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Development of Environmentally Friendly Oil Based Mud Using Almond Oil, Castor Oil and Groundnut Oil

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ABSTRACT: *With increasing environmental concerns today, Oil based muds are either prohibited or severely restricted in many areas including Niger Delta, Nigeria. In response to the harmful effects of diesel oil on the environment, researches are surveying more techniques of formulating and optimizing drilling fluids with the use of plant oils as diesel substitutes. This research work looked into the use of novel and locally available plant seed oil: Almond, Castor and Groundnut oil that will be environmentally safe and technically feasible to replace the conventional diesel Oil based mud. Physiochemical tests were carried out on the plant oils to know if it meets the requirements of oils used for oil based muds. Different samples of drilling muds were formulated with the plant oils and tests (mud density, rheology, filtration, pH, toxicity and Cutting carrying Index (CCI)) were carried out on it where diesel oil based mud was used as a control. Results indicate that almond, castor and groundnut Oil based muds have great chances of being among the technically viable replacements of diesel Oil based mud. Castor, groundnut and Almond Oil based muds are less toxic, environmentally friendly, possesses excellent cutting carrying capacities and biodegradable.*
KEYWORDS: Almond, Castor, Groundnut, Diesel, Rheology, Toxicity, Cutting Carrying Index, Oil based mud

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I. INTRODUCTION

A drilling process is incomplete without the drilling fluid which is an integral and indispensable component of any drilling operation (El Fakharany et al., 2017, Oseh et al., 2019). Drilling fluid or drilling mud is a complex (multi-component) and composite fluid used to help maintain well control and aid in the removal of drilling cuttings from the wellbore i.e. from the bottom of the hole to the surface (Apaleke et al., 2012, Fadairo et al., 2012, El Fakharany et al., 2017). The drilling fluid is usually a mixture of water or oil, clay, weighing materials and a few chemicals to give the fluid certain desirable properties.For any successful drilling operation, high performance rate of the circulating drilling fluid is required. The effectiveness or the performance of the drilling fluid is measured by its capacity to accomplish its job (El Fakharany et al, 2017, Oseh et al., 2019). During a drilling process, drilling fluids may be selected and/or designed so that the physical and chemical properties of the fluid allow their functions to be fulfilled (Fadairo et al., 2012). However, when selecting the fluid, three factors must be considered. They are: How friendly is the fluid to the environment (environmental impact), the cost of fluid and the fluid’s technical performance. The selection of the best suitable drilling fluid using these factors defines the success of the drilling operation (Fadairo et al., 2012, El Fakharany et al., 2017). Since the 1930s, it has been discovered that oil based mud (OBM) achieved better productivity than water based mud (WBM) which have enabled the upstream of the petroleum industry thrive on OBM (Fadairo et al., 2012, Anawe et al., 2014). Over the years, diesel oil have been used to formulate oil based mud which have posed various environmental problems due to its toxicity effluent and advert effects on the environment (Fadairo et al., 2012, Anawe et al., 2014, Oseh et al., 2014). In recent times, researches have been carried out to discover and formulate oils that can mitigate these environmental problems. Hence, synthetic oil based mud were discovered which possess low toxicity and high biodegradability. It is very important to increase the use of environmentally friendly and biodegradable sources of oil to formulate our OBM, thereby making it less expensive and environmentally safe and equally maintaining the basic functions of the drilling fluid such as maintaining of hydrostatic pressure, removal of cutting, cooling and lubricating the drill string and also to keep newly drilled borehole open until cementing is carried out (Yassin et al., 1991, Fadairo et al., 2012, Oseh etal., 2014).

The use of OBM has special considerations. These include cost and environmental considerations (disposal of cutting in an appropriate place to isolate possible environmental contaminations) (Oseh et al, 2014). Based on this, the type of oil used must be taken into consideration when formulating OBM. OBM is a type of mud where the based fluid is a petroleum product such as diesel fuel or other forms of oils (Fadairo et al., 2012, Oseh et al., 2014). Stakeholders in the petroleum industry have been tasked with the challenge of finding a solution to this problem by formulating optimum drilling fluids and also reduce the handling cost and negative environmental impacts on the conventional diesel based drilling fluid (Adewale and Ogunrinde, 2010, Fadairo et al., 2012, Oseh et al., 2014).

The research area of determining a substitute for the conventional diesel oil based fluid to meet the environmental specifications is relatively new (Apaleke et al., 2012). Researchers in this field have been using non-toxic, edible vegetable oils, non-edible oils and plant seed oils as the continuous or external phase in the development of an environmentally friendly (non-toxic, sustainable and biodegradable) oil based mud (Apaleke et al., 2012). The most popular being rapeseed oil, Jatropha oil, palm oil, soya bean oil, walnut oil, cottonseed oil etc (Fadairo et al, 2012).

However, in this research, the based oil used to develop an environmentally friendly mud system is the almond oil, castor oil and groundnut oil. These oil based muds will carry out the same functions as the diesel oil based drillingfluid and equally meet up with the HSE (health, safety and environment) standards.

II. MATERIALS AND METHODOLOGY

Four different mud samples were mixed, and the based fluid was varied. The base fluids were almond, castor, groundnut and diesel oils used in formulating the muds, where diesel based mud served as the control.

MATERIALS

The following equipment and materials were used to carry out the experiment

Table 1: List of materials and equipment used

Materials		Equipment	
1.	n-hexane	1.	Soxhlet extractor
2.	Diesel oil	2.	Weighing balance
3.	Almond oil	3.	Measuring cylinder
4.	Castor oil	4.	Hamilton beach mixer
5.	Groundnut oil	5.	Viscometer
6.	Bentonite	6.	Hydrometer
7.	Barite ($CaCO_3$)	7.	Oswald Viscometer
8.	Pac- R	8.	Mud balance
9.	Filter paper	9.	Automatic Pensky Martens Closed Cup Flash point tester
		10.	Rotary Viscometer
		11.	API Filter Press Multi unit
		12.	Meter Rule, pH meter

III. METHODOLOGY

1. Extraction

The method employed in this study is solvent extraction. Solvent extraction is aprocess which involves extracting oil from oil-bearing materials by treating it with a low boiling point solvent as opposed to extracting the oils by mechanical pressing methods(such as expellers, hydraulic presses, etc.). Here the equipment used was the Soxhlet extractor. A Soxhlet extractor is a piece of laboratory apparatus invented in 1879 by Franz von Soxhlet. It was originally designed for the extraction of a lipid from a solid material. The solvent extraction method recovers almost all the oils and leaves behind only 0.5% to 0.7% residual oil in the raw material.

The extraction procedure is given below:

i. The almond fruit was collected, de-hulled and the seeds ground.
ii. The ground sample were tied in filter papers and loaded into the main chamber of the Soxhlet extractor.
iii. About 300ml of n-Hexane was poured into a flask which was fitted to the main chamber containing tied up sample.
iv. The heating mantle was turned on and the system was left to heat.
v. At about 40 – 60^0C, the solvent began to boil and evaporate into the main chamber. The solvent was heated to reflux. The solvent vapor travelled up a distillation arm, and flooded into the chamber housing the solid wrapped in filter papers. The condenser condensed the solvent vapor, and the vapor dripped back down into the chamber housing the solid material. Then at a certain level, the siphon emptied the liquid into the flask.

vi. This cycle was repeated until the sample in the chamber changed color to a considerable extent, and the fluid mixture was collected in a beaker.
vii. The mixture was separated by allowing atmospheric evaporation of the n-hexane leaving the sported oil behind.
viii. The process was repeated for castor seed and groundnut seed.

2. Mud Preparation

The following procedure was used in the formulation of the almond oil, castor oil groundnut oil and diesel based muds respectively:

i. Using the weighing balance, the various quantities of materials as shown in Table 3.2 below were measured.
ii. The quantities of oil were measured using the measuring cylinder.
iii. Using the Hamilton Beach Mixer, the measured materials were thoroughly mixed until a homogenous mixture was obtained in the order as shown in Tables 2.

Table 2: Mud Sample Components

Oil Sample	Almond	Castor	Groundnut	Diesel	Mix. Dur. (Mins)	Mixing Order
Oil vol.	300ml	300ml	300ml	300ml	5	1
Bentonite	40g	40g	40g	40g	15	3
Barite ($CaCO_3$)	120g	120g	120g	120g	15	4
Pac-R	18g	18g	18g	18g	10	2

3. Mud Density

The following procedure was used in the measuring the densities of the mud samples formulated with almond oil, castor oil groundnut oil and diesel using the Bariod mud balance

i. Before beginning, the calibration was checked by using the calibration mark provided on scale for fresh water i.e. 8.33 lb/gal
ii. The mud cup was cleaned out and dried, then filled to the top with the formulated mud.
iii. The lid was placed on the cup, making sure the mud overflowed to remove any bubbles that might be trapped. The cup was wiped clean.
iv. The balance was placed in its base with the knife edges on the fulcrum rest and the rider moved along the arm until the cup and arm were balanced as indicated by the bubble.
v. The mud weight was read at the edge of the rider towards the mud cup as indicated by the arrow on the rider and was recorded.
vi. The calculated Mud density was determined using the equation

$$\rho_m = \frac{M_{bentonite} + M_{barite} + M_{oil} + M_{pac-R}}{V_{bentonite} + V_{barite} + V_{oil} + V_{pac-R}}$$

4. Viscosity

The following procedures were used to determine the viscosity of Castor oil, groundnut oil, almond oil and diesel oil based mud using rotary viscometer.

i. The mud sample was poured into the mud cup of the rotary viscometer shown in Fig 3.4and the rotor sleeve was immersed exactly to the fill line on the sleeve by raising the platform. The lock knot on the platform was tightened.
ii. The power switch located on the back panel of the viscometer was turned on.
iii. The speed knob was first rotated to the stir setting, to stir the mud for a few seconds, and it was rotated to 600RPM, waiting for the dial to reach a steady reading, the 600 RPM reading was recorded.
iv. The above process was repeated for 300RPM, 200RPM, 100RPM, 60RPM, 30RPM and 6RPM.
v. The plastic viscosity, apparent viscosity and yield point was determined using the formula respectively.

$$PV = \theta_{600} - \theta_{300}$$

$$AV = \frac{\theta_{600}}{2}$$

$$YP = \theta_{300} - PV$$

5. Gel Strength

The following procedures were used to determine the gel strength of almond oil, castor oil, groundnut oil and diesel oil based mud.

i. The speed selector knob was rotated to stir the mud sample for a few seconds, then immediately shut off.

ii. As soon as the sleeve stopped rotating, the knob was turned to the gel reading after 10 seconds and 10 minutes respectively. The maximum dial was recorded for each case.

6. Mud Filtration Properties

The following procedures were used to determine the mud cake and mud filtrate of almond oil, castor oil, groundnut oil and diesel oil based mud using API filter press multi-unit.

i. Each part of the 4 cells was cleaned, dried and the rubber gaskets were checked. The cell was assembled as follows: base cap, rubber gasket, screen, filter paper, rubber gasket, and cell body.
ii. A freshly stirred sample of each mud (diesel oil, groundnut oil, castor and almond oil based mud) was poured into the cells respectively to within 0.5 inch (13 millimeters) to the top in order to minimize contamination of the filtrate. The top cap was checked to ensure that the rubber gasket was in place and seated all the way around and complete the assembly. The cell assembly was placed into the frame and secured with the T-screw.
iii. A clean dry graduated glass cylinder was placed under the filtrate exit tube of each cell.
iv. The regulator T-screw was turned counter-clockwise until the screw was in the right position and the diaphragm pressure was relieved. The safety bleeder valve on the regulator was put in the closed position.
v. The air hose was connected to the designated pressure source. The valve on the pressure source was opened to initiate pressurization into the air hose. The regulator was adjusted by turning the T-screw clockwise so that a pressure was applied to the cell in 30 seconds or less. The test period begins at the time of initial pressurization.
vi. At the end of 7.5 minutes the volume of filtrate collected was measured. The air flow through the pressure regulator was shut off by turning the T-screw in a counterclockwise direction. The valve on the pressure source was then closed and the relief valve was carefully opened.
vii. The assembly was then dismantled, and the mud was removed from the cup.
viii. The filter cake for each mud sample was measured using a ruler to the nearest 1/32" (0.8 mm), and the measurements were recorded.

7. pH Test

The following procedures were used to determine the pH of almond oil, castor oil, groundnut oil and diesel oil based mud using pH meter.

i. The pH meter was turned on and allowed to warm up.
ii. The electrode was cleaned.
iii. The pH meter was dipped in almond oil based mud and the pH was recorded.
iv. The pH meter electrode was rinsed in water
v. Step iii and iv was repeated for other samples.

8. Toxicity Test

After the oil based mud samples have been formulated, each is then tested on a growing plant (that is on beans seedling), to see the effects on the plant growth and the living organisms in the soil. Bean seed was planted and exposed to 100ml of four different mud samples, with the following base fluids; diesel, castor, almond and groundnut the growth rate was measured, and the number of days of survival.

9. Cutting Carrying Index

Drilling data was obtained from Nigerian Petroleum Development Company Limited's daily report

Table 3: Drilling Parameters from Oredo-15

Well name	Oredo-15
Last casing	20"
Depth, ft	4083
Pump Type	HONGHUA
Stroke Length	12"
Pump Efficiency	97%
Bit Size	17-1/2"
Pump SPM	85
Pump GPM	424.83
Liner Size	6.5"
Pump Output, bbl/stk	0.119
Annular Vel.(DP), ft/min	74.05
Annular Vel. (DC), ft/min	85.98

The following procedures were used to calculate the cutting carrying index of almond oil, castor oil, groundnut oil and diesel oil based mud using the following correlations.

$$CCI = \frac{K \times V_a \times MW}{400{,}000}$$

$$where$$
$$V_a = Annular\ Velocity\ in\ ft/min$$

$MW = mud\ weight\ in\ ppg$ ppg
$K = Power\ law\ constant$ tant
$K = (511)^{1-n}(PV + YP)$
$n = 3.322\log\left[\frac{2PV + YP}{PV + YP}\right]$

IV. RESULTS AND DISCUSSION

RESULTS

Physiochemical Results

The results as obtained from measurements of density, viscosity and flash points of the oil samples

Table 4: Physiochemical Measurements of oil samples

Oil Sample	Density (ppg)	Viscosity (cp)	Flash Point (°C)
Almond	6.876	2.590	221
Groundnut	7.584	15.140	232
Castor	7.967	30.95	229
Diesel	7.167	1.05	51

Results for Mud Tests

Mud Density Results

The results as obtained from measurements of mud density using Bariod Mud Balance are contained in Table 5 below. Calculated Density was obtained

Table 5: Mud density results

Oil Sample	Measured Density (ppg)	Calculated Density (ppg)	Error
Almond	9.23	9.55	0.32
Groundnut	9.70	10.12	0.42
Castor	9.98	10.42	0.44
Diesel	9.40	9.78	0.38

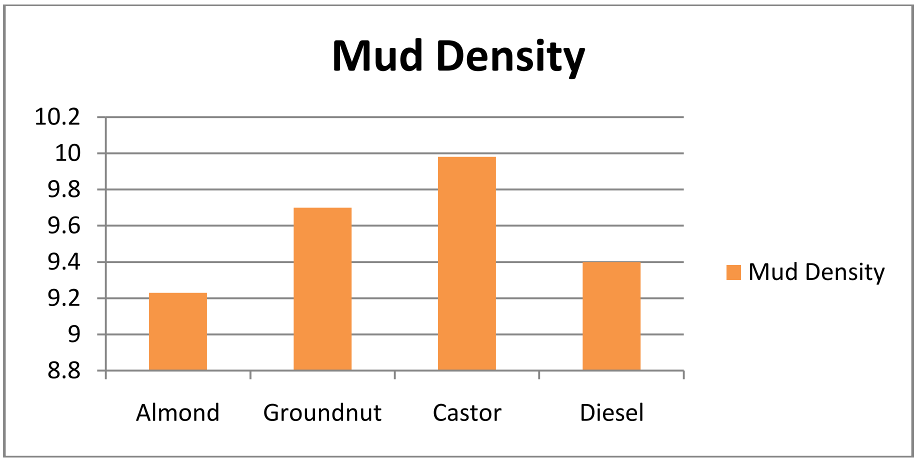


Fig 1: Mud density results of different mud sample

Viscosity and Gel Strength Results

The viscosity readings obtained from experiment using rotational viscometer are contained in Table 6 below. Table 7 contains the gel strength, plastic viscosity, apparent viscosity and yield point were calculated

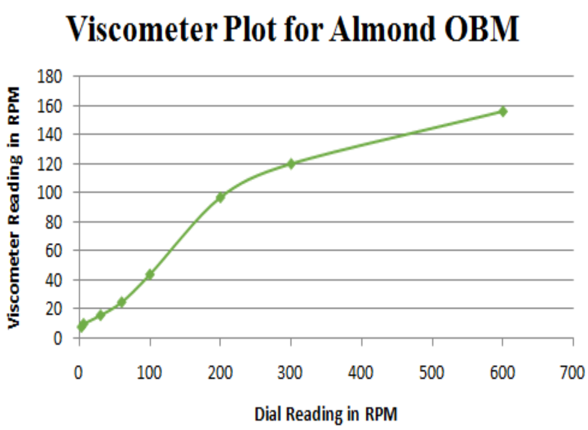
Table 6: Viscosity Variations at different viscometer readings

Dial Reading (RPM)	Almond	Groundnut	Castor	Diesel
600	156	400	680	177
300	120	288	550	125
200	97	156	380	108

100	44	102	225	47
60	25	55	140	29
30	16	34	77	17
6	10	17	25	11
3	8	12	20	9

Table 7: Rheological results of different mud samples

Rheological Properties	**Almond**	**Groundnut**	**Castor**	**Diesel**
Plastic Viscosity	36	112	130	52
Apparent Viscosity	78	200	340	88.5
Yield Point	84	176	420	73
Gel strength @ 10secs	10	17	25	11
Gel Strength @10 mins	8	12	20	9



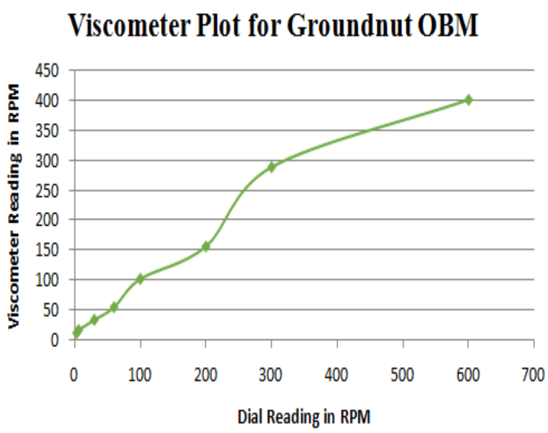
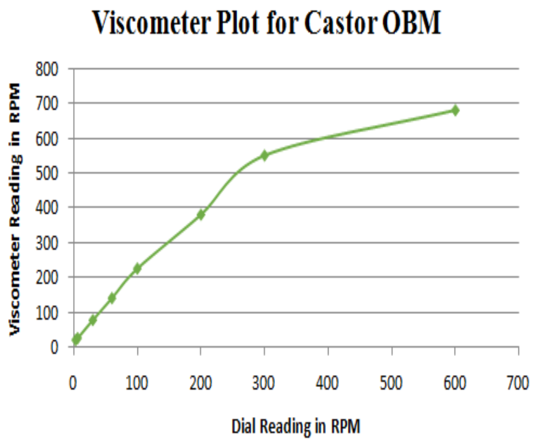


Fig 2: Viscometer Plot for Almond OBM **Fig 3: Viscometer Plot for Groundnut OBM**



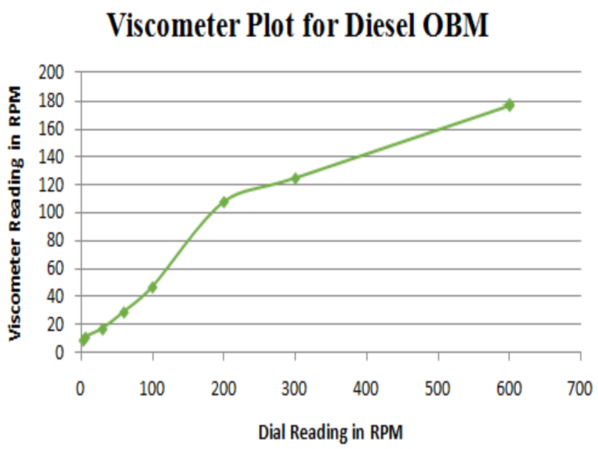


Fig 4: Viscometer Plot for Groundnut OBM **Fig 5: Viscometer Plot for Diesel OBM**

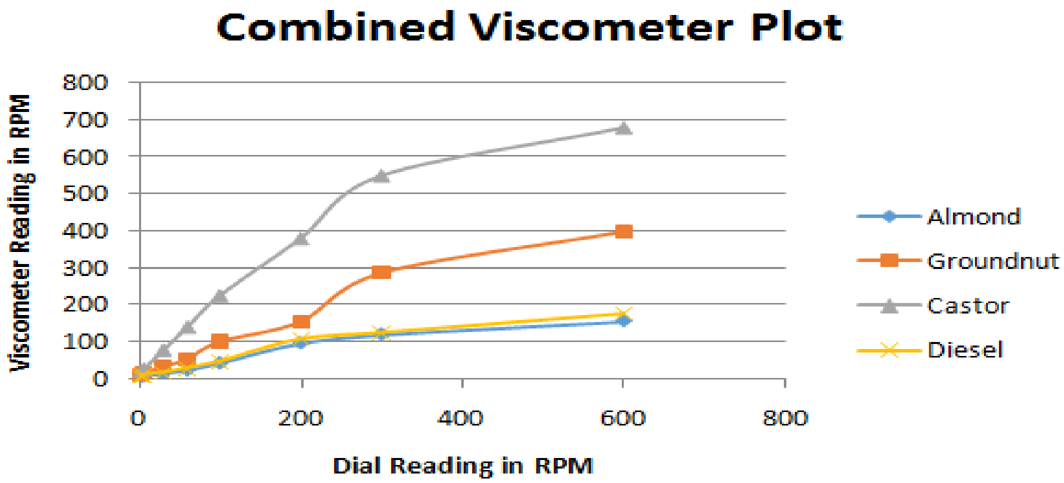


Fig 6: Combined Viscometer Plot for Almond, Groundnut, Castor and Diesel OBM

Mud Filtration Results

The results of the mud filtrate and mud cake thickness measurements after 7.5 minutes using the API filter press are contained in Table 8 below.

Table 8: Mud Filtration Results for the Mud samples

Mud Filtration Properties	Almond	Groundnut	Castor	Diesel
Mud Filtrate (ml)	170	72	38	140
Mud Cake Thickness (1/32")	24	10	7	21

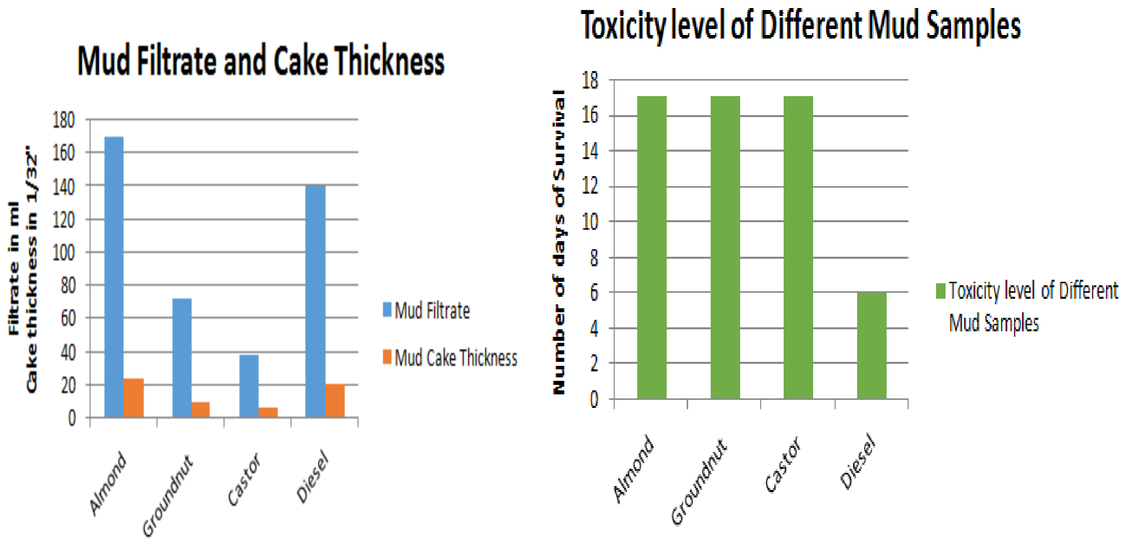


Fig 7: Mud Filtration and Cake Thickness of different Mud Samples, Toxicity results

pH Results

The results of the pH values of different mud samples using a pH are contained in Table 9 below.

Table 9: pH values for different mud samples

Mud Sample	**Almond**	**Groundnut**	**Castor**	**Diesel**
pH Value	7.4	7.6	9.5	6.7

Toxicity Results

The results of the toxicity test carried out for different mud samples on a bean plant are contained in table 10 below.

Table 10: Toxicity results for different mud samples

Mud Sample	**Number of days of Survival**
Almond	17
Groundnut	17
Castor	17
Diesel	6

Cutting Carrying Index

The cutting carrying Index of different mud samples was computed and are contained in table 11 below

Table 11: Cutting Carrying Index of Mud Samples

Mud Sample	**Cutting Carrying Index**
Almond	104.7
Groundnut Oil	264
Castor	518.9
Diesel	111

V. DISCUSSIONS

Effect of Oil Type on Oil Density, Viscosity, flashpoint

From Table 4the oil samples possess high specific gravity above 0.80 which shows they can be used to formulate mud with high densities. Castor Oil and Groundnut Oil possess high viscosity which can make them give better rheology than almond oil as well as diesel. Castor oil, groundnut oil and almond oil possess high flash point than diesel which shows they can minimize fire hazards as less hydrocarbon vapors is expected to generated above the mud to be formulated by them.

Mud Tests

Effect of Oil Type on Mud Density

Results showed in Table 5 shows that the castor oil's density was significantly highest followed by groundnut oil, diesel and almond oil. However, a benefit of the higher density of castor and groundnut oil is that less barite could be used, saving the cost of formulation. Also, the higher the density of the mud sample, the better it helps to maintain column or hydrostatic pressure and suspend cuttings in the mud leading to better clearing of the bore. Generally though, weighting materials are calculated and added to mud formulations to help achieve this one important property of the drilling mud. The density of the oil based mud to be used depends on the reservoir conditions. Some reservoirs require a denser drilling mud especially when faced with problems like influx of other fluids into the bore. Whereas, some other conditions like lost circulation would require a less dense fluid to regulate it. The performance of the other oils in comparison to diesel oil is quite encouraging and thus may serve as potential replacements for diesel in oil base mud formulations. The error differences between the calculated and measured densities all lie below 0.3, thus the readings obtained using the mud balance have a high accuracy.

Effect of Oil Type on Mud Viscosity

From Fig 6 and Table 7 all depict the variations of viscosities of the various oil based muds. High viscosity values were obtained for castor and groundnut oil based mud than those oil almond and diesel based muds. At 600 RPM, viscosities of castor and groundnut oil based mud were far greater than almond and diesel oil based mud. This shows that castor and groundnut oil based mud have the ability to suspend and carry cuttings more than almond and diesel oil based mud. Although, mud with low viscosities such as almond oil based mud will prove better for a reduced friction during drilling because of low resistance to flow and in turn leads to reduction in the wearing and tearing of drill string while increasing rate of penetration.

Yield Point evaluates the ability of mud to lift cuttings out of the annulus. A higher YP indicates that drilling fluid has the ability to carry cuttings better than a fluid of similar density but lower YP. The Castor OBM with highest YP values show best cuttings carrying capacity followed by groundnut OBM and almond OBM when compared to diesel OBM.

The gel strength is also a vital parameter in evaluating the drilling fluid performance. There isn't a large difference between the gel strength of the formulated mud samples; they all have a good gel structure. With proper gel strength solids are well suspended in the hole and allow them to settle out on the surface, excessive gel strength should not be encouraged as they can cause a number drilling problems.

Effect of Oil Type on Mud Filtrate and Mud Thickness

Table 8 showed the results of the mud filtration test of the mud samples. Almond OBM had the highest mud filtrate and mud thickness followed by diesel OBM and groundnut OBM whereas Castor Oil possesses the least mud filtrate and mud thickness. Hence Castor OBM will have fewer problems associated with mud filtrate and mud thickness.

Problems caused as a result of excessive thickness include: Tight spots in the hole that cause excessive drag, Increased surges and swabbing due to reduced annular clearance, Differential sticking of the drillstring due to increased contact area and rapid development of sticking forces caused by higher filtration rate, Primary cementing difficulties due to inadequate displacement of filter cake and Increased difficulty in running casing.

The problems as a result of excessive filtration volumes include: Formation damage due to filtrate and solids invasion, Damaged zone too deep to be remedied by perforation or acidization, Damage may be precipitation of insoluble compounds, changes in wettability and changes in relative permeability to oil or gas, formation plugging with fines or solids, and swelling of in-situ clays, Invalid formation-fluid sampling test. Formation-fluid flow tests may give results for the filtrate rather than for the reservoir fluids, Formation-evaluation difficulties caused by excessive filtrate invasion, poor transmission of electrical properties through thick cakes, and potential mechanical problems running and retrieving logging tools, Erroneous properties measured by logging tools (measuring filtrate altered properties rather than reservoir fluid properties) and Oil and gas zones may be overlooked because the filtrate is flushing hydrocarbons away from the wellbore, making detection more difficult.

Effect of Oil Type on pH

Drilling muds are always treated to be alkaline (i.e., a pH > 7). The pH will affect viscosity, bentonite is least affected if the pH is in the range of 7 to 9.5. Above this, the viscosity will increase and may give viscosities that are out of proportion for good drilling properties. For minimizing shale problems, a pH of 8.5 to

9.5 appears to give the best hole stability and control over mud properties. A high pH (10+) appears to cause shale problems.

The corrosion of metal is increased if it comes into contact with an acidic fluid. From this point of view, the higher pH would be desirable to protect pipe and casing.

The pH values of all the samples meet the requirements stated but Diesel OBM with a pH of less than 6.7 does not meet with specification. Castor, groundnut and Almond OBM's show better results since their pH values fall within this range.

Effect of Oil Type on Toxicity

From Table 10, it is clear that diesel oil is much more toxic than biodegradable oils. To illustrate the toxicity level of each drilling fluid, the test was performed by getting six bean plants and planting them in two parts, allowing them to sprout and exposing them to the two different mud samples. The plants were observed for a calculated amount of time and it was noted how long they survived. The plant where diesel base mud was immersed inside its soil survived for 6 days. While, the plants with almond mud survived above 2 weeks. This provides evidence of the non-biodegradability of diesel and its toxicity. The toxicity of diesel can be traced to high aromatic hydrocarbon content. Therefore, replacements for diesel should either eliminate or minimize the aromatic contents thereby making the material non toxic or less toxic. In general, green material i.e. plant materials containing oxygen within their structure degrade easier.

Effect of Oil Type on Cutting Carrying Index

Cuttings Carrying Index (CCI) is a measure of a drilling fluid's ability to conduct drilled cuttings in the hole. Higher CCI's, mean better hole cleaning capacities. Result s shown in Table 11 shows that Castor and groundnut OBM have high cutting carrying index and better hole cleaning capacities than diesel and Almond OBM.

VI. CONCLUSION

As the industry looks for an environmentally friendly drilling fluid, it is imperative to concentrate on these plant oils. The sources of these plant oils are in abundance in most parts of the country and can be produced on large scales to meet the needs of the industry. With the right formulations these oils could help address major geothermal drilling issues, temperature effects on fluid's rheology (fluid degradation) and issue of barite sagging, compressibility due to high pressure and fluid stability.

Based on the laboratory experiments performed in this research work, results indicates that almond, castor and groundnut OBM's have great chances of being among the technically viable replacements of diesel OBM. The results also show that additive chemistry must be employed in the mud formulation to make them more technically feasible. In addition, the following conclusions were drawn:

1. Castor OBM showed the highest mud density and almond OBM showed the lowest mud density.
2. From viscosity results, castor OBM and groundnut OBM will be able to carry cuttings better than almond and diesel OBM though low viscosity mud can prove better for a reduced friction drilling.
3. Castor, groundnut and Almond OBMs are less toxic, environmentally friendly and biodegradable.
4. Castor, Groundnut, Almond OBM has high CCI that means they possess better hole cleaning capacities.

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