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Experimental Study of Swelling Capacity of Ewekoro Shale, South Western Nigeria: Case Study-Using Oil-in-Water Emulsion Mud

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Abstract

The formulation of drilling mud plays a very important role in providing optimum drilling operations in reducing or preventing the occurrence of challenges in the wellbore. One of the most challenging formations faced by the drilling operators is the shale; it is been discovered that approximately 90 % of formation drilled in the oil and gas industry is shale, and about 70 % of the challenges during drilling are shale related. This study is focused on investigating the swelling capacity of shale from Dahomey basin in Nigeria in emulsion mud formulated with diesel oil and non-edible plant oils (*Hura crepitans* and *Calophyllum inophyllum*). The shale sample was studied under the influence of water-based mud and emulsion mud. The physicochemical properties of plant oil samples were analyzed, the mud was formulated and rheological and filtration properties were measured. The swelling rate and water absorbed of the shale samples were determined. It was discovered that the plant oil performed better than the diesel oil, with oil from *Hura crepitans* been efficient in reducing the shale/fluid interaction and by so doing, reducing the swelling rate and water absorbed by the shale. The volume of fluid loss was discovered to be less than that observed from diesel and *Calophyllum inophyllum* oil.

Keywords: Shale; Swell Rate; Oil-in-water emulsion mud; *Hura crepitans*; *Calophyllum inophyllum;* Rheology.

1. Introduction

The application of water-based mud (WBM) in areas where oil-based mud (OBM) have previously been used is been encouraged with support from environmental regulations due to the minimal toxicity associated with water-based mud [1]. OBM is preferred in areas where formation damage, torque, and drag, differential stuck pipe, and corrosion resistance, etc. is of high importance. However, they have their limitations in cost and in environmental concerns as they degrade both the offshore and onshore environment, and also expensive to formulate and dispose of. The complexity attached with some oil and gas wells requires the use of either oil-based mud, synthetic-based mud or enhanced water-based mud that has been improved by the application of some purposeful mud additives. One basic challenge in the application of conventional WBM's in drilling through shale dominated formation is the rock-fluid interaction between the fluid loss from the mud and the shale formation [2], which can cause swelling and caving of wellbore walls. The collapse of the borehole is a critical problem that most times, leads to downtime and require the high cost to restore the well back to normal. In view of the instability problem, it is imperative to formulate WBM that reduces the fluid interaction between the shale and fluid loss that sips into the formation. Water-based mud is environ-mentally friendly and cost effective, and researchers are exploring ways of improving it for drilling through shale formations [3-4]. The emulsion mud type which is defined as a type of WBM with oil existing in the dispersed phase has been used to free stuck pipe [5], the dispersed oil concentrations in the mud system has the capacity of minimizing the activity between the fluid loss and the shale thereby preventing wellbore instabilities.

Wellbore instability during drilling, completion, and production phases are alarming and unproductive; it is basically induced by either high in-situ stresses relative to the formation strength or physicochemical interactions of drilling fluid or a combination of the both [6]. Before drilling is done, the mechanical tensions in the formation are lower than the strength of the rock, and there also is chemical stability. However, after drilling, those rock formations near the wellbore experience an alteration in the compression, stress and shear loads because the core formation of the hole is taken off. This causes a series of chemical reactions accompanied by exposure of the formation to the filtrate from the drilling mud. Due to this, the formation rock close to the wellbore starts to distort, fracture and collapses into the wellbore or melts into the drilling mud [7]. This contamination of the mud affects the rheology and indirectly affects the performance of the mud. Hence shale/fluid interaction should be minimized by reducing the reaction between the drilling fluid and the shale. This work demonstrates the application of oil-in-water emulsion mud in formations composed of shale samples from Dahomey Basin, Ewekoro, and South Western Nigeria. The samples were investigated in the presence of water-based mud and water-based mud containing diesel, and selected non-edible plant oils in the dispersed phase.

The Dahomey Basin is a combination of inland, coastal, and offshore basin that stretches from southeastern Ghana through Togo and the Republic of Benin to southwestern Nigeria. It is separated from the Niger Delta by a subsurface basement referred to as the Okitipupa Ridge [8]. Its offshore extent is poorly defined. Sediment deposition follows an east-west trend. On land, Cretaceous strata are about 200 m thick [9]. The Cretaceous is divided into north and south geographic zones. The sequence in the northern zone consists of a basal sand that progressively grades into clay beds with intercalations of lignite and shales. The uppermost beds of the Maastrichtian are almost entirely argillaceous. The southern zone has a more complicated stratigraphy with limestone and marl beds constituting the major facies.

2. Challenges of Drilling Through Shale in Water-Based Mud

Shales are generally composed of silt-sized particles of basically quartz and calcite mixed with fine-grained (clay-sized) clastic sedimentary rock materials. When shales come in contact with fluid, they expand as result of water entering into the clay structure and when boreholes are introduced into the formation, the effective stress initially, is increased due to stress redistribution around the borehole, But as mud filtrates sips into the formation due to either low filter cake thickness that is permeable to the filtrates, or high pump pressure above the fracture pressure, the filtrates chemically interact with formation materials (shales) and causes swelling which is due to disequilibrium between shale and the mud filtrates (i.e. increase in pore pressure), this later reduces the effective stress. A sudden increase in pore pressure (abnormal pore pressure) during drilling operation due to swelling of shale is responsible for a lot of hole instability issues ranging from hole collapse, pipe sticking or tight hole and loss circulation. The problems of shale drilling are costly; it causes wellbore instability estimating over 500 million dollars a year [10]. Several reported works on understanding the onset of borehole instability are as a result of shale-fluid interactions confirmed by water adsorption, cation exchange and osmotic swelling as the main mechanisms. These include works by [11-14].

3. Materials and methods

The materials and equipment used in carrying out this research work include diesel (DI), seeds of *Hura crepitans* (HC) and *Calophyllum inophyllum* (CI) obtained from Covenant University, Ota, Ogun State, Nigeria. A Soxhlet apparatus for oil extraction. Oven for drying the seeds to determine and remove moisture content. Electrical stability (ES) meter for determining the stability or quality of the emulsion. The pH meter was used to determine the alkaline or acidic level of the mud. The mud and weighing balance to measure the weight of the mud and other additives respectively. The low pressure low temperature (LPLT) filter press for determining the fluid loss from the mud at ambient temperature and 120 psi. The Hamilton beach mixer for ensuring homogeneity during mixing of the mud. Heating mantle for heating up the mud filtrate and shale samples. KOH as pH modifier, CMC as a viscosity modifier. Bentonite is one of the most important additives that make up drilling mud. It lubricates, cools, reduces corrosion rate, and for cuttings transportation.

3.1. Seed processing

The seeds before were sourced from their trees in large quantities from Covenant University and cleaned to remove dirt's. The shells were now broken from the nibs (cotyledon) inorder to get the seeds where oil will be extracted from. The plant's seeds were further dried in the oven at 103°C for 17±1hr according to International Seed Testing Association (ISTA) standard to remove its moisture content. The next stage is grinding which involves crushing of the plant seed into paste or form of cake using a grinding machine to ease the release of oil during extraction. Figure 1 and figure 2 below shows the image of *Hura crepitans* and *Calophyllum inophyllum* respectively, both in their natural state and grinded form.

Figure 1. The Seeds of *Hura crepitans* (left) and its grinded Form (right)

Figure 2. The seeds of *Calophyllum inophyllum* (left) and its grinded form (right)

3.2. Extraction of oil from the grinded sample

The oil of *Hura crepitans* and *Calophyllum inophyllum* was extracted using a Soxhlet extractor method. 60 g of the individual grinded plant seed (*Hura crepitans* and *Calophyllum inophyllum*) was packed into a thimble and then to the extraction chamber of the Soxhlet extractor, and 300 mL of N-Hexane solvent is poured into a 500 mL round bottom flask of the extractor. The Soxhlet is then mounted on a heating mantle at 69°C and allowed to heat for about two hours. The extract is then filtered to remove available impurities and evaporated using a distillation evaporator set up to isolate the N-Hexane solvent present in the extracted oil. The weight of the oil was then measured. The percentage of the oil yield is evaluated from the weight of the sample and the oil obtained after evaporating using the formula below.

$$Percentage\ oil\ yield = \frac{weight\ of\ oil}{Weight\ of\ sample} * 100$$

3.3. Physicochemical properties of the oil samples

The following physicochemical properties: viscosity index, flash and fire point, oil density/ specific gravity, oil yield, and pH were measured for the plant oils using the American Society for Testing and Materials (ASTM) method. The viscosity index was measured using the kinematic viscosity tester, flash and fire point using the open cup flash point tester, and pH using the pH meter.

3.4. Preparation of mud samples

350 mL of water was measured using a measuring cylinder and poured into the mixer and agitated with the additives added individually in intervals of 20 minutes for homogeneity. The additives are 20 grams of bentonite, followed by 2 grams of CMC, and 0.2 grams of KOH. The WBM was formulated with and without any of the oil for preparing the oil-in-water emulsion mud. The mud properties such as the mud density, electrical stability, mud cake thickness, and filtration properties were then measured. The diesel oil (DIO), oil from *Hura crepitans* (HCO), and oil from *Calophyllum inophyllum* (CIO) were added to the WBM at different concentrations of 5mL, 10mL, 15mL, 20mL, and 25mL to determine their effect on the swelling capacity of the shale samples.

3.5. Experimental investigation of the Swelling Capacity

5 grams of 16 samples of shale from Dahomey basin around Ewekero ranging in depth of 6-7 ft from the top surface was cored using a coring machine and weighed. The sample was further placed in the beaker containing the filtrate gotten from the API filter press of WBM and that of the emulsion mud formulated with dispersed 5-25 mL of DIO, HCO, and CIO. The beaker containing the shale sample and filtrate was then sealed and placed on a heating mantle at a temperature of 122F. The sample was removed after every one hour for 6 hours and dried, weighed and recorded. The water absorbed and the swelling rate was further estimated for the shale sample under investigation in a different fluid sample of the WBM, and the emulsion mud formulated with dispersed diesel and the different plant oils.

$$Swell\ rate\ (\%) = \left\{\left(\frac{final\ dried\ weight\ (g) - initial\ dried\ weight(g)}{Time\ (hr)}\right)\right\}\left({}^{g}/_{hr}\right)$$

$$Water\ absorbed = \left\{\left(\frac{\text{final dried weight } (g) - \text{initial dried weight}(g)}{\text{initial dried weight } (g)}\right) * 100\right\}\ (\%)$$

4. Results and discussion

Table 1 shows the physicochemical properties of *Hura crepitans* and *Calophyllum inophyllum* oil extracted from their seeds. It can be seen that the flash and fire point is within the range according to the API standard, this, therefore, implies that the oil samples are less volatile which qualifies their usage in a volatile environment. The density of the two plant oils is higher than the API standard. The viscosity index of the oil from *Hura crepitans* is higher than that of *Calophyllum inophyllum* which means that the oil from the former is a potential oil to be used in applications where thermal stability of oil samples is of importance. *Calophyllum inophyllum* has a higher oil yield than *Hura crepitans*; this makes it a potential base oil due to the quantity yield.

Table 2 below shows the properties of the WBM formulated without any oil sample, the volume of fluid loss collected is higher than the API standard. Mud with high fluid loss is less performing as this have tendencies of forming thick cakes deposited on the formation and possible invasion of small particles into the formation that can cause damage to the permeable zones. The cake thickness is considered acceptable since it’s not greater than 2/32”. The rheological property values are still within the API standard.

Table 1. The physicochemical properties of the non-edible oils

Properties	*Calophyllum inophyllum* Oil	*Hura crepitans* Oil	API
Flash point $(°C)$	154	204	≥66
Fire point $(°C)$	162	260	≥93
Density (kg/m^3)	923	908	805-820
Kin. Viscosity at 40 $(°C)$	18.57	14.70	-
Kin. Viscosity at 100 $(°C)$	8.84	7.55	-
Viscosity Index	197	207	-
Oil yield (%)	71	45	

Table 2. The properties of water-based mud

Properties	Value	API	Properties	Value	API
pH	9.58	8.5-10	Gel strength @ 10 min $(Ib/100ft^2)$	17	8-30
Mud density (ppg)	8.6	7.5-22	Cake thickness (1/32'')	≈ 2/32″	2/32″
Specific gravity	1.02	-	Plastic viscosity (cp)	2	< 65
Filtrate loss after 30 mins (mL)	26	10-25	Apparent viscosity (cp)	21	-
Gel strength @ 10 secs $(Ibf/100ft^2)$	16	3-20	Yield point (Ib/ft^2)	38	15-45

Table 3 shows the properties of WBM formulated with oil from *Calophyllum inophyllum* (CIO), *Hura crepitans* (HCO), and diesel (DIO).

Table 3. Properties of the various oil-in-water emulsion mud

properties	5 mL			10 mL			15 mL		
	CIO	HCO	DIO	CIO	HCO	DIO	CIO	HCO	DIO
pH	9.25	9.14	9.35	9.54	8.92	9.42	8.50	8.83	9.56
MDens (ppg)	8.20	7.80	8.20	8.50	8.35	8.50	8.10	8.40	8.50
FL(mL)	22	21	20	21	20	19	21	18	19
ES	87	58	94	106	95	99	108	95	105
GS_{10s} $(\frac{Ibf}{100ft^2})$	12	13	8	23	11	6	24	19	15
GS_{10m} $(\frac{Ib}{100ft^2})$	13	15	9	24	12	9	23	20	15
CT (1/32″)	≈ 2/32″	≈ 2/32″	≈ 2/32″	> 2/32″	≈ 2/32″	≈ 2/32″	> 2/32″	> 2/32″	> 2/32″
PV (cp)	8	15	7	11	11	15	11	8	8
AV (cp)	21	28	15	26	20	18	29	23	20
YP (Ib/ft^2)	25	26	16	30	18	15	35	30	24

Properties	25 mL			30 mL			API
	CIO	HCO	DIO	CIO	HCO	DIO	
pH	8.48	8.87	9.68	8.77	8.86	9.87	8.5-10
MDens (ppg)	8.10	8.60	8.55	8.40	8.60	8.60	7.5-22
FL(mL)	18	16	19	17	15	18	10-25
ES	177	109	107	223	112	112	> 400
GS_{10s} $(\frac{Ibf}{100ft^2})$	23	18	21	25	14	21	3-20
GS_{10m} $(\frac{Ib}{100ft^2})$	23	18	21	25	12	22	8-30
CT (1/32″)	> 2/32″	> 2/32″	> 2/32″	> 2/32″	> 2/32″	> 2/32″	2/32″
PV (cp)	8	21	10	12	21	11	< 65
AV (cp)	29	28	27	30	28	28	-
YP (Ib/ft^2)	42	14	34	36	14	34	15-45

The pH, mud density (MDens), fluid loss (FL), and 10 minutes gel strength (GS_{10min}) of the WBM formulated with all the oil samples are within the range of the API standard. The electrical stability (ES) values are not within the API standard but increases with the concentration of the oil samples. The electrical stability values of WBM formulated with CIO is higher than other oil samples, and hence, the emulsion mud formulated from *Calophyllum inophyllum* exhibits a better emulsion stability. Gel strength at 10 seconds (GS_{10s}) did not conform to the API standard for mud formulated with CIO from the concentrations of 10 to 25 mL. The cake thickness (CT) obtained from the concentration of oil greater than 10 mL is not acceptable as they are greater than 2/32" for all the oil samples. The application of oil from HC reveals a lower fluid loss compared to the diesel and *Calophyllum inophyllum*. The plastic viscosity (PV), apparent viscosity (AP), and yield point (YP), and gel strength (GS) are the rheological properties. The PV, AP, and YP are appreciably within the API range.

Figure 3 is the plot showing the volume of fluid loss at different concentrations of the different oil samples used in the formulation. The WBM formulated without any of the oil reveal the highest volume of fluid loss (26 mL). On average estimation, the WBM formulated with *Hura crepitans* reveals a lower fluid loss than others and therefore performs better in acting as a fluid loss agent in the WBM. There is a consistent reduction of the fluid loss from 5 to 25 mL. The mud with lower fluid loss has less tendency to cause shale swelling as a less fluid loss will be available for interaction between the shale and the fluid that sips into the formation, and this is explained in figure 4 to figure 8. It can also be said that a higher the concentration of the oil leads to a lower volume of the fluid loss for all oil samples.

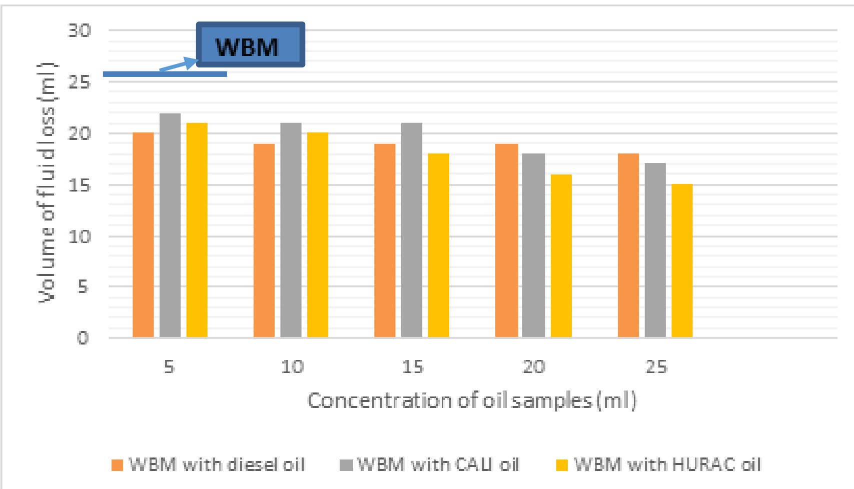

Figure 3. Volume of fluid loss at different concentrations of the various oil samples

Figures 4, 5, 6, 7, and 8 shows the plot of the swelling rate of shale and the water absorbed when immersed in the fluid loss obtained from WBM and the oil-in-water emulsion mud from the various oil samples. The shale sample in the presence of the filtrate from WBM has the highest swelling capacity and water absorbed and that explains why WBM is not recommended in formations where shale dominates, the fluid loss from WBM has a lower lubricity and hence, there is no reduction in the reaction between the shale and the sipped fluid from the WBM. The swelling capacity of shale and its water absorbed in the water based mud is also attributed to the high fluid loss as shown in figure 3, mud with a higher fluid loss has more tendency to cause interaction between the shale and the fluid that losses into the formation. There is much more interaction between the shale and the mud and this most times leads to wellbore convergence, formation damage causing stuck pipe and wellbore instability. It can also be seen that the plant oils performed better than the diesel oil in preventing shale expansion. The oil from *Hura crepitans* is more efficient in the emulsion mud than that of *Calophyllum inophyllum,* and this explains why the fluid loss collected from the emulsion mud formulated with *Hura crepitans* as shown in figure 3 reveals the lowest amongst all.

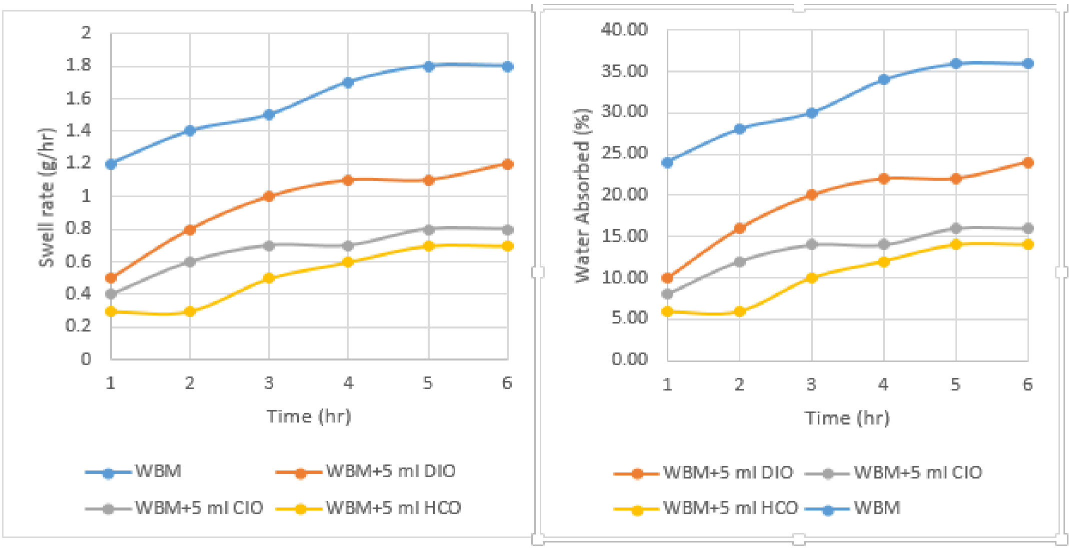

Figure 4. Swell Rate (Left) & Water Absorbed (Right) in 5 mL Oil-in-Water Emulsion Mud

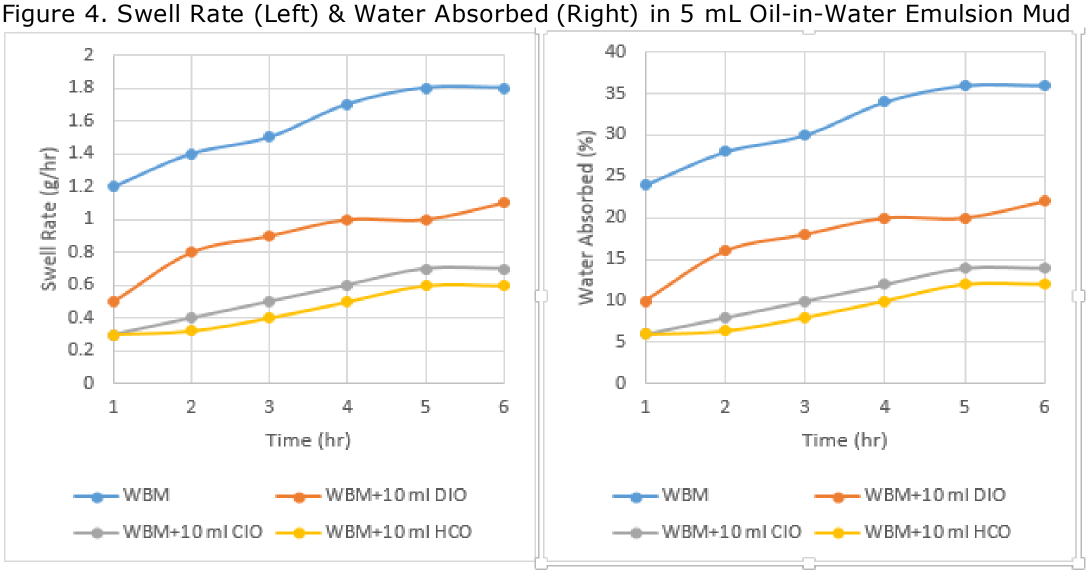

Figure 5. Swell Rate (Left) & Water Absorbed (Right) in 10 mL Oil-in-Water Emulsion Mud

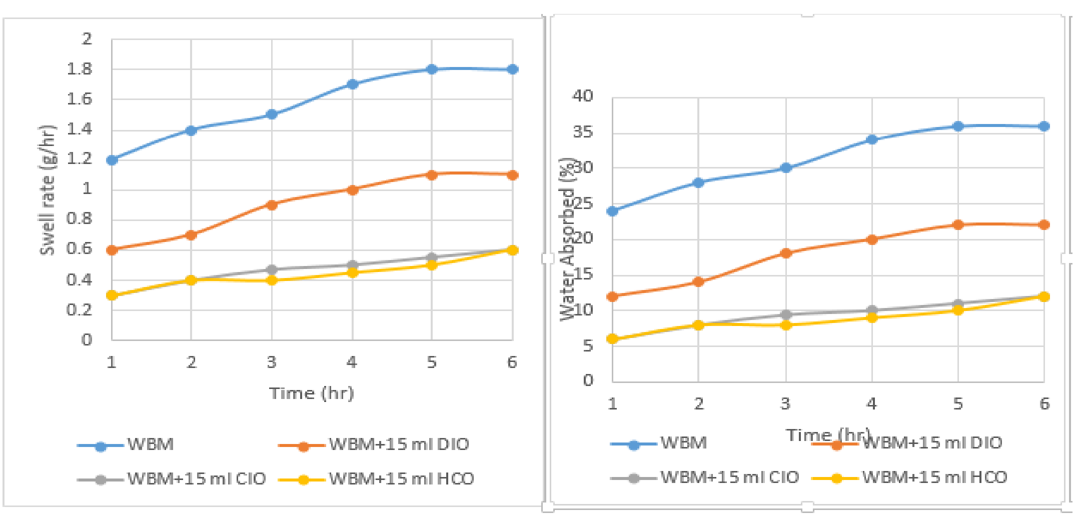

Figure 6. Swell Rate (Left) & Water Absorbed (Right) in 15 mL Oil-in-Water Emulsion Mud

Figures 6, 7, and 8 reveals an improved performance of *Calophyllum inophyllum* oil, the swell rate of the shale and water absorbed is close to that of *Hura crepitans,* this implies there is an improvement in the fluid loss at the 15 to 25 mL oil concentration resulting in reduction in the interaction between the fluid and the shale.

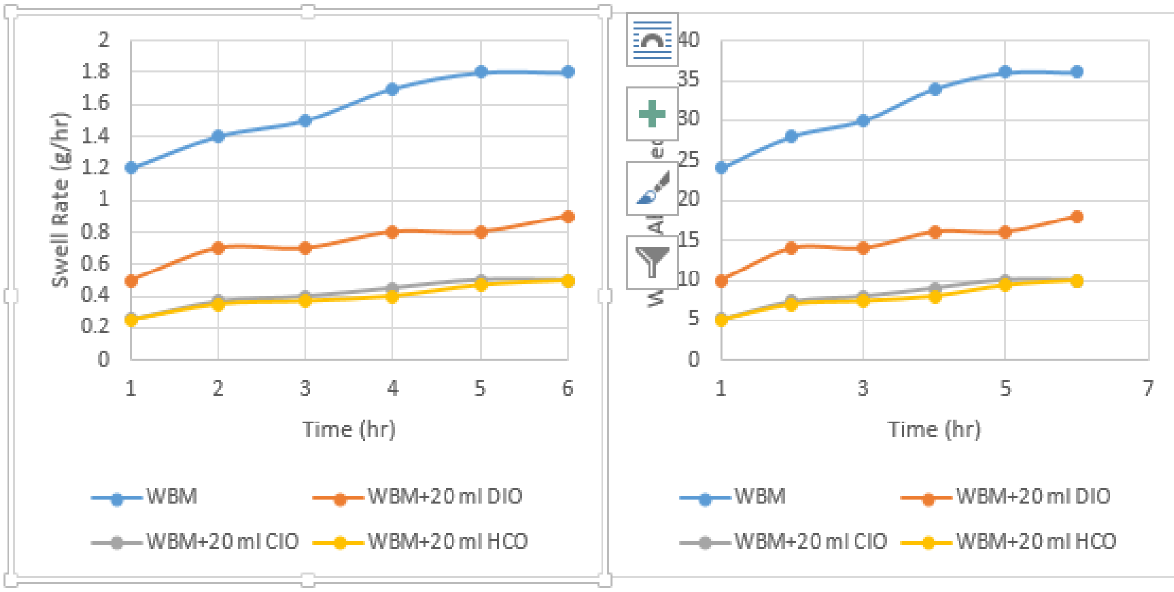

Figure 7. Swell Rate (Left) & Water Absorbed (Right) in 20mL Oil-in-Water Emulsion Mud

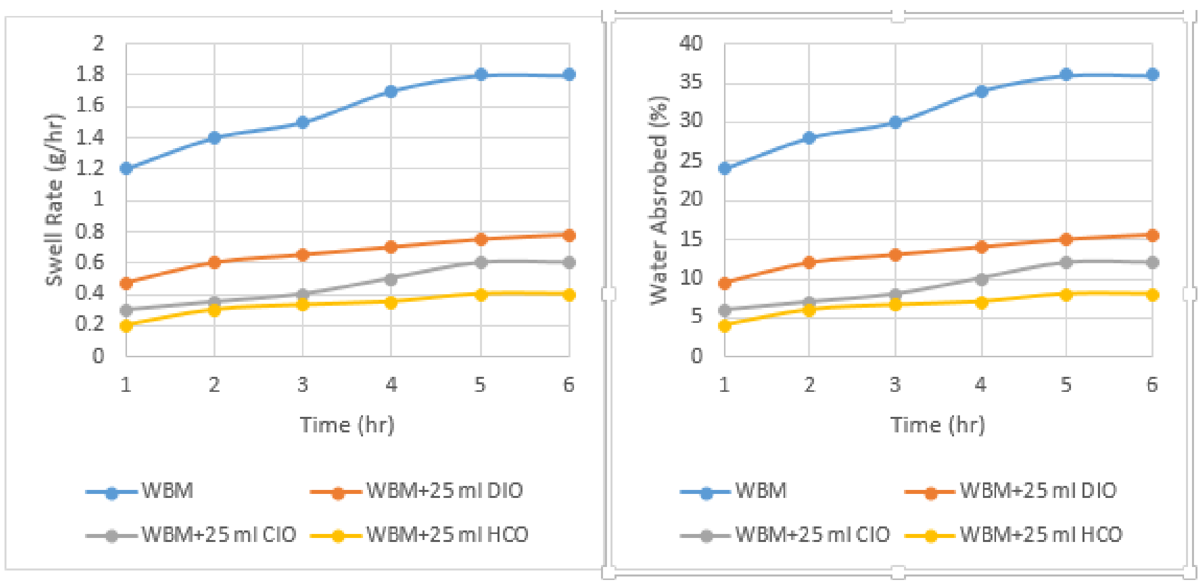

Figure 8. Swell Rate (Left) & Water Absorbed (Right) in 25mL Oil-in-Water Emulsion Mud

5. Conclusion

From the analysis made on WBM and the oil-in-water emulsion mud formulated with diesel, *Calophyllum inophyllum,* and *Hura crepitans*. It is deduced that

1. The oil from *Hura crepitans* performs better in reducing the volume of fluid loss from the mud and hence, less interaction with shale that may cause swelling and wellbore instability is expected.
2. The plant oils perform better than the diesel oil in preventing shale swelling.

3. The fluid loss and swelling rate of shale reduce with increase in the concentration of the oil used in the emulsion mud.
4. The oil-in-water emulsion mud formulated from *Hura crepitans* averagely prevents swelling of shale than and performs than *Calophyllum inophyllum* and diesel.
5. The swelling rate of shale increases with time of exposure because of the increased volume of fluid loss with time.

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