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EVALUATING THE PERFORMANCE OF *CALOPHYLLUM INOPHYLLUM AND HURA CREPITANS* PLANT OIL ON THE RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER-BASED MUD

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Abstract

The performance of drilling mud is a function of the rheological and filtration properties, if these properties are not properly managed, could lead to drilling challenges. This research work is aimed at evaluating the potential of plant oils in the rheological and filtration properties of the water-based mud. In this experiment, the *Calophyllum inophyllum and Hura crepitans* were extracted from their seeds using a Soxhlet extractor and a distillation apparatus. Water-based mud was formulated using bentonite, carboxyl-methyl-cellulose (CMC), potassium hydroxide (KOH), deionized water, and the diesel oil, *Calophyllum inophyllum and Hura crepitans* oil was added in 5, 10, to 25 ml concentrations. The flash point, fire point, specific gravity, emulsion stability, pH, the kinematic viscosity of oil were measured. The rheological, physicochemical, and filtration properties of the mud were also measured. The result revealed appreciable properties of *Calophyllum inophyllum and Hura crepitans* plant oil are within and close to the ASTM standard. The plant oils are better fluid loss controllers than the diesel oil as they reduced the volume of fluid loss when added to ordinary water-based mud. *Hura crepitans* oil-in-water emulsion mud had relatively acceptable rheological properties than the *Calophyllum inophyllum* and diesel oil-in-water emulsion mud. Increasing rheological properties was observed as the concentration of the *Calophyllum inophyllum*, *Hura crepitans*, and diesel oil was increasing.

Keywords*: plastic viscosity; yield point; gel strength; fluid loss; water-based mud.*

1. Introduction

Drilling mud is used in drilling operations whether offshore or onshore, to control or prevent so many unwanted challenges during drilling such as kicks and blow out, control formation pressure, maintain well integrity and prevent well collapse. The use of drilling mud in carrying out drilling operations is mainly for transportation, suspension and dropping off cuttings, supporting walls of the wellbore, lubricating the drill string thereby reducing friction, controlling pressure, and wellbore stabilization [1]. Oil based mud systems such as the diesel oil based mud or that of the synthetic are made to withstand certain undesired characteristics of water-based mud (WBM). This is basically because of the properties of water to break up salts, meddle with a stream of oil and gas through porous rocks, advance the crumbling and spreading of clays, and to react with shale resulting to swelling [4]. The use of oil based mud (OBM) has demonstrated compelling effects throughout the years. Nevertheless, they are costlier with potential contamination or pollution issues; this makes OBM a challenging decision for environmentally delicate regions.

Oil based drilling mud are in varying degree of toxicity; it is quite costly to handle in an environmentally friendly manner. The disposal of water-based mud is preferrably due to its low cost of formulation, less aromatic contents and toxicity, and low cost of disposal [5]. Hence, improving the technical performance of water-based mud will enhance their application since they have acceptable cost and environmental characteristics. The rheological and filtration properties of drilling mud are one of the mud properties that determine their performance in drilling operations [6]. Agricultural waste materials used in water-based mud have proved to be of technical benefit; they have been used to improve the rheological behaviour of mud and the filtration properties [9]. Plant oil has also been introduced in drilling mud formulation; they are known to be prospective environmentally friendly potential lubricant oil in WBM wit. They have lesser toxic content, low cost of production, with synonymous potential lubricity as the OBM [2-3]. The linear swelling test was carried out on shale samples in the presence of de-ionised water-based mud by [7], the interaction between the shale samples and mud caused swelling of the shale after been immersed for 24 hours. The introduction of plant oils in WBM is sometimes to reduce the mud fluid loss and minimize the interaction between the shale and mud, thereby inhibiting potential swelling. Plant oils have been introduced in water-based mud to measure the lubricity performance and ability to reduce the physicochemical interaction between the shale and mud filtrate [8], the plant oil reduced the interaction and further minimized the swelling rate of the shale when immersed in the mud filtrate. This work is focused on evaluating the effect of *Hura crepitans* and *Calophyllum inophyllum* plant oil on the rheological properties of water-based mud.

2. The rheological properties of drilling mud

The rheological and filtration loss properties are vital parameters of mud which determines the performance of the drilling mud. One important function of drilling mud is to clean the wellbore hole, suspend and carry cuttings to the surface. It is the rheological property that determines the cutting carrying capacity of cuttings to the surface, and are also used in analysing the equivalent circulating density, hole cleaning, barite sag, and surge pressure. It also determines the rate of penetration of drill bit and filtrate loss into the formation. The higher the fluid loss into the formation, the potential it is for the mud to form cakes on the wall of the formation, causing stuck pipe [6]. The rheology affects the differential pressure in the drill-pipe and the annulus, and by so doing affects the pumping rates and pressure required to initiate mud flow. The rheological properties are the plastic viscosity, gel strength, and yield point.

2.1. Plastic viscosity of drilling mud

The plastic viscosity relates to the resistance of fluid flow due to mechanical friction. The higher the plastic viscosity of the mud, the more viscous it is and difficult it is to initiate flow; hence, hole cleaning and cuttings transportation to the surface will be challenging. High viscous mud directly impacts on the frictional pressure drop, and this proportionally increases the pump rate required to flow the mud into the hole and up the annulus. The increase in pump rate of the mud will cause a corresponding increase in the cost of pumping the fluid, which may un-intentionally fracture the formation leading to wellbore instabilities. The higher the plastic viscosity, the higher the equivalent circulating density, the higher the surge and swab pressures, the higher tendency for differential pipe sticking due to possible, solid content, and the lower the rate of drill bit penetration.

2.2. Yield point of drilling mud

One important function of drilling fluid is in the lifting of cuttings to the surface; the Yield stress determines the capacity of the mud to carry cuttings generated during drilling to the surface under a dynamic condition. It is the yield stress extrapolated to a shear rate of zero. Hence, tt is the initial stress required to move the fluid into motion.

2.3. The gel strength of drilling mud

The gel strength is the shear stress of drilling mud that is measured at the low shear rate when static for a certain period. It is used to evaluate the forces binding the mud particles together, and by so doing, determines the setting rate of cuttings in the drilled hole. The gel strength is the mud property that determines mud capacity to suspend cuttings when circulation is static.

2.4. Fluid loss properties of drilling mud

The filtration or fluid loss property is also an important property in determining the performance of mud; there are two types called the API and HPHT fluid loss test. The previous measures the volume of fluid loss at ambient temperature and pressure of 100 psi while the latter determines the fluid loss at high temperature and pressures. Good drilling mud has a lower fluid loss, which leaves a thin and impermeable cake, but a poor drilling mud usually has a higher fluid loss, leaving thick and permeable cake from the mud. This thick cake has the possibility of causing pipe sticking as a result of the large contact area of the cake between the formation and the pipe [8].

3. Materials and methods

The seeds of *Hura crepitans* and *Calophyllum inophyllum* were harvested from the vicinity of Covenant University, Ota, Ogun State, Nigeria. It was then dried, cleaned, pilled, and pulverized for oil extraction. The extraction method is as stated below.

3.1. Extraction of oil from their seed

The oil extraction from the pulverized seed samples was done using the chemical extraction method, where 60 g of the pulverized seed was measured and packed into a thimble, and then into the Soxhlet extractor apparatus containing 250 mL of N-Hexane in the round bottom flask. The Soxhlet apparatus was then mounted on a heating mantle, controlled at 69°C and allowed to reflux for about two hours. The liquid containing the seed extract and solvent was filtered to remove impurities and evaporated using a distillation evaporator set up to remove the solvent. The percentage of oil yield was calculated by measuring the weight of the oil recovered and dividing by the weight of the seed samples used. The seed in its fresh form, dried/oven dried form, pulverized form, and extracted *Hura crepitans* oil (HCO) and *Calophyllum inophyllum* oil (CIO) are as shown in Figure 1 and Figure 2 respectively.

Figure 1. The seed and oil of *Hura crepitans*

Figure 2: The seed and oil of *Calophyllum inophyllum*

3.2. Properties of the oil samples

American Society for Testing and Materials was employed in measuring the following properties: viscosity index was measured using the kinematic viscosity tester, flash and fire point using the open cup flash point tester, oil density/specific gravity using the density bottle, and pH using the pH meter.

3.3. Preparation of mud samples

20 grams bentonite, followed by 2 grams CMC, and 0.2 grams KOH additives was poured in intervals of 20 minutes into a mixer containing 350 ml of deionized water. The rheological and filtration properties were measured, and oil samples of diesel, *Hura crepitans*, and *Calophyllum inophyllum* were added to the ordinary water-based mud at different concentrations of 5mL, 10mL, 15ml, 20mL, and 25mL. This is to measure the effect of the oil on the rheological and filtration properties. Other mud properties such as the mud density, electrical stability, and cake thickness were also measured.

4. Results and discussions

4.1. Analysing the properties of the oil samples

Table 1 shows the properties of the extracted *Calophyllum inophyllum* (CIO) and *Hura crepitans* (HCO) oil.

Table 1. Physicochemical properties of the oil samples

Properties	*Calophyllum inophyllum* oil	*Hura crepitans* oil	ASTM D6751
Flash point (°C)	164	204	≥120
Fire point (°C)	172	260	≥93
Density (kg/m^3)	923	908	860-900
Kin. viscosity at 40 (°C)	32.52	28.60	1.9-6
Viscosity index	163	167	-
Colour	Greenish black	Orange	

The flash and fire point conforms to the API standard. Hence, the plant oil samples are less volatile or flammable if used in a volatile environment. The density of *Calophyllum inophyllum* and *Hura crepitans* plant oils are higher than that of the ASTM standard. However, the density of the *Hura crepitans* oil is closer than that of the *Calophyllum inophyllum* oil. The kinematic viscosity of *Calophyllum inophyllum* oil was higher than of *Hura crepitans*, resulting in a higher viscosity index than the *Hura crepitans*. This property infers *Hura crepitans* oil is more thermally stable than the *Calophyllum inophyllum* oil.

4.2. Analysing the properties of the mud samples

Table 2 below shows the properties of the ordinary water-based mud without the application of the oil samples. The mud properties apart from the volume of the fluid loss are within the API standard range, the filtrate recovered from the ordinary WBM has a higher volume of fluid loss than the standard. The higher the mud fluid loss, the tendencies for more of the deposited thick filter cakes on the formation, the negative tendencies of this is pipe sticking and formation damage. The cake thickness is considered acceptable since it is not greater than 2/32". The rheological properties are also within the API standard with lower plastic viscosity value

Table 2. Properties of ordinary water-based mud without any oil

Properties	Value	API
pH	9.58	8.5-10
Mud density (ppg)	8.6	7.5-22
Specific gravity	1.02	-
Filtrate loss after 30 mins (mL)	26	10-25
Electrical stability (ES)	55	< 400
Gel strength @ 10 secs ($Ibf/100ft^2$)	16	3-20
Gel strength @ 10 min ($Ib/100ft^2$)	17	8-30
Plastic viscosity ($Ib/100ft^2$)	2	< 65
Yield point ($Ib/100ft^2$)	38	15-45
Cake thickness (1/32'')	≈ 2/32"	2/32"

Table 3 shows the properties of water-based mud formulated with diesel oil ranging from 5 to 25 mL. The pH, mud density, specific gravity, electrical stability, and gel strength were increasing with the concentration of the diesel oil. The increases of the mud properties are still within the API standard. Increase in the pH values makes the mud more alkaline, thereby reducing the rate of corrosion. Increase in the electrical stability denotes the emulsion stability between the mud components. Increase in the gel strength implies increases tendency in the suspension of cuttings when circulation is stopped. A decrease in the fluid loss was observed with increase oil quantity. However, the fluid loss remains constant between 10 and 20 mL, and cake thickness increased from 15 to 25 mL of the diesel oil in the water-based mud.

Table 3. Properties of WBM formulated with diesel oil

Properties	5 mL	10mL	15 mL	20 mL	25 mL	API
pH	9.35	9.42	9.56	9.68	9.87	8.5-10
Mud density (ppg)	8.20	8.50	8.50	8.55	8.60	7.5-22
Specific gravity	0.98	1.20	1.20	1.25	1.30	-
Filtrate loss after 30 mins (mL)	20	19	19	19	18	10-25
Electrical stability (ES)	94	99	105	107	112	< 400
Gel strength @ 10 secs ($Ibf/100ft^2$)	8	6	15	21	21	3-20
Gel strength @ 10 min ($Ib/100ft^2$)	9	9	15	21	22	8-30
Plastic viscosity ($Ib/100ft^2$)	7	15	8	10	11	< 65
Yield point ($Ib/100ft^2$)	16	5	24	34	34	15-45
Cake thickness (1/32'')	≈ 2/32"	≈ 2/32"	> 2/32"	> 2/32"	> 2/32"	2/32"

Table 4 shows the properties of water-based mud formulated with extracted oil from the seed of *Calophyllum inophyllum* ranging from 5 to 25 mL. The trend of the pH, mud density, emulsion stability, and specific gravity was not as stable as that of the diesel oil-in-water emulsion mud. An increase in the mud properties is seen in oil concentration of 5 to 10 mL, while a decrease is seen in the 15 and 20 mL the fluid loss decreases with increase in the oil concentration of the oil. The mud properties, however, are still within the API range.

Table 4. Properties of WBM formulated with oil from *Calophyllum inophyllum*

Properties	5 mL	10mL	15 mL	20 mL	25 mL	API
pH	9.25	9.54	8.50	8.48	8.77	8.5-10
Mud density (ppg)	8.20	8.50	8.10	8.10	8.40	7.5-22
Specific gravity	0.99	1.02	0.98	0.98	1.01	-
Filtrate loss after 30 mins (mL)	22	21	21	18	17	10-25
Electrical stability (ES)	87	106	108	177	223	< 400
Gel strength @ 10 secs $(Ibf/100ft^2)$	12	23	24	23	25	3-20
Gel strength @ 10 min $(Ib/100ft^2)$	13	24	23	23	25	8-30
Plastic viscosity $(Ib/100ft^2)$	8	11	11	8	12	< 65
Yield point $(Ib/100ft^2)$	25	30	35	42	36	15-45
Cake thickness (1/32'')	≈ 2/32″	> 2/32″	> 2/32″	> 2/32″	> 2/32″	2/32″

Table 5 shows the properties of water-based mud formulated with extracted oil from *Hura crepitans* ranging from 5 to 25 mL. The mud properties reveal an unstable trend similarly with the *Calophyllum inophyllum* oil. However, they are still within the API range. The fluid loss decreases with the concentration of the plant oil. The cake thickness increased beyond the API standard.

Table 5. Properties of WBM formulated with oil from *Hura crepitans*

Properties	5 mL	10mL	15 mL	20 mL	25 mL	API
pH	9.14	8.92	8.83	8.87	8.86	8.5-10
Mud density (ppg)	7.80	8.35	8.40	8.60	8.60	7.5-22
Specific gravity	0.94	0.99	1.01	1.03	1.03	-
Filtrate loss after 30 mins (mL)	21	20	18	16	15	10-25
Electrical stability (ES)	58	95	95	109	112	< 400
Gel strength @ 10 secs $(Ibf/100ft^2)$	13	11	19	18	14	3-20
Gel strength @ 10 min $(Ib/100ft^2)$	15	12	20	18	12	8-30
Plastic viscosity $(Ib/100ft^2)$	15	11	8	21	21	< 65
Yield point $(Ib/100ft^2)$	26	18	30	14	14	15-45
Cake thickness (1/32'')	15	12	20	18	12	8-30

From the mud properties in Tables 2, 3, 4, and 5, it was discovered that the ordinary water-based mud had a higher fluid loss than the various oil-in-water emulsion mud (Tables 3, 4, and 5). The fluid loss at 25 mL of *Calophyllum inophyllum* and *Hura crepitans* oil was better than that of diesel oil, revealing the high fluid loss is preventing the property of plant oil over the diesel oil.

4.3. Analysing the effect of the emulsion oil on the rheological properties

The effect of the oil samples was tested on the rheological properties of the formulated drilling mud. The plastic viscosity, yield point, and 10 s/10 min gel strengths were tested and calculated at room temperature. The diesel oil, *Calophyllum inophyllum* oil, and *Hura crepitans* oil samples were added to the water-based mud from 5 to 25 ml concentration, and rheological analysis was measured and calculated. Figure 3 is a plot of plastic viscosity for the ordinary water-based mud, diesel oil-in-water emulsion mud, *Calophyllum inophyllum* oil-in-water emulsion mud, and *Hura crepitans* oil-in-water emulsion mud. It can be observed that the ordinary water-based mud had the lowest plastic viscosity value. It was also observed that all the oil-in-water emulsion mud had increasing plastic viscosities with increasing oil concentration. The *Hura crepitans* having the highest, followed by the *Calophyllum inophyllum*, and diesel oil. Increase in plastic viscosities as lubricating oil is added to drilling fluid is undesirable. Hence, the plastic viscosities value with diesel and *Calophyllum inophyllum* have acceptable values. It was also noted that the plastic viscosity values are still within the API standard (<65).

The effect of the oil samples on the yield point values are as shown in Figure 4**,** the yield point values for ordinary WBM, WBM with diesel oil, WBM with *Calophyllum inophyllum* oil, and WBM with *Hura crepitans* oil are within the API standard of 15-45 $(Ib/100ft^2)$. The oil-in-water emulsion mud with *Calophyllum inophyllum* oil and diesel oil have increasing yield point values with incran ease in the oil concentration. Increase in yield values due to lubricant application is not desirable in drilling mud, the mud with *Hura crepitans* oil have a lower yield compared to other oil samples. Hence, they are acceptable. However, the yield point values for all the oil-in-water emulsion muds are within the API standard.

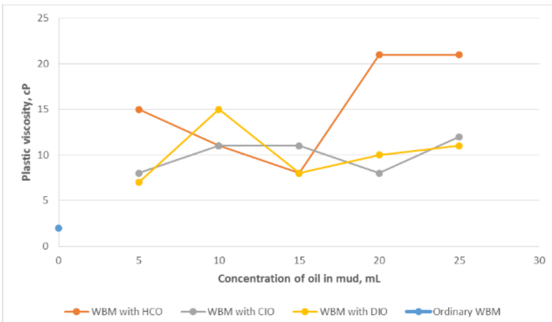

Figure 3. Plastic viscosity of the various oil-in-water emulsion mud

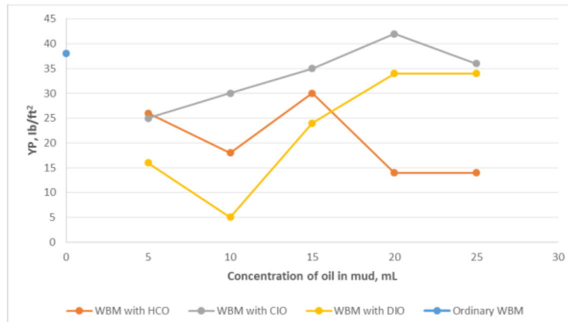

Figure 4. Yield point values of the various oil-in-water emulsion mud

The 10 s/10 min gel strength values of ordinary water-based mud, mud with diesel oil, mud with *Hura crepitans* oil, mud with *Calophyllum inophyllum* oil are shown in Tables 2, 3, 4, and 5. The gel strength values decreased when 5 mL of oil was added to the ordinary WBM, and start to increase as the oil concentration increases. The increase in the gel strength values is higher for the plant oils than the diesel oil, with *Calophyllum inophyllum* oil-in-water emulsion mud having the highest. However, the values are in the acceptable ranges of the API standard, except the 10 s gel strength of 20 and 25 ml oil concentration of the diesel oil and 10 to 25 ml of the *Calophyllum inophyllum oil*.

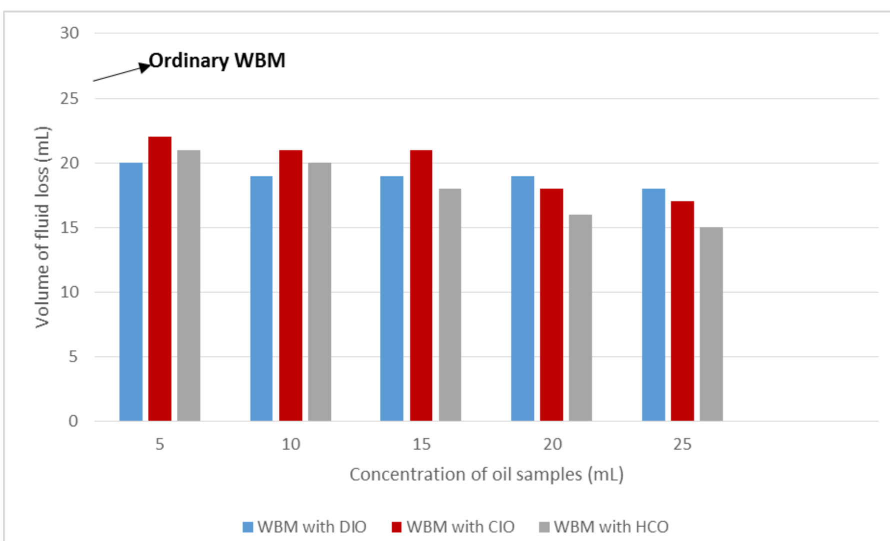

Figure 6. Volume of fluid loss of the various oil-in-water emulsion mud

4.4. Analysing the effect of the emulsion oil on the fluid loss properties

The API low temperature fluid loss of the drilling mud was tested using OFITE API filter press. The fluid loss of the ordinary water-based mud was measured, and the diesel oil, *Calophyllum inophyllum* oil, and *Hura crepitans* oil were added to the water-based mud in 5 to 25 mL. As observed from Figure 6**,** the fluid loss generally reduces with an increase in the volume of the oil for all samples. The ordinary WBM formulated without any oil has the highest volume of fluid loss (26 mL). The fluid loss decreased in addition to the oil samples. The diesel oil-in-water emulsion mud had the lowest fluid loss when 5 and 10 mL of oil was applied. The *Hura crepitans* oil-in-water emulsion mud reveals a lower fluid loss from 15 to 25 mL of the oil samples. The WBM formulated with *Hura crepitans* oil has a lower fluid loss than others, implying its ability to reduce tendencies of leaving the thick cake on the formation. The fluid loss reduces from an oil concentration of 15 to 25 mL.

5. Conclusion

In this study, the effect of diesel oil and two non-edible plant oil extracted from *Calophyllum inophyllum, Hura crepitans* seed was investigated on the rheological and filtration properties of water-based mud. The effect of the oil samples was also measured on the mud properties.

The application of the diesel oil in the water-based mud caused an increase in the pH, mud weight, specific gravity, and emulsion stability. The plant oils in the water-based mud were sensitive to the concentration of the oil as they increased and decreased at some concentrations.

The emulsion stability of all mud samples increased with the oil concentration. Mud formulated with *Hura crepitans* oil performed well in reducing the volume of fluid loss than that of *Calophyllum inophyllum*.and diesel oil. However, the plant oils are better fluid loss controllers than diesel oil. *Hura crepitans* oil-in-water emulsion mud reveals more stable and acceptable rheological properties than other oil samples

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