International Journal of Petroleum Engineering ISSN 5675-0715 Vol. 1 (2) pp. 024-030, November, 2014.
Available online at www.Internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Assessment of rheological properties of Detarium micocarpum, Brachystegea eurycoma utilizing Herschel-Buckley model and their business aaccessibility

Ewolo D. Micheal

Department of Petroleum Engineering, Faculty of Engineering, Ambrose Alli University, Ekpoma, Nigeria. Email: prof.ewolomike26@mwtr.edu.fr

Accepted 26 October, 2014

Drilling fluids were formulated from biomaterials such as *Brachystegea eurycoma* and *Detarium micocarpum*. The laboratory measurements were carried out, and their rheological properties then evaluated. The drilling properties such as yield point, apparent viscosity, and low shear rate yield point were determined from the experimental data. The field polypac additive that is currently in use was formulated and used as control sample to biomaterial products. Both were supplemented with equal concentrations of XC polymer additive and potassium chloride, weighted up with calcium carbonate and barite. Herschel-Buckley model was used to obtain the yield stress. Regression line was established. Plots of cutting transport ratio versus fluid flow rate, and cuttings concentration versus average annular velocity of the biomaterial mud and the existing polypac mud were made at both low and high flow rates for 8½ inch hole diameter. The biomaterial mud was compared with the existing polypac mud and results show that yield stress for low solids, and barite weighted muds are 36 and 30 lbs/100 ft^2 for biomaterial muds, respectively. The results for low solids and weighted muds of the existing polypac muds also show the yield stress of 35, 26 and 6 lbs/100 ft^2 for both regression lines. The plots of transport ratio versus fluid flow rate and cuttings concentration versus annular velocity for both biomaterial mud and the existing Polypac mud gave the same trend. Both mud types show good hole cleaning at high flow rates and small diameter holes. The investigations also show that biomaterial products are not commercially available to be used in preparing drilling fluids.

Key words: Biomaterial mud, Polypac mud, *Brachystegea eurycoma*, *Detarium micocarpum*.

INTRODUCTION

Drilling fluid’s effectiveness is measured based on its rheological properties among other yardsticks, which include mud weight, yield point, low shear rate yield point, plastic viscosity, fluid loss, gel strength and lubricity. The functions of drilling fluids that are dependent on these properties include:

1) Cuttings transportation along the wellbore annulus.
2) Cooling and lubricating the bit and drill string.
3) Maintaining sufficient hydrostatic pressure to withstand

the borehole pressure.

4) Being capable of suspending drilled cuttings and high gravity solids when the circulation is stopped.

5) Depositing of impermeable filter cake on the wall of the wellbore.

6) Transmitting hydraulic horsepower to the bit.

7) Ability to remove cuttings under the bit to avoid smaller particles from adversely affecting the penetration rate, bit life and mud properties.

One of the fundamental aspects of Fluid Engineering is the evaluation of rheology in order to predict behavior of fluids. To do so, it is necessary to select the parameters and utilize instruments that effectively measure them. There are many situations where some of the mud properties can be found to approximate the behavior of the actual fluid with accuracy which reflects the image of the measured fluid data. The study of the deformation of drilling fluids is not an exact standardized knowledge. They are based on mathematical models that closely describe the behavior of the fluids. Various physical properties of mud like plastic viscosity, yield point, low shear rate yield point, and gel strength are used in determining partially the rheological behavior of drilling mud. These physical properties influence the behavior of a drilling mud as it is circulated in the borehole. The relationship of these physical properties of a drilling fluid in conjunction with shear stress and shear rate are used to characterize the rheological behavior of fluid.

HERSCHEL BUCKLEY MODEL (MODIFIED POWER LAW MODEL)

Herschel-Buckley is a three parameter model that describes the behavior of yield-pseudo plastic fluids (Duru et al., 2005). This model combines the behavior of the Newtonian, Bingham plastic, and Power law models. The mathematical equation that is used to describe the model is:-

$$\tau = \tau_y + k\gamma^n \qquad (1)$$

The model perfectly describes the behavior of drilling mud. It has a yield stress at low shear rates responsible for hole cleaning in the annulus.

To obtain the Power law constant corresponding to fluid flow in annulus, the 300 and 3 rpm readings are used as shown in Equations 2 and 3 (Baker Hughes Inteq, 1991).

$$n_a = 0.5 \log\left(\frac{\theta 300}{\theta 3}\right) \qquad (2)$$

$$k_a = \frac{5.11 \times \theta 300}{511^{na}} \qquad (3)$$

Where n_a = flow behavior index, dimensionless; k_a = consistency factor, eq-centipoise.

Characterization/commercial availability of the biomaterials

Detarium micocarpum

The roots, stem, bark, leaves and fruits are all used to treat ailment e.g. tuberculosis, meningitis and diarrhea (Abdalbasit et al., 2009). The fruit is edible and rich in Vitamin C and the leaves and the seeds are also used in cooking. The pulverized seeds cotyledons are used as a thickener and emulsifier in traditional food preparations in some African countries. A compositional study of this legume revealed that it is a rich source of polysaccharide gum (Onweluzo et al., 1994). The dehulled seed flour contains 3.5% moisture, 3.5% ash, 2.9% crude fiber, 15% crude fat, 37.1% crude protein and 39% carbohydrate (Akpata and Miachi, 2001). Benzoylated carbohydrate fractions were isolated from the bark extract of *D. micocarpum* and they analyzed its carbohydrate content using chromatographic fractionation method (Abreu and Relva, 2002). The seed polysaccharide was evaluated as a stabilizer and gelling agent in some processed fruit products and were highly acceptable and had good storage stability for 2 months at ambient storage (Onweluzo et al., 1999). The fruit of *D. micocarpum* had the highest total phenolic, flavonoid and antioxidants values among fourteen wild edible fruits from Burkina Faso (Meda et al., 2008). A research work was carried out on the oil contents extracted from *D. micocarpum* seeds which contain about 7% of oil (Kyari, 2008). He concluded that the extracted oil from *D. micocarpum* seeds contain high levels of saturated fatty acids.

It is confined to West and Central Africa. It is typically a species of dry savanna (Leung et al., 1988). Among the Ibo tribe of South-eastern Nigeria, the plant is known as "Ofo". It is believed to be a "religious" tree which grows in God's own compound, symbolizing truth and honesty (Ejizu, 1986). It is the most investigated specie of the genus because of its popular use in Africa traditional medicine. In the eastern part of Nigeria, they are revered plants, mythically believed to be chip of the primal trees that germinate and grow in God's own garden by water or animal dispersal. The organization known as the Integration Action for Human Rights in Mali revealed that, 200 ha of degraded populations of *D. micocarpum* were restored/protected in 10 villages. 400 people in 10 villages trained and can apply biodiversity protection practices. 90% of people and involved in protecting *D. micocarpum* and it is their main source of income. Gender and social inclusion 500 to 800 men are involved in protection work. 600 children and 500 women are involved in making products and commercialization. 100 elders (village leaders) are involved in monitoring of environmental protection activities. Total revenue for 10

Table 1. Composition of weighted mud with calcium carbonate (low solids mud).

Composition	Concentrations
Biomaterial	
Fresh water	350 ml
Potassium chloride	10 g
Caustic soda	0.25 g
Detarium microcarpum	5 g
Brachystegia eurycoma	5 g
XCD polymer	1 g
Calcium carbonate	103.7 g
Existing	
Fresh water	350 ml
Potassium chloride	10 g
Caustic soda	0.25 g
Polypac	5 g
Calcium carbonate	103.7 g

Table 2. Composition of weighted mud with barite.

Composition	Concentrations
Biomaterial	
Fresh water	350 ml
Potassium chloride	10 g
Caustic soda	0.25 g
Detarium microcarpum	6 g
Brachystegia eurycoma	6 g
XCD polymer	1 g
Barite	75.4 g
Existing	
Fresh water	350 ml
Potassium chloride	10 g
Caustic soda	0.25 g
Polypac	6 g
XCD polymer	1 g
Calcium carbonate	75.4 g

villages in 2006 was $37,028US.

Brachystegea eurycoma

Their seeds are used in making soup as thickener. *B. eurycoma* was subjected to standard analytical techniques in order to evaluate the composition, physicochemical properties and contents of nutritional valuable elements and fatty acids of the seeds and oils (Ibironke et al., 2005). The analysis indicated that the oil content was 5.87 ± 0.30 mg/100 g. The seeds are rich in protein and carbohydrate. The protein content ranges from 11.82 ± 0.25 mg/100 g dry matter. These compare favorably with high protein animal sources like oyster, beef, pork and marine fishes. It contains 8% of oil. Eight nutritional valuable minerals were determined in the seed flours (Ibironke et al., 2005). The seeds are rich in potassium (52.1 mg/100 g - 131 mg/100 g). They also contain significant concentration of Iron (4.55 mg/100 g - 8.20 mg/100 g). *B. eurycoma* is one of the lesser known legumes, which have not been fully utilized to alleviate the problem of protein - energy malnutrition common in developing countries of the world such as Nigeria. It is a large crowded forest tree. It is 60 m high and common on stream banks. *B. eurycoma* is a woody plant mostly found in the rain forest zone, eastern part of the country. In order to boost the small *eurycoma* production and develop the new market opportunities to stimulate economic growth in the South-east of Nigeria, one would have to expand alternative utilization/processing techniques in Agro - food systems. The rate of *B. eurycoma* harvested as timber in tropical rain forest ecosystem of Nigeria, Ondo between 2003 and 2005 is 2693 trees (Adekunle et al., 2009).

METHODOLOGY

The rheology experiment was conducted from the D. micocarpum, B. eurycoma and the existing polypac. The experimental data shown in Tables 3 and 4 were used to evaluate the yield stress using Herschel-Buckley model. Different annular flow behavior index, na and the annular consistency factor, ka, were calculated at different temperatures using Equations 2 and 3. The fann readings were evaluated using shear stress versus shear rate as shown in Figures 1 and 2 were obtained for the regressed line, biomaterial and polypac muds.

Mud formulations/experimental procedure

Two sets of measurements were carried out, the proposed mud obtained from biomaterials: *D. micocarpum*, *B. eurycoma* and the existing polypac muds. Tests were conducted as per API standard. Formulations of the muds are shown in Tables 1 and 2. All tests were carried out at room temperature and temperatures of 120, 150, and 200°F. The tables show the laboratory measurements of the *D. micocarpum, B. eurycoma* muds, and the existing polypac muds. Equal concentrations were applied for *D. micocarpum*, *B. eurycoma*, muds and the existing polypac muds for easy comparison.

The seeds of *D. micocarpum* and *B. eurycoma* were grinded separately using Hamilton grinder to powder form, dried in the sun for 24 h and finally re-grinded. The coarse powdered materials were sieved until the fine powder of each specimen was obtained. Data for the calculation of the samples rheological properties were obtained using the Fann VG viscometer.

The rheological parameters calculated from the laboratory measured data were used to determine the rheological parameters for both the biomaterial and the existing polypac samples. The annular hole cleaning abilities of the mud samples were investigated using shear stress versus shear rate relationship and applying the Modified Power law model for the determination of yield stress, which is the major factor of consideration in annular hole cleaning studies.

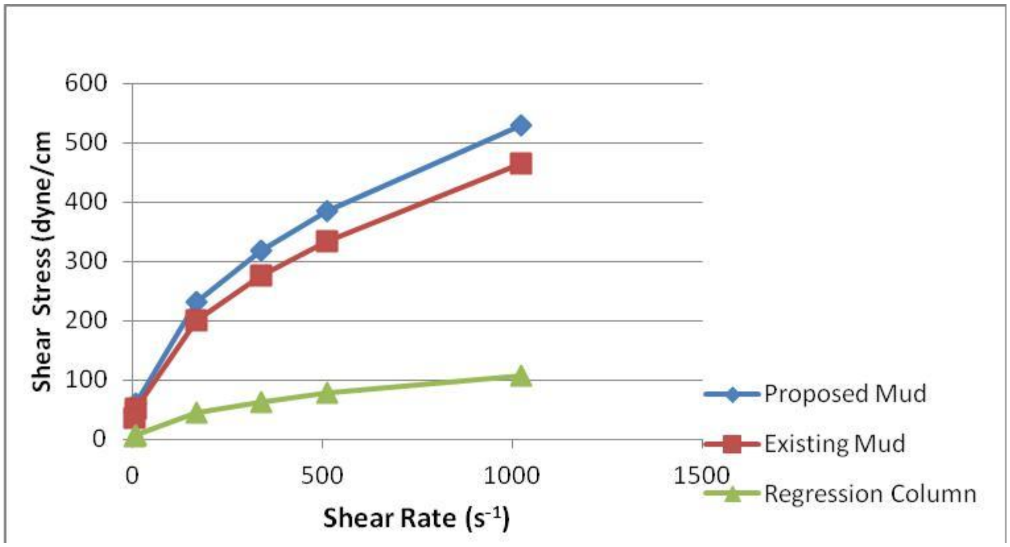

Figure 1. Estimation of yield stress for low solids muds using Herschel-Buckeley model.

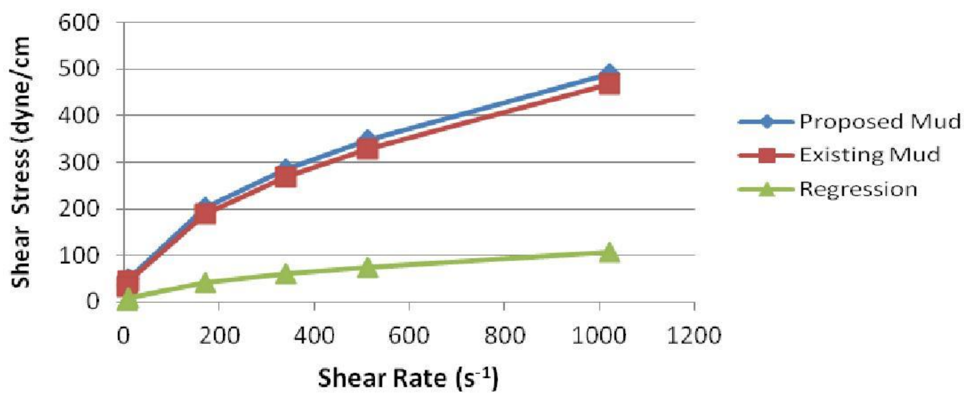

Figure 2. Estimation of yield stress for barite mud using Herschel-Buckeley model.

Hole cleaning efficiency validation

The evaluation of hole cleaning ability of 8½" hole for *D. micocarpum*, *Brachystegea eurycoma* muds and polypac muds were carried out. Cutting transport ratio, transport efficiency and cuttings concentration were determined to know the degree of effectiveness of the proposed muds in terms of annular hole cleaning (Baker Hughes Inteq, 1991).

The hole cleaning equations are stated from Equations 4 to 12. The step by step procedure followed in this study is shown as follows:

$$D_p = \frac{\tau_g}{10.4\left(\rho_s - \rho_f\right)} \quad (4)$$

Where τ_g *is* the gel strength, lbs/100 ft^2

The average fluid velocity can be obtained from Equation 5 (Baker Hughes Inteq, 1991).

$$V_a = \frac{q}{2.4484\left(d_2^2 - d_1^2\right)} \quad (5)$$

Where q is the fluid flow rate, (gpm)

The effective viscosity,(μ_{eff}) can be determined from Equation 6 (Baker Hughes Inteq, 1991).

$$\mu_{eff} = 100k_a\left(\frac{144v_a}{d_2 - d_1}\right)^{na-1} \quad (6)$$

T is the thickness of the particle, inches.

The particle shear rate □p can be obtained using Equation 7 (Baker Hughes Inteq, 1991).

$$□p = \left(\frac{\tau_p}{k_a}\right)^{1/n_a} \quad (7)$$

The particle shear stress, τ_p can be determined using Equation 8 (Baker Hughes Inteq, 1991).

$$T_p = 7.9\sqrt{T\left(\rho_s - \rho_f\right)} \quad (8)$$

Where □p is in s^{-1}.

For particle shear rate less than the boundary shear rate, slip velocity is determined from Equation 9 (Baker Hughes Inteq, 1991).

$$V_s = 1.22\tau\rho\left(\frac{\gamma_p d_p}{\sqrt{\rho_f}}\right)^{\frac{1}{2}} \quad (9)$$

Table 3. Viscometric readings with calcium carbonate (Low solids mud) at different temperatures.

Constituents	Room Temperature	120°F	150°F	180°F
	Fann readings			
Proposed mud				
Fresh water (350 ml)	116, 87, 72, 52, 11, 9	79, 59, 47, 34, 9, 8	77, 57, 47, 33, 9, 8	72, 52, 40, 30, 7, 6
Potassium chloride (10 g)				
Caustic soda (0.25 g)	10 s/10 min Gel = 9/11	10 s/10 min Gel = 8/10	10 s/10 min Gel = 8/9	10 s/10 min Gel = 7/9
Detarium microcarpum (5 g)				
Brachystegia eurycoma (5 g)				
Calcium carbonate (124 g)				
XCD ploymer (1 g)				
Existing polymer mud				
Fresh water (350 ml)	106, 75, 62, 50, 10, 8	73, 52, 44, 32, 8, 6	70, 50, 42, 30, 7, 6	67, 47, 38, 28, 6, 5
Caustic soda (0.25 g)				
Polypac (5 g)	10 s/10mins Gel = 9/11	10 s/10mins Gel = 7/9	10 s/10 min Gel = 7/9	10 s/10 min Gel = 6/8
XCD Polymer (1 g)				
Potassium Chloride (10 g)				

Where V_s is in ft/s.

Hence, the transport ratio (T_r) can be obtained using Equation 10 (Baker Hughes Inteq, 1991).

$$T_r = 1 - \frac{V_s}{V_a} \tag{10}$$

The cutting transport efficiency (T_c) can be determined from Equation 11 (Baker Hughes Inteq, 1991).

$$T_c = 1 \quad -\left(\frac{v_s}{v_a}\right) x\ 100 \tag{11}$$

Hence, the cuttings concentration (C_a) is calculated using Equation 12 (Baker Hughes Inteq, 1991).

$$C_a = \frac{(\text{rop}) d_2^2\ x\ 100}{14.7\ T_c q} \tag{12}$$

Where C_a is in vol. %; ROP is the rate of penetration, ft/hr.

Application of Modified Power law model

This involves the application of the Herschel-Buckley (Modified Power law) model which describes the behavior of the drilling fluids perfectly well. It indicates the yield stress especially at a very low shear rate of 3 and 6 rpm which demonstrates the hole cleaning in the annulus using Equations 1 and 2.

RESULTS AND DISCUSSION

The measured data were related to the Modified Power law model, for yield stress estimation which is one of the criteria for cuttings removal from the hole. Tables 3 and 4 show the experimental results got from Formulations 1 and 2 to be applied to obtain yield stress using Herschel-Buckley model.

Equations 2 and 3 were used to obtain different values of annular flow behavior index, n_a and consistency index k_a, at different temperatures. The calculations of the biomaterial mud and the polypac mud shear stress of weighted mud with calcium carbonate and barite were performed at different shear rates.

From Figure 1, the biomaterial mud gave the yield stress of 36 lbs/100 ft^2 as against 35 and 6 lbs/100 ft^2 for polypac mud and the regression line, respectively. In Figure 2, the weighted mud with barite gave 30 lbs/100 ft^2 for biomaterial mud, 26 lbs/100 ft^2 for polypac mud and 6 lbs/100 ft ^{2} for regression line. Yield stress is responsible for the annular hole cleaning during drilling. The hole cleaning at low shear rates prevents pipe stuck known as differential sticking which may occur as a result of poor hole cleaning. This will also lead to increase in equivalent circulating density due to increase in mud weight resulting from high cuttings concentration. Also, inadequate hole cleaning may result to reduction in penetration rate.

Furthermore, the flow behavior index of both proposed muds and the existing polymer muds for annular flow ranges from 0.4 to 0.5. For non-dispersed mud, n is usually between 0.4 and 0.7; for highly dispersed mud, n is usually between 0.7 and 0.9 (Mian, 1992). The lower the n value, the more non-Newtonian the mud, showing the property of shears thinning for drilling bits and nozzles cleaning. All the values of the annular flow behavior index for both biomaterial mud and the polypac mud ranges between 0.4 to 0.5, showing enough shear thinning at the bit for nozzles cleaning. The Biomaterial mud has a higher yield stress than the existing polypac mud and it is a function of good hole cleaning. Anything less than the reference line, called a critical line. This is the region of high cuttings concentration that will lead to poor hole

Table 4. Viscometric readings with barite as the weighting material at different temperatures.

Constituents	Room temperature	120°F	150°F	180°F
	Fann readings			
Proposed mud				
Fresh water (350 ml)				
Caustic soda (0.25 g)	95, 67, 56, 40, 9,7	86, 60, 50, 36, 7, 6	75, 54, 44, 31, 6, 5	64, 46, 37, 25, 6, 5
Detarium microcarpum (6 g)				
Brachystegia eurycoma (6 g)	10 s/10 min Gel = 9/11	10 s/10 min Gel = 7/9	10 s/10 min Gel = 7/9	10 s/10 min Gel = 6/8
Potassium chloride (20 g)				
XCD Polymer (1 g)				
Barite (75.4 g)				
Existing polymer mud				
Fresh water (350 ml)				
Caustic soda (0.25 g)	90,62, 51, 37, 8, 7	81,57, 46, 32, 6, 5	72, 51, 42, 30, 6, 5	60, 42, 36, 25, 5, 4
Polypac (6 g)				
Potassium Chloride (20 g)				
XCD ploymer (1g 74.5g)	10 s/10 min Gel = 8/10	10s/10 min Gel = 6/9	10 s/10 min Gel = 6/8	10 s/10 min Gel = 5/7

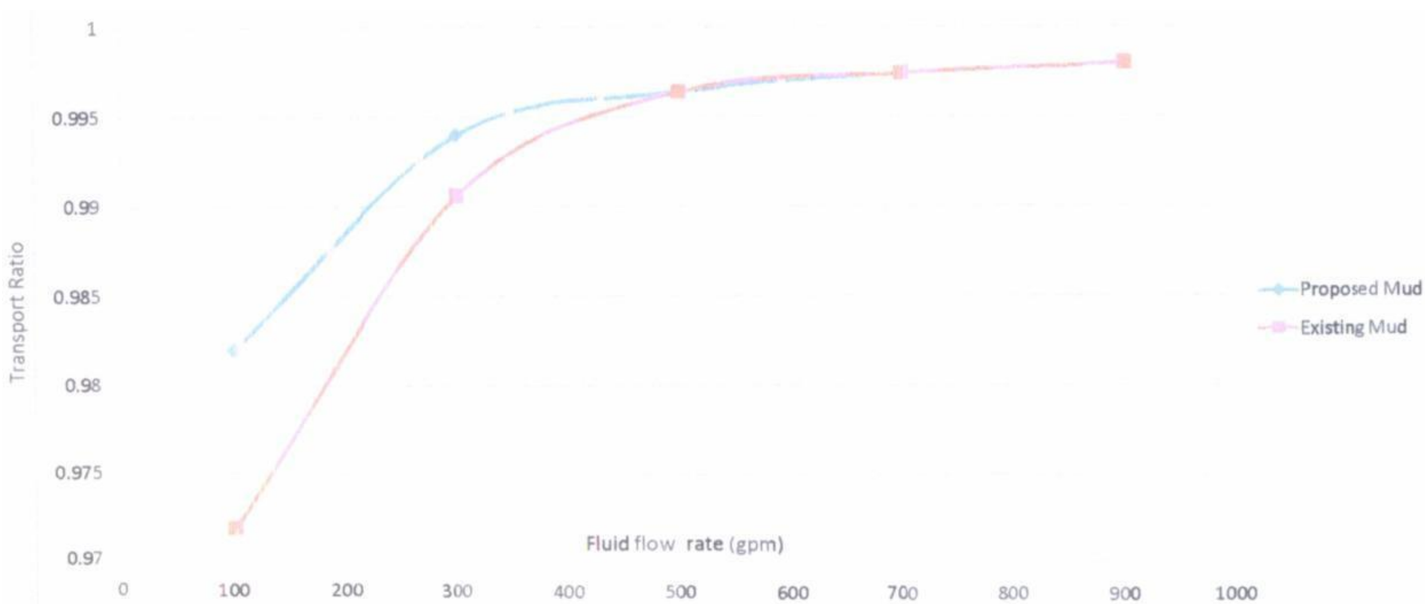

Figure 3. The relationship between transport ratio and fluid flow rate for 8.5 inch Hole Low-solids biomaterial mud and existing mud.

cleaning. In the other way round, the value of yield stress should not be excessively high to avoid surge and swab problems during tripping operations.

As shown in Figures 3 to 6, both show the same pattern, the flow rate increased with increase in cutting transport ratio, and slows down at 500 gpm. The cuttings concentration of the biomaterial mud and polypac mud were highly reduced for small diameter holes and high flow rates. The effect of annular velocity on cuttings concentration on biomaterial mud and the polypac mud show the same trend.

Conclusions

1) The rheological properties of the biomaterial muds and

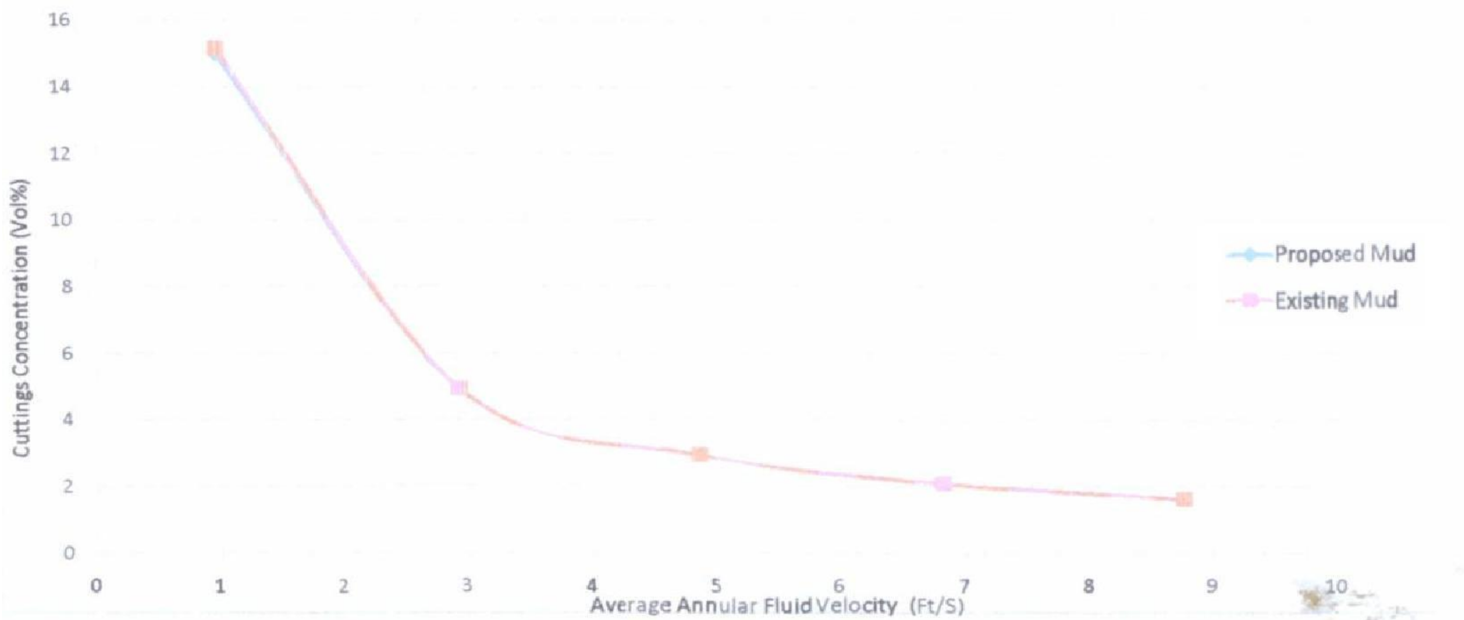

Figure 4. The relationship between cuttings concentration and average annular fluid velocity for 8.5 inch hole low-solids biomaterial mud and existing muds.

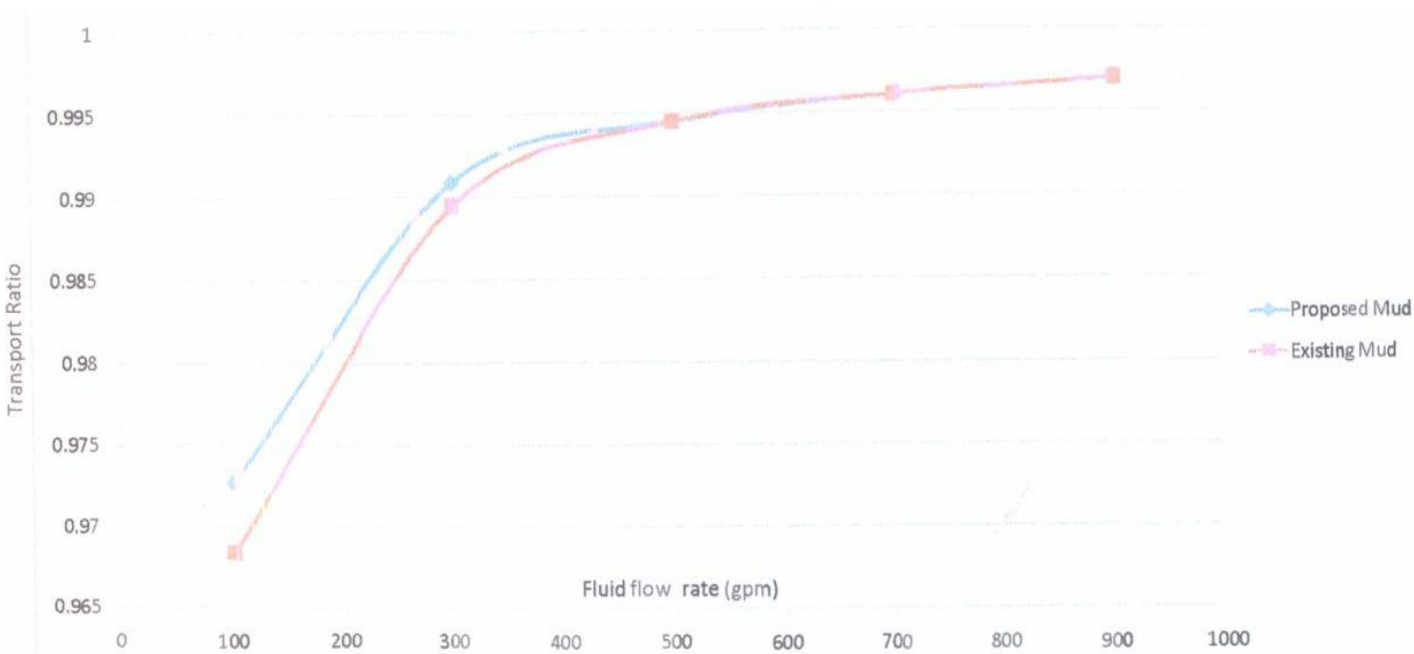

Figure 5. The relationship between transport ratio and fluid flow rate for 8.5 inch hole weighted biomaterial mud and existing mud.

the yield stress when evaluated using Herschel-Buckley model are slightly better than the existing polypac muds of equal concentrations.

2) The *D. microcarpum* and *B. eurycoma* muds and the existing polypac muds show good hole cleaning at high flow rates and small diameter holes. The cuttings concentration of 1.64 volume % and cutting transport ratio of 0.997 were recorded at 900 gpm flow rate and 8.5 inches hole size.

3) In all considerations, the rheological properties of the biomaterial muds are slightly better than the existing polypac muds, but the former are not commercially

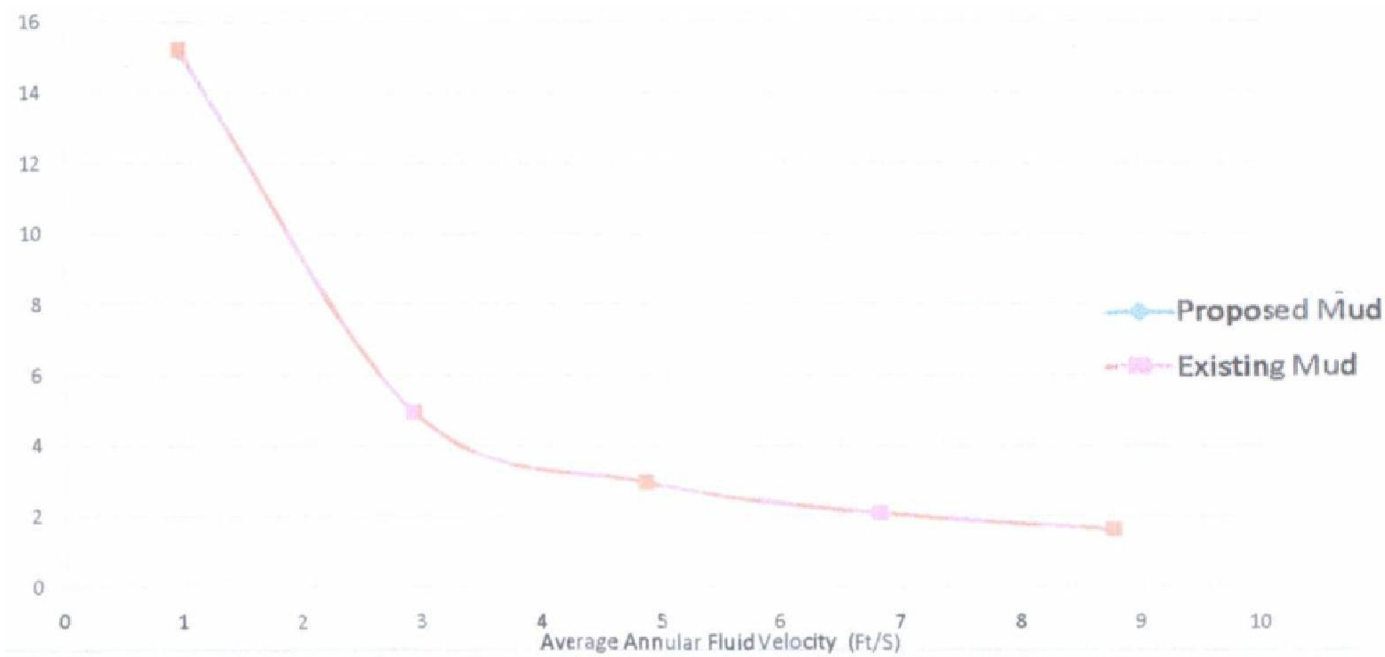

Figure 6. The relationship between cuttings concentration and average annular fluid velocity for 8.5 inch hole weighted biomaterial mud and existing muds.

available for preparing drilling fluids.

Contribution to knowledge

The major contribution of this study was to formulate drilling fluids from locally sourced biomaterials for effective drilling. Based on the result of the work, it is confirmed that the local products are not economically and commercially comparable to currently used polypac additive. Hence, the major contribution is to dissuade investors from using these products as they are, without further evaluation using the results of this work as a base.

ACKNOWLEDGEMENTS

We thank the management of Federal University of Technology, Owerri, Nigeria for allowing us to use their laboratory We are also grateful for the contributions and insights of Prof. Nnamdi Wailes, Dr. Shaka Frederick and Dr. W.E Caleb.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Abdalbasit A, Mohamed E, Amad B, Siddig I (2009). Detarium microcarpum Guill and Perr fruit proximkate Chemical Analysis and sensory characteristics of concentrated juice and jam. Afr. J. Biotechnol. 8:4217-4221.

Abreu P, Relva A (2002). Carbohydrates from Detarium microcarpum bark extract. Carbohydr. Res. 337(18): 1663–1666.

Adekunle V, Olagoke A, Ogundare L (2009). The rate of Timber Harvesting in Tropical Rain Forest Ecosystem of Nigeria. J. Forestry Res. 21(20):225-230.

Akpata M, Miachi O (2001). Proximate composition and selected functional properties of Detarium microcarpum plant foods. Human Nutr. 56:297-302.

Baker Hughes Inteq (1991). Drilling Fluids Manual. Hydraulics. Publishers Baker Hughes Inteq, ISBN 1-34654-084-6, 10:9-10.

Duru U, Chukwu G, Obah B (2005). Hydraulic Evaluation of Drilling Fluid Performance on Hole Cleaning for Different Rheological Models. 29^{th} Annual SPE Conference and Exhibition, Abuja.

Ejizu C. (1986). Igbo Ritual Symbols. Fourth Dimension Publishers, Enugu, Nigeria.190.

Ibironke A, Rotimi A, David O, Joseph I (2005). Oil content and fatty acid composition of some utilized legumes from Nigeria. An Acticle by Department of Chemistry, University of Ibadan, Nigeria, Nigerian Institute for Social Economic Research, Ibadan, Nigeria, International Institute for Tropical Agriculture, Ibadan, Nigeria. pp. 22-26.

Kyari M (2008). Extraction and Characterization of seed oils. An Article by Department of Science Lab. Technol. Ramat Polytechnic, Maiduguri, Nigeria pp. 42-59.

Leung W, Busson F, Jardin C (1988). Food consumption table use in Africa. FAO, Rome, Italy. 306.

Meda A, Lamien C, Compaore M, Meda R, Kiendrebeogo M, Zeba B, Millogo J, Nacoulma O (2008). Polyphenol Content and Antioxidant Activity of Fourteen Wild Edible Fruits from Burkina Faso. Molecules 13(3): 581-594

Mian M (1992). Experimental Study of flow behavior index of both dispersed and non dispersed mud. SPE J. 12(4).

Onweluzo J, Obanu Z, Onuoha K (1994). Functional properties of some lesser known tropical legumes. J. Food Sci. Technol. 31:302-306.

Onweluzo J, Vijayalakshmi M, Vijayanand P, Eipeson W (1999). Detarium microcarpum polysaccharide as a stabilizer in processed fruit products. J. Food Sci. Technol. 32:521-526.