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Investigating the potential of *Calophylluminophyllum* plant base oil for oil and gas drilling mud operations

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Abstract. The environmental and cost advantage of non-edible plant oil for potential base oil in oil and gas drilling mud formulation is a drive for its use. The seed of *Calophylluminophyllum*the plant oil was processed, pulverized, and oil extracted using chemical method. The extracted plant oil and commercial synthetic oil was used to formulate drilling mud and comparative analysis were made using the physicochemical properties of the oil samples, mud rheological properties under sixteen hours and 240 °F aging and non-aging effect for a 7 and 9 g viscosifier, and rheological models in describing the mud. The commercial synthetic oil and *Calophylluminophyllum* oil shows a flash point of 101 ± 0.1 and 164 ± 0.1; density of 108 and 172 $\left(\frac{kg}{m^3}\right)$; viscosity index of 192 and 163; acid value of NIL and 24.24; and oil yield of NIL and 71 % respectively. The rheological properties of *Calophylluminophyllum* oil-based mud were higher than the synthetic oil-based mud. It was also observed that the increase in temperature and viscosifer decreases and increases the rheological properties respectively of all mud samples. The synthetic and *Calophylluminophyllum* oil-based mud increased in the rheological properties after aging test. In the overall estimation of the root mean square error (RMSE) values, coefficient of determination (R^2) values, and the fitted plots analysis. The Herschel Bulkley and the Sisko model had a much better description in predicting the experimental data for the synthetic oil-based mud. The hyperbolic, Herschel Bulkley and Sisko model had good description for the experimental data of the *Calophylluminophyllum* oil-based mud.

Key words: Synthetic oil; *Calophylluminophyllum* oil; plastic viscosity; yield point; gel strength

1. INTRODUCTION

In the formulation of drilling mud, it is important to consider its environmental impact, the technical performance, and the cost of production. The environmental challenges associated with oil and gas drilling mud operations are among the major issues facing world communities. The disposal of oil-based mud (OBM) even after treatment has some level of toxicity which contaminates the environment of deposition. In the Niger delta region of Nigeria, the release of drilling waste from oil-based mud into the water bodies adversely affects the dwelling organisms. This has caused a reduced rate of biodegradability by this organisms on the mud due to their toxic chemical components [8].

In time past, oil-based drilling mud were originally made from diesel oil fractions containing aromatic constituents, this chemical contents are not friendly to the environment. Diesel has been the primary base oil used as the dominant or continuous phase in preparing oil-based mud. Due to the environmental safety demands, especially in the offshore environment, the use of vegetable oil is now being encouraged. Stringent regulations concerning the use of diesel oil discourages its applications, hydrocarbon fractions substantially free from aromatic compounds or containing low amount of aromatic content such as the mineral oil was proposed.

Oil-based mud (OBM) have been designed to overcome certain undesirable characteristics of water-based muds (WBM). The reaction of shale dominated formation with WBMs causes swelling which further result into wellbore instabilities challenges. OBM provides good wellbore stability, good lubrication that leads to faster rate of penetration, temperature stability, shale stability, better lubricity, lowers rate of corrosion, reduce risk of differential sticking and low formation damage, lower friction and torque values than the WBM [12]. However, their application is limited by their high cost, environmental issues, and difficulties encountered during their processing.

In providing solution to the environmental issues caused by OBM, researchers found vegetable oil to be an alternative replacement to the petroleum-based oil [1;4]. This is due to the biodegradability, environmental friendliness, and non-toxic nature of vegetable oil. The possibility of replacing diesel base oil with plant base oil from jatropha and groundnut oil was investigated by [1], it was observed that oil-based mud from Jatropha and groundnut oil displays synonymous rheological properties to that of the diesel oil-based mud. However, the rheological properties of the plant oil were higher than that of the diesel oil. [4]formulated oil-based mud in an attempt to replacing diesel oil-based mud. The base oils used were algae, *Moringaoleifera*, diesel and *Jathrophacurcas* oil, while diesel-based mud was used as the control. The result of their analysis showed that *jatropha, moringa* and canola OBM's have better chances of technically replacing diesel OBM.

Studies have also shown that waste hydrocarbon-based lubricants are highly toxic to human health and the environment, and are slow in degradation [7]. In ensuring safety of the environment, drilling companies and offshore oil explorations are advised to explore the greener lubricant application [6]. In 1994, Randlesreviewed the need for formulating acceptable environmentally friendly lubricants in different countries, In Germany, Austria, and Switzerland; laws and regulations are in place encouraging the use of biolubricants thereby discouraging hydrocarbon-based lubricants around inland waterways and in forest areas through their laws and regulations. The Swedish City of Gothenburg encouraged the manufacturing industry to switch to biolubricants. In the Scandinavian countries, a tax exemption on biolubricants is in place. In Italy, tax is placed on mineral oils and products that contain them. Belgium enacted laws that requires biolubricants to be used in all operations that take place near non-navigable waters. In the Netherlands, the Dutch Ministry of Spatial Planning, Housing and the Environment issued a policy and action program in favor of biolubricants. In 1996, within the United States of America, the Department of Agriculture proposed the establishment of guidelines for the designation of items made from bio-based products, as required under the Farm Security and Rural Investment Act of 2002.

The implementation of the Nigerian local content Act also encouraged the need to boost the local materials by reducing the importation of petroleum products and rather producing them locally. The local content development Act 2010 signed into law, is considered to provide a solution and amend the insufficient value addition of the local content to the Nigerian economy from the industrial sector, especially in the petroleum industry [2;3]. The product substitution for imported oil industry products like the hydrocarbon-based oils as contained in the local act content is a drive for the production of biolubricant from the non-edible vegetable plants. The Nigerian oil industry, in time past, depended on the importation of drilling materials for the formulation of the OBM, which increases operational cost of the oil industry [9]. Efforts are being made to reduce this cost by exploring local materials that are environmentally friendly and also have positive impact on the local content revenues. In this regard, there is a need to explore the use of biolubricants as they are biodegradable, environmentally friendly and has a net zero greenhouse effect [10].

The rheological properties such as the plastic viscosity, apparent viscosity, yield point, and gel strength largely determines the performance of drilling mud [5]. The yield point is yield stress extrapolated to a shear rate of zero, it is used to evaluate the cutting carrying capacity of cuttings to the surface. The plastic viscosity determines how viscous is the mud which relates the flow resistance due to mechanical friction to flow. The gel strength parameter determines the ability of the mud to suspend drill solids ad weighting material when circulation is ceased. The ability of drilling mud in suspending cuttings when static, and still flow when stress is initiated is described by the gel strength.

This research work is aimed at evaluating the performance of drilling mud using commercial synthetic and *Calphylluminophyllum* plant oil. As the demand for oil and gas increases, so does the need for economic and environmental demands. Therefore, there is a need to conduct research on environmentally friendly, cost effective, and technologically acceptable materials that could be used in enhancing the performance of drilling mud.

2. METHODOLOGY

2.1. Processing of Calophylluminophyllum Plant seed

The various processing steps were used for the plant seeds before the oil extraction

- Sourcing: the plant seeds was gotten from Covenant University, Ota, Ogun State.
- Cleansing: this involves removal of dirt’s or unwanted materials from the plant seeds.
- Seed separation: it involves peeling of the outer covering to remove the seed.
- Drying: it involves oven drying of the pilled seed at 103 °C for 17+-1hour according to International Seed Testing Association (ISTA) standard.
- Grinding: it involves pulverization of the plant seed into oily or powdered form, this weakens or rupture the cell walls to ease the release of oil for extraction.

*Calophylluminophyllum*seed in its original state **(a)**, pilled and oven dried state **(b)**, pulverizedliquid form**(c)**, and the extracted oil**(d)**are as shown above in **Plate 1**.

Plate 1: The seed and extracted oil of *Calophylluminophyllum*

Oil Extraction Using Chemical Method

Oil was extracted from the pulverizedseed sample of *Calophylluminophyllum* using soxhlet extractionapparatus. 60 grams of the seed samplewas measured and poured into the thimble of the soxhlet extractor, and 250 ml N-Hexane solvent was poured into a round button flask of 500 ml volume. The soxhlet apparatus was then mounted on a heating mantle at a temperature of 67 °C, and allowed to reflux for roughly 2 hours. The oil extracted from the seed flowed down the thimble into the round button flask containing the solvent. The liquid was then filtered to get rid of existing impurities, and then vaporized with a distillation evaporator set-up to separate the solvent from the oil. This process was repeated until the desired quantity of oil was obtained.

Measurement of the Physicochemical Properties of Base Oil Samples

The viscosity, viscosity index, flash point, fire point, and density of the base oils (commercial synthetic oil and *Calophylluminophyllum*oil) weremeasured using the glass capillary viscometer, flash point tester, and a density bottle respectively.

2.2. Laboratory Preparation of the Synthetic and Calophylluminophyllum Oil-based Mud

The mud samples were prepared using the base oils individually and the additives in the following order. In preparing the commercial synthetic oil-based mud (SOBM), 245 ml of synthetic based-oil was poured into the Hamilton beach mixing cup, and 20 ml of omni tech emulsifier, 3 g of lime, 105 ml of distilled water, varying concentration of 5 and 7 g of the viscosifier, and finally 40g of barite. The mixture was mixed in intervals of 20 minutes and final mixture was totally mixed for one hour. The same process was used for the *Calophylluminophyllum*oil-based mud (CIOBM).The plastic viscosity, yield point, and gel strength at 10 minute were measured at the varying concentrations of the viscosifier, and temperatures of 113 and 158 °F.

Aging of Mud Samples

The mud samples were poured into the high pressured aging cell, and into the dynamic rolling machine to simulate downhole condition of temperature for 16 hours at 240 °F in a dynamic rolling machine to simulate downhole condition of temperature. After hot rolling (AHR) of the mud samples, the shear stress and rheological properties were measured and compared to the conditions before hot rolling (BHR). Analysis of the aged synthetic oil-based mud (ASOBM) and aged *Calophylluminophyllum*oil-based mud (ACIOBM) are shown in **Table 2-5**.

2.3. Taguchi Design Methodology

The effect of temperature and concentration of the viscosifer was investigated on the rheological properties using the Taguchi design methodology. The input variables are the temperature and concentration of the viscosifier, this were varied at low and high values so as to evaluate how they affect the output variables which are the shear stress/shear rate, plastic viscosity, gel strength, and yield point of the plant and synthetic oil-based mud. The low and high temperature chosen for this analysis are 113 °F and 158 °F respectively, while the low and high concentration of the viscosifier are 7 g and 9 g respectively. The following models were analyzed using the Taguchi research design to describe the experimental rheological data of the mud samples.

Herschel Buckley Rheological Model

The three parameter model (equation 2.1) relates the shear stress to shear rate as represented mathematically in equation below

$$\tau = \tau_{01} + K_1 * (\dot{\gamma})^n \tag{2.1}$$

Where the $\tau, \tau_{01}, \dot{\gamma}, K_1, n$ represents the shear stress, yield stress, shear rate, correction parameter, and flow behavior index respectively.

Hyperbolic Rheological Model

The shear stress-shear rate relationship model (equation 2.2) below defines the hyperbolic model.

$$\tau = \tau_{02} + \frac{\dot{\gamma}}{A+B\dot{\gamma}} \tag{2.2}$$

Where τ_{02} is the yield stress, A and B are the model parameters.

Sisko Rheological Model

The Sisko model (equation 2.3) relates the shear stress-shear rate using three parameters

$$\tau = K_2\dot{\gamma} + K_3(\dot{\gamma})^m \tag{2.3}$$

Where $K_2, K_3, and\ m$ are the coefficient of viscosity, consistency coefficient, and fluid flow index respectively.

Casson Rheological Model

Two parameters are used in the Casson model (equation 2.4) to relate the shear stress-shear rate

$$\tau^{1/2} = {\tau_{03}}^{1/2} + {K_4}^{1/2}(\dot{\gamma})^{1/2} \tag{2.4}$$

Where k_4 and τ_{03} are model constant and yield stress respectively.

2.4. Accuracy of Rheological Model Estimations

The comparison and accuracy of the various models were quantified using the Root Mean Square Error (RMSE) in equation 2.5, and coefficient of determination $(R)^2$ in equation 2.6.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{N}} \tag{2.5}$$

$$R^2 = \left[\frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\sqrt{\sum_i (y_i - \bar{y})^2}}\right]^2 \tag{2.6}$$

3. RESULTS AND DISCUSSION

3.1. The yield of Calophylluminophyllum oil is as calculated below

$$\text{Weight of sample used } (\mathrm{W_s}) = 60\ g,\ \text{Weight of oil recovered } (W_{or}) = 43\ g$$

$$\text{Oil yield} = \frac{\text{Weight of oil recovered } (W_{or})}{\text{Weight of sample used } (\mathrm{W_s})} * 100 = 71\ \%$$

The seed and oil of *Calophylluminophyllum* are as shown above in **Plate 1**. The seed is green in the original state **(a)**, turns white-brown due to interaction with moisture when pilled, and brown when oven dried**(b)**, liquid in the pulverized form **(c)**, and extracted oil is greenish-black in color**(d)**.

3.2. Analyzing the Physicochemical Properties of the Base Oils

Table 2shows the physicochemical properties of the commercial synthetic oil (CSO) and *Calophylluminophyllum* oil (CIO) used in the mud formulation. The European union standard (EN14214) and the ASTM D6751 standard were used as basis for comparison.

Kinematic Viscosity

The kinematic viscosity of base oil is one of the fluid parameter that determines the capacity of oil to withstand temperature. It is used in calculating the viscosity index. According to **Table 1**, the kinematic viscosity of the CSO (14.62) and CSO (32.52) are far above the EUS (EN14214) and ASTM D6751 standard. Kinematic viscosity of the plant oil was more than twice that of the commercial synthetic oil.

Viscosity Index (VI)

The viscosity index in practice, is used in estimating the thermal stability of petroleum product. It is determined from the variation of the kinematic viscosity of oil at 40 and 100°C. **Table 1** shows the viscosity index of the synthetic oil (192) is higher than the *Calophylluminophyllum* oil (163). This signifies that the CSO will experience smaller change in the kinematic viscosity with increase in temperature than the CIO. The VI of standard was not specified (N/S).

Flash and Fire Point

The flash and fire point of the base oils, as shown in **Table 1**, are within the range of the EUS (EN14214) and the ASTM D6751 standard. The flash and fire point of *Calophylluminophyllum* oil are higher than that of the commercial synthetic oil. Hence, the plant oil is less volatile than the commercial synthetic oil.

Density

The density of the CSO and CIO are shown in Table 1, the plant oil density is close to the EUS (EN14214) and the ASTM D6751 standard.

Acid Value

The acid value, been a measure of the free fatty acid (FFA), is high and will need to be reduced by transesterification reaction for biodiesel production. The high acid value and FFA of *Calophylluminophyllum* oil is be due to the high degree of unsaturation.

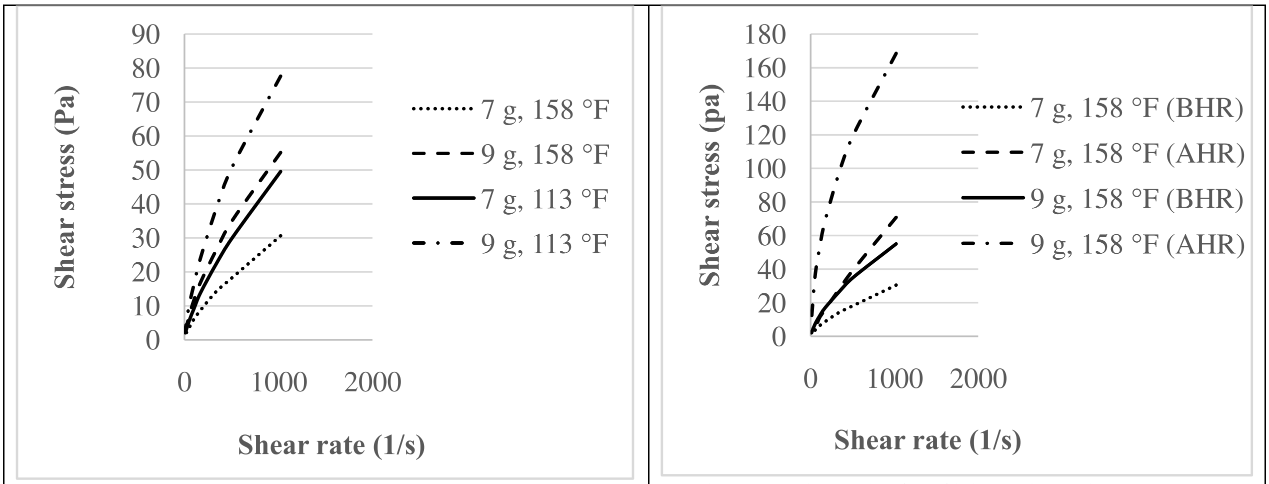
Table 1: Physicochemical Properties of the Base Oil Samples

Oil Properties	**CSO**	**CIO**	**(EN14214)/ASTM D6751**
Flash point (°C)	101	164	≥120
Fire Point (°C)	108	172	≥93
Density (kg/m^3)	806	923	860-900
Kin. visc @40 °C $\left({mm^2}/{s}\right)$	14.62	32.52	1.9-6
Viscosity Index (VI)	192	163	**N/S**
Acid value (mgKOH/g)		24.24	≤ 0.8
Free fatty acid (%)	10.69	12.12	≤ 2
Oil yield (%)	NIL	71	**N/S**
Color	Colorless	Greenish black	

3.3. Shear Stress-Shear Rate Analysis of the Synthetic and CalophylluminophyllumOil-based mud

Shear Stress and Shear Rate of the Synthetic Oil-based Mud

Figure 1 presents the shear stress-shear rate profile of the synthetic oil-based mud **(a)** and the effect of aging on the synthetic oil-based mud **(b)**in a shear rate range of 10-1020 S^{-1}, for temperatures of 113 and 158 °F, and 7 and 9 g concentration of viscosifiers.In **figure 1a**, the shear stress increases with increase in the concentration of the viscosifer, and decreases with increase in the temperature. This shows that the carbogel is viscosifying agent while temperature causes a decreasing effect on the mud. The shear thinning effect of the mud is in the lower shear rate range of 10 s^{-1} to about 400 s^{-1}, and increases linearly as a result of the effect of temperature. The shear stress-shear rate relationship was found to be non-linear and so, the viscous flow curves exhibit a non-Newtonian flow behaviour over a wide range of shear rate. The aging effect on the synthetic oil-based mud is shown in **Figure 1b**, an increase in the shear stress was observed after the mud was hot rolled. The increase is as a result of the thickening effect of the mud caused by the interaction of the internal structures of the mud under the influence of aging time and temperature.



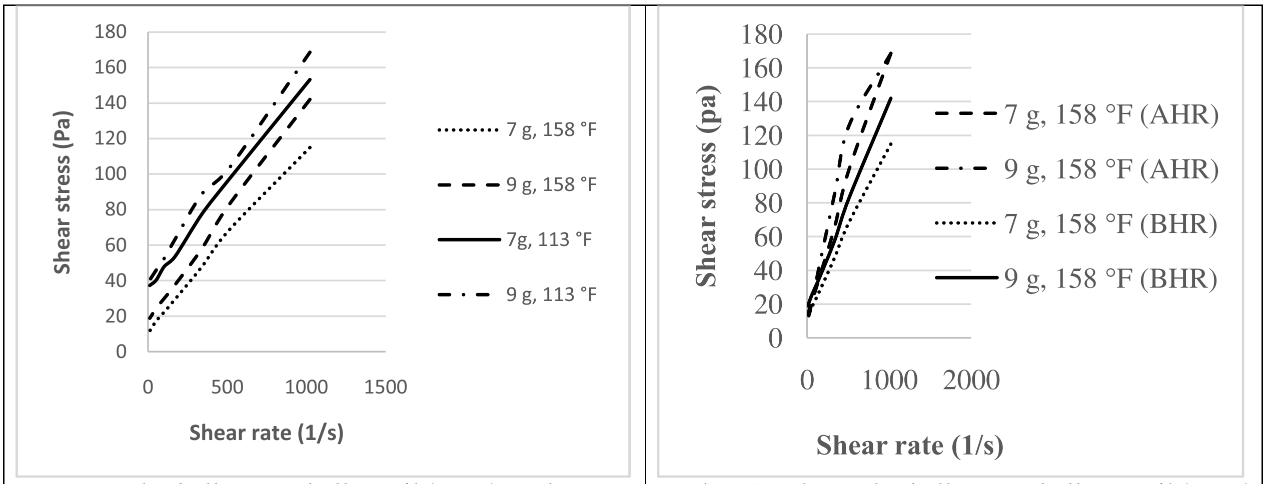
a. Synthetic oil-based mud

b. Aged synthetic oil-based mud

Figure 1: Effect of the viscosifier and temperature on the shear stress-shear rate of the synthetic and aged synthetic oil-based mud

Shear Stress and Shear Rate of the CalophylluminophyllumOil-based Mud

Figure 2 presents the flow curves of aged and un-aged mud prepared with the *Calophylluminophyllum* oil. In **Figure 2a,** a deflection was observed at a shear rate of about 400 s^{-1}. The viscous flow curves exhibit a synonymous Newtonian flow behavior over a wide range of shear rate, this is due to the linearity of the plot most especially after the shear rate of 400 s^{-1}. However, the viscosity is not constant. The shear stress-shear rate increases with increase in the viscosifier, and a decreaseswith temperature increase from 113 °F to 158 °F. The shear stress-shear rate profile of CIOBM was observed to be higher than the SOBM. This is due to the higher viscosity of the *Calophylluminophyllum* oil as shown in **Table 1.** The effect of aging on the *Calophylluminophyllum* oil-based mud is as shown in the **Figure 2b**.The shear stress-shear rate profileincreases in same manner as the SOBM after hot rolling. The similar increase in the shear stress is due to yielding effect of the mud under the effect of temperature.



a. *Calophylluminophyllum* oil-based mud

b. Aged *Calophylluminophyllum* oil-based mud

Figure 2: Effect of the viscosifier and temperature on the shear stress and shear rate of *Calophylluminophyllum* oil-based mud

3.4. Rheological Properties of the Mud Samples

Plastic Viscosity of the Mud Samples

As shown in **Figure 3**, the plastic viscosity values of the plant oil are significantly higher than the SOBM. The higher the plastic viscosity values are also as a result of the high viscous oil property of the plant oil. It was also observed that the plastic viscosity of the SOBM and CIOBM reduces with increase in temperature, and increases with increase in the viscosifier. However, *Calophylluminophyllum* oil-based mud has more than twice the plastic viscosity value of the synthetic oil-based mud, this is due to the high viscosity of the plant base oil. The effect of hot rolling on the plastic viscosity of the synthetic and *Calophylluminophyllum* oil-based mud was also investigated. It was observed that the plastic viscosity values for SOBM and CIOBM increased after aging. The increase is as a result of the linking of the internal structures, and the thickening effect on the mud samples at elevated temperature under aging.

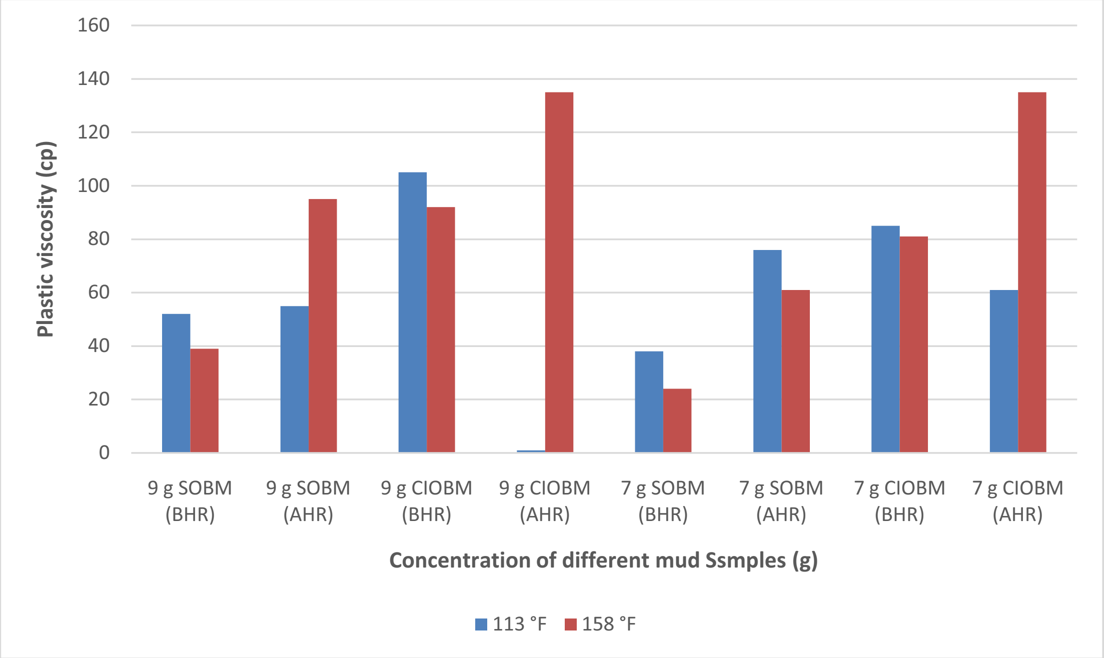


Figure 3: Effect of viscosifier and temperature on the plastic viscosity of synthetic and *Calophylluminophyllum* oil-based muds

Yield Point of the Mud Samples

Figure 4 shows the yield point values of synthetic and *Calophylluminophyllum* oil-based mud (before and after hot rolling). Before hot rolling, the 9 g mud samples are higher than the 7 g mud samples for SOBM and CIOBM. Both mud types also experienced a reduction in the yield value when temperature was increased from 113 °F to 158 °F. The higher yield point value of*Calophylluminophyllum* oil-based mud over the synthetic oil-based mud suggest CIOBM requires a higher stress to initiate flow of mud. The higher yield value of CIOBMalso suggest the ability of mud to lift cuttings out of the annulus. After hot rolling, the yield point values increased for the synthetic and *Calophylluminophyllum* oil-based mud. The cause of the increase is also as a result of the thickening effect, also known as thermal gelation.

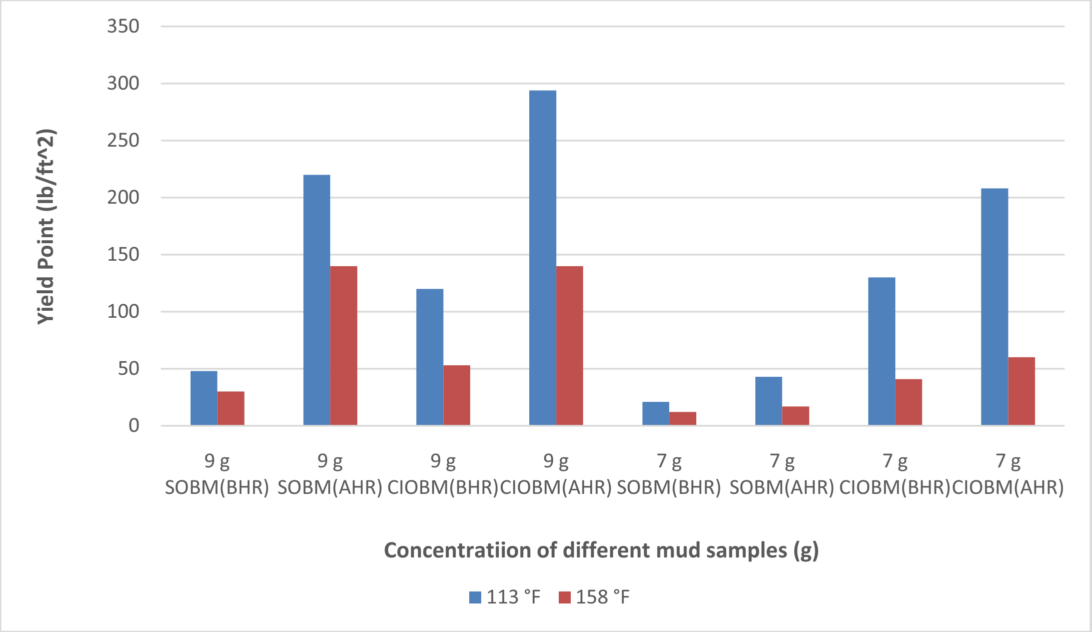


Figure 4: Effect of viscosifier and temperature on the yield point of synthetic and *Calophylluminophyllum* oil-based muds

Gel Strength of the Mud Samples (10-min)

Figure 5 shows the effect of temperature and the viscosifier on the all the aged and un-aged mud samples. Before hot rolling, the gel strength values for CIOBM is higher than the SOBM, this can result into difficulty in initiating movement of the fluid after a break in the drilling operation. Increase in concentration of the viscosifier causes a corresponding increase in the gel strength, while temperature causes a decreases in the gel strength. This implies plant base mud would require more pump pressure and cost than the SOBM to initiate flow due to the high gel strength values. After hot rolling, the SOBM and CIOBM increased after aging. Increase in the gel strength is as a result of thermal gelation which is a gelling effect of the mud under aging conditions.

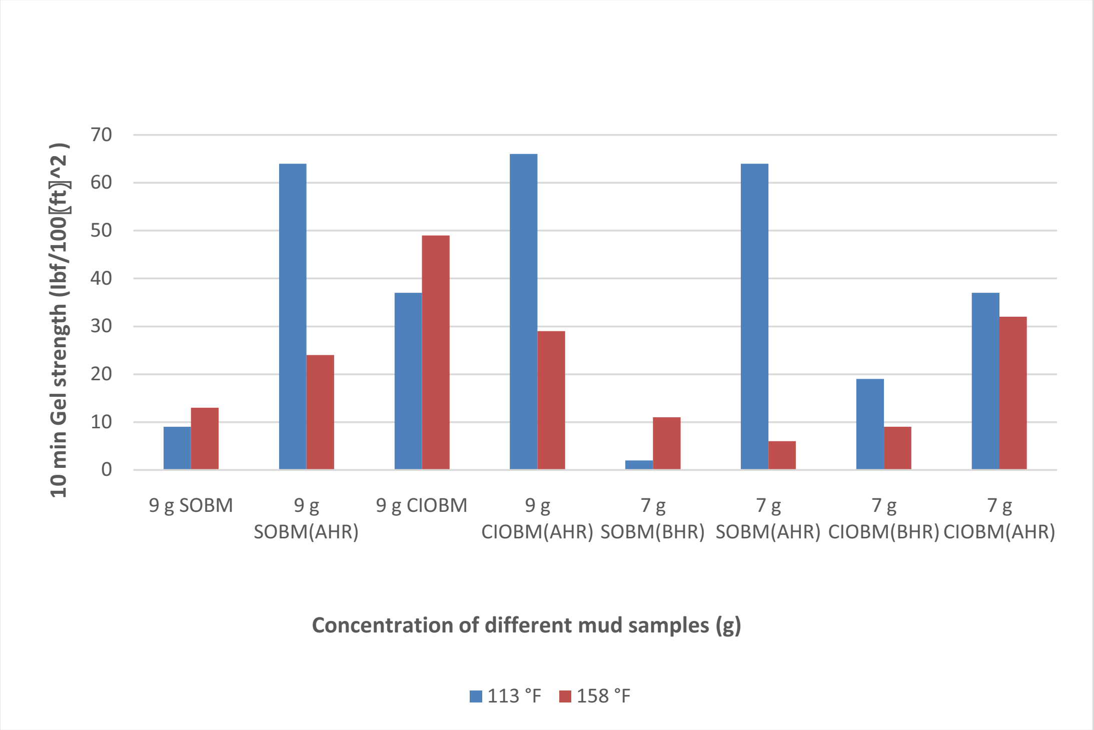
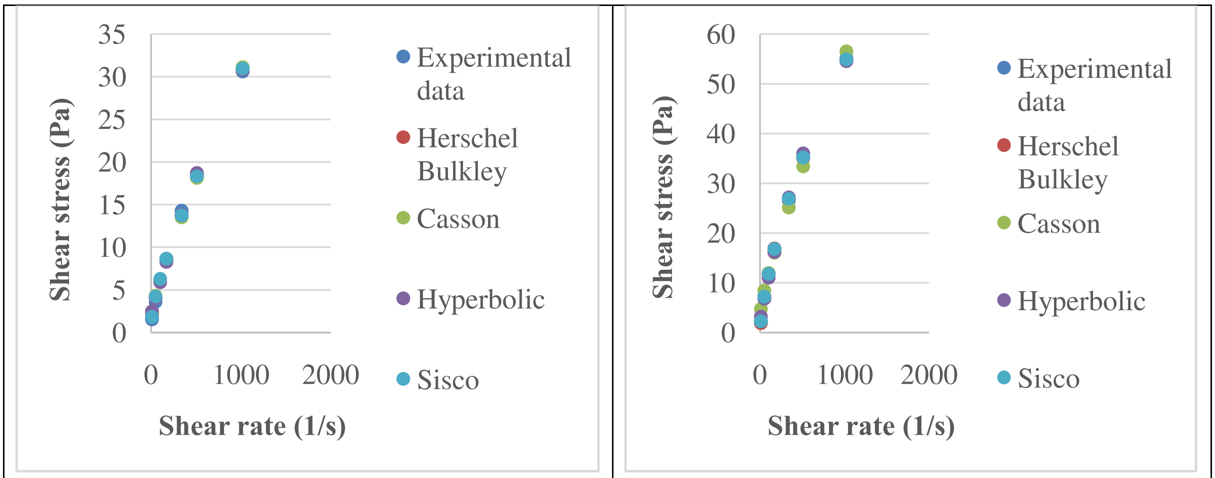


Figure 5: Effect of viscosifier and temperature on the 10 min gel strength of aged and un-aged synthetic and *Calophylluminophyllum* oil-based mud

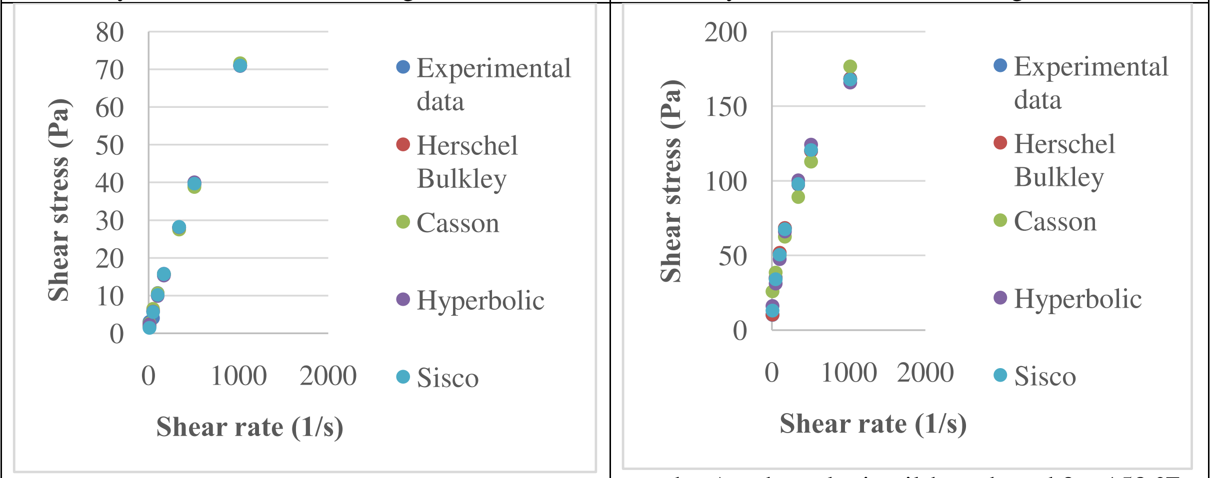
3.5. Describing the Rheological Experimental Data

Figure 6 shows the plot of the measured and predicted shear stress and shear rate using Herschel Bulkey, Casson, hyperbolic, and Sisco rheological model in describing the experimental data. **Figure 6 (a)** shows the shear stress-shear rate plot of SOBM with 7 g viscosifer at 158 °F. **Figure 6 (b)** shows the shear stress-shear rate plot of SOBM with 9 g viscosifer at 158 °F. **Figure 6 (c)** shows the shear stress-shear rate plot of aged SOBM with 7 g viscosifer at 158 °F, and **Figure 6 (d)** shows the shear stress-shear rate plot of aged SOBM with 9 g viscosifer at 158 °F



a. Synthetic oil-based mud 7g, 158 °F

b. Synthetic oil-based mud 9g, 158 °F

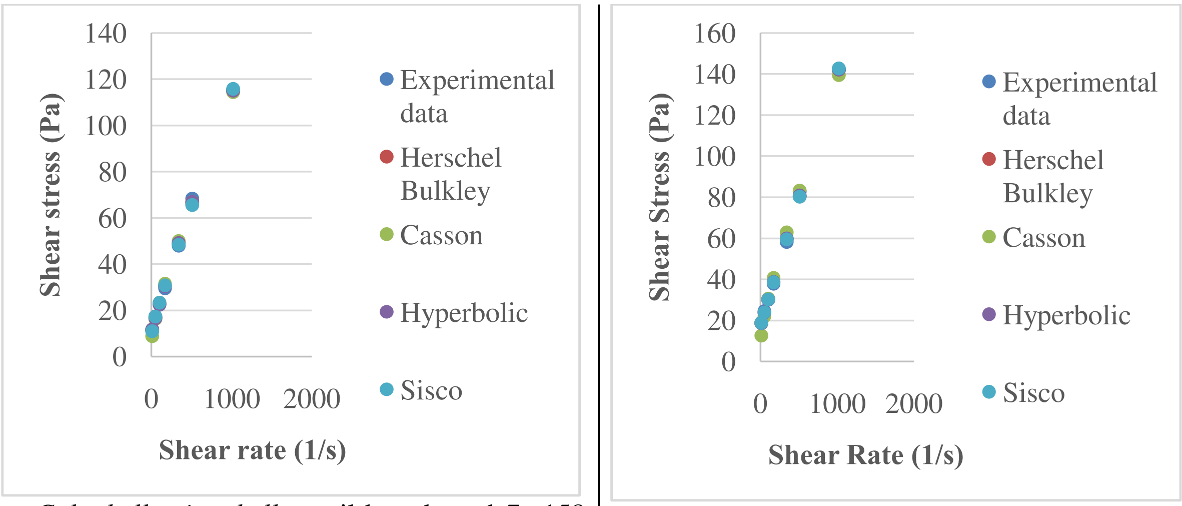


c. Aged synthetic oil-based mud 7g, 158 °F

d. Aged synthetic oil-based mud 9g, 158 °F

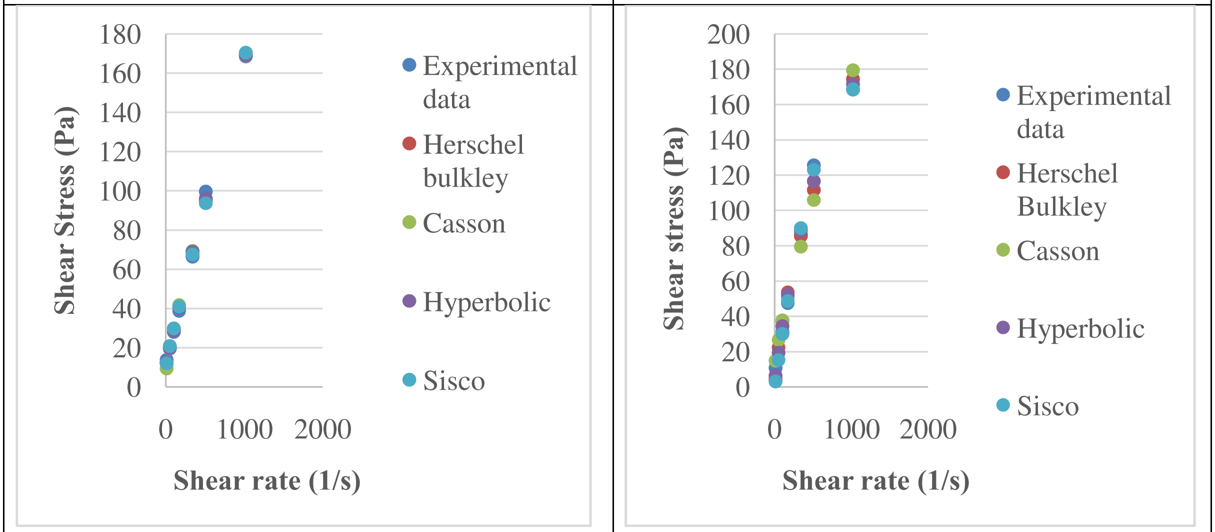
Figure 6: Measured and predicted shear stress-shear rate of the synthetic oil-based mud

Figure 7(a) shows the plot for 7 g viscosifer at 158 °F of CIOBM. **Figure 7 (b)** shows the plot for 9 g viscosifer at 158 °F of CIOBM. **Figure 7 (c)** shows the plot for 7 g viscosifer at 158 °F of aged CIOBM, **and Figure 7 (d)** shows the plot of 9 g viscosifer at 158 °F of aged CIOBM.



a. *Calophylluminophyllum* oil-based mud 7g,158 °F

b.*Calophylluminophyllum* oil-based mud 9g,158 °F



c. Aged*Calophylluminophyllum* oil-based mud 7g, 158 °F

d. Aged*Calophylluminophyllum* oil-based mud 9g, 158 °F

Figure 7: Measured and predicted shear stress-shear rate of *Calophylluminophyllum* oil-based mud

3.6. Comparison of the Rheological Models

The various rheological models used in describing the experimental data were evaluated using statistical analysis of the R^2, RMSE values, and the fitted plots **(Figure 6 and 7)**. $R^2$and RMSE values are summarised in **Table 2-5. Table 2** showed that the Herschel Bulkley coefficient of determination, R^2, accounted for 99.1% to 100% of the variance between the experimental data points for the rheological relationship, and the fitted regression model. The 7 and 9 g viscosifier of SOBM and CIOBM had 100% of data points accounted for, this is reduced when the mud was hot rolled. 100 % of the data point was also accounted in the 9 g aged synthetic oil-based mud (ASOBM). The Hyperbolic model accounted for 99.6% to 100% of the variance, with a higher estimation of 100 % obtained for the 7 and 9 g viscosifier of the CIOBM. The Sisko model accounted for 99.7% to 100% of the variance, with 100% estimation for the 7 and 9 g viscosifier of the SOBM. 9 g ASOBM and CIOBM accounted for 100 % of the data point. The Casson model accounted for 98.4 % to 99.9 %, with 99.9 % estimation for the 7 g SOBM and CIOBM. In the overall estimation of the RMSE values, R^2 values, and the fitted plots analysis, the Herschel Bulkley and the Sisko model had a much more better description in predicting the experimental data for the mud samples, this is in agreement with the R^2 and RMSE values as shown in (**Table 2 and 5** respectively), the models has a higher R^2 and lower RMSE values.

Table 2: Herschel Bulkley model parameters for SOBM and CIOBM

Mud Type	**Viscosifier (g)**	$\tau_{01}(\mathrm{Pa})$	$K_1[(\mathrm{Pa})s^n]$	n	$\mathrm{RMSE(Pa)}$	R^2
SOBM	7	1.240	0.13227	0.781	0.365	1.000
	9	-1.129	0.69894	0.633	0.180	1.000
ASOBM	7	0.585	0.18280	0.860	1.131	0.999
	9	-12.161	7.94320	0.451	0.397	1.000
CIOBM	7	9.672	0.20557	0.901	1.385	1.000
	9	17.343	0.13540	0.985	1.475	1.000
ACIOBM	7	9.751	0.28729	0.913	3.082	0.999
	9	-6.229	2.52018	0.617	9.467	0.991

Table 3: Hyperbolic model parameters for SOBM and CIOBM

Mud Type	**Viscosifier (g)**	$\tau_{02}(\mathrm{Pa})$	$A[(\mathrm{Pa})s]^{-1}$	$B[Pa]^{-1}$	$\mathrm{RMSE(Pa)}$	R^2
SOBM	7	2.087	25.88820	0.009	0.584	0.999
	9	2.215	10.70700	0.009	1.034	0.999
ASOBM	7	1.511	11.8037	0.003	1.027	0.999
	9	12.089	2.46050	0.004	5.181	0.997
CIOBM	7	10.487	8.32030	0.001	1.089	1.000
	9	17.314	7.90913	0.0003	1.417	1.000
ACIOBM	7	10.555	5.51607	0.001	2.560	0.999
	9	2.897	2.92665	0.003	6.099	0.996

Table 4: Sisko model parameters for SOBM and CIOBM

Mud Type	**Viscosifier (g)**	$K_2[(\mathrm{Pa})s^{-1}]$	$K_3[(\mathrm{Pa})s^m]$	m	$\mathrm{RMSE(Pa)}$	R^2
SOBM	7	0.019	0.61492	0.423	0.344	1.000
	9	-0.032	0.43817	0.764	0.253	1.000
ASOBM	7	-0.173	0.21361	0.870	1.169	0.999
	9	-0.080	3.23716	0.627	1.757	1.000
CIOBM	7	0.095	7.35784	0.134	1.742	0.999
	9	0.122	17.36810	0.006	1.505	1.000
ACIOBM	7	0.147	7.44009	0.150	3.582	0.999
	9	0.305	-0.00005	2.133	4.947	0.999

Table 5: Casson model parameters for SOBM and CIOBM

Mud Type	**Viscosifier (g)**	$\tau_{03}(\mathrm{Pa})$	$K_4[(\mathrm{Pa})s^{-1}]$	**RMSE(Pa)**	$\mathbf{R^2}$
SOBM	7	1.159	0.01986	0.399	0.999
	9	2.523	0.03446	1.934	0.996
ASOBM	7	0.707	0.05690	1.253	0.999
	9	17.613	0.08097	9.859	0.986
CIOBM	7	4.429	0.07237	2.020	0.999
	9	6.893	0.08264	4.080	0.997
ACIOBM	7	3.794	0.11964	3.434	0.998
	9	7.815	0.11002	11.658	0.984

4. Conclusion

The following conclusions were made from this research work.

i. *Calophulluminophyllum*is a potential base oil for drilling mud. This was concluded based on the oil yield and the physicochemical properties.
ii. The rheological properties and shear stress of the synthetic and *Calophylluminophyllum* oil-based mud reduced with increase in temperature, and increased with the concentration of the carbogel. Hence carbogel is a good viscosifier.
iii. The rheological properties of *Calophulluminophyllum*oil-based mud is higher than the synthetic oil-based mud, this is as a result of the high viscosity of the plant oil over the synthetic oil.
iv. The rheological properties profile of the synthetic and *Calophulluminophyllum* oil-based mud increased after undergoing aging,
v. The synthetic oil-based mud exhibited more of the non-Newtonian fluid behavior than the *Calophulluminophyllum*.
vi. The Herschel Bulkley model was a good fit for the mud samples. This was concluded based on the fitted plot, root mean square error, and coefficient of determination.

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References

[1] Anawe, P. A. L., Efeovbokhan, V., Ayoola, A., & Akpanobong, O. (2014). Investigating alternatives to diesel in oil based drilling mud formulations used in the oil industry. *Journal of Environmental and Earth Science*, *4*(14), 70–78.

[2] Ayonmike, C. S., & Okeke, B. (2015). The Nigerian local content act and its implication on technical and vocational and traininig (TVET) and the Nation’s economy. *International Journal of Education Learning and Development*, *3*(1), 26–35.

[3] Bello, O. (2010). Jonathan inaugrates Nigerian content governing council, orders strict compliance. *Business Day*, p. 6.

[4] Fadairo, A., Falode, O., Ako, C., Adeyemi, A., & Ameloko, A. (2012). Novel Formulation of Environmentally Friendly Oil Based Drilling Mud. *New Technologies in the Oil and Gas Industry*, 49–79. https://doi.org/10.5772/51236

[5] Habib, N. S. H. A., Yunus, R., Rashid, U., Taufiq-Yap, Y. H., Abidin, Z. Z., Syam, A. M., & Irawan, S. (2014). Transesterification reaction for synthesis of palm-based ethylhexyl ester and formulation as base oil for synthetic drilling fluid. *Journal of Oleo Science*, *63*(5), 497–506.

[6] Kania, D., Yunus, R., Omar, R., Rashid, S. A., & Jan, B. M. (2015). A review of biolubricants in drilling fluids: Recent research, performance, and applications. *Journal of Petroleum Science and Engineering*, *135*, 177–184.

[7] Martin, D., Khan, I., Dai, J., & Wang, Z. D. (2006). An overview of the suitability of vegetable oil dielectrics for use in large power transformers. In *Euro TechCon* (pp. 4–23).

[8] Ogeleka, D. F., & Tudararo-Aherobo, L. . (2013). Assessment of the toxic effects of oil-based drilling mud (drilling waste) on brackish water shrimp (Palaemonetes africanus). *Bulletin of Environment, Pharmacology and Life Sciences*, *2*, 113–117.

[9] Oghenejoboh, K. M., & Ohimor, E. O. (2013). Application of re-refined used lubricating oil as base oil for the formulation of oil based drilling mud -A comparative study. *Journal of Petroleum Technology and Alternative Fuels*, *4*(4), 78–84. https://doi.org/10.5897/JPTAF2013.0089

[10] Onuh, C. ., Dosunmu, A., Anawe, P. A. L., Efeovbokhan, V., & Adebisi, A. (2017). Transesterification of Non-Edible Vegetable Oil for Lubricant Applications in Water-Based Mud : A Review. *International Journal of Applied Engineering Research*, *12*(18), 7397–7401.

[11] Randles, S. J. (1994). Formulation of environmentally acceptable lubricants. In *49th STLE Annual Meeting, May 1-5*. Pittsburgh.

[12] Sönmez, A., Verşan Kök, M., & Özel, R. (2013). Performance analysis of drilling fluid liquid lubricants. *Journal of Petroleum Science and Engineering*, *108*, 64–73.