



Formulation of Oil Based Mud from Ricinus Communis

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ABSTRACT

In the last few decades, drilling operations involving conventional diesel oil-based mud, have posed a serious threat to the environment. Consequently, operators have been looking towards formulating eco-friendly drilling mud. This paper is aimed at formulating a synthetic oil-based drilling fluid from castor oil as a substitute for the usual diesel oil-based mud. To determine the suitability of castor oil as drilling fluids, the physiochemical properties (Kinematic Viscosity, pour point, Aniline Point, Flashpoint and specific gravity) and rheological properties (Mud Density, Mud pH, Mud Viscosity, Gel strength, and filtration) were tested. A hydrometer was used to determine the specific gravity, the KV-8 temperature-controlled bath was used to determine the kinematic viscosity. Also, mud balance was used to determine the Mud weight, while the OFITE model 900 viscometer was used to measure the viscosity, gel strength and yield point of the drilling mud. The result of the physiochemical analysis of Castor was observed to be in agreement with the available literature on base fluids that are required for drilling fluids formulation. Thus, qualifying castor oil to be used as base oil in drilling fluids. In addition, the result for the rheological analysis of the newly formulated Castor oil-based mud demonstrated great viability for the muds to be used as replacement for diesel-based oil muds. Nevertheless, the only drawback observed for castor oil formulated fluid was its relatively high gel strength – which is not a desirable feature. However, it was established that some chemical additives could be added to the formulated fluid to improve the quality of gel strength.

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INTRODUCTION

Increasing world population has led to a significant rise in energy demand, and thus leading to increased demand for raw materials. This development is the driving force behind the recent advancement in the expansion of unconventional petroleum reservoirs which come with its own peculiar challenges. The unconventional reservoirs come with their own challenges with regards to the type of drilling fluids that will be used. Oil wells have different functions depending on the type of well and the purpose it will be used for. These wells can either be exploration, appraisal, development, product, and relief or injection wells. There are various steps involved in the process of drilling. Some of these

steps involve boring the hole, circulation (drilling mud circulation), casing, completion, production and abandonment.

However, to successfully drill a well, factors such as bit penetrating the rock, cleaning of the bit face, transportation of the cuttings to the surface, and the support of the borehole must be considered (Mitchell and Miska, 2012). To achieve this, the type of drilling fluid used becomes paramount. Drilling fluids are often required to circulate drilling cuttings out of the well. They also assist in maintaining wellbore stability by preventing caving due to accumulated cuttings in the borehole. Drilling fluids are usually used as a primary well control mechanism to prevent kicks that could result in blowout (Khodja *et al.*, 2010).



There are basically three classes of drilling fluid; Oil-based mud (OBM), water-based mud (WBM) and Pneumatic/gas-based mud (GBM). WBM as the title implies, are drilling fluid types that are made of freshwater or saturated brine as the base fluid. These fluids are environmentally friendly; this is because the drill cuttings from using them can be easily disposed. A conventional water-based mud uses polymers as viscosifying agents (Shah *et al.*, 2010). The majority of the oil wells already drilled were drilled with water-based mud (Mitchell and Miska, 2012). Conversely, OBMs are developed for cases where WBM were found to be inefficient (Khodja *et al.*, 2010). They are mostly made up of gas oil (diesel) as the base fluid (Shah *et al.*, 2010). Generally, they are inverted emulsions of brine into a majorly oil continuous phase stabilized by surfactants. Other additives are often added to the mud mix that is the organic phase, such as organophilic modifiers of the clay surface (Khodja *et al.*, 2010). More so, pneumatic (gas) drilling fluids include dry gas (Natural gas, Nitrogen and air) foam, gasified muds and mist which are mostly used in areas of low reservoir pressure, potential loss circulation zones and in underbalanced drilling operations (Azar and Samuel, 2007). Due to their wide application in underbalanced drilling, they are also called underbalanced fluids and are employed for drilling poorly consolidated or fractured formations (Khodja *et al.*, 2010).

Selecting the type of drilling fluid or mud to be used on a particular well depend on the characteristics of the formation to be drilled, the source and quality of water to be used in building the fluid, and the ecological and environmental considerations (Mitchell and Miska, 2011). Drilling fluids that are designed to meet industry specifications with high efficiency are mostly expensive; therefore, companies strive to maintain an "economic-ecological" balance when it comes to choosing drilling-fluid systems and additives (Adesina *et al.*, 2016).

Over the years, water-based drilling fluids are mostly used in shallow wells (Udoh *et al.*, 2012). The problems that arise from this included the pipe (drill pipe) being stuck in the well, this leads to delays in drilling, which in turn causes loss of time and money. According to Cameroon

et al. (2001), oil-based drilling fluids have been used as replacements for water base fluids in these challenging areas of extended reach wells where more challenging borehole sections are encountered. This is because oil-based drilling muds have advantages ranging from optimal shale inhibition, drag resistance to contamination, increasing lubricity, low torque to greater cleaning abilities with less velocity and higher drilling rates. This advantage makes them preferable than water-based muds, but the oil-based fluids are very expensive and have a negative impact on the environment (Adesina *et al.*, 2017). In recent times, organic and synthetic polymer-based drilling fluids have been developed to provide viscosity, fluid loss control, shale inhibition and prevention of clay dispersion which is common with fresh water or salt water-based drilling fluids. Synthetic based drilling fluids were designed to provide the high regarded drilling performance characteristics that conventional oil-based fluids have while significantly reducing the toxicity of the base fluid (Mitchell and Miska, 2012). For this reason; these fluids are mostly used offshore, and they continue to meet the increasing rigorous toxicity standards. The new fluids that are being produced are made from less toxic, environmentally friendly vegetable oils, which are used as based fluids in the formulation of these drilling fluids. These base fluids are expected to meet certain standards to make sure they will be sustainable; these standards are measured from the physio-chemical properties of these fluids. These properties include the kinematic viscosity, the pour point, flash point, aniline point temperature. These properties determine the quality of drilling fluids that will be produced (i.e. that affect the rheological properties of the drilling fluids).

Nevertheless, this paper seeks to analyze the physiochemical properties of Castor oil and justify it for use as base fluid for drilling fluids. It also focuses on formulating an oil-based fluid using castor oil (*Ricinus communis*) while analyzing its rheological properties in comparison with commonly used base fluids.



THEORIES AND DEFINITIONS

Synthetic Based Muds

In the course of the last decade, drilling operations have shifted from conventional methods to unconventional methods, thereby giving rise to the need to develop drilling fluids that are most suitable for the unconventional trends. This has led to the development of Synthetic Based Muds (SBM) which are also known as Low Toxicity Oil Based Muds (OBM). SBMs were developed to have the highly regarded drilling performance characteristics of the conventional Oil Based Muds with reduced toxicity (Mitchell and Miska, 2012). SBMs are mostly used on offshore rigs because of its properties, especially because of the similarity of its properties with that of the OBM and the toxicity of the fluid fumes are much less than that of the conventional OBM (Sharma, 2015).

Although these fluids continue to meet the increasingly rigorous toxicity standards imposed by the regulatory bodies, the cost per barrel is considerably higher when compared to the equivalent density of Water-Based Muds (WBM). Synthetic based muds facilitate a higher Rate of Penetration (ROP) and minimise wellbore stability problems when compared to the other mud types therefore, the overall well construction cost for the wells are greatly minimised except in cases where severe lost circulation occurs (Mitchelle and Miska, 2012).

Burke & Veil (1995) and Neff *et al.* (2000), compared the cost of drilling wells using SBMs and those drilled using WBMs and it was discovered that using SBM reduced the drilling times by 50 – 60% and the overall well cost was reduced in half because the cuttings were discharged into the sea. If the cuttings will not be discharged, the added cost of transportation to the shore for land disposal may make using SBM cost-prohibitive.

Recent Developments in Synthetic Oil Based Drilling Muds

Formulated a synthetic based mud from soybeans oil extracted using the Soxhlet Extraction method and compare the properties with that of the conventional diesel-based mud (Agwu *et al.*, 2015). This study showed that drilling

mud from soybean oil displayed characteristics of a fluid with a Bingham plastic rheological model having a relevant low gel strength and yield point when compared to the diesel-based mud. On comparing the mud weight, it showed that the weight/density of the mud formulated using soybeans oil was slightly higher than that of the diesel-oil based mud.

Agwu *et al.* (2015) revealed that the result from the filtration revealed the filtrate loss from the soybeans oil-based mud was less than that of the diesel OBM, this means that when using the soybean oil-based mud, the filter cake formation will be better and there will be less interaction between the formation fluids and the mud. It was then concluded that the soybean oil had superior rheological properties when the conventional OBM and other vegetable oil-based muds. In comparison with previous published works in the literature, the soybean oil mud exhibits superior rheological and filtration properties over other vegetable oil-based muds. Also, the newly formulated mud had desirable properties which would compare favourably with that of the diesel-based mud. Problems with stuck pipe during drilling will be averted. Meaning that soybean oil can be used to formulate drilling muds of better properties with little or no environmental concerns.

The challenge with this new formulation however remains that the cost of soybeans oil per barrel is higher than the cost of diesel per barrel. This will increase the total cost of formulating the drilling fluid. However, this cost will be offset by the superior rheological properties of the mud, which will reduce the total rig time, thereby reducing the total drilling cost. Also, soybean oil is environmentally friendly (biodegradable) when compared to diesel in terms of cutting disposal and minimal liability in case of spillage (Agwu *et al.*, 2015)

Other researchers developed an oil in water emulsion system using jatropa oil (Paswan *et al.*, 2016). This was done to find an alternative to diesel-based oil base muds in order to overcome the strict environmental regulations limit. The study analysed thoroughly the effect of bentonite clay, oil and carboxymethylcellulose (CMC) on the rheological properties and fluid loss control



parameters of the developed. The result showed that the jatropha oil in water emulsion system had better filtration and rheological properties compared to the diesel-based mud. The newly developed mud had a lower friction coefficient compared to the diesel OBM, this means it has a relatively higher lubricating power in comparison. The Jatropha oil-in-water mud system has a low formation damage effect and high shale recovery performance when core flow study and shale recovery test was carried out. For this study, the zeta-potential measurements were done to examine the emulsion stability when adding the different additives. The result showed that the stability of the emulsion was enhanced with the addition of CMC (0.1 – 1.0 wt./v%) and clay (0.5 – 4.0 wt./v). Hence the conclusion that the Jatropha oil in water emulsion mud system has a great potential in the development of emulsion muds desired for drilling wells (Paswan et al, 2016). In a similar approach, Udoh *et al.* (2012) developed a synthetic based mud using palm fruit pulp and tested its rheological properties alongside its pH and density. Results from this analysis show that the tested properties of the new mud compare favourably with those of the conventional OBM though its density and pH were slightly below the acceptable standard for any drilling operation. The properties of the newly formulated mud were improved using soda ash (Na_2CO_3), local starch (cassava), barite (BaSO_4) and local charcoal, with the addition of these additives, the properties improved substantially. Udoh *et al.* (2012) further stated that properties such as yield point and plastic viscosity increased by 11% and 34.62% respectively with the addition of 4.0g Na_2CO_3 , 6.0g local charcoal and 10g local starch to the formulated drilling fluid. Also, the pH value improved by about 58.27% and the mud density increased by about 15.66% when 15g Barite (BaSO_4) was added to the system. It was concluded from the results that with the right additives, the palm oil-based drilling mud can be used in place of the conventional oil-based mud, because it has low toxicity; therefore, cuttings for disposal meet the environmental regulation limits without any need for further treatment. Similarly, Nwakezie and Ogbeide (2017), extracted oil from Gmelina which is a non-food plant seed oil to use

as base fluid for the drilling mud. The oil was tested to ensure that it certifies the requirement for based fluids in drilling fluid formulation. Results from this analysis revealed that Gmelina seed oil met the requirements and is suitable for use as base fluids in the formulation of drilling muds. An oil in water emulsion of ratio 60/40 was formed, and 50g of bentonite and barite were finally added to build up the density to 10ppg. Rheological properties of the mud were carried out and compared to the properties of the conventional diesel OBM. Tests such as toxicity, filtration, pH, viscosity and density were carried out on the samples to ensure that they will be suitable for use in drilling operations. From the results obtained, it was noticed that the Gmelina seed oil-based mud had a lower viscosity meaning less resistance to flow at low pressures. The toxicity test confirmed that Gmelina is safer and less harmful compared to diesel which is highly toxic due to its high hydrocarbon content. The final result of this study showed that Gmelina seed oil-based muds is a possible replacement for the conventional diesel OBMs that is technically and environmentally viable. More so, in a review conducted by Ashraf et al. (2021), it was established that biodiesel can be used for formulating drilling fluids. The review demonstrated the characteristics of biodiesel such as non-toxicity, excellent biodegradability, high flash point etc. that qualifies it as an eco-friendly base fluid. However, some bottlenecks identified in its use are as follows;

1. Biodiesels were found to possess high chemical reactivity, thus causing them to react with some drilling mud additives.
2. Also, at high temperatures of about 125°C , the resulting drilling mud becomes deficient.

Flow models of fluids

According to Rajput (2013), fluid flow models are basically classified into two; Newtonian and Non-Newtonian fluids. This classification is based on the resistance of fluid flow, i.e. viscosity. However, Newtonian fluids are in accordance with Newton's law of fluid flow which states that the shear stress on the fluid element layer is directly proportional to the rate of

shear strain (Rajput, 2013). A Newtonian fluid is one in which the shear rate increases linearly with shear stress over a wide range of shear rates, provided the temperature and pressure remains constant. Some examples of Newtonian fluids include water, organic solvents, oil, gasoline,

alcohol, glycerine, and honey. For those fluids, viscosity is only dependent on temperature. Newtonian fluids give a linear relationship between PV and shear rate. Meanwhile, Non-Newtonian fluids are non-linear in relationship.

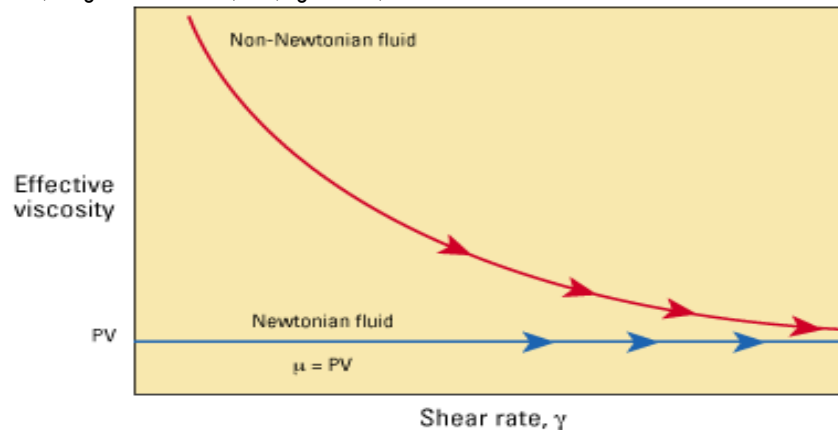


Figure 1: Linear relationship between shear stress and shear strain of Newtonian fluids (Schlumberger Oilfield Glossary online: <https://www.glossary.oilfield.slb.com>)

Conversely, for non-Newtonian fluids, they tend to exhibit a mixture of both liquid and solid properties. These fluids under certain conditions exhibit Newtonian behaviour, but in other conditions they exhibit plasticity. Meanwhile, plasticity, strength and elasticity are properties of solids. Also, the viscosity of this type of fluids changes with a change in shear rate. Most non-Newtonian fluids are said to contain a second phase in suspension and the ratio of the shear rate to the shear stress is not constant and the apparent viscosity of the fluid is a function of the shear rate. That is, it exhibits rheological properties. Figure 1 shows a graphical relationship between effective viscosity and shear rate for Newtonian and Non-Newtonian fluids.

Castor oil

This is a product of castor bean and has been considered as a product with a considerably significant commercial value majorly in the manufacture of lubricants, coating and soaps, among many others. The oil is gotten by pressing the seeds of the castor plant (Patel et al., 2016).

The plant is mostly cultivated in Africa, South America and India (Patel et al., 2016). Castor oil is known to be mostly grown in Eastern Africa but was introduced to China and India about 1400 years ago. India has been identified as the major exporter of oil, accounting for over 90% while the United States, European Union and China top the importers table. Castor oil is considered very important to the global raw material used in the chemical industry and this is because it is the only commercial source of hydroxy fatty acid (Severino et al. 2012). Though it accounts for only about 0.15% of the total vegetable oil production of the world, its world consumption has increased to more than 50% during the last 25 years growing up to about 610,000 tonnes in 2010 from about 400,000 tonnes which was recorded in 1985 (Severino et al. 2012; Scholz and Da Silva, 2008). Patel et al., 2016 further states that on an average, the total consumption of castor oil around the world increases by about 7.32 thousand tonnes per year and the current rate of production is insufficient to meet the anticipated increasing demand. Figure 2 shows a specie of castor seeds.



Figure 2: A specie of castor seed

The plant grows optimally in tropical summer rainfall areas hence its origin from Africa. It grows in the wet tropics and subtropical dry regions, having an optimal growing temperature of 20 - 25°C (Patel et al., 2016). The high oil content of the seed can be linked to the warm climate which it thrives in, though temperatures over 38°C lead to a poor setting for the seeds. It has also been known that the plant will not survive temperatures that a low enough to cause frosting. Various methods of methods of extracting oil from castor seeds have been developed in recent times. These processes include continuous screw presses, hydrate presses, and solvent extraction.

However, the most effective is using the hydrate press followed by the solvent extraction method (Ogunniyi, 2006; Mohammed *et al.*, 2017). The castor plant is mostly cultivated for their seed which yields a viscous, pale yellow, non-volatile non-drying castor oil (Patel et al., 2016). The physical properties of the oil have been studied and are presented in Table 1. According to Kassem *et al.* (2014), comparing the values of thermal conductivity, viscosity, pour point, and density showed that these values were high for castor oil than those of a standard lubricant (SAE 40 engine oil).

Table 1: Physical properties of castor oil (Patel et al., 2016)

Parameter	Value
Viscosity (Centistokes)	889.3
Density (g/mL)	0.959
Thermal Conductivity (W/m°C)	4.727
Specific heat (kJ/kg/K)	0.089
Flash Point (°C)	145
Pour Point (°C)	2.7
Melting Point (°C)	-2 to -5
Refractive index	1.480

Shrirame *et al.* (2011) and Ismail *et al.* (2014) stated that castor oil can be distinguished by its high content of ricinoleic acid (about 85% - 90%), other constituents of this oil include 4% linoleic, 3% oleic, 1% stearic, and less than 1% linolenic fatty acids. No other vegetable oil contains a high portion of hydroxy acids, which is a function of the ricinoleic acid present in the oil.

This property gives the oil oxidative stability, a relatively high shelf life compared to other oils by preventing peroxide formation. The oil has a very high molecular weight of about 298g/mol, very low melting point of about 5°C, very low solidification point of -12°C to -18°C making it industrially useful and it is known to have the most stable viscosity compared to other vegetable oils (Ismail *et al.*,

2014). The chemical structure of castor oil (see Figure 3) is of great interest, and this is because of the wide range of reactions it affords to the

oleochemical industry and the unique chemicals derived from it.

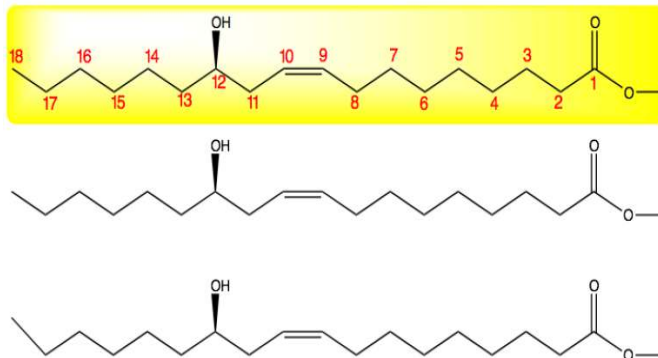


Figure 3: chemical structure of the castor oil Ricinoleic acid primary constituent (Patel et al., 2016)

METHODOLOGY

The castor seeds used in this paper, was sourced from Jos, Plateau State, Nigeria. The castor seeds were sundried and dried further in the oven at a temperature of about 180°C. They were roasted, then crushed using a pestle and mortar until well grounded. Oil was extracted from the castor seeds through the use of a Soxhlet extractor which operates on the principle of solvent extraction.

Equipment used for this study were from different laboratories which include the Chemistry, Drilling Engineering and Reservoir Engineering laboratory at Nile University of Nigeria Abuja, Quality Control Laboratory at the Kaduna Refinery and Petrochemical Company (KRPC), and the National Research Institute for Chemical Technology (NARICT). The reagents and materials/equipment used for this paper include; Bentonite, Barite, Water, castor seeds, Cork, Filter Papers, Soxhlet Extractor, Mass Balance, Conical Flasks, Rotary Viscometer, pH Meter, Separating Funnel, Mixer, Hot Plate, Stirrer, API Filter Press, Mud Balance, Resistivity Meter, Beakers, Heating Mantle, Retort and Clamp, Measuring Cylinder, Condensers, Round-Bottom Flasks, Reagent Bottles, Mortar and Pestle, Spatula, Vernier Calliper, Oven, Cleveland Open Cup Flash Tester, Methanol, and Sodium Hydroxide.

Mud formulation and Physiochemical Properties Characterisation

Castor oil-based drilling mud was formulated to see if it can be used as an alternative to the conventional diesel oil-based drilling mud in the industry. To formulate the drilling mud, the materials to be used are mixed together using either a mud mixed or a simple hand blender. 245ml of castor oil was measured in the measuring cylinder and kept, 105ml of water was measured in another measuring cylinder and kept. The same was done for 10ml of emulsifier in a measuring cylinder and the weighed 25g of Bentonite. The measured castor oil was then poured into the mixing cup and mixed thoroughly for 5mins before adding the measured water and allowing it to mix for another 5mins before adding the emulsifier. The mixer was allowed to run for 10 mins and the emulsion stability was tested using the electric stability tester. Another 10ml of emulsifier was added to improve the emulsion stability, and it was allowed to mix for 5mins. This was continued until a suitable stability was reached. 25g of bentonite was then added carefully to avoid the formation of lumps, then allowed to mix for another 10mins. The mud sample was then poured into a beaker and allowed to age for 24 hours.

Meanwhile, physiochemical properties of the extracted castor oil sample were obtained via the use of relevant apparatus as indicated in



the previous sections. Properties that were obtained include; kinematic viscosity, flash point, specific gravity, pour point, aniline point. The flashpoint was determined to measure the temperature at which the castor oil will begin to burn, and to also know whether the oil will make a suitable base fluid for the formulation of the drilling fluid. More so, rheological properties of formulated mud sample from castor oil were determined using relevant apparatus. Rheological properties of

formulated mud tested include; mud weight, mud filtration, emulsion stability and mud viscosity.

RESULTS AND DISCUSSION

To determine the physiochemical properties of castor oil, the following tests were carried out in the laboratory; pour point test, flash point test, specific gravity, aniline point test and kinematic viscosity test. Table 2 below gives a summary of the results of this analysis, comparing them with the standard requirements of base oils to be used for the formulation of drilling fluids.

Table 2: Comparing properties of Castor oil, and the standard requirements for base oil properties

Property	Specific gravity (g/cm ³)	Kinematic viscosity at 40°C (Cst)	Flash Point (°C)	Pour point (°C)	Aniline Point (°C)	Acidity
Required properties	N/A	2.3 – 3.5	>66	< Ambient temperature	>65	N/A
Castor oil	0.953	315.19	85	-15	147	13.98

In the pour point test, the measured pour point temperature for the castor oil was -15°C. This result is in a range less than ambient temperature and therefore is suitable for use as base fluid/oil for oil-based drilling fluids (Agwu *et al.*, 2015). Since properties of the base fluids determine the properties of the mud, having a very low pour point will mean that drilling fluids formulated with these base fluids can be stored at very low temperatures and still be easily pumped in and out of the drilled well. Also, the result of flashpoint test for castor oil showed a value of about 85°C which is above 66°C. According to Agwu *et al.* (2015), base oils must have flash point greater than 66°C, and thus makes the castor oil a suitable candidate for use as base oil for formulating drilling fluids. Results from the specific gravity test showed that the castor oil has a specific gravity of 0.953 at 28.2°C. This result tallies with the 0.953 according to Patel *et al.*, (2016). Compared to the specific gravity of jatropha oil (0.904 g/cc) castor oil has a considerably higher specific gravity, this means the drilling mud produced will have a higher mud density. Result for the determination of the kinematic viscosity at 40°C shows that castor oil has a viscosity of about 315.19 centistokes. This value is higher than the standard requirement for

viscosity as stated in Agwu *et al.*, (2015) – which is meant to be between 2.3- 3.5 centistokes. In addition, the aniline point temperature for the extracted castor oil was estimated as 147°C. This qualifies the oil as a good base fluid since it surpasses the minimum requirement of 65°C.

Table 3 presents the mud density result in pounds per gallon (ppg), the equivalent density, pH and specific gravity. This property is important as it controls the hydrostatic pressure in the wellbore, thereby preventing caving in of the well and the flow of the formation fluids into the well. It is important to control the density of the mud because when the weight/density of the drilling mud is too high, it can lead to loss of circulation through propagation and then the filling of the rock fractures. The weight of the castor oil-based drilling mud was measured as 8.10ppg (pounds per gallon) while its pH was observed to be 8.20. As compared to the mud density of diesel oil-based drilling mud, castor oil was observed to have a higher mud weight than that of diesel oil-based mud. This is reflective that castor oil-based drilling mud is capable of providing a higher hydrostatic pressure burial while drilling, thus making it suitable as a primary kick control method. The pH of the mud is important because

it allows operators to monitor the corrosive capabilities of the drilling fluid.

Table 3: Result of pH, Mud weight and the calculated Specific Gravity

Sample	Mud Weight (ppg)	SG	Mud weight (Kg/m ³)	pH
Castor Oil-based mud	8.10	0.972	970.59	8.2
Diesel oil-based mud	6.89	0.828	826.00	-

The results for the emulsion stability (ES) with increasing emulsifier volumes for the castor oil-based mud is illustrated in Figure 4. The emulsion stability is a parameter that represents

how stable an emulsion is. However, it was noted from the chart that the ES values increased with increasing amounts of the emulsifier.

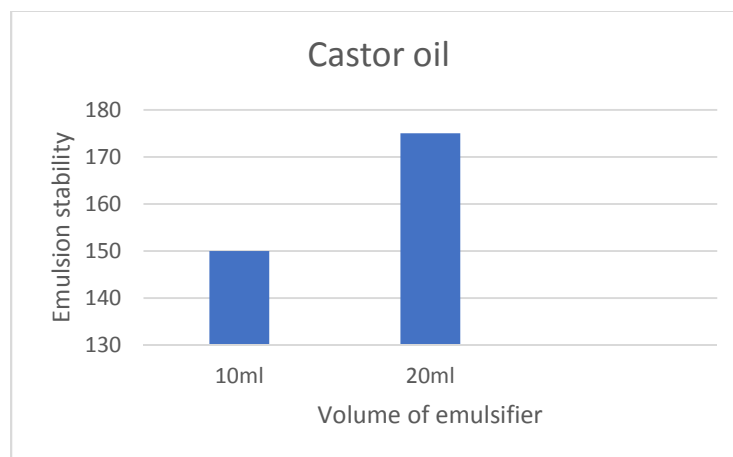


Figure 4: Emulsion Stability with increasing volume of Emulsifier for castor oil

Moreover, shear stress and shear rate of the castor oil formulated mud were recorded in lb/100ft² and the viscometer readings in centipoise. The values of plastic viscosity, yield point, and the 10 seconds and 10 Minutes gel strength was obtained from the viscometer while the apparent viscosity was calculated from the equation below.

$$\text{Apparent Viscosity} = 1/2 \times \theta_{600} \quad (1)$$

As shown in figure 5, the castor oil formulated mud was observed to have a Bingham

Plastic model behaviour at low shear rate. That is, until the shear stress exceeds the yield point, the fluid will not flow. This is similar to the model exhibited by soy oil-based mud. This same behaviour is exhibited by other vegetable oil-based drilling muds such as the algae, jatropha, canola, and moringa and soy oil (Agwu *et al.*, 2015). However, a different behaviour was observed at high shear rates. This may be attributed to the presence of contaminants.

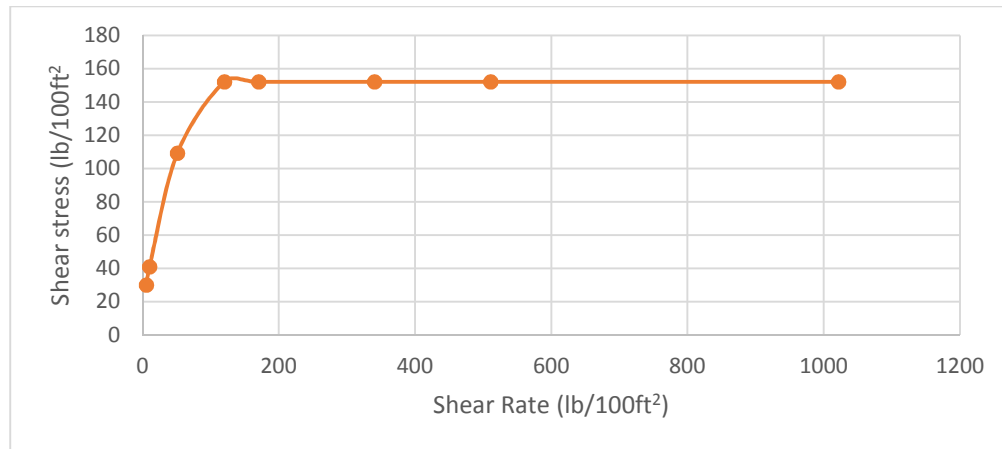


Figure 5: Shear Stress – Shear Rate Profile for castor oil-based formulated mud

Often times, when the yield point is exceeded, changes in the shear stress become proportional to the shear rate and the constant of proportionality is referred to as the 'plastic viscosity'. From Table 4, it can be noted that the castor oil-based drilling mud has a somewhat low plastic viscosity of 0.1cp. However, a high yield point of 152.1Pa was observed for the formulated mud. This means it could bring about problems of pressure loss when used. This property can be adjusted to meet requirements with the addition of mud additives.

The gel strength is a key parameter to determine the fluid's ability to suspend drilled solids and weighing agents in an instance when the mud circulation is stopped. The 10 sec and 10 min gel strength values are presented in Figure 6. This shows that the castor oil-based mud has a high gel strength of 135cp at 10secs and 62cp at 10mins. This feature is not desirable in drilling fluids because high gel strength can lead to a breakdown in the circulation pressure which will require a high pump power to fix, thereby increasing cost. Notwithstanding, some additives could be added to improve gel strength quality.

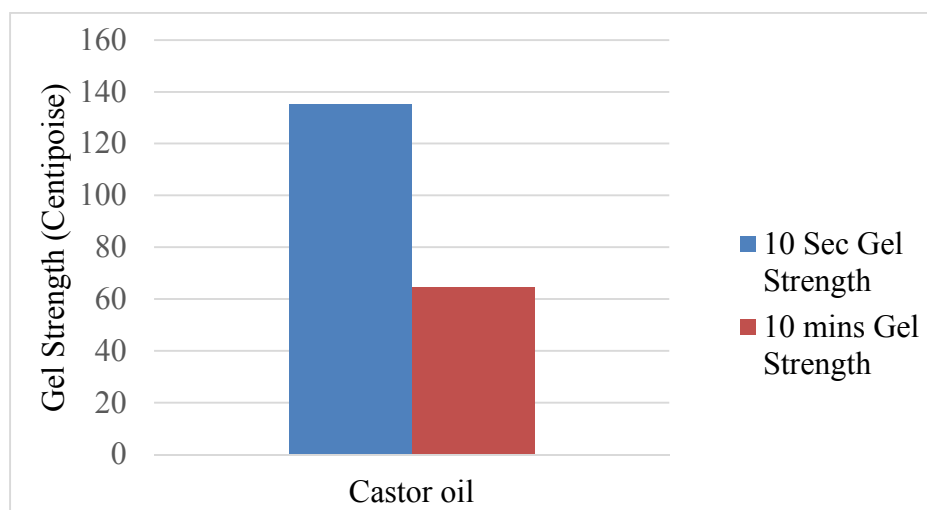


Figure 6: Gel Strength of castor oil-based drilling mud



Table 4: Result for Plastic Viscosity, Apparent Viscosity, Yield Point, And Gel Strength of Castor oil-based Formulated Drilling Muds

Property	Value
Plastic viscosity (cP)	0.1
Apparent Viscosity (cP)	74.50
Yield Point (Pa)	152.1
10 Sec gel strength	135.3
10 Mins Gel Strength	64.9

Finally, the next rheological property that was obtained from the formulated drilling mud sample is filtration rate – which was determined from conducting a filtration test experiment. The filtration rate is a very important property to measure for drilling muds, especially when it will be used to drill loose formations with abnormal pressure. Having a good control of the filtration

can reduce the chances of differential sticking, and improve wellbore stability (Agwu, 2015). The filtrate loss from the newly formulated mud after 30 minutes can be found in Figure 7. From the result, it can be noted that the total filtrate volume was highest in the castor oil formulated mud after 30 minutes (which was 10ml).

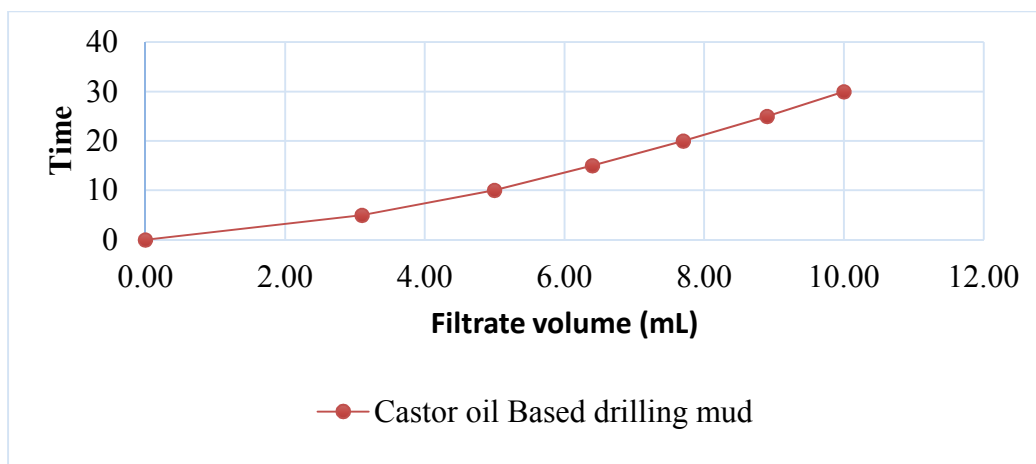


Figure 7: Rate of Filtration of the Mud during Filtration Test

CONCLUSION

This paper has successfully demonstrated that castor oil-based drilling fluid can be used in the place of diesel oil-based mud. First, castor seeds were sourced from a local market in Plateau State, Nigeria. After that, castor oil was extracted from the castor seeds using a combination of soxhlet extraction and mechanical pressing (traditional method) for optimum recovery of castor oil from the seeds. However, laboratory tests were performed on castor oil to obtain the physiochemical properties of the oil. Invariably, results from the experiment were compared with other synthetic oils from literature, and it was established that castor oil is in

agreement with API standards for base fluids. An oil-based drilling fluid was formulated using castor seed, and analysis was performed on the rheological properties of the formulated fluid. The rheological properties were also in compliance with standard API requirements. Moreover, the gel strength of the formulated drilling mud did not perform well enough as desired. Thus, it was recommended that future research be performed to improve the quality of gel strength for castor oil-based synthetic drilling mud.

To sum up, this paper has proved that formulation of synthetic-based mud using castor oil can be used to replace diesel oil-based mud during drilling. This is necessary as the former is



more environmentally friendly than the latter and thus, would reduce treatment costs while complying with environmental agencies.

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