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Comparison of Drilling Mud Formulated from Plant Oils and Conventional Synthetic Drilling Mud

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ABSTRACT : *This study investigates the use of locally sourced biodegradable plant oils for synthetic mud that could have minimal or no impact on the environment and less cost of production while achieving same technical efficiency with typical Oil Based Muds (OBMs). Mud samples were prepared from moringa oil and coconut oil as continuous phase and the rheological properties with fluid loss behavior measured and compared with conventional Synthetic Based Mud (SBM) formulated from EDC-99 and gypsonite. The suitability of using kernel chaff as fluid loss control agent was analyzed comparatively with conventional gypsonite. The results showed that despite slightly superior properties of the EDC-99 in most of the mud parameters, a competing interest exists among the options with the moringa oil based samples slightly better than the coconut oil based samples. At 80^{o}F and a shear rate of 1021.8/s, the EDC-99 recorded a maximum shear stress of 76.824Ib/100ft^2 and 94.963Ib/100ft^2 for the gypsonite and kernel chaff additives respectively while those of moringa oil and coconut oil based samples were 51.216Ib/100ft^2 (for gypsonite); 53.35Ib/100ft^2 (for kernel chaff) and 48.015Ib/100ft^2 (for gypsonite); 50.149Ib/100ft^2 (for kernel chaff) respectively. At 180^{o}F, the EDC-99, moringa oil and coconut oil based samples recorded a maximum shear stress of 37.345Ib/100ft^2, 35.21Ib/100ft^2 and 32.01Ib/100ft^2 respectively for the gypsonite additive and 35.21Ib/100ft^2, 32.01Ib/100ft^2 and 21.34Ib/100ft^2 for the kernel additives. The results of the Yield Point(YP) and Plastic Viscosity(PV) showed that the moringa oil sample is more thermally stable with lowest YP values for each additive while the EDC-99 has better PV when used with kernel chaff. EDC-99 with gypsonite gave better fluid loss of 1.6ml while other sample combinations showed relatively more competitive performance. Hence, the use of kernel chaff as fluid loss agents can only be preferred to the gypsonite where there could be considerable severe economic implications and/or strict environmental regulations. Also better rheological results could be obtained from the proposed alternatives by enhancing the mud formulations using suitable additives. Results have proven that moringa or coconut oils will be suitable for preparation of SBMs and reduce environmental impact because of its biodegradability.*

KEYWORDS: *Synthetic Mud, Moringa Oil, Coconut Oil, Gypsonite, Kernel Chaff, Rheology.*

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I. INTRODUCTION

Drilling fluids are integral part of rotary drilling processes in drilling oil and gas wells for both onshore and offshore locations. These fluids serve several functions during the overall drilling activities that include cuttings transportation to the surface, balancing formation pressure with the exerted mud hydrostatic pressure and thereby preventing blowout, cooling and lubrication of the bit, ensuring wellbore stability, etc. The composition of these fluids depends on the particular mud scheme (mud type) which in turn influences its rheology and overall performance. However, the performance of the base fluid (typically the continuous phase) can be significantly altered with the use of special additives/agents. The influence of these agents in many cases, are still limited by the presence of other additives and most importantly, the choice of the continuous phase.

Based on the continuous phase, drilling fluids can be generally classified as water based mud, oil based mud, air based mud or synthetic based mud. In previous times, the preference of a particular drilling mud scheme over the other depends on the actual well economics (cost consideration), the type of formation in consideration, the operating conditions and the geology of the subsurface formation. The combination of these factors eventually decides the economic and technical efficiency of a drilling operation with regards to the choice of drilling fluid used. However, in more recent times, there has been more stringent legislations towards drilling fluid formulations especially with regards to the base fluids. This has been prompted by the observed global trend towards increased environmental awareness and the complexity of drilling operations (Frederick & Aryind, 2011; Amorin *et al.*, 2015). The preferred drilling mud for most normal drilling operations is the water based mud (WBM), (Ismail, 2001). However, drilling through geologically difficult formations (swelling clay and shale) and geothermal (High Temperature, High Pressure, HTHP) wells has not been efficiently achieved using the conventional WBMs. This therefore, presents oil based muds (OBMs) as better alternatives owing to its technical advantage and thermal stability. These OBMs have oils sourced from petroleum products (such as diesel) as the continuous phase and as such, subject to environmental issues (Hamed *et al.* 2014). The resulting cuttings from these muds are eventually contaminated with aromatic hydrocarbon residues which are not easily biodegradable (Praveen *et al.*, 2014; Okorie *et al.*, 2015).

The technology of drilling with synthetic based muds (SBMs) is directed towards leveraging on the technical advantage of OBMs while eliminating the environmental hazards associated with them. Summarily put, the preference of SBM over WBM and OBM is based on the following advantages (Jassim *et al.*, 2015; Neff, 2005 and Dardir & Hafiz, 2013).

i. They offer similar technical advantage similar to those of the OBMs and far more superior to those of WBMs
ii. They contain zero percent aromatic hydrocarbons compounds and as such can be discharged into the environment without any deleterious effect
iii. They have far lower cost of disposal since they are generally biodegradable.
iv. They also have reduced irritant effects making it safer to handle.

Several studies have been presented by various authors proposing local additives as a viable option to cost cutting for reduced OPEX (Ademiluyi *et al*, 2011; Udoh & Okon, 2012; Amorin *et al*, 2015; Akinade *et al*, 2018; Peretomode, 2018). These studies and several others have clearly illustrated that local materials have the potential of bringing about economic breakthrough in well drilling operations.

In the works of Amorin *et al* (2015), an economic assessment of the viability of using local pseudo-oils for drilling formulation was presented. The study was based on the cost investigation of prospects of producing and eventual disposal of drilling fluids formulated from local pseudo oils and options comparatively analyzed for both conventional (imported) OBM and the SBM. When compared to traditional Oil Base Muds (OBM), the initial cost of synthesizing Synthetic Base Muds (SBM) may be twice, but when the cost of containment, transporting, and disposal of OBM after usage is included in, the cost of employing SBM becomes relatively cheaper. This study used API standard performance standards to evaluate the formulation and disposal choices (onshore and offshore), as well as the cost benefit of employing seven local antioxidized pseudo-oils (vegetable esters) SBM vs commercial OBM at an average offshore and onshore temperature. Offshore and onshore, the average cost percent reduction from using the seven indigenous vegetable oils over commercial synthetic base fluid was 48.32 percent and 56.30 percent, respectively. Thus, when compared to currently imported oil-based drilling fluids, the usage of local ester oils for drilling fluid formulation showed to be more cost effective.

The motivation for the use of SBMs in drilling operations can be linked with the issues associated with WBMs and OBMs. The industrial practice was primarily aimed at establishing a meeting line between the environmental benefits of a WBM and the technical efficiency of an OBM. In the early works of Candler *et al.* (1983), the issue concerning the regulations on the use of synthetic based fluids was presented. This follows from the imposed legislative measures imposed on the use of synthetic based fluids that were inherent from the conventional OBMs dating back to a decade ago from the time of the study. From their findings, it was shown that synthetic based muds offered even greater waste reduction tendency than water based muds and are capable of drilling through troublesome shales. The report also claimed that SBMs show a good prospect to the industry.

In the works of McKee *et al.* (1995), a notable development towards the use of synthetic based fluids was noted. The result show that in complying with environmental legislation, a SBM at low synthetic base fluid to water ratio, high mud density, high temperature and in the presence of contaminants, can perform similarly with conventional oil based muds. These results were supported by field data which resulted to good rates of penetration with minimum mud re-conditioning and low solid cuttings retention when discharged into the sea. The researchers also complied marine toxicity, bioaccumulation and biodegradation data base for the SBM which were adopted for use in the UK and Norwegian waters.

Over the time, much awareness in the development of a SBM has been based on the choice of the continuous phase. This is because the continuous phase (base fluid) is the major difference in the conventional oil based fluids. In Udoh *et al. (*2012), a synthetic mud was formulated with palm fruit pulp (“abak” mud) and analyzed for rheology, density and pH. A comparative analysis of the results shows a favourable comparison with a mud sample formulated with bentonite. However, the tested properties were below acceptable standards for any drilling operation. For this reason, the formulated mud sample with palm fruit pulp was treated with soda ash, local starch, barite and local charcoal which improved the properties appreciably. Therefore, the authors concluded that with proper and adequate additives, synthetic base fluids such as "Abak mud" can compete favourable with conventional alternatives such as bentonite muds.

A notable investigation by Orji *et al* (2016) was based on the evaluation of C10 esters as synthetic base fluids for drilling mud formulation. The C10 esters used were derived from octanoic acid and acetic acid. Their suitability as a base fluid for drilling mud formulation was analyzed by comparing its physiochemical properties with those reported in literatures. The rheological properties were tested from 80^oF to 200^oF and compared with a commercially available synthetic base mud. As reported by the authors, the performance of the formulated SBM showed that with the inclusion of key additives, the formulated mud can perform up to those of the reference commercially available SBM.

Adesina *et al.* (2017) presented a study on the formulation and evaluation of synthetic drilling mud for low temperature regions. Non-edible algae oil (ethyl biodiesel) was used as the base fluid to formulate a SBM. The formulated SBM was analyzed in the laboratory at temperature condition of -5^oC TO 20^oC for rheological properties. A conventional SBM obtained from an offshore drilling company were similarly analyzed and the rheological properties compared with those of the formulated synthetic base muds with ethyl biodiesel. The results showed that ethyl biodiesel-based mud had a lower viscosity than industrial biodiesel mud, implying that the mud flowed more freely. It also possessed a more consistent density than the industrial counterpart, as well as a lower mud cake thickness, greater gel strength, and pH. Similarly, the ethyl biodiesel mud was shown to be more biodegradable than the industrial version in a toxicity test.

In the Orji *et al.* (2018) study, different catalysts were used to formulate ester based synthetic muds. The catalysts used included potassium hydrogen sulphate, molecular iodine and sulphamic acid for the extraction of esters of propanol and isopropanol with lauric acid at temperature range of 100^oC to 120^oC. The most efficient catalyst was known to be sulphamic acid and it was preceded by iodine and then potassium hydrogen sulphate. After analyzing the rheology of the esters gotten, it was found out that the esters have suitable physiochemical properties as synthetic base muds. Further analysis of the rheology of the mud showed that the muds prepared with propanol and isopropanol have higher electrical stability than a reference base fluid. More so, the isopropanol derivative mud had better thermal stability than the propanol derivative.

One of the most promising features of SBMs over OBMs is its biodegradable nature. In the works of Razali *et al.* (2018), a review study was presented for predicting the prospects of biodegradable synthetic based fluids. The base fluid considered were esters with biodegradability and bioaccumulation features since there are rated as flash prospects in the synthetic base fluid technology. In the study, the following were identified as critical parameters for the use of ester based drilling fluids: kinematic viscosity, pour point, flash point, thermal stability, hydrolytic stability and elastomer compatibility. For an ideal scenario, low values of kinematic viscosity, pour point and flash point with high values of thermal stability, hydrolytic stability and compatibility with elastomer are often required. However, due to high temperature and pressure conditions at bottomhole, these requirements often vary. From the findings of the study, it was clearly illustrated that ester based fluids are very outstanding at normal borehole depth and complexity. The influence of certain constraints such as low temperature at seabed (in an offshore environ) and high temperature & pressure at bottomhole may be different for an ester based fluid as a result of differences in molecular structures. As a way of combating this phenomenon, the authors proposed the use of low viscous, high thermal and hydrolytic stability esters. From empirical experience, this can be remarkably achieved with the use of special enhancers/agents.

The above notable literatures clearly illustrate that advancement towards the development of synthetic based fluids as better alternatives to the conventional oil based muds are majorly directed towards the base fluid. However, the influences of other key additives in the mud that can have economic, technical and environmental implications on the formulated SBM have not been addressed in details. In this work therefore, a synthetic based mud will be formulated using conventional EDC 99 synthetic oil as continuous phase and Gypsonite as its fluid loss control agent in comparison with two separately formulated muds having Moringa oil and Coconut oils as continuous phases with kernel chaff as their fluid loss control agents.

II. MATERIALS AND METHODS

A. Formulation of the Samples

Table 1 below lists the materials/additives used in this study and their functions and concentration per sample concentrations. The resulting samples formed are similarly described below.

Table 1: Table showing Additives, their Functions and Concentrations

S/No	Additives	Function	Concentrations
1	Synthetic/plant oil	Continuous Medium	210.00ml
2	Organophyllic clay	Viscosifier	17.00g
3	Primary Emulsifier	Emulsifier	15.00g
4	Secondary Emulsifier	Emulsifier	5.00ml
5	Lime	Alkalinity Agent	9.00g
6	Brine	Salinity Source	15.00ml
7	Gypsonite/Kernel Chaff	Fluid Loss Control	5.00g
8	Barite	Weighting Agent	74.00g
	TOTAL	-	**350ml**

i. Sample A (Conventional EDC 99 Synthetic oil as continuous medium and Gypsonite as fluid loss agent) with all other additives remaining the same.

ii. Sample B (Conventional EDC 99 Synthetic oil as continuous medium and kernel chaff as fluid loss agent) with all other additives remaining the same.

iii. Sample C (Moringa oil as continuous medium and Gypsonite as fluid loss agent) with all other additives remaining the same.

iv. Sample D (Moringa oil as continuous medium and kernel chaff as fluid loss agent) with all other additives remaining the same.

v. Sample E (Coconut oil as continuous medium and Gypsonite as fluid loss agent) with all other additives remaining the same.

vi. Sample F (Coconut oil as continuous medium and kernel chaff as fluid loss agent) with all other additives remaining the same.

B. Sample preparation procedure (Sample A: Conventional EDC 99 Synthetic Oil + Gypsonite)

The following outline the procedure for the formulation of the samples.

i. 210 ml of EDC 99 synthetic oil was measured using a measuring cylinder.

ii. The measured synthetic oil was poured into the Hamilton Beach Mixer cup and allowed to stir for one minute.

iii. With the use of the Electric Weighing Balance, the required additives were measured namely: Organophyllic clay (17g), Primary Emulsifier (15g), Secondary Emulsifier (5ml), Lime (9g), Brine (15ml), Gypsonite (5g) and Barite (74g).

iv. With the use of the Hamilton Beach Mixer, each of the additives was added slowly at intervals of 5 minutes and the sides of the cup was scraped to ensure that all the mixture entered the suspension.

v. Barite was then added last to avoid flocculation of the mud.

vi. The complete mixture was stirred continuously for 15 minutes to attain homogeneity.

vii. The formulated mud Sample A was measured as 350ml laboratory barrel unit and stored for analysis.

viii. The above procedure was repeated for samples C and E in which the conventional EDC 99 synthetic oil was replaced with equal volumes of Moringa and Coconut oils respectively while using gypsonite as fluid loss agent and the again for samples B, D and F in which the gypsonite fluid loss agent was replaced with kernel chaff.

C. The Rheological Property Measurement

The freshly prepared samples described above (samples A – F) were distinctly subjected to the same test conditions and the rheological properties measured. By using standard laboratory procedures, the specific rheological properties determined are:

i. Density – using mud balance
ii. Viscosity – using viscometer and dial readings taken at 600, 300, 200, 100, 6, 3 and gel
iii. Plastic viscosity – correlated from dial readings of the viscometer
iv. Yield Point – correlated from dial readings of the viscometer
v. Fluid Loss – using HPHT Filter Press
vi. Cake Thickness – using HPHT Filter Press
vii. Shear Stress/ Shear Rate – empirical relationships

III. RESULTS AND DISCUSSION

A. Fluid Rheological Behavior at Different Temperatures

As has been shown in the previous chapters, the fundamental aim of mud formulation with various additives is to achieve some desired specifications of rheological parameters. From the scope of this investigation, the formulated samples of mud described in chapter three involves a conventional EDC-99 synthetic mud and other two locally formulated samples with Moringa oil and Coconut oils respectively. Each of the samples was subjected to similar laboratory conditions and rheological tests carried out at varying temperature ranges. The results of the rheological tests at 80°F and 180°Fare presented in Tables 2-5 of the Appendix and are extensively discussed in the preceding sections.

The results of these tests are used in the establishment of rheograms for appropriate rheological model selection. The Shear stress and the Shear rate were calculated using the equations below:

$$\boldsymbol{\gamma = 1.703\emptyset} \quad \mathbf{1}$$

$$\boldsymbol{\tau = 1.067R} \quad \mathbf{2}$$

Where γ = shear rate in sec^{-1}

$\emptyset$ = dial RPM

τ = shear stress in $Ib/100ft^2$

R = dial reading

The results of Figures 1 – 4 below present a characteristic rheological model of the analyzed mud samples. The behavior of the graph and trend lines show that the samples are non-Newtonian and similarly does not conform to the ideal behavior of Power-Law model. At lower shear rates (typically below 400/sec), the closest approximation of the fluid model is the Bingham-plastic model. However, future trends above this shear rate will indicate possible existence of a power law or polynomial relationships such that the representative fluid model is given by the equation below:

$$\boldsymbol{\tau = \tau_o + a\gamma + b\gamma^2 + c\gamma^3 + \ldots + k\gamma^n} \quad \mathbf{3}$$

Where a, b, c, k, and n are constants that could be obtained via curve fitting. The implication of the above equation is that the sample rheogram can be approximated with Herschel-Bulkley model at a = b = c = 0. This shows that in the absence of adequate experimental data, the Herschel-Bulkley model could be used to provide a more accurate prediction of the fluid sample rheology than the Power Law Model and the Bingham Plastic Model.

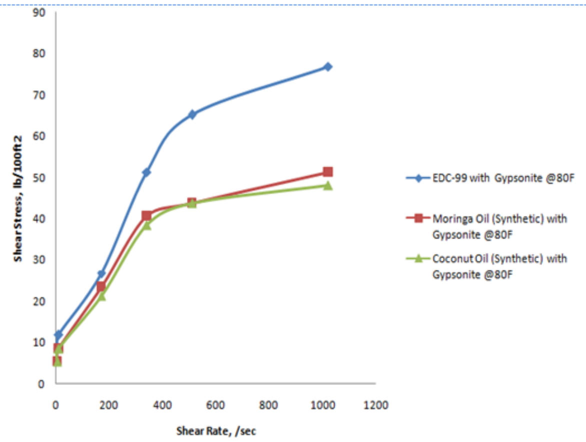

Figure 1: Fluid Rheogram at 80°F (with Gypsonite Additive)

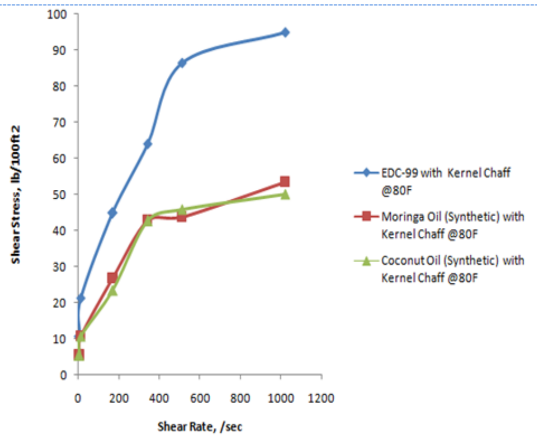

Figure 2: Fluid Rheogram at 80°F (with Kernel Chaff Additive)

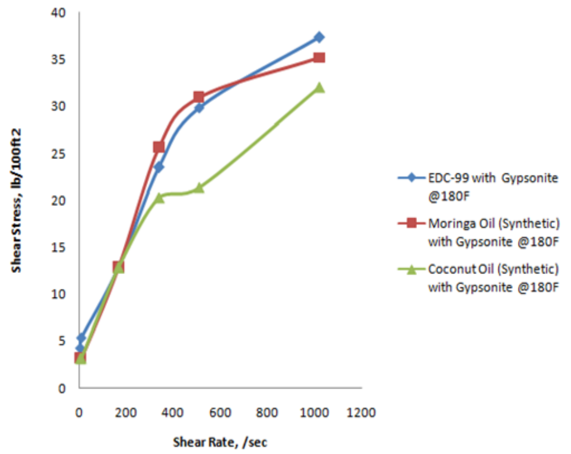

Figure 3: Fluid Rheogram at 180°F (with Gypsonite Additive)

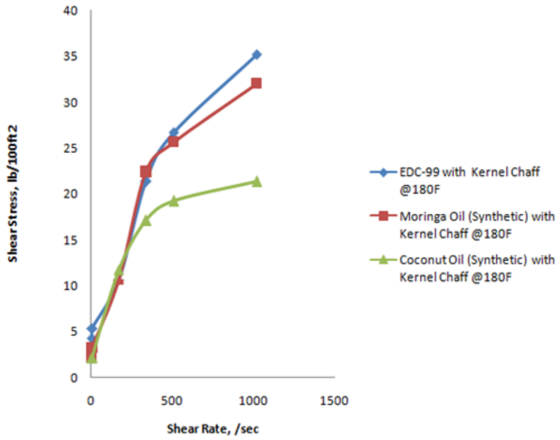

Figure 4: Fluid Rheogram at 180°F (with Kernel Chaff Additive)

The results as presented in Figures 1 and 2 showed that at the initial test condition (80°F), the conventional EDC-99 synthetic mud exhibited a remarkable deviation from the other two samples. However, at higher temperatures (180°F) as seen in Figures 3 and 4, a more compromising performance is reached between the two samples with the Moringa oil based sample showing the best match with the EDC-99 sample. Since in very real field situations, the bottomhole circulation temperature is relatively within this range, Moringa oil and Coconut oil based samples are clear suitable alternatives to the EDC-99 owing to the added economic value in sourcing the base fluids locally.

B. Fluid Yield Point (YP) at Different Temperature

The results of Figures 5 and 6 compares the fluid yield point with each additive at different temperature ranges. The yield point of a drilling fluid is a very important rheological parameter. It measures the ability of a drilling mud to lift cuttings from the hole to the surface. The yield point was calculated using the relationship below:

$$YP = \emptyset_{600} - \emptyset_{300} \quad \textbf{4}$$

In Figure 5, it was shown that EDC-99 has a much better hole cleaning performance at the initial temperature conditions. However, the relatively fast decline with temperature increment raises an important concern. This odd phenomenon is generally observed in the three samples but comparative analysis showed that the Moringa as a base fluid of a synthetic mud could offer some superior thermal stability making it ideal for high temperature drilling operations. The result of Figure 6 shows that the presence and the choice of fluid loss additives is an important factor to consider in the choice of any SBM. The Moringa oil based sample still retained the thermal superiority but the other samples were influenced positively at higher temperatures.

It must be noted that in normal drilling operations in which temperature does not pose considerable challenges, EDC-99 could still be preferred to the other samples except for economic considerations.

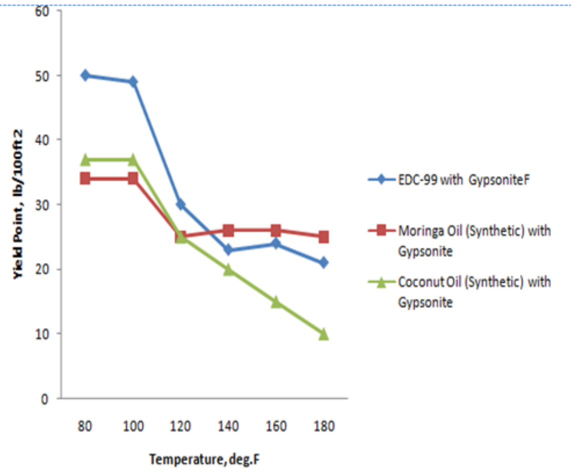

Figure 5: Effect of Temperature on Yield Point (Sample with Gypsonite Additive)

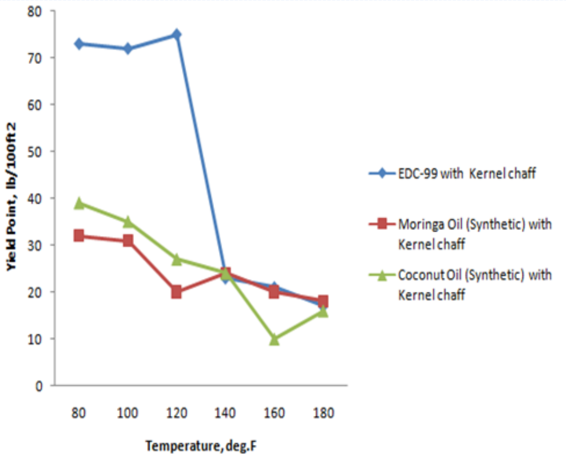

Figure 6: Effect of Temperature on Yield Point (Sample with Kernel Chaff Additive)

C. The Influence of Temperature on Plastic Viscosity (PV)

The PV of any mud sample gives an indication of its suitability for achieving high Rate Of Penetration (ROP). A low PV shows the sample is less viscous and can achieve faster drilling than a high PV counterpart due its excessively viscous nature. For most muds, PV generally decreases with time. The PV was calculated using the equation below:

$$PV = \emptyset_{300} - YP \quad (5)$$

In the Figure 7 and 8, a seemingly complex trend is observed for each sample. However, a close observation shows that the Coconut Oil Based sample exhibited a unique trend characterized by increasing PV after moderate initial decline. This means that the sample becomes more viscous making it susceptible to reduced drilling rate. With the substitution of Gypsonite with Kernel Chaff, a more haphazard relationship is observed for both EDC-99 and the Coconut Oil Based sample. This validates the previous observation that the choice of other additives has a combined influence of the rheology of the drilling mud. It was observed that the EDC-99 has better PV values with the Kernel Chaff additive at lower temperatures.

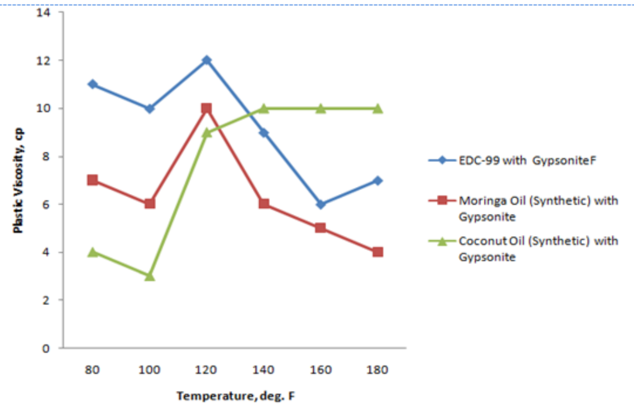

Figure 7: Effect of Temperature on Plastic Viscosity, PV (Sample with Gypsonite Additive)

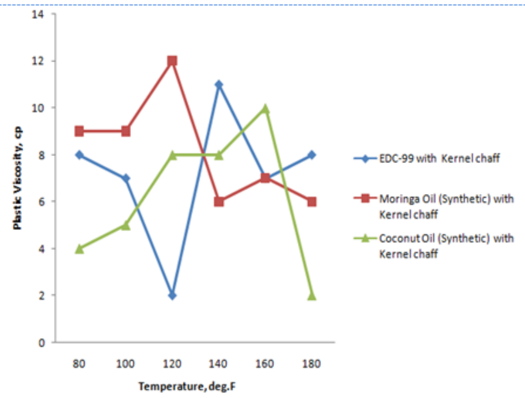

Figure 8: Effect of Temperature on Plastic Viscosity, PV (Sample with Kernel Chaff Additive)

D. Fluid Gel Strength versus Temperature

The gel strength of any mud sample characteristically determine its ability to suspend solids and it is integrally connected with it hole cleaning efficiency. In Figure 9, the results of the 10-min gel strength of the samples for each additive are shown. It is shown that while kernel shaft increases the gel strength of the conventional EDC-99 synthetic based mud, the reverse is observed with the two other locally formulated samples from Moringa and coconut oils. General observation shows that temperature remarkably impacts the gel strength of the samples. As temperature increases, the gel strength reduces due to reduced fluid viscosity. By comparative analysis, it is shown that the Moringa oil with coconut chaff has the most desirable gel strength value while those of the EDC-99 with kernel chaff performs most poorly. The other samples showed a more competing interest.

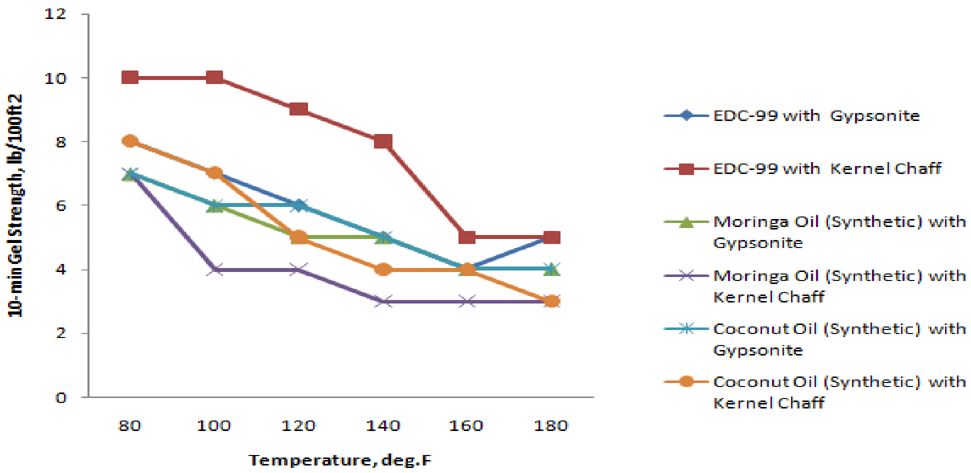

Figure 9: Gel Strength versus Temperature

E. The Fluid Loss/Filter Cake Thickness Results

The results in Figure 10 generated from this study were used to investigate the suitability of kernel chaff as viable alternative to gypsonite. As could be easily seen from the table, the use of gypsonite with the EDC-99 sample makes most outstanding among other options investigated. However, the thin cake thickness raises much concern for this option. By substituting gypsonite with kernel chaff, a more competing performance is observed among all the options considered which resulted to an increase in cake thickness. By comparing the two local formulations, it is evident that the moringa oil based sample has better filtration loss control than the coconut oil counterpart. However, it must be noted that increased cake thickness with the kernel chaff formulation as fluid loss agent must be within optimally acceptable range that will be dependent on the well configuration, lithology, formation fluid type and depth.

The results of cake thickness seem more competitive within the samples than those of the fluid loss. This explains the influence of the additives on the fluid loss behavior of the samples.

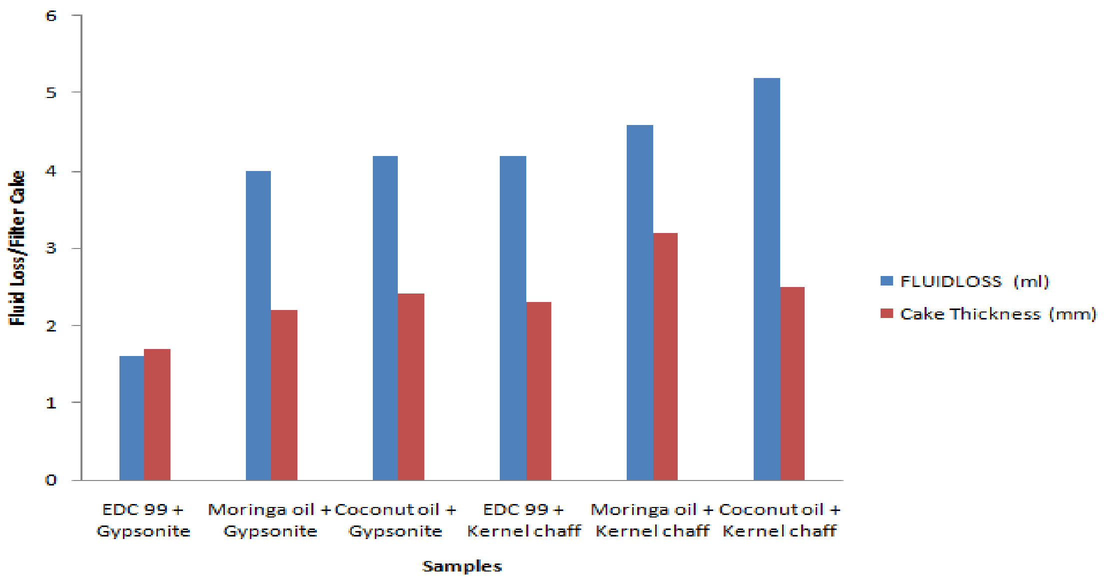

Figure 10: Fluid Loss/Filter cake Thickness Results of the Samples after 30mins Filtration Period using HPHT Filter Press

IV. CONCLUSION

This study has provided an extensive investigation into the suitability of biodegradable plant oils for the formulation of synthetic based fluids. As a way of improving the local content formulations of these fluids, kernel chaff was investigated as a viable alternative to EDC-99. The laboratory investigations were done at varying temperature conditions that ranged from 80°F to 180°F and the rheological behavior of the samples duly studied. From the analysis provided in the study, the following conclusions were arrived at:

- The moringa oil based sample and the coconut oil based samples showed potentials of better rheological behavior at higher temperatures
- The use of kernel chaff as fluid loss agents can only be used in situations where significant economic implications and severe environmental regulations could be associated with the conventional gypsonite.
- The EDC-99 conventional SBM outperformed the locally formulated samples in nearly all the analysis. However, comparative results showed that the local formulations could be further enhanced for better performance
- The kernel chaff resulted to increased cake thickness even though it has fluid loss control slightly below that of gypsonite
- The presence of other additives jointly plays to influence the overall fluid rheology even though its application may be targeted for a particular rheological parameter.
- The use of moringa and coconut oil as base fluids of a synthetic mud is highly recommended. However, further treatment is required for enhancing its rheological performance.

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APPENDIX

LABORATORY CALCULATIONS – Rheological Parameters

Table 2: Rheology of Mud at 80°F with Gypsonite

Shear Rate, 1/sec	**Shear Stress, lb/100ft^2**		
	EDC-99	Moringa oil	Coconut oil
1021.8	76.824	51.216	48.015
510.9	65.087	43.747	43.747
340.6	51.216	40.546	38.412
170.3	26.675	23.474	21.34
10.218	11.737	8.536	8.536
5.109	8.536	5.335	5.335

Table 3: Rheology of Mud at 80°F with Kernel chaff

Shear Rate, 1/sec	**Shear Stress, lb/100ft^2**		
	EDC-99	Moringa oil	Coconut oil
1021.8	94.963	53.35	50.149
510.9	86.427	43.747	45.881
340.6	64.02	42.68	42.68
170.3	44.814	26.675	23.474
10.218	21.34	10.67	10.67
5.109	10.67	5.335	5.335

Table 4: Rheology of Mud at 180°F with Gypsonite

Shear Rate, 1/sec	**Shear Stress, lb/100ft^2**		
	EDC-99	Moringa oil	Coconut oil
1021.8	37.345	35.211	32.01
510.9	29.876	30.943	21.34
340.6	23.474	25.608	20.273
170.3	12.804	12.804	12.804
10.218	5.335	3.201	3.201
5.109	4.268	3.201	3.201

Table 5: Rheology of Mud at 180°F with Kernel chaff

Shear Rate,1/sec	**Shear Stress, lb/100ft^2**		
	EDC-99	Moringa oil	Coconut oil
1021.8	35.211	32.01	21.34
510.9	26.675	25.608	19.206
340.6	21.34	22.407	17.072
170.3	10.67	10.67	11.737
10.218	5.335	3.201	2.134
5.109	4.268	2.134	2.134

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