accepted 22 May 2019
Published online 22 April 2019

Abstract

Oil reserves are found in deep formations where the conditions of temperature and pressure are always high. These conditions have direct effects on the rheological properties of drilling fluid as they vary with increasing temperatures and pressures. Two sets of experiment were carried out on weighted and unweighted mud samples at a temperature of 250°F and 500psi pressure. The presence of locally sourced additives helped the mud to remain pseudoplastic at these conditions and also retained essential properties of the mud need for drilling operations. The plastic viscosities of the weighted and unweighted mud were 36cP and 27cP respectively. The yield stresses were 149lb/100^{2}ft and 110lb/100^{2}ft for the weighted and unweighted samples while the fluid loss volumes were approximately equal. The thickness of the cake for the weighted sample is 3.7mm and 4mm for the unweighted sample. The weighted sample with a reasonably higher PV has a better hole cleaning ability than the unweighted sample. *Mucunna Solannie* performed excellently to retain the essential properties of these formulations at 250°F and is therefore recommended as a HPHT drilling mud additive.

Key words: HPHT; Mucunna Solannie; Deep formations; HPHT filter press

Duru, U. I., Onyejekwe, I. M., Uwaezuoke, N., & Isu, D. O. (2019). Performance Evaluation of a Biomaterial in an Aqueous-Based Drilling Mud at High Pressure High Temperature. *Advances in Petroleum Exploration and Development*, *17*(1), 100-104. Available from: http://www.cscanada.net/index.php/aped/article/view/11130
DOI: http://dx.doi.org/10.3968/11130

INTRODUCTION

The success or failure of any drilling operation is ultimately determined by the type and characteristics of drilling fluid used. Drilling fluids range from water or oil to more complex mixtures carefully enhanced to achieve a specific purpose during drilling operations. Drilling properties of the fluid that can be enhanced to achieve a given objective include filtration, viscosity, weight, pH/Alkalinity, fluid loss control etc. This enhancement is done by the introduction of specially prepared additives into the mud formulation and thoroughly stirred to homogenize.

Drilling fluids to a large extent determine the economics and safety of a drilling program as their functions amongst others are:

- Balancing of formation pressure for proper well control
- Transportation of drilled cuttings and sloughing to the surface
- Stability of the well and lubrication of drill string and bit (Awele, 2014).

To achieve all these functions in a drilling fluid, a best overall compromise is needed to create a balance as the most significant functions in a particular drilling operation should be given more preference in the formulation of the drilling fluid (Awele, 2014).

Oil and gas deposits are found in deep formations and there is an increase in temperature and pressure with depth. Production from these deep zones pose several drilling, completion and production challenges to engineers. Notably among the challenges is the alteration of the rheological properties of the drilling fluid (Amani & Al-Jubouri, 2012).

An increase in temperature affects the rheological properties of the mud and its drilling performance, hence the need to source for additives that can withstand high temperature, high pressure conditions and retain the essential properties of the mud. The behaviour and stability of mud in deep reservoirs are the major factors that determine the safety and efficiency of any drilling operation in HPHT wells as the degradation of the mud components is temperature and time-dependent and can affect other mud properties (Kinate & Kluivert, 2018).

1. LITERATURE REVIEW

Different scholars have tried to study the performance of different drilling additives at high pressure high temperature conditions.

The effect of temperature a water based mud with nano (zinc oxide particle) additives at ranging temperatures was studied (Kinate & Kluivert, 2018). To ensure the accuracy of the experiment, all the equipment were calibrated and the rheology of different mass fractions at different temperatures were studied. Results showed that the gel strength, yield point and viscosity decreased with increasing temperature. Also, an increase in the quantity of the zinc oxide additives increased the gel strength, mud density, electrical conductivity and plastic viscosity. irrespective of the temperature. The yield point decreased at higher temperatures with an increase in the zinc particles (Kinate & Kluivert, 2018).

Sodium Bentonite from three sources (XiaJiang, Shandong, Inner Mongolia) and HPS were experimented at different temperatures for 16hrs (Wenjun, et al, 2014).

At different temperatures, the HPS water dispersion had a low viscosity. Sodium bentonite from Shandong and Inner Mongolia decreased in shear force and apparent viscosity at temperatures above 150^{o}C. For the sodium bentonite from Xianjiang, there was a corresponding increase in viscosity and shear force as the temperature increased. This particular additive also had good filtration properties at high temperatures with an increasing amount of the bentonite (Wenjun, et al, 2014).

Carboxymethyl cellulose (CMC) is a common additive that increases mud viscosity while barite is a density control additive. Cassava (manihot manifera) and water yam (Discoria alata) were studied in a laboratory and their effects in a drilling fluid formulation compared to CMC and barite (Ohenhen, et al, 2018). The rheological properties of interest were the apparent viscosity, yield point, plastic viscosity, filtration properties, gel strength and mud density at different high temperatures of 120-150oF and pH value. It was found that the two local materials increased the mud density more than barite; hence they can be used as weighting agents. At room and high temperatures, water yam had a better filtration properties than CMC. Finally, the cassava and water yam samples were non-acidic and thus less corrosive than the CMC (Ohenhen, et al, 2018).

The effect of temperature on the density of water based drilling mud was investigated (Ebikapaye, 2018). A formulation comprising of a Nigerian Bentonitic clay from Isoko in Delta State of Nigeria, barite, CMC and distilled water was prepared. This was tested at varying temperatures and results showed that the mud density decreased with increasing temperature (Ebikapaye, 2018).

Maize (Zea mays) and Cassava (Manihot esculanta) as a water based drilling mud additives were studied at different temperatures and their time-dependent behaviour analyzed (Sarah & Isehunwa, 2015). A water containing 100ppm sodium metabisulphate was soaked with fresh cassava tubers that were washed, peeled and cut. This was filtered with a muslin cloth and the suspension was left overnight for the starch to settle. The starch from maize was obtained by steeping the maize in hot water for 10hrs and then grinding. This was centrifuged to allow the starch to settle also. Results showed that the plastic viscosity increased with increase in temperature. Above 62oC, there was a decrease in PV as starch crystalinity was lost and gelatinization occurred. The behaviour of the cassava starch was closer to the control than the maize starch.

The following experiments investigated the effects of Mucunna Solannie on weighted and unweighted mud samples under high pressure and high temperature conditions.

2. MATERIALS AND METHODS

Two fresh mud samples were prepared with water as a continuous phase and a carrier for mud additives in the mixture. The compositions of each sample and the concentrations of various additives used are stated in Table1.

The additives were locally sourced from common plants, pods and shrubs that have been long known to possess some characteristics. For example, Brachysteria eur. popularly known as ‘Achi’ in the south eastern part of Nigeria is a common food thickener and will improve the gel strength of the mud. Pleurotus will control fluid loss in the mud due to its high fiber content. The pH of the formulation will be controlled by the caustic soda (NaOH). The XCD polymer is a viscosity enhancer and also reduces fluid loss in the formulation.

Mucuna Solannie (M.Solannie) is a traditional soup thickener in the Igbo tribe of Nigeria. This characteristic makes it a good viscosifier and gelling agent in the mud samples.

Sample A is an unweighted mud sample while Sample B is a weighted mud sample. The difference between the two formulations is the addition of Barite and Potassium Chloride into sample B. Barite is a weighting agent that helps to maintain well stability and efficient cuttings removal while the Potassium Chloride (KCI) will prevent the hydration of the clay.

Table 1
Amounts of additives for weighted and unweighted mud samples

Material	Unweighted mud	Weighted mud
Fresh water	350ml	350ml
Caustic soda	0.25g	0.25g
Mucuna solannie	3g	6g
Brachystegia eur.	3g	6g
Pleurotus	3g	8g
XCD polymer	0.75	1g
Potassium chloride	-	20g
Barite	-	75.4g

The samples were prepared by adding the right concentrations of the additives as given in Table 1 into a $350cm^3$ of water in a mixing cup. Aging was achieved by allowing the mixture for 10hrs, and then mixing began with the aid of the Hamilton Beach mixer for 1:30mins. Homogeneity was achieved as the additives were uniformly distributed in the mixture. Then the agitation was stopped. A temperature of 250^oF was achieved with the use of a water bath.

Viscometer readings were obtained by placing the sample in an OFITE six-speed model viscometer and readings taken at 600rpm, 300rpm, 200rpm, 100rpm, 6rpm and 3rpm according to the API guidelines.

A HPHT filter press equipment helped to determine the static fluid loss properties as the sample was left for 48hrs inside it. The filtrate was collected in a measuring cylinder and readings taken for the fluid loss volume and filter cake thickness.

Similar steps were followed for sample B (weighted mud). The only additional requirements in the formulation of the sample is the addition of 75.4g of barite and 20g of Potassium Chloride for weighting and hydration inhibition purposes.

3. RESULTS AND DISCUSSIONS

Table 2 and Table 3 show the viscometer readings at different rpm at 250^0F for the weighted mud samples. Other mud properties were derived from their expanded equations based on the viscometer readings.

Equations 1 – 8 are used to calculate the yield point (Υ_p), plastic viscosity (Pv), apparent viscosity (Av), shear rate, shear stress, viscosity, flow behaviour index (n) and consistency factor (k) respectively (Udoh & Okon, 2012).

$$\Upsilon p = \Theta 300 - Pv \quad (1)$$

$$Pv = \Theta 600 - \Theta 300 \quad (2)$$

$$Av = \frac{\theta_{600}}{2} \quad (3)$$

$$\text{Shear rate} = 1.703 \times RPM \quad (4)$$

$$\text{Shear stress} = 5.11 * \text{Dial reading} \quad (5)$$

$$\text{Viscosity} = \frac{shear\ stress}{shear\ rate} \quad (6)$$

$$n = 3.32\log\left(\frac{\theta_{600}}{\theta_{300}}\right) \quad (7)$$

$$k = 5.11\left(\frac{\theta_{300}}{511^n}\right) \quad (8)$$

where: Θ_{600} and Θ_{300} represent the dial readings at 600 and 300 rpm respectively.

Table 2
Results for Weighted Mud

Shear rate	Value
600rpm	221
300rpm	185
200rpm	147
100rpm	109
6rpm	56
3rpm	42
Pv	36
Av	110.5
Yp(lb/1002ft)	149
n	0.26
k	187
Fluid loss volume	>25ml
Filter cake thickness	3.7mm

Table 3
Results for Unweighted Mud

Shear rate	Value
600rpm	164
300rpm	137
200rpm	113
100rpm	79
6rpm	34
3rpm	25
Pv	27
Av	82
Yp(lb/1002ft)	110
n	0.26
k	138
Fluid loss volume	>25ml
Filter cake thickness	4mm

The calculated values for the different variables using the above expanded equations are given in Table 4 and Table 5 for the weighted and unweighted mud samples respectively.

Table 4
Computed Results From Weighted Mud Sample

Rotor speed (rpm)	Dial Reading	Shear Rate (1/s)	Shear Stress (Pa)	Viscosity (cp)
600	221	1022	1129	1.1
300	185	511	945	1.85
200	147	341	751	2.2
100	109	170	557	3.3
6	56	10	286	28.6
3	42	5	215	43

Table 5
Computed Results From Unweighted Mud Sample

Rotor speed (rpm)	Dial Reading	Shear Rate (1/s)	Shear Stress (Pa)	Viscosity (cp)
600	164	1022	838	0.82
300	137	511	700	1.37
200	113	341	577	1.7
100	79	170	404	2.4
6	34	10	174	17.4
3	25	5	128	25.6

3.1 Discussions

Tables 4 and 5 show that viscosity varies indirectly with the rotor speed. This is because a Non-Newtonian fluid requires a certain amount of shear stress to initiate flow, then additional stress is needed as the shear rate increases. Figure 1 shows the curves for different fluid types.

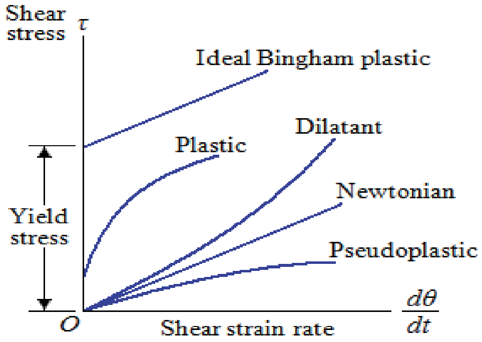

Figure 1
Flow curves for different fluids

From Figure 2, the weighted sample has higher shear stress than the unweighted sample and this is due to the presence of weighting solids that made it more viscous.

A high temperature decreases the viscosity of the liquid phase in a drilling mud sample and also leads to the breakdown of the bonds within the polymer chains resulting in thermal degradation of Mucunna Solannie.

Mucunna Solannie sustained the viscosity of the mud to a reasonable extent at 250°F and therefore can be recommended as a good viscosifier provided the right amount is used.

The plastic viscosity is a function of the viscosity of the liquid phase and the number of solids a mud contains. It describes the expected behaviour of the mud at the bit. A decrease in the PV reduces the viscosity at the bit; hence resulting to a higher rate of penetration.

When the PV is too high, there is an increase in the pressure drop down the drill string. This retards the flow rate and has a negative effect in the lifting capacity of the mud (Awele, 2014).

Experimental result shows that the weighted and unweighted sample have reasonable PV (36cP and 27cP respectively) at 250°F and this implies a good hole cleaning ability. Therefore, Mucunna Solannie performs well under HPHT conditions.

The yield point measures the attractive forces due to opposite charges between solids in a mud. This causes initial resistance to flow. The yield point depends on the concentrations of the solids, types of solids and their surface charges, type and concentration of other ions and salts.

The yield point of the weighted mud sample is higher. This can be caused by flocculation or high concentration of solids. Flocculation is usually caused by high temperature, lack/insufficient deflocculant.

A high Yp can cause lost circulation or swabbing but it's good for hole cleaning (Awele, 2014). In high density mud, the need to maintain a low Yp outweighs any advantages of a higher Yp (Max & Annis, 1996).

An ideal filter cake is thin, tough, impermeable and flexible. At the wellbore well, it should be able to separate the wellbore fluids from pore fluids. This helps to achieve wellbore stability and prevent differential sticking.

An increase in depth leads to an increase in temperature and filtration pressures. As the filtrate viscosity decreases with increasing temperatures, the increase in pressure accelerate the formation of filter cake but, on the other hand, prevents the normal decrease in the permeability of the filter cake with increasing pressure (Rommetveit & Bjorkevoll, 1997). The fluid loss and filter cake thickness for both samples are approximately equal.

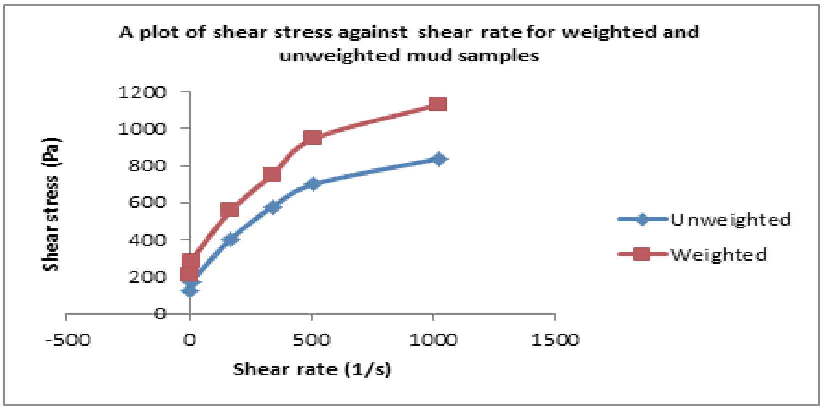

Figure 2
Rheogram for weighted and unweighted mud samples

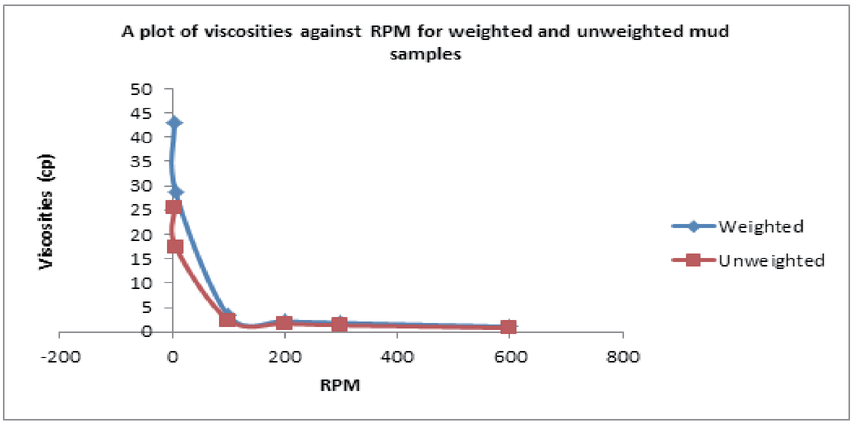

Figure 3
Viscosities against RPM for weighted and unweighted mud samples

The flow behaviour index for both samples is less than 1; hence it's a pseudoplastic and a shear-thinning fluid. For this type of fluid, the apparent viscosity decreases with increasing shear rate[1].

CONCLUSION

From the results available, temperature and pressure greatly affect the performance of drilling fluid additives. At high temperature zones usually encountered in deep formations, the viscosity of the mud decreases due to the thermal degradation of its constituent additives. Also, other properties that define the functions of a drilling mud are also affected by these conditions. Mucunna Solannie performed excellently to retain the essential properties of these formulations at 250°F and is therefore recommended as a HPHT drilling mud additive.

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