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Performance evaluation of *Mucuna solannie* as a drilling fluid additive in water-base mud at cold temperature

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Weighted and unweighted aqueous mud formulations from a biomaterial, at cold temperature of 5°C, were tested for their rheological characteristics. Based on API guidelines and recommended equipment for drilling fluid tests, the rheological properties of the formulations were determined. The muds exhibited pseudoplastic behaviour. The fluid loss volumes of the weighted and unweighted muds are 14 and 21 ml, respectively, while the filter cake thicknesses are 2.5 and 3 mm, respectively. The yield stresses of the weighted and unweighted muds are 209 and 159 lb/100 ft^2, respectively. Plastic viscosity of 42 cP for the weighted mud against 23 cP for the unweighted mud showed that the weighted mud has a better cutting lifting capacity if PV is used as an indicator. *Mucuna solannie* additive can also perform in cold temperature, and has the potential to be used in cold temperature drilling.

Key words: Biomaterial, cold temperature, fluid loss, rheological properties.

INTRODUCTION

Drilling fluids for oil and gas industry are complex mixtures of natural and synthetic chemical compounds used to achieve several goals in drilling operations. In addition to several functions, drilling mud has historically served as a vehicle for cuttings removal from the borehole but presently, it has diverse applications that have made the assignment of a specific function difficult as these functions are almost equally important in any drilling program.

Three principal functions of a drilling fluid amongst others are:

(1) Removal of cuttings from below the bit to the surface and control subsurface pressure.
(2) Lubrication and cooling of the bit and drill string
(3) Formation of filter cake to prevent fluid loss and maintain wellbore stability

These functions demonstrate the importance of drillings fluid in any drilling operation and the need to carefully study its formulation and properties, since one property can provide more than one function.

Drilling fluids are non-Newtonian and generally pseudoplastic in nature. They do not conform to Newtonian law due to large particles they contain in significant quantities and thus are classified as non-

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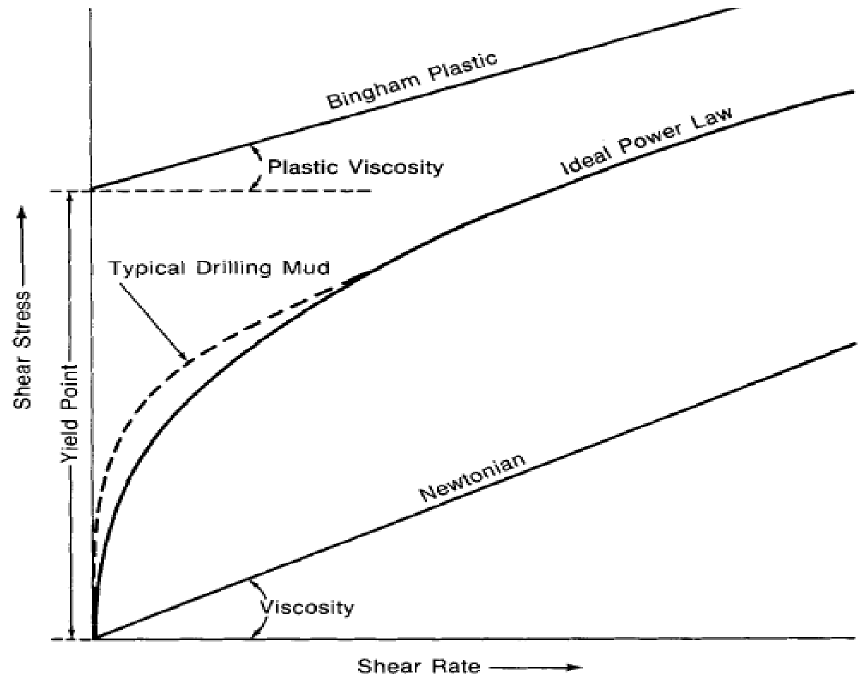

Figure 1. Ideal consistency curves for common flow models[1].

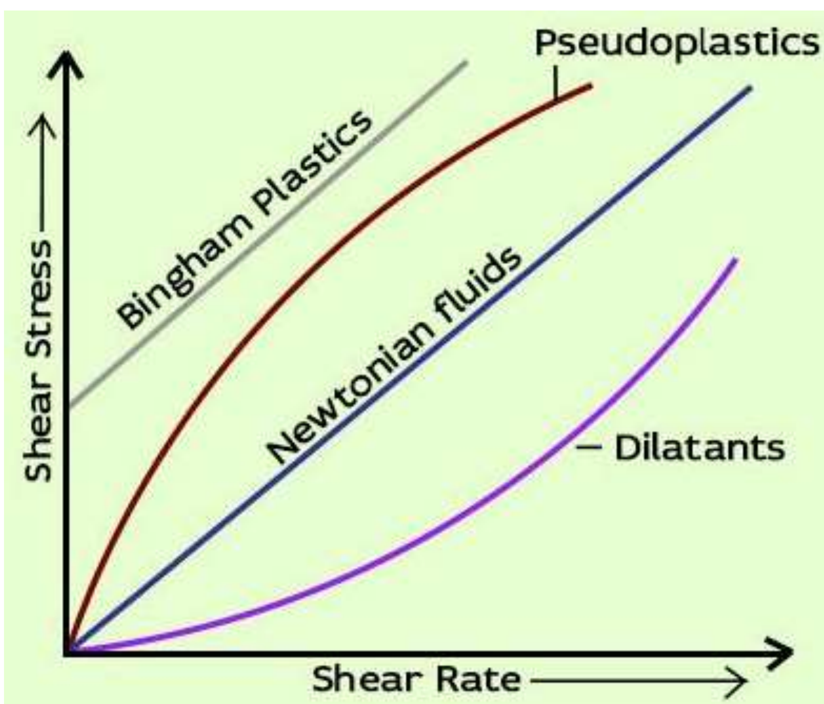

Figure 2. Comparison of shear stress, shear rate properties and yield point [2].

Newtonian fluids [1] as shown in Figures 1 and 2. It ranges from ordinary water-base or oil-base to more complex systems like the compressed air and synthetic polymers (Darley and George, 1998). Drilling fluid is related either directly or indirectly to most drilling problems in the field, hence, the selection and maintenance of the best drilling composition is a careful task of the entire drilling crew as the success of the operation greatly depends on it (Chukwu, 2012).

Drilling problems vary for different formations and to effectively tackle the challenge at hand, the drilling mud composition needs to be fine-tuned accordingly. This may include giving specific attention to the properties of the drilling mud that is needed to solve the problem.

Some of the properties of the drilling fluid are viscosity, yield point, density, gel strength, filtration properties, electrical conductivity, shear rate, shear stress, etc. This study focuses on the viscosity, yield point, shear forces and filtration properties as they are needed to fully substantiate the effect of *Mucunna solannie* as a useful drilling additive.

Drilling fluid additives are solids or particles introduced into the drilling mud to make prominent certain properties of interest and achieve a desired composition for a given purpose. These additives comprise viscosifiers, dispersants, weighting materials, surfactants, shale inhibitors, lost circulation materials, filtration control additives and salinity control chemicals.

The number of additives present in a particular composition depends on the type of formation being drilled, subsurface conditions (pressure and temperature), local experience, costs, logistics and the recommended drilling program (Darley and George, 1998).

Drilling fluid additives can be locally or foreign sourced. The continual use of synthetic polymers from the foreign market has become expensive, environmentally hazardous and in most cases, not suitable for some formations in Nigeria. Therefore, the need to source for local materials with peculiar characteristics to introduce specific behaviors to the drilling mud formulation cannot be overemphasized. This is completely in line with the local content policy currently advocated in Nigeria.

LITERATURE REVIEW

Many researchers have studied the effects of local materials additives on drilling fluid characteristics. Mostly, the concentration has been on the rheological behavior (viscosity and fluid loss properties) of these additives on aqueous mud.

The advantages of aqueous formulations include high true yield strength, higher shear thinning, reduced circulating pressure losses and good bit hydraulics (Carney et al., 1988). More so, it is less expensive.

Use of rice husk in aqueous mud as a fluid loss control additives has been studied. A sample of rice husk from a local mill was dried by placing it in the vacuum for 3 to 4 h at about 45°C and the moisture content was removed. The dried sample was ground into smaller sizes with a blender and then sieved to 125 microns to obtain fine particles (Okon et al., 2014). It was found that rice husk compares favorably with standard polymers like poly-anionic cellulose (PAC) and carboxymethyl cellulose (CMC) except that it requires twice the quantities of the standard polymers (Okon et al., 2014). This is due to the presence of lignin (phenylpropanoid polymer) which is naturally present in the rice husk. It was also found that the rice husk has less filter cake thickness than the standard polymers. This shows that the bound mud particles in rice husk are more compressible than those of the standard polymers (Okon et al., 2014).

Another research investigated the use of cassava starch flour in bentonite as an additive to control fluid loss and viscosity in aqueous mud (Dankwa et al., 2018). Different samples of mud were formulated from different masses of cassava starch flour (2, 4, 6 and 8 g) and an additional one being the control bentonite (0 g of cassava starch flour). Fluid loss and rheological tests were conducted to determine the yield point, gel strength, plastic viscosity and other rheological parameters of the various samples (Dankwa et al., 2018).

Results show that the introduction of cassava starch flour into the mud samples from concentrations of 2 to 8 g reduced its fluid loss by an average of 8% (Dankwa et al., 2018). The swelling ability of the cassava starch flour caused an increase in the quantity of the cassava starch flour in the aqueous mud and increased mud viscosity. Also, greater suspension ability of the cuttings (gel strength) and reduced filter cake thickness was observed with lesser amount of cassava starch flour (Dankwa et al., 2018).

Another research work investigated the effect of locally biodegradable and environmentally friendly additives such as corn cobs from *Zea mays* and coconut shells from *Cocos nucifera* on rheological properties (Onuh et al., 2017). With different concentrations, their effects were evaluated on fluid loss properties using low pressure low temperature (LPLT) filter press at 90°C and 100 psi. The results of the formulated mud with the two additives (corn cobs and coconut shell) were compared to the individual mixtures of corn cobs and coconut shells, and without any additive (Onuh et al., 2017). Results from the experiments show that a decrease in pH values was observed with increasing concentration of the 3 samples. As the concentration of the additives increased, the density of the mud increased also. But the reverse is the case for the third sample which is the combination of the two additives. Another result showed that corn cobs are better fluid loss control additives than the coconut shell but the combination of both yields a better result (Onuh et al., 2017).

Similarly, a comparative analysis of the effects of cashew and mango extracts on the rheological behaviour of aqueous mud has been carried out (Omotioma et al., 2014). Fresh leaves of mango and cashew were washed and rinsed with tap and distilled water, respectively (Omotioma et al., 2014). The raw materials were added in different concentrations to the mud formulation and three different samples were prepared (Omotioma et al.,

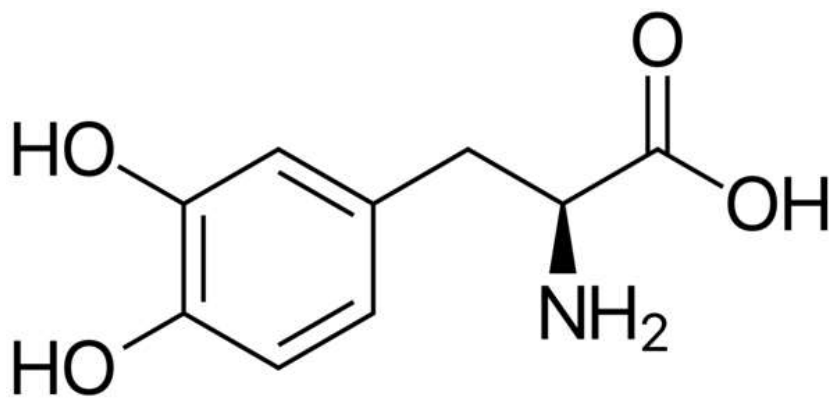

Figure 3. Structure of L-3,4-dihydroxyphenylalanine.

2014). The mud had a pH of 9.1 which is alkaline. Increase in concentration of the two extracts showed an increase in gel strength but the mango extract sample gave the highest gel strength. From all the parameters studied, it is concluded that mango extracts improve rheological properties more than cashew extract (Omotioma et al., 2014).

METHODOLOGY

Equipment and raw materials

A good drilling fluid additive should be able to alter the rheological properties of the mud to achieve a required objective. However, the additive does not work in isolation. It is always in a mixture of other substances whose functions have been well established and their impact or behaviour in the overall mixture is known. Any deviation in the expected property can be attributed to the new additive under study.

The effect of *M. solannie* on the properties of a drilling fluid sample is demonstrated through an experiment. A drilling mud sample is prepared from local additives that are readily available, cost-effective and environmentally friendly. The experiment carried out under a cold temperature of 5°C evaluates the performance of *M. solannie* under two different samples of weighted and unweighted mud compositions, respectively.

The equipment used include the mud balance, rotary viscometer, spatula, weighing balance, wash bottle, measuring cylinder, beaker, stop watch, mixer and low pressure low temperature (LPLT) filter press.

The raw materials used for the unweighted mud are fresh water, caustic soda, *M. solannie, Brachystegia eurycoma, Pleurotus* and XCD polymer. The additional raw materials for the weighted mud are barite and Potassium chloride. The functions of each of the materials are listed as:

(1) Water: This is the base fluid and acts as a carrier for mud additives.
(2) Potassium Chloride (KCl): Potassium chloride inhibits clay hydration.
(3) XCD Polymer: This is used to achieve viscosity and fluid-loss control in mud formulations.
(4) Sodium hydroxide (Caustic soda): This controls the pH of the formulation.
(5) *Pleurotus* contains high concentration of fiber and can function as the main source of the fluid loss control in mud (Uwaezuoke et al., 2017).
(6) *Brachystegia eurycoma* locally known as ‘Achi’ in Igbo Language serves as a thickener to improve the gel strength of the mud.
(7) Barite is the weighting agent and increases the ability of drilling mud to balance the formation pressure and suspend cuttings.
(8) *Mucuna* is of the family of Fabaceae. It is a genus of over 100 accepted species of climbing vines and shrubs (Uwaezuoke et al., 2017). The plants bear pods and their seeds are buoyant in aqueous medium. Common among the species are *Mucuna pruriens*, *Mucuna hoitoni*, *Mucuna flagellipes*, *M. solannie*, etc.
(9) *M. solannie* commonly known as 'Ukpo' in Igbo Language is traditionally used as efficient food thickeners. This species can equally be used in beverage and other food producing industries. *M. solannie* is added to the drilling mud formulation to act as a viscosifier and a gelling agent.

The roots, leaves and seeds of the *Mucuna* family are known to produce secondary chemical agents. The commonest of them is the non-protein phytotoxic compound known as L-3,4-dihydroxyphenylalanine (L-DOPA) which is used to treat symptoms of Parkinson disease (Soares et al., 2010). The structural formula of L-DOPA is as shown in Figure 3.

L-DOPA binds to tyrosyl in bacterial cells and to phenylalanyl-tRNA synthesizes in prokaryotic-eukaryotic cells (Soares et al., 2010). This makes L-DOPA a key compound in the formation of mussels and other marine adhesive proteins. The binding ability of L-DOPA which is a major constituent of *M. solannie* accounts for its viscous effect as they try to bind or adhere to the particles of other substances in the mixture.

The *M. solannie* used for the experiment was bought from nearby market in Port Harcourt. The pods were cooked for 6 h and allowed to cool. The shells of the cooked pods were then removed and the seeds brought out. The seeds were ground into powder with the help of a grinding machine. The required quantity for the experiment was then measured out for the respective cases.
The compositions of these additives are shown in Table 1.

Experimental procedure

The unweighted mud (Sample A) was prepared by pouring 350 cm^3 of water into a mixing cup and other additives were added in the concentrations shown in Table 1. This mixture was allowed for 10 h

Table 1. Concentrations of additives for weighted and unweighted mud.

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

Table 2. Rheological test results for weighted and unweighted sample.

Shear rate and rheological properties	Weighted	Unweighted
600 rpm	293	205
300 rpm	251	182
200 rpm	213	145
100 rpm	169	112
6 rpm	97	59
3 rpm	72	43
Pv	42	23
Av	147	103
Y_p (lb/100 ft^2)	209	159
Fluid loss volume	14 ml	21 ml
Filter cake thickness	2.5 mm	3 mm

for aging. Then mixing was carried out with the Hamilton Beach mixer for 1 h: 30 min to achieve homogeneity.

After this time interval, agitation was stopped and the sample passed through a cold water bath. The temperature was checked to make sure it is within the 5°C temperature target. The mud weight was taken with a mud balance.

The next step was the determination of the viscometer readings and the sample was placed in an OFITE six-speed model viscometer where readings at 600, 300, 200, 100, 6 and 3 rpm were taken in accordance with the API guidelines.

The sample was then placed in the low pressure filter press equipment for 48 h and the filtrate was collected in a measuring cylinder. Readings for the filter cake thickness and fluid loss volume were taken.

The same procedure was followed for the weighted mud (Sample B) except that the formulation composed of a 75.4 g barite ($BaSO_4$) and a 20 g Potassium chloride (KCl). These additives were introduced for weighting and clay hydration inhibition purposes.

Readings for the different parameters were recorded and tabulated as shown in Tables 2 to 4.

RESULTS AND DISCUSSION

The density requirement of a particular drilling operation determines if the mud should be weighted or unweighted. In both cases, available results show that the mud sample exhibited good viscosity and this can be attributed to the binding ability of L-DOPA in *M. solannie*.

The viscometer readings at 600, 300, 200, 100, 6 and 3 rpm for the weighted and unweighted mud formulations are shown in Tables 2 and 3, respectively.

The expanded equations for plastic viscosity (Pv), apparent viscosity (Av) and yield point (Y_p) from viscometer readings are shown in Equations 1 to 3 (Udoh and Okon, 2012):

$$Y_p = \Theta_{300} - Pv \quad (1)$$

$$Pv = \Theta_{600} - \Theta_{300} \quad (2)$$

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

These equations are used to calculate the values for the plastic viscosity, apparent viscosity and yield point as shown in Table 2.

Property variations due to M. solannie

The effect of *M. solannie* on mud properties is discussed

Table 3. Calculated results from weighted mud test.

Rotor speed (rpm)	Dial reading	Shear rate (1/s)	Shear stress (Pa)	Viscosity (cp)
600	293	1022	1497	1.46
300	251	511	1283	2.5
200	213	341	1088	3.19
100	169	170	864	5.08
6	97	10	496	49.6
3	72	5	368	73.6

Table 4. Calculated results from unweighted mud test.

Rotor speed (rpm)	Dial reading	Shear rate (1/s)	Shear Stress (Pa)	Viscosity (cp)
600	205	1022	1048	1.03
300	182	511	930	1.82
200	145	341	741	2.17
100	112	170	572	3.36
6	59	10	301	30.1
3	43	5	210	42

and emphasis is on the acceptable operating range to achieve an effective drilling task.

Plastic viscosity is the resistance to the flow of fluid caused by mechanical friction within the fluid. This friction results from the interaction of solids, liquids and the deformation of liquid that is under shear stress.

An increase in the solid content present in a drilling mud will result in high plastic viscosity. Solids can be weighting materials like barite, lost circulation materials, drill solids, etc. Hence, the weighted sample has more plastic viscosity than the unweighted sample. To lower the PV, solid control equipment can be used.

Yield point Y_p is the resistance to initial flow or the stress needed to start the movement of fluid. The yield point evaluates the ability of mud to lift cuttings out of the annulus. A higher Y_p means the drilling fluid can lift cuttings better than a fluid of similar density (Udoh and Okon, 2012).

The yield point for both samples (209 and 159 lb/100 ft^2) is within the API recommendations for a good drilling mud.

Fluid loss is the amount of filtrate that passes through the filter cake (Udoh and Okon, 2012). Some factors affect the fluid loss capacity of a mud such as cake compressibility, temperature and time. Also the amount, size and nature of solids in the fluid affect it.

From the results, more fluid was lost in the unweighted mud sample (21 ml) than in the weighted mud sample (14 ml). This can be attributed to the presence of barite and a double quantity of *M. solannie.* This shows that *M. solannie e* can equally serve as a fluid loss control additive.

A good drilling mud should form a filter cake on the walls of the hole to prevent the formation from caving into the wellbore. This filter cake can prevent the invasion of the formation by mud filtrates. The quantity of the filter cake should be reasonable to minimize excessive buildup of cakes in the wall which can cause formation damage and probably, differential sticking (Chukwu, 2012). When the drilling fluid contains different sized particles, the larger particles form the skeleton of the filter cake, whereas smaller particles bridge the pore spaces (Udoh and Okon, 2012). This whole process is called 'wellbore stabilization'.

The weighted mud sample formed a filter cake of 2.5 mm thick while the unweighted mud formed a filter cake of 3 mm thick.

Filter cakes formed by both samples is reasonably accepted for their individual concentrations. Similarly, Equations 4 and 5 are used to compute the values of the shear rate, shear stress and viscosity (Udoh and Okon, 2012).

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

$$\text{Shear stress} = 5.11 \times \text{Dial reading} \qquad (5)$$

1.06 = Geometry factor of the viscometer and 0.4788 = Conversion factor from lb/100ft^2 to Pascal

$$\text{Viscosity} = \frac{shearstress}{shearrate} \qquad (6)$$

The shear rate, shear stress and viscosity values for the various readings are tabulated in Table 3.

The same procedure is followed to determine the different parameters for the unweighted mud sample and

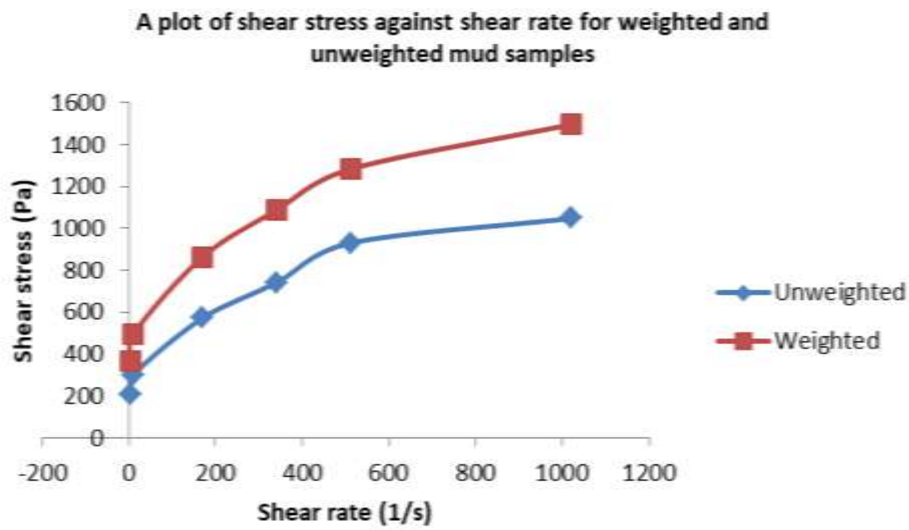

Figure 4. Rheogram for weighted and unweighted mud samples.

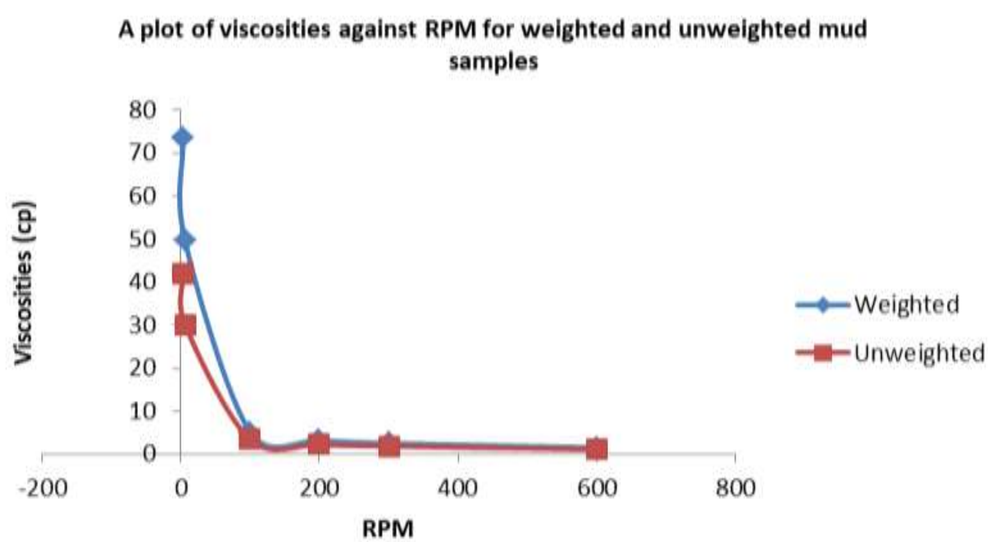

Figure 5. Viscosities against RPM for weighted and unweighted mud samples.

calculated parameters for shear rate, shear stress and viscosity from results are presented in Table 4.

From Tables 3 and 4, there is a variation of viscosities at different spindle speeds. Viscosity increases as the rotor speed reduces. This is in agreement with the behavior of a drilling mud. Figure 4 shows the behavior of non-Newtonian fluids on a plot of shear stress against shear rate for the weighted and unweighted mud samples and conforms with Figures 1 and 2. Figure 4 shows that the formulated sample in this research is a pseudoplastic liquid and can be used as a drilling mud.

The shear stress of the weighted mud sample is higher than that of the unweighted formulation. The rheological properties of the aqueous mud in Figure 2 show that as the shear stress increases with increasing shear rate, viscosity decreases due to the high shear rate as the additives increase in concentration.

One characteristic of a good viscosifier is its ability to maintain stable viscosity under the attack of sodium and calcium ion (Darley and George, 1998). From the results presented, *M. solannie* has proven to be a good adhesive for both samples as it ensured the samples remained viscous (Figure 5).

The presence of *M. solannie* did not affect the performance of other biomaterials in the mud sample and thus should be given more attention as a local viscosifier.

M. solannie is available in large quantities from local market and is far cheaper than the synthetic polymers from foreign market. Therefore, cost is minimized and the product is available for extensive application.

Also, *M. solannie* is non-toxic and environmentally friendly; hence, another cost is saved from detoxification of wastewater before disposal.

Conclusion

An increase in the shear stress results in a decrease in the viscosity and *M. solannie* proved to be a good viscosifier as it maintained relatively stable velocity. Also, the formulations exhibited good fluid loss properties; the weighted mud sample had a lower fluid loss volume and filter cake thickness. Moreso, the weighted formulation showed better lifting capacity due to higher plastic viscosity. Generally, it can be concluded that *M. solannie* has a potential as an additive in a cold temperature drilling environment due to the understandable properties the drilling muds exhibited.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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