International Journal of Advances in Applied Sciences (IJAAS)
Vol. 10, No. 1, March 2021, pp. 47~59
ISSN: 2252-8814, DOI: 10.11591/ijaas.v10.i1.pp47-59

Performance of rubber seed oil as an alternative to diesel in oil-based drilling mud formulation

Amanze Josiah Destiny[1], Fortune Chukwuebuka Amanze[2]
[1]Department of Petroleum Engineering, University of Uyo, Akwa Ibom, Nigeria
[2]Department of Electrical Engineering, University of Nigeria, Nsukka, Nigeria

Article Info

Article history:

Received May 7, 2020
Revised Jul 9, 2020
Accepted Nov 20, 2020

Keywords:

Bingham plastic
Diesel
Oil-based mud
Rubber seed oil
Soxhlet extraction

ABSTRACT

The formulation of an oil-based mud was made possible with the oil extracted from rubber seeds using the famous Soxhlet extraction method. The mud was formulated using the American Petroleum Institute (API) standard of 25 g of bentonite to 350 mL base fluid. The choice of rubber oil comes as a result of its flash point and aniline point which lie in the range of base oils used for mud formulation. The rheological properties of the rubber oil-based mud (OBM) were beyond the scope of the viscometer and hence thinner was added to reduce its viscosity and its suitability to compete favorably with diesel OBM was checked. The 10 sec and 10 min gel strength of the rubber OBM were recorded as 68 lb/100 ft^2 and 69 lb/100 ft^2 respectively while that of Diesel was 65 lb/100 ft^2 and 67 lb/100 ft^2. The plastic viscosity of rubber OBM was 12 cp while that of Diesel was 17 cp. They both exhibited Bingham Plastic behavior and a similar yield point of 146 lb/100 ft^2. The formulated mud samples were subjected to temperatures of 60 ºC and 75 ºC and it was discovered that rubber OBM was more likely to retain its rheological property than diesel OBM. Comparison with other rheological properties of diesel OBM showed that the formulated mud could be used alternatively for diesel in drilling operations.

Corresponding Author:

Fortune Chukwuebuka Amanze
Department of Electrical Engineering
University of Nigeria, Nsukka
University Road, 410001, Nsukka, Enugu State, Nigeria
Email: fortuneamanze@gmail.com

1. INTRODUCTION

From antiquity, man has always sought for means to keep on living and avoid extinction. He has evolved from an ordinary man who used to hunt with sticks and stones to a complex human with extraordinary thinking capabilities. His desire and pursuit to continue remaining relevant have led him to various innovations. From the internal combustion engine created in 1859 to the modern-day computers, man has known no end to his quest for sustenance. Energy is a vital force that has shaped human development, spanning through several decades, man's hunger for energy continues to increase. There are various forms of energy which has been found to be beneficial to man; from solar energy to geothermal energy to hydropower energy, to mention but a few. But of all these forms of energy, fossil energy seems to be more accessible. The discovery of oil in Titusville, Pennsylvania by Col. Edwin Drake in 1859 marked the evolution of the Petroleum industry.

The Petroleum industry since its inception has always looked for means to extract the oil stored in the pore spaces of reservoir rocks stored beneath the earth up to the surface. Petroleum Engineering which is a subset of engineering is concerned with the activities related to the production of hydrocarbons and has various branches ranging from drilling engineering, reservoir engineering, production engineering, petroleum economics, and natural gas engineering. The pivotal responsibility of the drilling Engineer is to ensure that the drilling process of a well is managed as safely and efficiently as possible. To do this, one of the criteria to look at is the drilling fluid which could be thought of as "the blood of the drilling process". The drilling engineer is mostly saddled with the responsibility of selecting and maintaining the optimum drilling fluid for the drilling operation as drilling fluid performs various functions which includes exerting adequate hydrostatic force against underground formations to prevent the flow of formation fluids into the well, cleaning the rock particles from underneath the bit and transferring them to the surface, cooling, and lubricating the rotating drillstring and bit and preventing collapse of the new drilled borehole until steel casing is cemented in the hole. Conventional oil-based mud (OBM) used for drilling utilizes Diesel as its continuous phase. The right and optimum choice of drilling fluid is advantageous to the drilling process both in terms of economic analysis and problem minimization. With the advent of technology, several alternatives have been sought out for to improve the drilling process both in terms of cost, environmental friendliness and even operating conditions.

Rubber (*Hevea brasiliensis*) tree is the source of latex that is a feed stock for the production of rubber tyres used on motor vehicles, motor cycles and bicycles. It is inedible and so does not compete with food, but is eaten by cows in Nigeria [1]. This study utilizes the oil derived from rubber seed to modify drilling fluid properties which include viscosity, gel strength etc. and suppress environmental concerns that occurs when drilling with conventional based mud. The Petroleum industry is concerned with maximizing profits at the lowest possible cost of expenditure and operation in the safest way possible. The use of diesel oil in oil-based mud is a major drawback to this ideology as diesel oil is quite expensive and also poses a threat to the environment as its disposal requires more stringent pollution control procedures. Due to this problem, government has enacted laws and imposed sanctions on defaulters to safeguard its environment and citizens from the lethal effects of OBM disposal [2]. To mitigate these problems, this project utilizes the oil derived from rubber seeds to formulate oil-based drilling mud.

This study aims to critically access the rheological characteristics of oil-based mud formulated with oil obtained from rubber seeds and how it can be used to improve drilling operation. The objectives of this study include:

a. To extract and characterize rubber seed (*Hevea brasiliensis*) and its oil derivative.
b. To evaluate the rheological characteristics of the oil based mud prepared with Rubber seed oil.
c. To use the results obtained from rubber OBM and diesel OBM in comparing and analyzing the economic viability and suitability of using rubber seed oil as a replacement in oil-based mud.

The right choice of drilling fluid is very important in drilling operations. Therefore, this study will be helpful in reducing the environmental pollution that comes from the disposal of mud, reduce the cost of drilling fluid and hence drilling operation and lastly reduce problems that are encountered while drilling. The research work is limited to the laboratory. Oil based muds will be formulated for use for the experiment and the test carried out include mud weight, plastic viscosity, yield point, aniline point, pH, filter cake thickness, and gel strength. With advancement in drilling-fluid technology, it is now possible to implement during well-construction process a cost-effective, custom-made system for each interval of the well [3]. It is worthy to note that researchers over the years have made studies trying to find a substitute to diesel oil in oil-based mud [4]. The focus of these studies has been geared towards various vegetable oils. Some of the findings made by researchers related to vegetable oils as a replacement to diesel oil in drilling fluid is given below:

Agwu *et al.* [5] formulated an oil-based mud with soybean oil derived from soybean. They compared the rheological properties of the formulated soybean mud particles with diesel oil mud particles. They obtained that the OBM displayed Bingham plastic model, possessed low yield point and gel strength as against diesel OBM. The mud density recorded showed that Soybean oil-based mud was a bit higher than that of diesel oil-based mud. Filtration loss tests also indicated that soybean oil-based mud fluid loss volume was a little less than that of diesel OBM. They further concluded that soybean oil-based mud displayed good drilling mud properties that would compare favorably with those of diesel OBM. The result obtained from their work is summarized in Table 1 and Table 2.

Table 1. Mud rheological parameters value

Mud properties	Diesel oil	Soybean oil
Gel strength 10 sec, lb/100 ft^2	7	5
Gel strength 10 min, lb/100 ft^2	9	6
Plastic viscosity, cp	16	14
Yield point, lb/100 ft^2	20	11
Apparent viscosity, cp	25.5	19

Table 2. Mud filtration loss results

Filtrate properties	Diesel OBM	Soybean OBM
Total fluid volume (mL)	27	23
Oil volume (mL)	12	10
Wter volume (mL)	15	13
Cake thickness (mm)	2.5	2.0

Another research by Adewale and Ogunrinde [2] made use of palm oil and groundnut oil in the preparation of drilling fluid. Their work compared the toxic effect of diesel OBM and the vegetable oils on the environment. Corns were first planted on humus soil beds prepared with palm. They were then exposed to the three mud samples to compare their toxicity. The result of the experiment showed that the corn exposed to Palm oil and Groundnut oil retained its green colour while that exposed to Diesel oil lost its greenness and died. In conclusion, they encouraged oil-based mud preparation with the vegetable oils (palm oil and groundnut oil in this case) because of its biodegradable nature, better eco-toxicological properties, and the reduced cost of treatment of the cuttings.

Fadairo *et al.* [6] used oil developed from Jatropha and Canola seeds as the base fluid for drilling mud samples. The mud samples formulated alongside diesel mud sample was tested for toxicity, filtration, pH, viscosity, and density to ascertain their suitability properties for drilling operation and their degree of safety to the environment. From experiments carried out, Jatropha not only had the lowest viscosity but also proved to be safer and best fit for plant life and soil microorganisms as against diesel which happened to be the most toxic among the three samples. In conclusion, they postulated that Jatropha oil-based mud could potentially replace conventional diesel oil-based mud.

Another study conducted by Fadairo *et al.* [7] determined the rheological characteristics of Jatropha oil-based mud when chloride salts of sodium and potassium was introduced and how temperature variations affected the rheological properties. Results from analysis showed that the flow properties of the fluid were negatively impacted by salinity and temperature. It further showed that diesel OBM was a better performer than Jatropha in conditions of high salinity and temperature, hence it was necessary to improve rheological properties of Jatropha OBM when working in conditions as these.

Agwu *et al.* [8] carried out an investigation on the cost, properties and availability of vegetable oils used in drilling fluids. To achieve the objectives of cost effectiveness, availability and good rheological and filtration properties, comprehensive evaluation of the viability of each vegetable oil was performed. The results obtained had olive oil ranking the least in meeting all of these objectives while palm oil, soybean oil followed by rapeseed oil fulfilled all of the objectives to a reasonable extent.

The research carried out by Yassin *et al.* [9] involved carrying out tests on derivatives of palm oil as the continuous phase for oil-based drilling fluids, and the toxicity effect on plant and aquatic life. The oil derivatives used in this case include methyl esters of crude palm oil, and methyl esters of distilled palm fatty acid. Rheological tests carried out on formulated mud samples showed that the high plastic viscosities and high gel strengths of the palm oil ester-based muds can be effectively treated by adding adequate proportion of thinners.

Xiaoqing *et al.* [10] successfully developed modified natural macromolecule-based fluids which were environmentally acceptable, composed mainly of shale inhibitor agents, fluid loss control agents, bloomless white asphalt, and dry powders of poly alcohols. Results from a series of tests revealed that it had the ability to withstand temperatures as high as 284 and had strong inhibitive and formation damage control and anti-contamination abilities. The formulation could be employed for both land and marine drilling activities, and its use did not affect as production, casing, and well logging field operations.

Brief description of rubber (Heavea Brasiliensis)

Known for its lactiferous system from which latex is extracted by tapping the trunk, the rubber tree grows so fast possessing deep tap-roots. It has a smooth and straight trunk alongside a greyish bark [11]. The rubber tree begins fruit bearing at approximately four years of age with each fruit containing three or four seeds. On ripening, the fruit splits and fall to the ground. On the average, a tree yields as much as 800 seeds (1.3 kg) twice yearly. The seeds, as seen in Figure 1, consists of a thin hard shell and a kernel containing oil. These are sometimes extracted together, yielding an undecorticated oilcake or meal with a very high fiber content. The oil can either be expressed (hot or cold) or extracted. The extracted meal has only 2-4% while the pressed cake contains 8-15% residual oil.

Figure 1. Rubber (*Hevea brasiliensis*) seeds

Distribution

The rubber tree is largely found in the tropical rainforest of the Amazon basin and the Guianas. It is widespread in the northern part of South America and have in later times been introduced into South-East Asia and Africa. Rubber grows best between 15 °N and 10 °S and from sea level up to 600 m, with the optimal altitude being below 200 m. It is not very tolerant to soil erosion on hill slopes or to strong winds. It performs well with a day temperature between 26 °C and 28 °C, and with annual rainfall ranging from 2000 to 3000 mm. The Rubber could be planted in rows, squares and rectangular pattern depending on the type of land. The best season to cultivate Rubber happens to be the periods between June and July [12]. The physicochemical properties of rubber seed oil were also carried out by Bello and Otu [1] and these properties are presented in Table 3. Longeron *et.al*. [13] gave a summary of the tests common on oil-based mud. The following is the summary.

Table 3. Rubber seed oil physico-chemical properties

Property	Rubber seed oil	Property	Rubber seed oil
Density kg/m^3 at 25	910	Peroxide value (gI$_2$/100g)	25.30
Relative density kg/m^3 at 15	0.911	Oxidation stability (hours) at 110	17
Cloud point	25	pH value	7.4
Pour point	18	Saponification value (mgKOH/g)	183.7
Cold filter Plug Point	22	Soap content %	0
Flash point	165	Cold soak filtration	320
Dynamic viscosity (mN s/m^2) at 40	67.72	Water and sediments % vol	13.00
Kinematic viscosity (mm^2/s) at 40	74.31	Moisture content (ppm)	3530.00
Lower heating value (KJ/kg)	40	Refractive index at 15	1.467
Higher heating value (KJ/kg)	37	Sulfated ash % (mol/mol)	0.90
Cetane number	46.30	Carbon residue % (mol/mol)	0.20
Free fatty acid %	23.68	Copper strip corrosion test (3 h, 50)	4
Acid value (mgKOH/g)	47.12	Distillation temperature 90%	383
Iodine value (gI$_2$/100g)	106		

Mud density

Mud density synonymous with mud weight is reported in units of lbm/gal, Kg/m^3 or G/cm^3, lb/ft^3 or in hydrostatic gradient, lb/in^2/ft (psi/ft) or pptf (psi/1000ft). The control of hydrostatic pressure and prevention of unwanted flow into the wellbore is a key function of the Mud weight. Mud weight also prevents collapse of casing and the open hole. Excessive mud weight can cause lost circulation by propagating, and then filling fractures in the rock. Procedures on using a mud balance to test Mud weight have been standardized and published by the American Petroleum Institute (API) [14].

Flash point

From [15], "The flash point is the lowest temperature at which application of a flame to the test chamber of a tester causes vapors of the sample in the chamber to ignite". This test can be applied to base fluids being considered for use in a synthetic mud, an oil mud or to any flammable liquid to determine the temperature an explosion hazard exists. The test methods established by ASTM and API include closed-cup and open-cup tests.

Pour point

From [16], "The the pour point is the lowest temperature (in °F or °C) at which a liquid remains pourable (meaning it still behaves as a fluid)". Synthetic muds or oil with high pour points may suffer from poor screening and excessive pressure, surges in deep water wells or other operations subject to low temperatures. In oils, the pour point is generally increased by high paraffin content. The pour point of liquid additives is an important consideration for artic drilling operations.

Aniline point test

The aniline point is the temperature below which an oil containing 50% by volume aniline (C6H5NH2) becomes cloudy [17]. Higher aromatics have low aniline point whereas the opposite occurs in lower aromatic content. An Aniline Point below 120 °F (49 °C) for Diesel oil is probably risky to use in OBM. The API has developed test procedures that are the standard for the industry. According to Yassin et. al. [18], for oil to be used as a base fluid for drilling mud, it has to meet the following requirements: it should be non-toxic and have low aromatic content, the base oil must form a stable emulsion, the kinematic viscosity should be as low as possible. This tends to allow the formulation of the OBM at lower oil water ratios and provides better rheology (lower plastic viscosity) especially at a low mud temperature and flash point greater than 100 °F. Higher flash points would minimize fire hazards as less hydrocarbon vapours generation is expected above the mud, its pour point should be lower than the ambient temperature to allow for pumpability of mud from storage tanks and its aniline point of the oil should be above 65 °C (149 °F) to minimize the deterioration of rubber components on the rig.

Viscosity

From [19], “The viscosity of a fluid is defined as its resistance to flow. The desired viscosity for a particular drilling operation is influenced by several factors, including mud density, hole size, pumping rate, drilling rate, pressure system and requirements, and hold problems”.

Fluid loss

From [20], “Fluid loss is defined as the leakage of the liquid phase of the drilling fluid, slurry or treatment fluid containing solid particles into the formation matrix. The resulting buildup of solid material or filter cake may be undesirable, as the penetration of filtrate through the formation. Fluid-loss additives are used to control the process and avoid potential reservoir damage”.

Fluid loss tests

There are two types of tests for fluid loss measurement. API Static filtration test (standard low pressure and temperature and high pressure and temperature) and Dynamic filtration test. The Static filtration test includes the standard API test at room temperature and pressure difference of 100 psi and is the field test for fluid loss measurement. The high-pressure, high-temperature test is a laboratory test and is conducted at a differential pressure of 500 psi and a temperature of 300 °F. The Static tests are indicative of the loss of fluid and the buildup of the filter cake when the fluid is not moving. The dynamic test represents the loss of fluid and the filter cake buildup while the drilling mud is in circulation. Dynamic tests are strictly laboratory conducted tests.

Gel strength

This is the ability of a drilling mud to suspend drilled solids, weighting material as well as the cuttings when circulation is stopped. This property of a drilling fluid denotes the thixotropic properties and is a measure of the mud’s attractive forces while at rest or under static conditions. Drilling muds ordinarily have gel strengths between 5 and 30 lb/100 ft^2. Basically, there are two types of gels; flat or fragile gels whose 10 seconds and 10 minutes gel strength value are similar and strong or progressive gels whose 10 seconds and 10 minutes gel value continue to increase linearly or exponentially [21].

Hydrogen Ion concentration (pH)

The hydrogen ion concentration or pH is a measure of the relative acidity or alkalinity of a substance. The pH value ranges from 0-14. Value of 0-6 represents acidity and 7-neutral, 8-14 being alkaline [21]. Mathematically, pH is defined as given in (1).

$$pH = log[H+] \tag{1}$$

Where, H^+ is the hydrogen ion concentration in moles/litre. K_W is the ion product constant of water having a value of 1.0×10^{-14} mol/litre at room temperature.

2. RESEARCH METHOD

Table 4 is the list of all materials and apparatus used in the experiment.

Table 4. List of materials and apparatus used for the experiment

Value	Description
Materials used in oil extraction.	i. Extraction solvent (N-hexane). ii. Water, which was needed for cooling the heated gaseous hexane. iii. Filter paper in which the flaked rubber seeds were put. iv. Sewing thread which was used in tieing the filter paper housing the samples.
Materials used for the formulation of the Oil based Mud.	i. Water ii. Diesel Oil iii. Rubber seed oil iv. Viscosifier (Bentonite) v. Barite vi. Caustic Soda (NAOH) vii. Emulsifier viii. Filtration Control Additive (Carboxy Methyl Cellulose)
Apparatus for oil extraction from the rubber seeds.	i. Sohxlet apparatus ii. Heater iii. Glass beaker iv. Measuring Cylinder
Apparatus used for the determination of the mud's rheological properties	i. Stop watch: used to measure the elapsed time. ii. Fann V-G meter: used to measure mud gel strength and viscosity. iii. Marsh Funnel: field instrument which was used to measure viscosity. iv. Low pressure-low temperature filter press (6 chambers) unit: used to measure the mud's filtration characteristics at ambient temperature and up to 100 PSI. v. Graduated Cylinder: for measuring the volume of mud. vi. Blender: for thorough mixing of the mud. vii. Mud balance: for measuring the density of mud. viii. Test-tube. ix. Stirrer. x. Stopper xi. pH meter xii. Thermometer: used for determining mud temperature.

2.1. Procurement and preparation of seed

The rubber seeds were collected from a Rubber Plantation located in Itu Local Government; Akwa Ibom State situated in the Southern part of Nigeria. The seeds were first decorticated manually to separate the kernels from the shells. The separated kernels were milled to reduce their diameters and to allow for faster and more oil extraction. The flaked rubber seeds were then oven dried as seen in Figure 2 at an average temperature of 85 to remove the excess moisture present.


(a) (b)

Figure 2. Grinded rubber seeds by (a) before been placed in oven and (b) after been placed in oven

2.2. Oil extraction from rubber seeds

The solvent extraction method was used because it has proven to be a beneficial method for solid-liquid extraction in numerous fields such as pharmaceuticals, environment and foodstuffs. Ground rubber seeds weighing 10 kg was measured and tied in a filter paper as seen in Figure 3 and loaded into the sohxlet extraction chamber as seen in Figure 4. About 500 mL of n-hexane was then poured into the round bottom flask contained in the heating mantle of the system. The heating mantle was then turned on to heat to 60 °C (140 °F). This allowed the solvent to be heated to reflux while the solvent vapor travelled up the distillation arm and flooded into the chamber housing the thimble of the rubber seed. The primary function of the condenser is to ensure that any solvent vapor cools and drips back down into the chamber housing the samples. The chamber containing the samples was now slowly filled with the warm n-hexane. Some of the desired compound (Rubber Oil in this case) was then dissolved in the warm solvent. When almost full, the Sohxlet chamber was automatically emptied by a siphon side arm with the solvent running back down to the distillation flask. The whole cycle was repeated until the liquid in the flask increased in color concentration. At this point, a steam bath was then used to separate the fluid mixture (n-hexane and Rubber oil) that had been collected in a glass beaker.

Figure 3. Rubber seeds tied in filter paper

Figure 4. Soxhlet extractor

2.3. Mud preparation

The mud was prepared in two stages; one which involved Diesel oil & another with Rubber oil. The formulation specifications were based on API standard of 25 g bentonite to 350 mL base fluid for nontreated bentonite. The two mud samples were thus formulated based on the concept of maintaining the same component proportions in each fluid. The oil-water ratio used in formulating the mud was 70 to 30.

The following is a step by step procedure used in formulating the mud for either case;

a. Emulsifier was added to 245 ml of base oil and blend for ten minutes.
b. 0.10 g of filter loss agent CMC was added and the mixture was stirred for another five minutes.
c. 105 ml of water was added to the sample formed from the processes above and stirred for fifteen minutes.
d. 25 g of bentonite was added and stirred for extra five minutes.
e. 0.25 g of NAOH was added and stirred also for five minutes.
f. The mud was allowed to age for 24 hours.
g. 10 g of barite was added to the formulated mud and stirred for 10 minutes.

2.4. Determining mud density

Before determining the mud density, calibration of the mud balance was first performed followed by the measurement of the mud weight.

Test Procedure

a. The mud balance was first calibrated with water and it was ensured that the rider was set on 8.33 when the level vial was centered.
b. After calibration, the water in the cup was replaced with the mud to be tested.
c. The cup's lid was rotated until firmly seated, making sure some mud was expelled through an opening in the cup.
d. The expelled mud was then wiped.
e. The balance arm was placed on the base, with the knife-edge resting on the fulcrum.
f. The rider was moved until the graduated arm was horizontal as indicated on the level of the beam.
g. The density of the mud in pounds/gallons (ppg) was read at the rider's left-hand edge, without disturbing the rider.
h. The mud temperature corresponding to density was noted down.

2.5. Determining mud viscosity

For routine Field measurements, the marsh funnel is used to obtain viscosity of drilling mud. In the laboratory, the fann V-G meter may be used to obtain the apparent viscosity, gel strength, plastic viscosity, and yield point.

2.6. Gel strength determination

The mud sample was first stirred thoroughly at 600 rpm before determining its gel strength. Then the RPM knob was turned to STOP position. The desired rest time (10 seconds) was waited. The RPM knob was then switched to the gel position and the maximum deflection of the dial before the Gel breaks was recorded as the 10 seconds gel strength in lb/100 ft^2. The first two steps were repeated and then allowed for 10 minutes. The RPM knob was switched to the gel position and the maximum deflection of the dial was recorded before the gel breaks, as the gel strength in lb/100 ft^2 was recorded as 10 minutes gel.

2.7. Yield point and plastic viscosity

The Fann V-G viscometer was efficient in determining the yield point and plastic viscosity of the mud samples. The Fann V-G meter cup was filled to the 350 cc position (this is also the barrel equivalent volume) with freshly agitated sample and place the cup on the moveable work table. The table was then adjusted until mud surface was at the scribed line on the rotor sleeve. The motor was started by placing the switch in the high-speed position with the shift to the left. This was taken as the 600 RPM setting. The 600 RPM reading is recorded by waiting for a steady indicator dial value. The (2), (3), and (4) was used to obtain values.

$$\text{Plastic Viscosity (PV) in centipoise} = \Theta_{600} - \Theta_{300} \quad (2)$$

$$\text{Yield Value } \Theta_{300} - \text{PV} \quad (3)$$

$$\text{Apparent viscosity} = \frac{\Theta_{600}}{2} \quad (4)$$

2.8. Mud filtrate and wall building cake determination

The following procedures was used in carrying out Static filtration test:

a. The mud cell was detached from the filter press frame. Image of the filter press is seen in Figure 5.
b. The filter cell's bottom was removed and the right filter paper size was placed in the cell bottom.
c. The mud to be tested as seen in Figure 6 was introduced into the cup assembly and the filter paper and screen was put on top of mud tighten screw clamp.
d. With the air pressure valve closed, the mud cup assembly was clamped to the frame while the filtrate outlet end was finger tight held.
e. A graduated cylinder was placed underneath to collect filtrate.
f. Air pressure valve was opened and timing was started simultaneously.
g. The cubic centimeters of filtrate collected was reported for specified intervals up to 30 minutes.
h. The results were tabulated in an appropriate table.
i. All pressures were released from the cell. The CO_2 pressurizing assembly was removed from the cell cap. The relief valve was pulled out and the T-screw was slowly opened to allow any remaining pressure to escape. The empty CO_2 cartridge was discarded.
j. The cell was removed from the frame and it was disassembled. The remaining mud was discarded.
k. The filter paper and the deposited cake was carefully saved. Gentle water stream was then used to wipe the excess filter cake on the paper.
l. The thickness of the filtrate cake was measured and recorded to the nearest 1/32" (0.8 mm) using a steel rule. Acceptable cake thickness is usually less than 2/32".
m. The cake's quality, softness, toughness, hardness, firmness, rubberiness, flexibility, slickness and sponginess of the mud sample was observed and recorded.

Figure 5. API filter press

Figure 6. Filter cake characteristics for the two formulated muds

2.9. Hydrogen Ion concentration (pH)

Laboratory determination of the Hydrogen ion concentration was made possible using the pH meter. The pH meter determines Hydrogen ion concentration by measuring difference in potential difference and the dial reading indicates the pH of the sample. For accurate measurement of pH, the pH meter should be used.

3. RESULTS AND ANALYSIS

Table 5 is the comparison of the physiochemical property of both Diesel and Rubber oil. After formulation of rubber OBM, the viscometer reading of the mud was too high and beyond the scope of the viscometer and hence 10 mL of thinner was added to reduce the mud viscosity to compare with those of diesel OBM. The viscometer reading of the diesel OBM and rubber OBM to which the thinner was added is given in Table 6. Table 6 shows diesel and rubber OBM almost having the same rheological properties with slight discrepancies.

Table 5. Diesel and rubber oil physicochemical properties

Property	Diesel oil	Rubber oil
Physical form	Liquid	Liquid
Density at 25	830 kg/m^3	910 kg/m^3
Solubility in water	Immiscible	Immiscible
Flash point	70	165
Cloud point	-9	25
Kinematic viscosity	6	74.31
Pour point	-18	18

Table 6. Viscometer readings for mud samples after addition of thinner to rubber OBM

Speed	Diesel oil		Rubber oil	
(rpm)	Dial reading	Shear stress	Dial reading	Shear stress
600	180	190.80	170	180.20
300	163	172.78	158	167.48
200	130	137.80	126	133.56
100	70	74.20	65	68.90
6	59	62.5	43	45.58
3	37	39.22	29	30.74

Table 7 shows the mud rheological parameters values with rubber OBM having greater gel strength than diesel OBM. Figure 7 shows a shear stress-shear rate profile for diesel and rubber OBMs, Figure 8 is the graph displaying the gel strength of diesel and rubber OBMs. Table 8 and Table 9 shows the behavior of diesel OBM and rubber OBM when subjected to temperatures of 60 ℃ and 75 ℃. As can be seen, rubber OBM is more stable than diesel OBM with elevated temperature conditions. Figure 9 shown as shear stress-shear rate profile for diesel and Figure 10 shows a shear stress-shear rate profile for diesel and rubber OBM at 75 ℃.

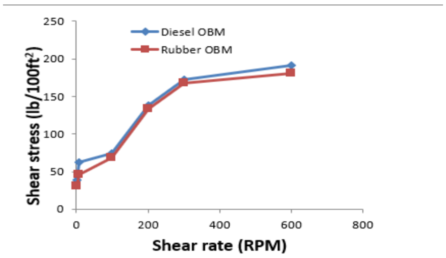

Figure 7. Shear stress-shear rate profile for diesel and rubber OBMs

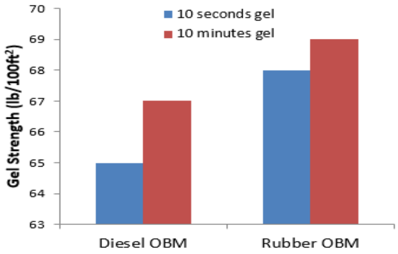

Figure 8. Diesel and rubber OBMs gel strength

Table 7. Mud rheological parameters value

Mud properties	Diesel oil	Rubber oil
Gel strength (lb/100 ft^2)	65/67	68/69
Plastic viscosity (cp)	17	12
Yield point (lb/100 ft^2)	146	146
Apparent viscosity (cp)	90	83

Table 8. Viscometer readings for mud at 60ºC

Speed (rpm)	Diesel oil		Rubber oil	
	Dial reading	Shear stress	Dial reading	Shear stress
600	155	164.30	158	167.48
300	100	106.00	113	119.78
200	75	79.50	94	99.64
100	50	53.00	57	60.42
6	37	39.22	39	41.34
3	23	24.38	25	26.50
Gel Strength 10 sec	60 lb/100ft^2		63 lb/100 ft^2	

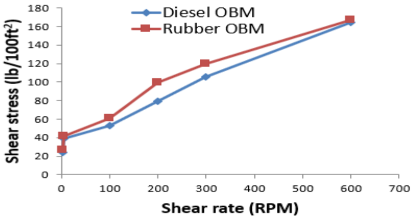

Figure 9. Shear stress-shear rate profile for diesel and rubber OBM at 60 ℃.

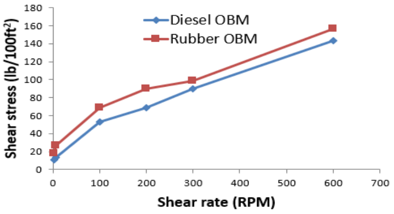

Figure 10. Shear stress-shear rate profile for diesel and rubber OBM at 75 ℃

Table 10 give the values for the filtration volume with diesel OBM having a greater filtrate volume at the end of 30 mins and also have a greater cake thickness of 1.93 mm than compared to rubber OBM with 1.78 mm cake thickness. Figure 11 shows a filtration volume plot for diesel and rubber OBMs, and Figure 12 shows a mud cake thickness comparison for diesel and rubber OBMs.

Table 9. Viscometer readings for mud at 75 ℃

Speed (rpm)	Diesel oil Dial reading	 Shear stress	Rubber oil Dial reading	 Shear stress
600	135	143	148	156.88
300	85	90.10	93	98.58
200	65	68.90	85	90.10
100	50	53.00	65	68.90
6	13	13.78	25	26.50
3	10	10.6	17	18.02
Gel Strength 10 sec	50 lb/100ft^2		58 lb/100 ft^2	

Table 10. Mud filtration loss results

Filtrate properties	Diesel OBM	Rubber OBM
Volume of total fluid (ml)	26	22
Volume of oil (ml)	12	10
Volume of water (ml)	14	12
Thickness of cake (mm)	1.9	1.78

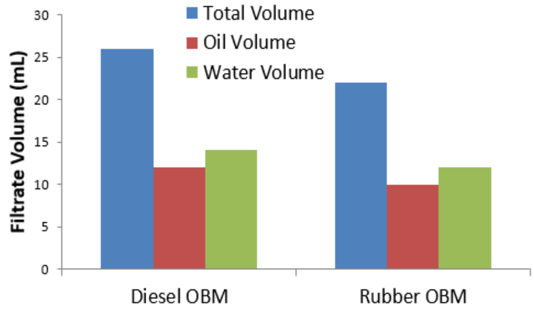

Figure 11. Filtration volume plot for diesel and rubber OBMs

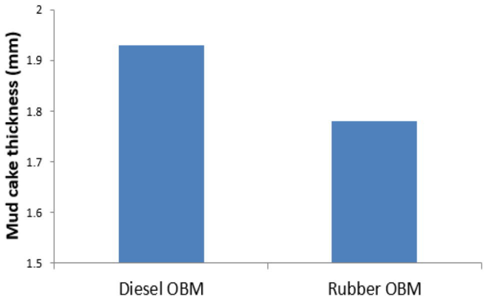

Figure 12. Mud cake thickness comparison for diesel and rubber OBMs

Table 11 shows how the density of rubber OBM and diesel OBM varies with addition of 10 g barite, with diesel OBM having a higher percentage increase in weight than rubber OBM under the same addition of 10 g Barite. Table 12 is the calculated mud filtration for the two different mud type. Figure 13 shows time comparison of filtrate loss. Figure 14 shows comparison of mud pH with addition of NAOH

Table 11. Mud density values with barite content

Barite (g)	Diesel OBM	Rubber OBM
0	7.7	8.0
10	8.0	8.2
% increase in wt	3.90	2.5

Table 12. Calculated mud filtration

Mud type	Time (minutes) 5	 7.5	 10	 15	 30
Diesel OBM (mL)	11	13	14.7	18	26
Rubber OBM (mL)	9.5	11	13.5	15	22

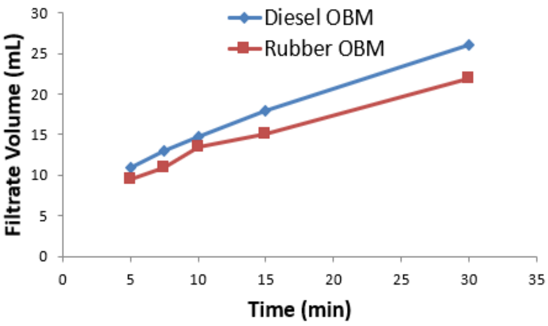

Figure 13. Time comparison of filtrate loss

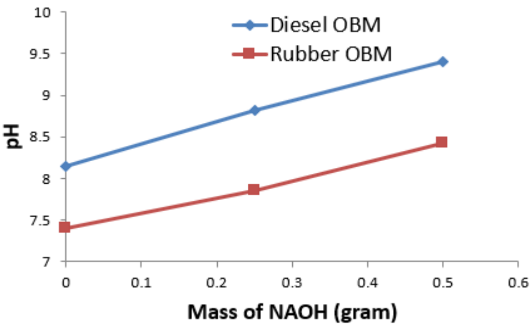

Figure 14. Comparison of mud pH with addition of NAOH

3.1. Discussion

The rheological properties of a mud i.e., yield point, gel strength, filtration properties, plastic viscosity, fluid loss, and filter cake thickness play an important role in the overall performance of a drilling fluid. The drilling mud's ability to lift cuttings out of the annulus is mostly determined by the yield point property of that mud. Non-Newtonian fluid exhibits a high yield point and is a better cuttings carrier than a fluid of similar density but lower yield point. It is however important to note that if yield point is excessively high, pressure losses could occur as mud is being circulated. The shear rate and shear stress are the conversions of the viscometer speeds and dial readings respectively.

3.1.1. Viscosity

From Table 7, both Diesel and Rubber oil have the same yield point value of 146 lb/100 ft2. As seen in Figure 7, rubber OBM has a lower plastic viscosity than compared to diesel OBM. This necessarily means that diesel OBM offers a greater opposition to fluid flow which would lead to circulating pressures being high and therefore increasing pumping costs. Hence, rubber OBM with a lower viscosity will offer less resistance to fluid flow and would lead to a turbulent flow at low pump pressure which would result in good hole cleaning. Therefore, rubber OBM is a good prospect for drilling.

3.1.2. Mud density

Mud density is essentially required to control pressures exerted by the formation and the capacity of the mud to carry drilled cuttings as the suspending fluid could be achieved by an increase in mud density as this has an associated buoyancy effect on the cuttings. As shown in 11, rubber OBM has a higher mud density of 8.0 ppg than compared to diesel OBM with a density of 7.7 ppg. Table 11 also depicts how each mud sample varies with the addition of 10 g of Barite. The result shows a 2.5% increase in the weight of rubber OBM and 3.9% increase in weight of diesel OBM. This implies that the density of rubber OBM can be increased by addition of barite in the event of hole problems that require a high mud weight as the solution.

3.1.3. Filtration loss

A relative indication of how the mud is controlling loss of the base fluid into the formation is given by the fluid loss. This becomes essential when porous formations, particularly those containing oil or gas, are drilled. In porous and permeable formations, the drilling fluid may penetrate the rock and damage the formation. Proper filtration control can minimize or prevent wall sticking and drag and, in some cases, borehole stability could be improved. Figure 11 and Table 10 show volume of filtrate for both muds collected after 30 minutes. The result illustrates that the water volume collected from diesel OBM (14 mL) was higher than that obtained from the rubber OBM (12 mL). The volume of oil collected from diesel and rubber OBM are 12 and 10 mL respectively. Figure 13 shows how filtrate volume increased as time elapsed up to 30 minutes.

3.1.4. Mud cake thickness

The diesel OBM has a greater mud cake thickness than rubber OBM as is shown in Table 10 and illustrated in Figure 12. This is in accordance with the fact that high filtrate volumes are associated with thick filter cake because the cake is formed by deposition of clay particles on the walls of the hole during loss of filtrate to the formation. In view of this, rubber OBM has a thinner mud cake (1.78 mm) than diesel OBM (1.93 mm) as presented in Figure 10. A thick mud cake increases the area of contact that exists between the drill pipe and cake because the effective diameter of the drilled wellbore is reduced as a result of the thick mud cake. The effect of this is an increased risk of stuck pipe incidents.

3.1.5. Heat stability

As can be seen from the trends in Figure 9 and Figure 10, there is a sharp decrease in rheological properties of diesel OBM than compared to rubber OBM when temperature is increased from 60 ºC to 75 ºC. This indicates that rubber OBM will retain its rheological properties than diesel OBM when both are subjected to situations that lead to temperature increase.

3.1.6. Mud pH

The pH of the diesel oil is relatively high and requires little amount of base to increase its pH to the required range of pH for drilling fluids. Unlike the diesel oil, the rubber oil requires more amount of NAOH to bring its pH up to the standard drilling mud pH. Figure 14 shows how the same addition of NAOH to diesel Oil and rubber Oil affect their individual pH.

3.1.7. Economic analysis

Cost for the extraction of rubber oil using Soxhlet method is N3,000 as the rubber seeds were gotten from the rubber tree and the N-hexane (1 liter) costs N3,000. This shows that the cost for the extraction of rubber oil using the Soxhlet method is significantly higher than a liter of diesel which goes for N250 as at the time of this work. If mechanical method had been used, there would have been no expenditure in getting the oil. However, this initial high cost will later be offset when the disposal of rubber OBM and diesel OBM is considered. Unlike diesel oil, rubber oil is easily biodegradable and hence the cost of containment, hauling and disposal of its mud will be cheaper than compared to diesel OBM. Furthermore, rubber used to be a major source of foreign exchange, but with the advent of oil and gas, the rubber industry has suffered neglect with little or no assistance from the government to maintain the rubber plantations. An increase in the demand for rubber oil for use in oil-based mud formulation could lead to revitalization of the Rubber industry and in turn increase in the gross domestic product of the country.

4. CONCLUSION

The drilling fluid’s performance during drilling operation is highly dependent on its properties such as mud density, pH, filtration loss and viscosity, among others. This project has looked at how rubber oil could be made to compete favorably with diesel oil as regards OBM formulation. The following conclusions can be drawn based on the results obtained from this study,

a. Rubber OBM is very viscous and demonstrates fragile gel characteristics.
b. Rubber Oil is highly biodegradable and have better eco-toxicological properties compared to diesel.
c. The formulated rubber OBM has a Bingham plastic rheological model with high gel strength and yield point, mud property desirable for turbulent flow at low pump pressure for effective hole cleaning.
d. Although, the rubber OBM density is relatively high, densifiers can be added to increase its density to desirable values during predictions of equivalent circulating density (ECD) predictions so as to obtain a successful drilling operation.
e. The rubber OBM filtration loss property compared favourably with diesel OBM after thinner was added to reduce the viscosity of the rubber OBM.
f. The pour point of rubber oil is pretty high and hence rubber OBM is not advised to be used in low temperature wells whose temperatures are below rubber oil pour point.
g. Rubber OBM is more thermally stable than diesel OBM and can thus be employed in wells where temperature increases is expected.

REFERENCES

[1] Bello, E. I. and Out, F., “Physicochemical properties of rubber (Hevea brasilienes) seed oil, its biodiesel and blends with diesel,” *British Journal of Applied Science of Technology*, vol.6, no. 3, pp 261-275, 2015.
[2] Adewale, D. and Ogunrinde, J. O., “Development of environmentally friendly oil-based mud using palm-oil and groundnut oil,” *34th Annual International Conference and Exhibition, Tinapa, Calabar, Nigeria,* 31st July-7th August, 2010.
[3] West, G., Hall, J. and Seaton, S, *Drilling Fluids Petroleum Engineering Handbook*, vol.5, pp 89-118, 2006.
[4] Nwaichie, J., “Selection and application of drilling fluids,” 2015. [Online]. Available: http://www.researchgate.net/publication/275334398. [Accessed: 13/03/2019].
[5] Agwu, E. O., Okon, A. N. and Udoh, D. F., “A comparative study of diesel oil and soybean oil as oil-based drilling mud,” *Journal of Petroleum Engineering*, vol. 2015, no. 82845, pp. 1-10, 2015. [Online]. Available: https://www.researchgate.net/publication/275335996. [Accessed: 28/03/2019].
[6] Fadairo, A., Ameloko, A., Adeyemi, G., Ogidigbo E. and Airende, O., “Environmental impact evaluation of a safe drilling mud,” *Society of Petroleum Engineers Middle East Health, Safety, Security and Environment Conference and Exhibition, Abu Dhabi, UAE,* 2nd-4th April 2012.
[7] Fadairo, A. S., Tozunku, K. S. and Kadiri, T. M., “Investigating the effect of electrolytes and temperatures on rheological properties of Jatropha oil-based mud,” *Society of Petroleum Engineers Nigerian Annual International Conference and Exhibition, Abuja, Nigeria,* 6th-8th August, 2012.
[8] Agwu, E. O., Isemin, A. I. and Akpabio, G. M., “Cost benefit analysis of vegetable oils used as alternatives to diesel in the formulation of oil-based muds,” *Nigerian International Conference and Exhibition, Lagos, Nigeria,* 4th-6th August 2015.
[9] Yassin, A.M., Kamis, A. and Abdullah, M. O., “Palm oil Diesel as a base fluid in formulating oil-based drilling fluid,” *Society of Petroleum Engineers Asia-Pacific Conference Perth,* Western Austria, 1991, pp. 190-206.
[10] Xiaoqing, H and Zheng, L., “Research on the Application of Environment Acceptable Modified Natural Macromolecule Based Drilling Fluid,” *Society of Petroleum Engineers Asia Pacific Health, Safety, Security and Environment Conference and Exhibition, Jakarta, Indonesia*, 8th August, 2009.

[11] Feedipedia.org. *Rubber (Hevea Brasiliensis)* [online] Available From: https://www.feedipedia.org/node/39 [Accessed: 10/3/2019].

[12] Anusom62, [Online]. Available: https://www.dreamstime.com/stock-photos-rubberseed-image27353203. [Accessed: 28/03/2018].

[13] Longeron, D., Alfenore, J. and Guiliaume, G., "Drilling Fluids Filtration and Permeability Impairment Performance Evaluation of Various Mud Formulations," *Annual Technical Conference and Exhibition, New Orleans, Louisiana*, 16th September, 1998.

[14] Schlumberger Oilfield Glossary. [Online]. Available: https://www.glossary.oilfield.slb.com/terms/m/mud_density.aspx. [Accessed: 26/03/2018].

[15] Schlumberger Oilfield Glossary. [Online]. Available: https://www.glossary.oilfield.slb.com/terms/f/flash_point.aspx. [Accessed: 26/03/2018].

[16] Schlumberger Oilfield Glossary. [Online]. Available: https://www.glossary.oilfield.slb.com/terms/p/pour_point.aspx. [Accessed: 26/03/2018].

[17] Baker Hughes INTEQ, *Fluid facts Engineering*, Handbook, Baker Hughes, Houston, USA, pp. 397, 1999

[18] Yassin, A.M., Kamis, A. and Abdullah, M. O. "Formulation of environmentally safe oil based drilling fluid," *Paper presented at the Society of Petroleum Engineers Asia-Pacific Conference Perth*, Western Austria, 1991.

[19] King Fahd University of Petroleum and Minerals, *Drilling Engineering Laboratory*, Manual. pp 2., 2003.

[20] Schlumberger Oilfield Glossary. [Online]. Available: https://www.glossary.oilfield.slb.com/terms/f/fluid_loss.aspx. Accessed: 26/03/2018.

[21] Adam, T.B., Keith, K.M., Martin, E.C. and Young, F.S., "Applied drilling engineering," *Society of Petroleum Engineers, Richardson, Texas,* 1986.

BIOGRAPHIES OF AUTHORS

Destiny Josiah Amanze is a graduate researcher who has a flair for Energy systems and efficient utilization of Energy. His research approach is aimed at seeking alternatives to already existing energy sources and efficient use of current energy sources to increase productivity.
Email: destiny.amanze.josiah@gmail.com

Fortune Chukwuebuka Amanze is a graduate researcher at the Department of Electrical Engineering, University of Nigeria, Nsukka in Enugu State Nigeria. His research interests are Renewable Energy Systems, Power Sytems, Power Electronics and Control Systems Engineering. Email: fortuneamanze@gmail.com