FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 3 No. 3, September, 2019, pp 177 –182

MODELLING THE RHEOLOGY AND DETERMINATION OF FLUID LOSS OF DRILLING MUD FORMULATED FROM ORGANOPHYLLIC CLAY DEVELOPED FROM LOCALLY SOURCED NIGERIAN BENTONITIC CLAY

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ABSTRACT

In this work, organophyllic clay was developed from Nigerian bentonitic clay sourced from Sabon Garin Ngalda and Wyoming standard bentonite. The organophyllic clays were characterised using x-ray diffraction (XRD) and montmorillonite peaks at 2ϴ of 5.887^0 and 4.106^0 for raw local clay and organophyllic local clay respectively was noticed, indicating that the clay is bentonitic. Water in oil emulsion drilling mud was formulated from the organophyllic clays, the rheological and filtration properties of the drilling mud formulated using oil to water ratios of 90:10 and 80:20 volume percent were measured and modelled into rheological models. 90:10 formulations were best fitted into Herschel Bulckley model with R-square values of 0.9897 and 0.9958 for organophyllic Wyoming formulation and organophyllic local bentonite respectively with sum of square errors of 0.001874 and 4.19E-04. 80:20 formulations were best fitted into Herschel Bulckley and Bingham plastic model with R-square values of 0.9996 and 0.9855 for organophyllic local clay and organophyllic Wyoming clay respectively with sum of square errors of 6.93E-05 and 0.001349559 respectively. Herschel Bulckley model was found to estimate the initial yield stress better for 90:10 and 80:20. 90:10 formulations have shown consistency indices of 0.7548 and 0.7097 for organophyllic Wyoming bentonite and organophyllic local bentonite respectively while 80:20 formulations have shown consistency indices of 0.865 and 1 indicating that the drilling muds are shear thinning. 90:20 formulations using organophyllic local sample have shown fluid loss of 14ml however, after soda ash activation with viscosifier treatment, fluid loss of 9ml was recorded. 80:20 formulations using local organophyllic has shown fluid loss of 15ml but reduced to 6ml after soda ash activation. These values are within American Petroleum Institute (API) specification.

Keywords: rheological, API, organophyllic clay and emulsion, fluid loss, R-square, Montmorillonite

INTRODUCTION

Drilling is a process of using drill bit to cut circular hole in earth sub surface with the objective of reaching oil or water reservoir. Drilling mud is fluid used in drilling operation in which the mud is circulated from the surface, down the drill string, through the bit and back to the surface via the annulus with objective removal of cuttings, cooling and lubricating drill bit, supporting some portion of the drill bit, controlling corrosion etc. Drilling mud is divided generally into three that is, water based mud where water is the continuous phase, oil based mud where oil is the continuous phase and emulsion based mud where oil and water are mixed to form a single phase in the presence of an emulsifier (Bourgouyne *et al.*, 1991).

Drilling fluids in use are made up of fluid components such as water, oil, chemical additives like viscosifiers and fluid loss control additives such as clay, dispersants and weighting agents such barite. Sodium based bentonitic clays have shown very good viscosity control and fluid loss with good cutting carrying capacity. The calcium based type has shown low swelling capacity and consequently poor rheological and filtration properties (Subhash *et al.*,2010).

Fluids have shown different behaviour with time when they are subjected to shear stress. Rheopectic fluids like gypsum paste and inks have shown increase in viscosity with increase in shear stress. Thixotropic fluids such as drilling mud shows reversible decrease in viscosity with increase in shear stress. Due to their compositions, drilling mud exhibit an internal structure which is liable to modification according to flowing and shear conditions. This non-Newtonian flow behaviour has been attributed to mechanisms in which the shear stress, transmitted through the continuous medium, orients or distorts the suspended particles in opposition to the randomizing effects of Brownian motion (Folayan *et al.*, 2017).

In terms of both practical and fundamental significance, the two most important rheological properties of suspensions such as drilling muds are thixotropic and yield stress (Bird *et al.*, 1982). Hence, Model that account for yield stresses are known as viscoplastic models or yield stress models (Dardir, 2014). The rheological model for non-Newtonian fluids may be grouped under three categories. We have the empirical model which is derived from examination of experimental data and an example is power law rheological model (Dardir, 2014). The structurer model includes the casson model and the Hershel Buckley model (Folayan *et al*., 2017). Also there is theoretical model which indicates factors that influences a rheological parameter and examples are the Krieger-Dougherty model for relative viscosity and the Bingham Plastic model (Hemphill *et al.*, 1993). The yield power law (Herschel-Buckley) rheological model accurately predicts mud rheology and offers many advantages over the Bingham plastic and power law rheological models because it more accurately characterizes mud behaviour across the entire shear rate (Barnes et al.,1985). Though the concept of yield stress in Hershel-Buckley model has been challenged because a fluid may deform minutely at stress values lower than the yield stress (Folayan *et al.*, 2017).

The major component of drilling mud is bentonite. Nigeria is blessed with more than 700 million tonnes in north east alone with average consumption of 100 000 tonnes per annum (RMRDC, 2010). Most of this clay is calcium based as shown by X-ray fluorescence with poor rheological and filtration properties.

Organophyllic clay is a material formed from treatment of bentonic clay with cationic surfactant. Organophyllic clay is characterised by good swelling capacity when mixed with oil or emulsion. It has the advantage of being oil wet, low fluid loss and lower vulnerability to structural collapse when used as drilling mud constituent (Pankil *et al.*, 2012)

In this research work, organophyllic clay was developed and used to formulate water in oil emulsion drilling mud. The rheological property and fluid loss of the mud with and without prior soda ash activation were determined. Shear stress shear rate data was generated and the rheology was modelled using rheological models

MATERIALS AND METHODS

The materials used are bentonitic clay sourced from Sabon Garin Ngalda in Fika formation, API grade Wyoming bentonite, Hexadecyltrimethyl ammonium bromide (CTAB), Sorbitan mono Oleate, water, diesel, 200 mesh size sieves and homogenizer, FANN35SA viscometer, thermometer and computer in which MATLAB is installed, API filter press

Reynold (1989) procedure was used for the analysis. The powdered sample was prepared using the sample preparation bloc and compressed in the flat sample holder to the samples were analysed using the reflection –transmission spinner stage using the two-theta setting. The tube current of 40 mA and voltage of 45 kV were used. The spacing of each peak was then obtained by solution of the Bragg equation for the appropriate value of lamda. Once all the d-spacing of the unknown is matched to those of known materials, the material is identified.

$\tau_{exp} = 0.51078*\Theta i *N$……………………………..1

$\gamma_{exp} = 1.703*RPM$……………………………..2

τ = shear stress, Pa

γ = shear rate, sec^{-1}

N= spring constant which is 1 for the viscometer spindle used

Models employed are Bingham plastic, Herschel Bulckley, Casson and Sisko model as shown in Equation 3, 4, 5 and 6 respectively

$\tau=\tau 0+k\gamma$…………………………………………………...3

$\tau=\tau 0+k\gamma^n$……………………………………………..…..4

$\tau^{1/2}=\tau 0^{1/2}+k^{1/2}\gamma^{1/2}$……………………………………….5

$\tau=a\gamma+b\gamma^n$………………………………………………6

Organophyllic clay sample was developed by adding an equivalent weight of the cationic surfactant (CTAB) based on Cation Exchange Capacity (CEC) of the clay and the resultant clay was sun-dried, ground to required particle size

The clay sample was then given prior treatment by adding 12 wt% soda ash (Bilal, 2015) and allowed to stand for 24 hours (Ibrahim, 2016) before conversion to organophyllic clay The CEC of the clay samples was determined using the ammonium acetate saturation method

The organophyllic clay was developed by dissolving about 20 g of physically beneficiated clay in 1 L of water at 70-80 ^{0}C and homogenized at 250 rpm for 90 min; calculated amount of CTAB based on CEC of the clay was added to 500 ml of water containing about 4 ml of HCl. The two are mixed together and further homogenized for another 250 rpm for 90 min. The precipitated sample was then filtered using suction pump with continuous washing to remove halides that may be present as a result of treatment with CTAB. After the filtration the residue was collected, sun-dried, ground and sieved to 63 µm using 200 mesh size sieve.

Drilling mud was formulated by fluid of 350 ml of a mixture containing water to oil ratio by volume of 90:10 and 80:20.

The drilling mud was formulated by firstly dissolving about 7 wt% of the total fluid phase as organophyllic clay in the oil phase followed by about 4 wt% of the oil phase Sorbitan monooleate as emulsifier and viscosifier followed by the aqueous phase (Schmidt *et al* 1987).

Rheological properties were obtained using dial readings at 600 rpm, 300 rpm, 200 rpm, 100 rpm, 6 rpm and 3 rpm. The shear stress-shear rate data was determined using Equation 1 and 2

The modelling was carried out using the curve fitting tool box in MATLAB called CF Tool which has a feature that allows you to generate MATLAB code that will carry out the same fitting as you have set up in the tool

Low temperature API filter press was used for fluid loss measurement. The sample drilling fluid was poured into the API filter press cell to about three quarter of the cup.

The filter cell was then placed in the frame. The top cap was placed to ensure that the gasket was firmly secured in place. The top cap was then placed to ensure that the casket was firmly secured in place and graduated cylinder placed under the drain tube to collect the filtrate. Having ensured that the unit was tight and a pressure of 100 psi supplied by mini CO_2 cartridge was applied to the filter cell through a regulator and the filtrate collected after 30 minute. The volume of filtrate was read from the graduated cylinder in cm^3. The system was then relieved of the pressure and the cell removed and the mud discarded and the filter paper replaced for another round.

RESULTS AND DISCUSSION

The unmodified (non organophyllic) clay, non soda ash activated organophyllic clay, the soda ash activated organophyllic clay and modified API Wyoming bentonite were subjected to x-ray diffraction and montmorillonite peaks at 2Ɵ of 5.887^0, 4.106^0, 3.5^0 and 3.697^0 with interlayer spacing of 15 A, 21.5 A , 25 A and 24 A were observed respectively. The decrease in d-spacing could be attributed to intercalation of hexadecyltrimetyl ammonium ions in between the inter layer spacing of the clay matrix. Decrease in 2Ɵ angle is due to shift in the interlayer distance as explained by Pankil, 2012. Montmorillonite peaks were noticed even after the modification implying that even after modification, the clay is bentonitic. Plot of XRD result is shown in Figure 1

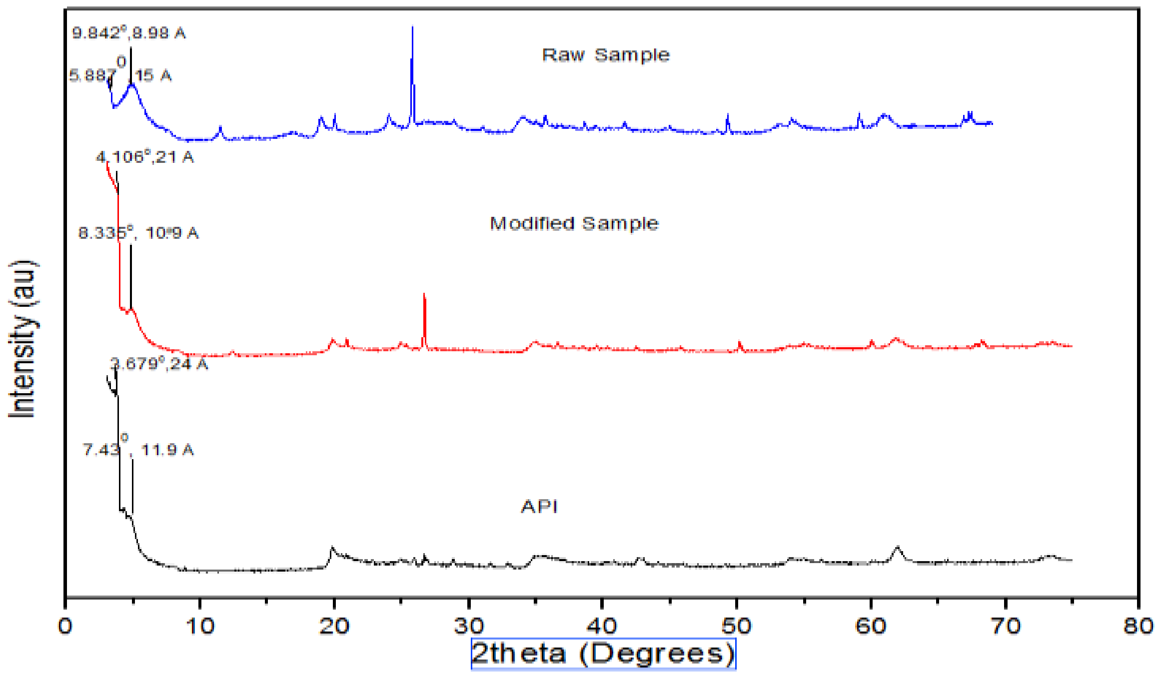

Fig. 1: XRD results of Raw, modified Local and modified Wyoming

The shear stress-shear rate data was generated for various formulations. Table 1 shows the data for 90:10 formulations and it was observed that as dial reading decreases shear rate decreases due to decrease in shear stress this property characterizes shear thing behavior of drilling mud. The initial yield strength was estimated at dial reading of 3 rpm and found to be 0.03198 Nm^{-2}, these values of initial yield stress were closely estimated by the software as shown in Table 5. Similar trend is shown for 80:20, 70:30 and 60:40 formulations as shown in Table 2, 3 and 4

Table 1: Shear stress-Shear rate data for API Wyoming organophyllic 90:10 formulation

Dial Speed(rpm)	Dial Reading (cP)	Shear Rate (s^{-1}	Shear stress(Nm^{-2})
600	50	1021.8	0.533
300	29	510.9	0.30914
200	27	340.6	0.28782
100	14	170.3	0.14924
6	4	10.218	0.04264
3	3	5.109	0.03198
FL (ml)	8		

Table 2: Shear stress-Shear rate data for soda ash pre-treated organophyllic 90:10 formulation

Dial Speed(rpm)	Dial Reading (cP)	Shear Rate (s^{-1}	Shear stress(Nm^{-2})
600	42	1021.8	0.44772
300	25	510.9	0.2665
200	22	340.6	0.23452
100	14	170.3	0.14924
6	5.5	10.218	0.05863
3	5	5.109	0.0533
FL (ml)	9		

Table 3: Properties of 80:20 modified API Wyoming bentonite formulation

Dial Speed(rpm)	Dial Reading (cP)	Shear Rate(s^{-1}	Shear stress(Nm^{-2})
600	48	1021.8	0.51168
300	28	510.9	0.29848
200	21	340.6	0.22386
100	12.2	170.3	0.130052
6	4	10.218	0.04264
3	4	5.109	0.04264
FL(ml)	7		

Table 4: Properties of 80:20 soda ash pre-treated organophyllic formulation

Dial Speed(rpm)	Dial Reading (cP)	Shear Rate(Nm^{-2}	Shear stress (Nm^{-2})
600	53	1021.8	0.56498
300	34.5	510.9	0.36777
200	31	340.6	0.33046
100	16	170.3	0.17056
6	7	10.218	0.07462
3	6.5	5.109	0.06929
FL (ml)	6		

The shear stress-shear rate data was modeled using CFTOOL by imputing the appropriate model after writing the MATLAB code by specifying the shear stress and shear rate data and then called for program to be executed. The interface of the modeling for the various formulations is shown in Figure 1, 2, 3 and 4

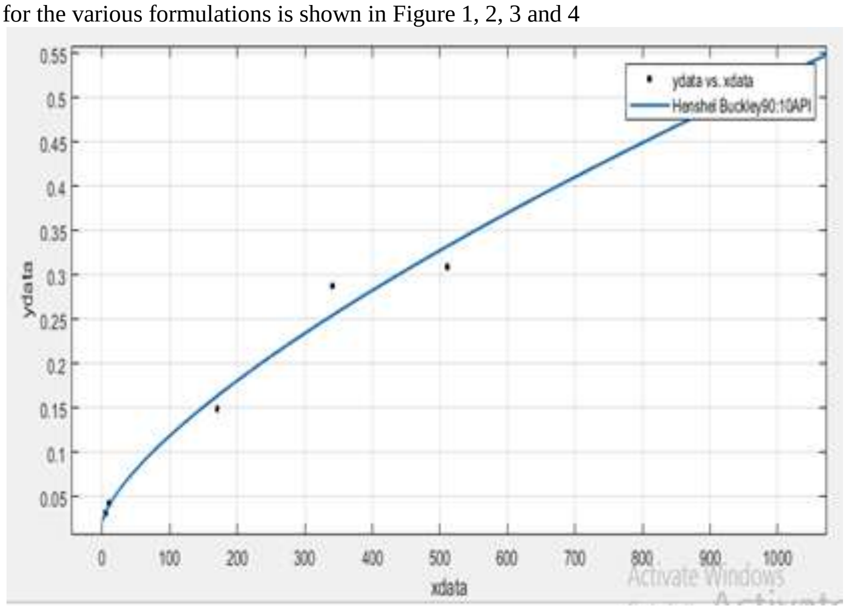

Fig. 2: API Herschel Bulckley model

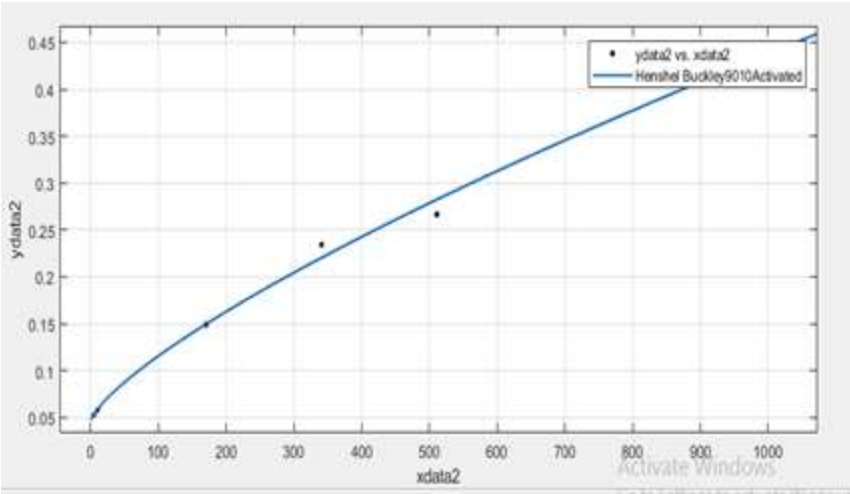

Fig. 3: 90:10 Soda ash pre treated Hershel Bulckley model

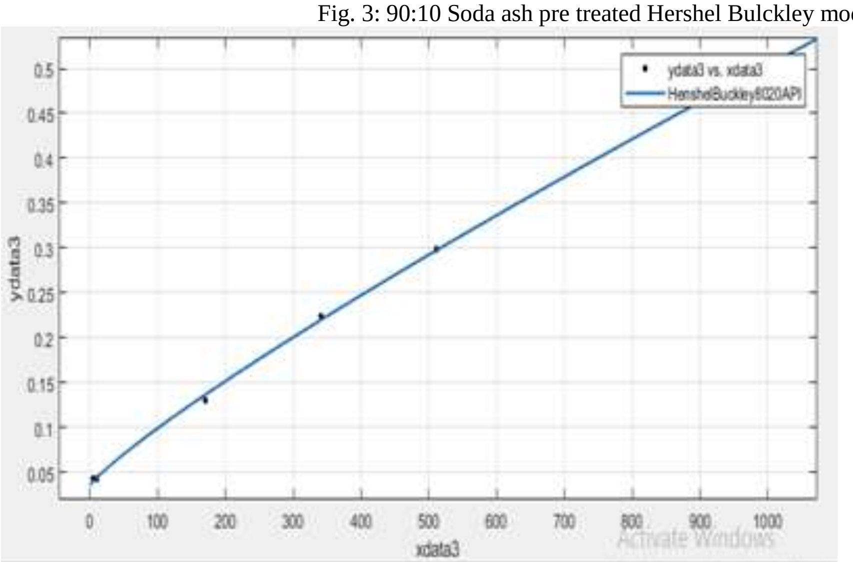

Fig. 4: 90:10 API Herschel Bulckley model

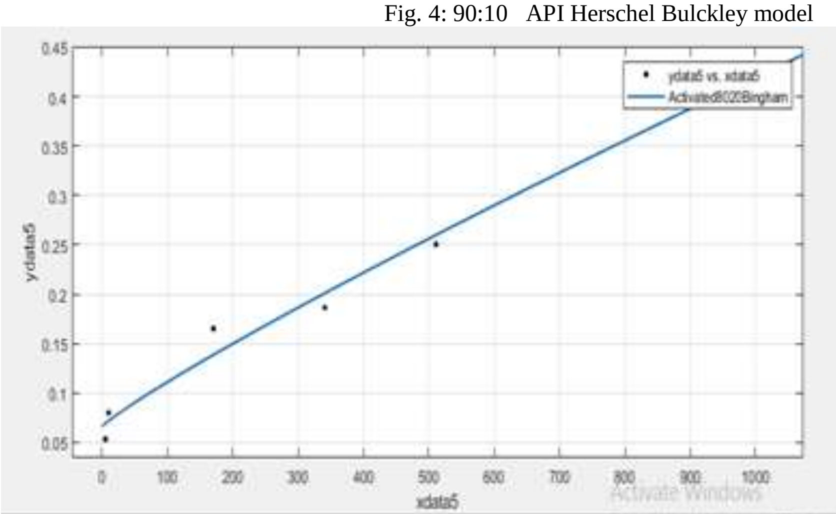

Fig. 5: 80:20 Soda ash pre treated Bingham model

The rheology of mud formulated from organophyllic clay developed from API Wyoming and that developed from organophyllic clay from locally sourced Nigerian bentonitic clay was modeled and the best fit model selected using R-Square and Adj R-Square value and at the same time, Sum of Square error was obtained. It was found that 90:10 formulations with modified (organophyllic) API Wyoming and soda ash pre treated locally sourced bentonitic clay were found to be modelled best by Herschel-Bulckley model with R-Square and Adj R-close to 1 with almost negligible sum of sum of square error. Other models such as Casson model, Sisko model and Bingham plastic failed to estimate the initial yield stress good enough as done by the Herschel-Bulckley model. The consistency factor (K) for the muds were also estimated by the software and API formulation was seen to have a higher value of 0.003726 as against that of the soda ash pre treated sample formulation. This cannot be unconnected with the fact that K increases with apparent viscosity of mud where the API formulation was seen to have higher value. The consistency index (n) for both formulations was determined for the modified API and soda ash pre treated and found to be 0.7097 and 0.7548 respectively; values which are between 0 and 1 implying that the formulated mud is shear thinning; a very desirable property for drilling mud

Furthermore, 80:20 formulations were found to be best modelled by Herschel Bulckley and Bingham plastic model modified API and soda ash pre treated sample respectively with R-square and Adj R-square values close to 1. It has shown the least sum of square errors compared Casson and Sisko models. Modified API formulation has shown consistency factor higher than that of soda ash pre treated sample which cannot be unconnected with higher apparent viscosity of the modified API formulation. The drilling mud formulated were found to be shear thinning with consistency index of 0.865 and 1 for modified API and soda ash pre treated sample formulation respectively

The fluid loss for the formulated muds was also determined and found that modified API formulations for 90:10 and 80:20 have shown lower fluid loss of 8 ml and 7 ml respectively. While soda ash pre treated samples have shown fluid loss of 9 ml and 6 ml respectively. All the values are within API specification of 15 ml for 30 minutes. There was decrease in fluid loss with increase in aqueous phase composition from 10 vol% to 20 vol%. (Schmidt *et al* 1987). Summary of the curve fitting data is shown in Table 1

Table 5: Curve fitting for the selected models

Formulation	**Model**	**R-Square**	**Adj R-Square**	**SSE**	**$\tau 0_{ext}$**	**$\tau 0_{exp}$**	**K**	**n**
90:10 API	Hershel Bulckley	0.9897	0.9829	0.001874	0.03097	0.03198	0.003726	0.7548
Soda ash pre treated 90:10	Hershel Bulckley	0.9958	0.9937	4.19E-04	0.04682	0.0533	0.002127	0.7097
80:20API	Hershel Bulckley	0.9996	0.9993	6.93E-05	0.03487	0.25584	0.001192	0.865
80:20 Soda ash pre treated	Bingham	0.9855	0.9759	0.001349559	0.06599	0.06929	0.000736	--------

CONCLUSIONS

The rheological properties of the mud were determined by obtaining their shear stress-shear rate data. 90:10 formulations were best modelled by Hershel Bulckley model with R-square value of 0.9897 and 0.9937 for organophyllic API Wyoming and local bentonite formulation respectively, while 80:20 organophyllic API Wyoming bentonite formulation was best modelled by Hershel Bulckley with R-square value of 0.9996 while organophyllic local bentonite 80:20 formulation was best modelled by Bingham plastic model with R-square value of 0.9855. All the formulated muds were found to be shear thinning with consistency index (n) between 0 and 1. The filtrate loss was also determined and found to be 8 ml and 9 ml for the soda ash pre-treated sample formulations which are within API specification for filtrate loss.

REFERENCES

Bilal S. (2015): Investigation and Enhancement of Quality of Nigerian Bentonitic Clay Samples for Oil and Gas Drilling Operation. Unpublished *Ph.D Thesis*, Department of Chemical Engineering Ahmadu Bello University, Zaria, Nigeria.

Bird, R.B.; Grance, D.and Yarusso, B.J. ,(1982), "The Rheological and Flow of Viscoplastic Materials". *Review in Chemical Engineering* (1), pp .1-70

Bourgouyne, A. T., Millhiem, K.K., Chenevert, M.E., Young, F.S. (1991). Applied Drilling Engineering, 2nd edition, Society of Petroleum Engineers, Richardson,Texas

Dardir, M.M., Ibrahime, S, Soliman, M., Deasouky, S.D., and Hafiz. A.A., (2014)," Preparation of some estramides as Synthetic Based Drilling Fluid," *Egyptian Journal of petroleum*. 23(1), pp. 35-43.

Hemphill, T.; Campos, W.; and Pilehvari, A.,(1993), 'Mud Rheology*". Oil and Gas Journal*, 91, pp .34

Folayan, J.A., Anawe, P.L., Abioye, P.O and Elehinafe, F.B. (2017) 'Selecting the Most Appropriate Model for Rheological Characterization of Synthetic Based Drilling Mud' *International Journal of Applied Engineering Research* ISSN 0973-4562 Volume 12, Number 18 (2017) pp. 7614-7629

Ibrahim A.O. (2016): Enhancement of Gambe Bentonic Clay using Fermentable and Unfermentable Polymers for Drilling Fluid Application Unpublished *MSc Thesis*, Department of Chemical Engineering Ahmadu Bello University, Zaria, Nigeria.

Pankil Singla, Rajeev Mehta, Siddh Nath Upadhyay (2012)'Clay Modification by the Use of Organic Cations' http://dx.doi.org/10.4236/gsc.2012.21004 Accessed on February 2012 (http://www.SciRP.org/journal/gsc)

RMRDC. (2010). *Non-Metallic Mineral Endowments in Nigeria: Bentonite.* Abuja: Raw Materials Reserch and Development Council

Schmidt D. O.,Roos A.F and Cline J.T, (1987) Interaction of Water With Organophilic Clay in Base Oils to Build Viscosity. A conference paper presented at the 62nd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers held in Dallas, TX September 27-30.