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Evaluation of Local Viscosifiers as an Alternative to Conventional Pac-R

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Abstract

Hole cleaning is a key parameter in every drilling program. Efficient bottom hole cleaning is achieved through adequate transportation of cuttings from the wellbore to the surface. Modified natural polymers like Poly anionic cellulose regular (PAC-R), with bentonite clay has been used to achieve good carrying capacity of drilled cuttings in water base mud (WBM). These conventional polymers have adverse effect on the environment, especially the mud-filtrate which pollutes and contaminates the aquifer and the spent mud that requires caution for its disposal. In this work, Local viscosifers were obtained from Mucuna Flagellipe (Ukpo), Brachystegea Eurycoma (Achi), Afzelia Africana (Akpalata) and Detarium microcapum (Ofor) as a substitute for the imported viscosifiers (PAC R) used as a drilling fluid additives. Water-based muds were formulated from the aforementioned locally sourced viscosifiers and that of the conventionally used viscosifier (Pac-R). Laboratory tests were carried out on the different muds formulated and their rheological properties evaluated, such as yield stress, , shear stress plastic viscosity and shear rate. The concentrations of the locally sourced viscosifiers were varied and rheological tests performed show that Mucuna Flagellipe (Ukpo) had a better viscosity compared to Achi, Akplata and Ofor of the same concentration. It was also observed that 5g of Mucuna Flagellipe (Ukpo) and 8g of detarium microcapum (Ofor) gave an equivalent rheological properties of 27lb/100ft^{2}and 26lb/100ft^2 as yield stress when compared to2g of Pac-R which gave a yield point of 29lb/100ft^2 at a temperature of 180˚F. Also, 8g of Mucuna Flagellipe (Ukpo) gave an equivalent of 5g of PAC-R. Hole cleaning parameters such as slip velocity, annular velocity and cuttings transport efficiency were also considered for evaluating the effectiveness of the proposed muds with local viscosifiers and conventional viscosifiers on hole cleaning. 5g and 8g of Mucuna Flagellipe (Ukpo) compared favourably with PAC-R in terms of hole cleaning. Finally in terms of cost, the locally sourced viscosifiers are cost effective when compared with the conventional vscosifier. Therefore, locally sourced viscosifiers (Mucuna Flagellipe, Ukpo) can be used as a substitute to the conventional Pac-R when drilling top hole at a temperature of 150˚F and below since these holes are drilled within a thermal gradient of 150˚F and below in the Niger delta region of Nigeria.

Key words: Hole cleaning; Viscosifier; Cutting transport; Rheology; Yield stress

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INTRODUCTION

The exploration for hydrocarbon in the Niger Delta region dates back to the early1950s when the first oil (hydrocarbon) reserve was discovered at Oloibiri in the present day Bayelsa State in 1956 (Etu-Efeotor, 1997). Drilling is the process of creating a passage for the discovered hydrocarbon to be produced at the surface. It involves the penetration of the earth's crust to several thousand feet where the hydrocarbons are accumulated in the reservoir by means of rotary drilling process . (Udoh & Okon, 2012). Rotary drilling process utilizes drilling fluid which performs several functions during operation. Drilling fluids are heterogeneous mixture of chemical, water or oil and clay materials (Ogunrinde & Dosunmu, 2012) that aid in the transportation of drilled cuttings from the wellbore to the surface (Ogunrinde & Dosunmu, 2012; Hassiba & Amani, 2013). Thus, the transportation of drill cuttings and efficient hole cleaning are absolutely necessary parts of any drilling program (Ofesi et al., 2017). Failure of the drilling fluid to accomplish the above stated function will lead to cuttings accumulation in the annulus of the wellbore. Poor hole cleaning and inefficient cuttings transport may lead to unwanted drilling problems such as excessive equivalent circulating density (ECD), high torque and drag, lost circulation, formation fracture and stuck pipe. All these events increase the non-productive time (NPT) and drilling costs of the well (Ogunrinde & Dosunmu, 2012). In order to evaluate the efficiency of any drilling fluids in terms of cutting removal, certain measurable parameters are required such as drilling mud viscosity, flow rate, pipe rotation, wellbore geometry, rate of penetration, slip velocity and cuttings transport efficiency. Viscosity is one of the key parameters. However, to achieved the desired objectives, viscosifiers are added to enhance the viscosity of the drilling mud for effective hole cleaning. (Unegbu, 2010)**.** Drilling fluid's effectiveness is measured based on its rheological properties among other yardsticks, which include yield oint, shear rate, shear stress, and plastic viscosity and gel strength. The functions of drilling fluids that are dependent on these are cuttings transportation along the wellbore annulus (Igwilo& Zakka, 2014; Izuwa, 2015). The major factors that describe cuttings transport are fluid velocity and particle settling velocity. For efficient cleaning of the wellbore, fluid velocity must precede cuttings settling velocity and has to be adequate to transport these cuttings to the surface of the wellbore (Noah, 2013). Modified natural polymers like Poly anionic cellulose (PAC), xanthan gum, guargum and carboxyl methylcellulose (CMC) have been used successfully with bentonite clay to achieve good carrying capacity of drilled cuttings in water base mud (WBM). These conventional polymers have adverse effect on the environment especially the mud-filtrate which pollutes and contaminates the aquifer and the spent mud must be disposed with caution. Therefore the development of new set of viscosifers is paramount (Izuwa, 2015). In this work, local viscosifiers were evaluated to ascertain their effectiveness to substitute conventional viscosifier used as additive in drilling mud in Nigerian oil and gas industry. Four different drilling mud formulations were proposed from local biomaterials as viscosifiers, their rheological properties like effective viscosity, yield stress, shear rate and shear stress were determined and their effect on wellbore cleaning obtained. These were compared with those of conventional viscosifier also formulated in this study.

1. METHODOLOGY

1.1 Preparation of the Samples (Local Viscosifiers)

The Local viscosifiers used for this work were collected from the Niger Delta region of Nigeria. The seeds of the local viscosifiers are Detarium micocarpum (ofor), Brachystegea eurycoma (achi), Afzelia Africana (Akpalata) and Mucuna Flagellipe (ukpo) as shown in figures 1, 2, 3 and 4 respectively. The seeds were extracted

Figure 1
Offor (Detarium Micocarpum) Seed

Figure 2
Achi (Brachystegea Eurycoma) Seed

Figure 3
Afzelia Africana (Akpalata) Seed.

Figure 4
Mucuna Flagellipe (Ukpo) Seed.

by removing the thick bark of the fruit and the pulp was scrapped off using a spatula.

The seeds were blended into fine powder using an electric blender. The grinded seed was dried in a roller oven at 120˚F for 5hours and finally re-grinded. The coarse powdered materials were sieved using a sieve of 80microns until a fine powder was obtained. The powder obtained from the seed was weighed which was used as a viscosifier for the preparation of the water based mud. Rheological data used for the samples calculations were obtained using FannVG (six- speed) viscometer and the viscometer readings were taken at 600, 300, 200, 100, 6 and 3 rpm using the API standard guidelines.

1.2 Formulation of Mud Samples

Four (5) different mud samples (A, B, C, D and E) were formulated while the concentration of the viscosifiers were varied (2g, 5g, and 8g respectively) in equal proportions. The compositions of the various mud samples are shown in Table 1, and then the next variation will be 5g and 8g respectively as stated above.

Table1
Composition of 10ppg Water Based Mud Samples With 2g of Polymer Viscosifiers

Addictives	Sample A	Sample B	Sample C	Sample D	Sample E
Water (ml)	322	322	322	322	322
Caustic soda(g)	0.25	0.25	0.25	0.25	0.25
Soda ash(g)	0.25	0.25	0.25	0.25	0.25
Bentonite(g)	10	10	10	10	10
Potassium chloride(g)	28	28	28	28	28
Pac r(g)	2.0	-	-	-	-
Ukpo(g)	-	2.0	-	-	-
Achi((g)	-	-	2.0	-	-
Akpalata(g)	-	-	-	2.0	-
Ofor (g)	-	-	-	-	2.0
Barite(g)	77	77	77	77	77

2. LABORATORY PROCEDURE

2.1 Mixing Procedure for Mud Samples

322mls of drilled water was measured and 0.25g of soda ash was added to pre-treat the water to remove any hardness. 10g bentonite was added to the treated water and the bentonite slurry sheared for 15 minutes, then allowed to static yield for 10hours. After Pre-hydration for 10hours, the bentonite slurry was agitated and 0.25g caustic soda was added to the slurry and mixed for 2minutes. 28g KCL was also added and mixed for 2minutes. Thereafter, 2g of Poly Anionic Cellulose- Regular (Pac- R) was added and mixed for 3minutes. 77g of Barite was added and agitated for 20minutes. The above procedure was repeated for 5g and 8g of Pac-R, as shown in table 2 and 3. The mixing was done at medium speed using Hamilton Beach mixer and total mixing time was 30minutes. The same mixing Mixing Procedure for Pac R mud (Sample A) was also applied for samples B, C, D and E. But in this case instead of adding Pac R (sample A), samples B, C, D and E were added respectively in each of the muds prepared.

2.2 Rheology Test:

Fann 35 viscometer shown in Figure 7 was used to determine the rheological properties of the mud. The viscometer was calibrated before taking the rheological properties of the water based mud. The mud sample was heated to 180˚F using a thermo-cup. At the attainment of 180˚F the rheological parameters were taking by placing the viscometer nub on 600, 300, 200, 100, 6 and 3rpm respectively while the dial reading was also taking at intervals. The gel strength was taking at 10minutes intervals by placing the nub at 3rpm.The above test procedure was repeated for samples 2, 3 and 4 respectively.

2.3 Field Parameters for This Study

Some of the field parameter acquired from Niger delta NDU well 1, were used as fixed values for hole cleaning calculations for the different mud samples. These parameters are – hole size, pump rate, drill string size, well depth, density and diameter of drilled cuttings as shown in Table 2

Table 2
Field Parameters

PARAMETERS	VALUES	UNIT
Hole size	16.0	inch
Previous casing size	19.142	inch
Drill pipe ID	4.408	inch
Drill pipe OD	5.0	inch
Bit size	16.0	inch
Pump (flow) rate	1000	gpm
Well depth	5500	ft
Density of cuttings	21.6	ppg
Diameter of cuttings	0.25	inch

2.4 Validation of Hole Cleaning Efficiency

The Herschel Buckley model which is a modified power law model (Baroid, 1998; Duru *et al*., 2005; Igwilo and Zakka, 2014) was used for hole cleaning validation. It is a generalized model of a non-Newtonian fluid which is described by three-parameter rheological model (k, n and τ_0), of a pseudo-plastic fluid whose viscosity decreases as shear rate increases (Duru *et al*., 2005; Igwilo and Zakka, 2014). Water-base polymer muds, especially those made with polymer viscosifiers perfectly fit the Herschel-Buckley model mathematical equation better than the power law or even to say the Bingham plastic model. The equation is expressed as (Mme U. and Skalle P. (2012; Hassiba and Amani, 2013; Igwilo and Zakka, 2014; Muherei, 2016):

$$\tau=\tau_0+K\gamma^n$$

where: τ= share stress, γ = share rate or the velocity gradient, n = flow behavior index, and k = consistency index and τ_0 is the fluid yield stress when the shear rate is zero. If n is 1 the fluid is Newtonian fluid. If n is less than 1 the fluid is pseudoplastic and, if n is higher than 1 it is dilatants (Hassiba and Amani, 2013). To get the Power law constant that corresponds to the flow of fluid in the annulus, 100 and 3 rpm readings were used as stated below (Baroid, 1998).

$$n_a = 0\ 657\log\left(\frac{\theta_{100}}{\theta_3}\right)$$

$$K_a = \left(\frac{511x\theta_3}{5.11^{n_a}}\right)$$

API recommended that for Herschel Buckley rheological parameters, R6/R3 should be used for calculating the yield shear stress (τ_0). Thus τ_0 is given as (Muherei, 2016):

$$\tau_0 = 2\tau_3 - \tau_6$$

Where: k_a, n_a, τ_3 and τ_6 are consistency index in the annulus, flow behavior index in the annulus, shear stress at 3rpm and 6rpm respectively

To achieve effective annular hole cleaning by the proposed muds, the following equations are utilized (Baroid, 1998; Baroid, 2006):

$$V_a = \frac{0.408xPO_{GPM}}{ID_h^2 - OD_{dp}^2}$$

Where: D_h is the diameter of hole or inside diameter of casing (inches), OD_{dp} is outside diameter of drillpipe or drillcollar (inches), PO_{GPM}, is pump output (g/min), V_a is average mud velocity inside the annulus (ft/sec). Then, the effective viscosity is calculated from the equation below (Igwilo and Zakka, 2014):

$$\mu_{eff} = 100k_a\left(\frac{144V_a}{d_h - d_{dp}}\right)^{n_a-1}$$

We now compute the laminar slip velocity (V_s) with the equation below (Baroid, 1998):

$$V_s = 12.0\left(\frac{\mu_{eff}}{d\ x\ \rho_f}\right)\left[\sqrt{1+\left(7.27xdx\left(\frac{\rho_p}{\rho_f}-1\right)\left(\frac{dx\rho_f}{\mu_{eff}}\right)^2\right)}-1\right]$$

[1] Where: d = average particle diameter, ρ_f is density of drilling fluid and ρ_p is density of particle

To determine whether drilled cuttings are falling under laminar or turbulent condition, the Reynolds number, N_{Res} is calculated

$$N_{Res} = \frac{d\ x\ V_s\ x\ \rho_f}{\mu_{eff}}$$

If N_{Res}< 10, the particle is falling in laminar slip and if N_{Res}>100, the particle is falling in turbulent slip and the turbulent slip velocity of the particle is given as:

$$V_{st} = 32.355x\sqrt{d\ x\left(\frac{\rho_p}{\rho_f}-1\right)}$$

The most important function of the drilling fluid is to transport cuttings from the bit (wellbore) up the annulus to the surface. The inability of the drilling mud to remove cuttings from the wellbore, impede drilling (Baker Hughes Integ, 1999; Igwilo and Zakka, 2014). There is therefore need to calculate the cutting net rise velocity, which is given below (Osei, 2009))

$V_t=V_a-V_s$

If the cutting net rise velocity is positive, then there is good flow rate and cutting will be easily carried in the wellbore. If on the contrary, the cutting net rise velocity is negative, it then means the flow rate is not enough to carry cutting from the wellbore (Osei, 2009; Darwesh *et al.,* 2018). The cutting transport efficiency $T_E$is then computed from the equation given below (Baroid, 1998; Baroid, 2006; Igwilo and Zakka, 2014):

$$T_E = \left(\frac{V_a - V_{slip}}{V_a}\right)x100$$

3. RESULTS AND DISCUSSION

Five water-based mud samples with Pac R, Mucuna Flagellipe (Ukpo), Brachystegea eurycoma (Achi), Afzelia Africana (Akplata) and Detarium micocarpum (Ofor) as viscosifiers were tested in this work. Various parameters were studied to ascertain the effectiveness of the proposed muds on wellbore cleaning.

3.1 Rheological Properties Measurement

From the test results obtain in figure 5, Pac R at 2g gave a yield stress (τ_0) of 29lbs/100 ft^{2}which is within the API limit (25lb/100ft^2-45lbs/100ft^2) while that of the local viscosifiers - Ukpo, Achi, Akplata and Ofor gave a yield stress (τ_0) of 18lb/100ft^2, 10lb/100ft^2, 9lb/100ft^2 and 1lb/100ft^2 respectively at the same concentration of 2g each. The yield stress gotten from the local viscosifiers falls below the recommended API specification

(25lb/100ft^2-45lbs/100ft^2) for 16inch hole section. The yield stress (τ_0) is responsible for the annular hole cleaning during drilling. Effective hole cleaning prevents stuck pipe known as differential sticking which may occur as a result of poor hole cleaning. Poor cutting transportation leads to an increase in equivalent circulating density due to increase in mud weight resulting from high cuttings concentration. In other to improve on the cuttings carrying capacity for the local mud, the concentration of the viscosifiers were increased from 2g to 5g as shown in Figure 6. It was observed that Ukpo mud had a better yield stress of 27lb/100ft^2 and Pac-R had 34lb/100ft^2 which falls within the required API specification for 16inch hole section while Ofor, Achi and Akpalata had lower values of 21lbs/100ft^2, 12lbs/100ft^2 and 7lbs/100ft^2 respectively. Hence good hole cleaning will not be achieved when using 5g of Ofor, Achi and Akpalata as water based mud viscosifiers for 16inch hole section as obtained in this study. Furthermore, the concentration of the viscosifiers were increased from 5g to 8g as shown in figure 7. It was observed again that Pac R at 8g had a yield stress (τ_0) of 38lb/100ft^2 when compared with 37Ib/100ft^2 for 5g concentration. This show that at higher concentration, the yield stress does not increase significantly. Ukpo mud on the other hand, gave a better yield stress of 37lb/100ft^2 while Ofor mud gave 26lb/100ft^2 which falls within the API specified yield stress for 16inch hole section. This gives a better hole cleaning and suspension of both drilled and commercial solids. Achi and Akpalata muds even at higher concentration of 8g had a low yield stress of 21Ib/100ft^2 and 16Ib/100ft^2 respectively which are less than the API specified range for 16hole section

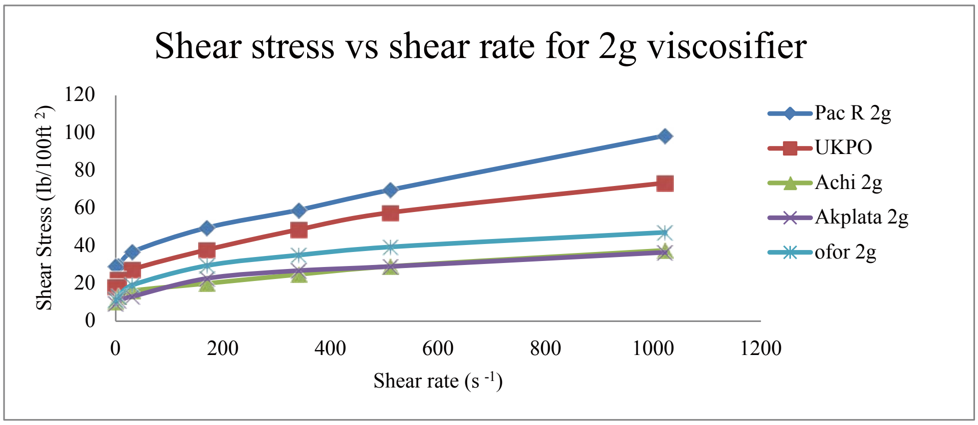

Figure 5
Plot of Shear Stress vs Shear Rate of Mud Samples with 2g Viscosifiers Each at a Temperature of 180˚F.

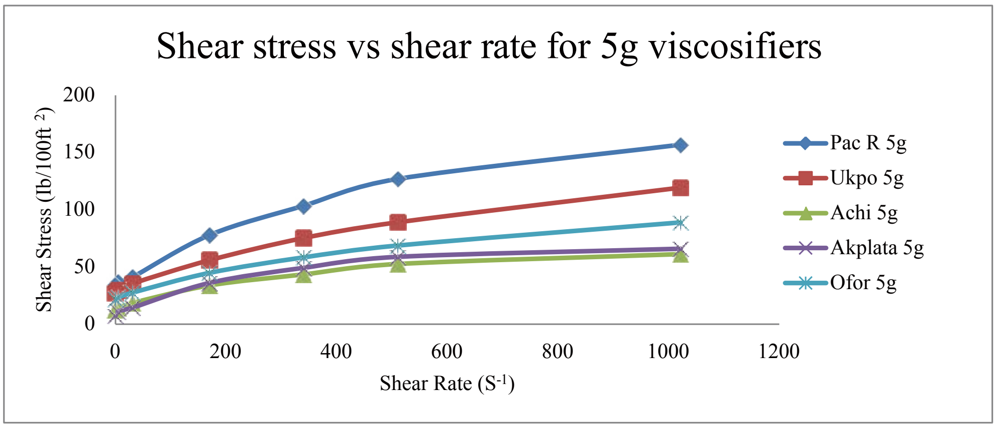

Figure 6
Plot Of Shear Stress vs Shear Rate of Mud Samples with 5g Viscosifiers Each at a Temperature of 180˚F.

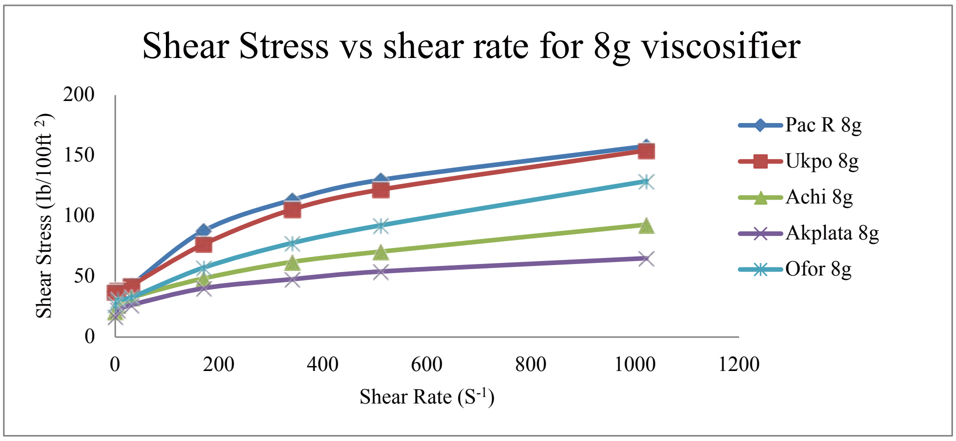

Figure 7
Plot of Shear Stress vs Shear Rate of Mud Samples with 8g Viscosifiers Each at a Temperature of 180˚F.

Figure 8 shows that Particles will settled faster in the local muds when compared with that of Pac-R mud which has a lower slip velocity of 19.67ft/min of the same viscosifiers concentration of 2g each. Furthermore in other to inhibit faster settling of solids in the local muds, the viscosifier concentration was increased from 2g to 5g and then to 8g respectively. It was observed that 5g of Ukpo gave a slip velocity of 19.37ft/min which is an equivalent value of 2g of Pac-R of 19.67ft/min. Although 5g of Pac-R gave a better slip velocity of 11.30ft/min compared to any of the local viscosifiers of the same concentration. Furthermore, 8g of ofor mud gave a slip velocity of 20.26ft/min which is an equivalent value of 2g of Pac-R mud of 19.67ft/min while Ukpo gave 12.86ft/min and Pac-R had 9.32ft/min at 8g respectively. For all the locally sourced viscosifiers, Ukpo gave better cuttings suspension with minimal slip velocity as compared to Ofor, Achi and Akplata of the concentration. But, if the annular velocity is higher than the cuttings slip velocity as shown in table 3 for 5g viscosifier concentration, then all cuttings will be transported up to surface which is true also for 2g and 8g. But on the other hand if the slip velocity is higher than the annular velocity the transported cuttings will settle at the lower side of the wellbore

Table 3
Calculated Values Using 5grams for All Polymers Viscosifiers

Hole cleaning parameters (Flow rate 1000gpm)	n	K	Annular Vel. (ft/min)	μ_{ff}	Slip vel. (ft/min)	Transport Eff.
Pac-R mud	0.296	18.74	147.8	1462.9	11.30	92.4
Ukpo mud	0.485	2.234	145.1	289.72	19.37	86.90
Achi mud	0.660	0.490	139.7	99.98	27.61	81.32
Akpalata mud	0.653	0.461	137.5	92.16	28.36	80.80
Ofor mud	0.545	1.335	140.2	202.49	21.82	85.24

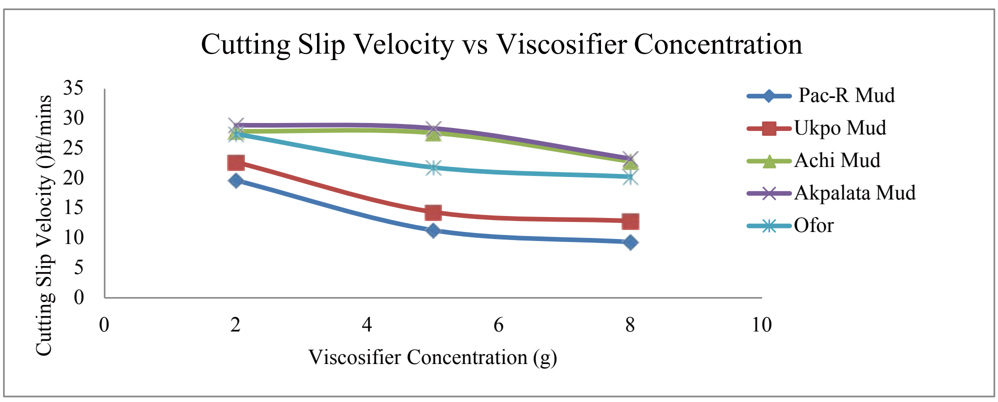

Figure 8
The Effect of Viscosifiers Concentration on Cuttings Slip Velocity

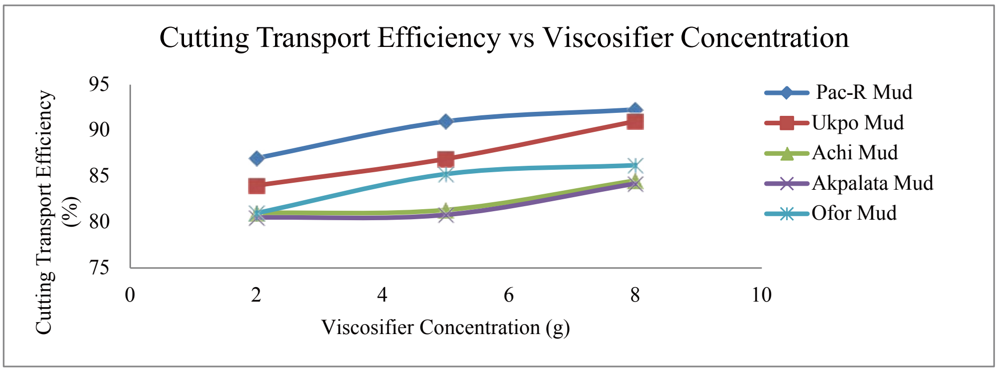

Figure 9
The Effect of Viscosifiers Concentration on Cutting Transport Efficiency

3.2 Cuttings Transport Efficiency (%T_{eff}).

During drilling operation, drilled cuttings transport efficiency is used to describe hole cleaning. When the percentage transport efficiency of drilled cuttings is greater than 85percent, the wellbore is termed to be cleaned. In Figure 9, it was observed that the water based mud samples formulated with both the locally viscosifiers and the conventional Pac-R shows similar flow pattern, as increase in concentration of the viscosifiers increases the cutting transport efficiency of the various mud samples. As shown in figure 9, at a concentration of 2g ,Pac-R mud gave a better cutting transport efficiency of 87% which is above the 85% API recommended for 16inch hole section while the local viscosifiers (Ukpo, Achi, Akplata and Ofor) gave a transport efficiency less than the API recommended (84%, 81%, 80.5% and 81% respectively). As the concentration of the viscosifiers was increased to 5g for all mud samples, Ukpo mud gave a cuttings transport efficiency 86.9% which the API recommended. As the viscosifiers concentration was increased from 5g to 8g Ukpo mud gave a better cuttings transport efficiency of 90% and Ofor mud gave an improved cuttings transport of 86% as compared to Achi and Akpalata which gave less than the minimum required for 16inch hole of 84.5% and 84.2% respectively.

CONCLUSION

The following conclusions are drawn from this work:

The formulated muds with local viscosifiers are suitable for top hole drilling because of the temperature range of 150°F and below used in this study.

The formulated muds with local viscosifiers had higher yield stress, effective viscosity, annular velocity and ransport efficiency and then low slip velocity at 5g and 8g concentrations especially the Ukpo mud which is an indication of better cuttings carrying capacity than the conventional PAC-R mud used in this study.

Higher transport efficiency gives better bottom hole cleaning during drilling which is dependent on cutting density, cutting diameter, annular velocity and the rheology of the fluid. The use of Herschel-Bulkley model for the validation of hole cleaning was necessary to ensure the effectiveness of the proposed muds to adequately clean the wellbore.

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