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Performance evaluation of oil based drilling fluid formulated with castor oil

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Oil based muds formulated from diesel oil have proven to be quite expensive and environmentally unfriendly. This current study focused on investigating the suitability of castor oil in formulating oil based muds. The experiment in this work was conducted at different temperature conditions ranging from 40 to 80°C. The density and specific gravity of castor oil based mud were found experimentally to be 0.3 ppg and 0.4 higher than the density and specific gravity of diesel oil based mud, respectively. Plastic viscosity and gel strength of castor oil based mud were found to be 2 cp and 2 lb/100 ft^2, respectively found to be less than those obtained for diesel oil based mud (15 cp and 4 lb/100 ft^2, respectively) indicating the ability of castor oil in enhancing rate of penetration and efficient in hole cleaning. Results also show that a thinner filter cake was obtained for castor oil based mud in comparison to diesel muds. This shows that with castor oil based mud, undesirable effects such as differential sticking, loss circulation and poor primary cement jobs are minimized. The result from toxicity test also implied that the drilling mud formulated with castor oil can be easily disposed with less post drilling treatment. In conclusion, oil based mud formulated with castor oil can be used as an alternative to diesel oil based mud for drilling operations because its properties show that it can effectively perform its functions as a drilling fluid. It is also environmentally friendly.

Key words: Oil based mud, castor oil, diesel oil, rheological properties, drill cuttings.

INTRODUCTION

The petroleum industry is a vital sector globally considering the numerous industries and activities that depend on the oil industry for production and service delivery. Drilling of wellbores is an important operation involved in the development of an oil field; as it enables the installation of tubing and pipes for conveying crude oil from the reservoir to the topsides (Rao, 2000). Also, considering the typical geology of the reservoir in focus, drilling operations could be expensive in terms of the general cost of operation (Khodja et al., 2010). Currently in the industry, water based mud and oil based mud are the main categories drilling fluids used in oilfield drilling

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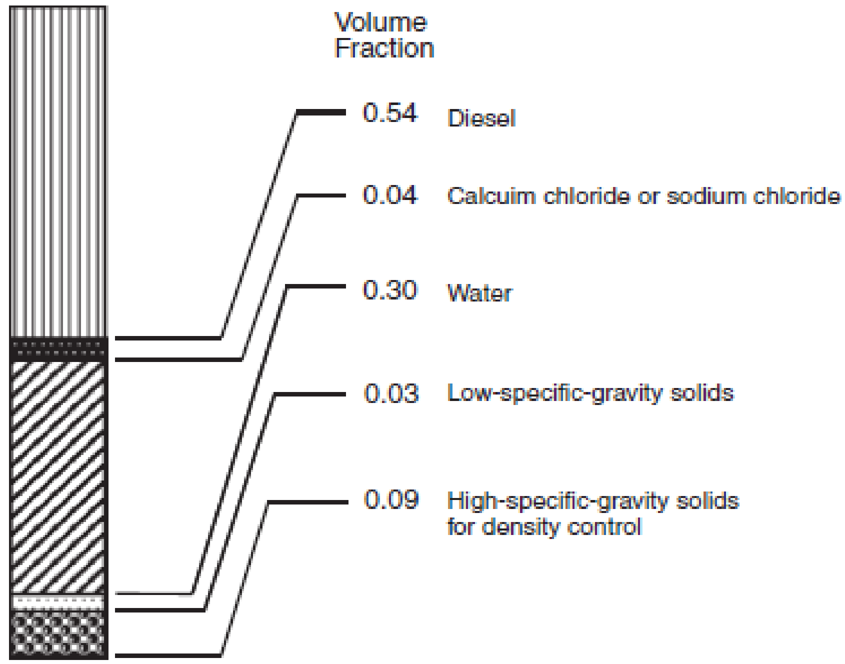

Figure 1. Components of an oil based mud.
Source: Bourgoyne et al. (1991)**.**

operations (Meng et al., 2012). OBM is the most efficient type of drilling mud; as it ensures stability within the wellbore at varying temperatures, enhancement of borehole stability and lubrication of drilling equipment (Khodja et al., 2010).

Drilling muds are quite critical to the smooth execution of drilling operations as they play a vital role in completing a well safely and enhancing the economics (Petri and Queiroz, 2010). Properly designed drilling muds often assists the operator to attain the target depth at an optimum cost, good rate of bit penetration, more efficient bit cooling, mitigation of possible damage of the borehole, efficient movement of drill cuttings to the topsides after drilling operations and subsequent adherence to environmental regulations (Amanullah and Yu, 2005).

A drilling fluid must typically withstand high temperature without collapsing or failing to perform its functions. In the oil industry, usage of Oil-Based Mud (OBM) is specially considered. Some special considerations for oil based mud are as follows: environmental issues such as proper disposal of drill cuttings in a suitable location and to avoid contamination of the environment. Typically, the category of oil for deployment in an OBM system should be carefully considered when formulating oil based drilling mud. OBM could be formulated via a base fluid from refined petroleum, such as diesel oil or other types of oils. According to Bourgoyne et al. (1991), a typical oil based mud is made up of about 54% by volume of diesel oil, 30% by volume of water, 4% by volume of calcium chloride or sodium chloride, 3 and 9% by volume of low and high specific gravity solids (Figure 1). Oil Water ratios for OBM ranges from 90:10 to 60:40.

Oil based muds formulated with diesel oil have proven to be effective in drilling troublesome and high saline shale formations despite being expensive and unfriendly to the environment (Fadairo et al., 2012). This has prompted oil and gas industry stakeholders to carryout research aimed at formulating environmentally friendly oil based mud solutions which can serve as alternatives to the industry standard diesel oil based mud. Drilling fluid properties such as mud density, mud viscosity, pH, filtration loss, gel strength, etc., influence the performance of drilling fluids during drilling operations, and these properties will be used in making comparisons between the conventional diesel oil and castor oil in formulating OBM in this paper.

Different researchers have conducted different studies to evaluate the effectiveness of oil based muds formulated with different types of oils other than diesel. The researchers made technical performance, economic and environmental comparisons of these oil based muds with those formulated with the industry standard diesel oil.

Dosunmu and Ogunrinde (2010) developed oil based muds from palm oil and groundnut oil and compared their rheological and eco-toxicological properties with that of diesel oil. Results from their study showed that palm and vegetable oil based muds were eco-friendly, highly biodegradable, possess better eco-toxicological properties and drill cuttings treatment cost were lower in comparison with oil based mud formulated with diesel oil.

Anawe et al. (2014) conducted a comparative assessment of the performance of *Jatropha* and groundnut oils with diesel oil in formulating oil based muds for drilling operations. Results from their study showed that oil based muds formulated with *Jatropha* and groundnut oils were more effective than that formulated with diesel oil indicated by viscosities for *Jatropha* and groundnut oil based mud being higher than that of diesel based muds at all temperatures. Also, the mud density for the *Jatropha* and groundnut oil based mud was also found to be higher than that of diesel oil based mud. This makes these two oils more preferable than oil based muds formulated with diesel oil.

A comparative study was conducted to investigate the rheological properties of oil based mud formulated with diesel oil and plant seed oil or *Gmelina* (Nwanekezie and Ogbeide, 2017). A toxicity test was also conducted by the authors and *Gmelina* was found to be safer and less harmful in comparison to diesel which was found to be highly toxic. In summary, results from this study show that *Gmelina* seed oil can serve as an alternative to conventional diesel oil based mud because it is technically viable and environmentally friendly.

Soybean oil has also been investigated by El Fakharany et al. (2017) as an environmentally friendly, technically viable and cost effective solution for formulating oil based muds. It possesses excellent physiochemical and rheological properties and high thermal stability in HPHT wells.

Kumar et al. (2020) used extracts from Indian mango seed oil together with methyl ester in formulating an oil-in-water drilling mud which was found to perform better than the industry standard diesel oil based mud.

Optimum drilling fluids from well formulated OBM could also moderate the cost of handling involved in drilling operations, and the negative environmental effects associated with standard diesel OBM (Dosunmu and Ogunrinde, 2010). OBMs are basically a combination of asphalt and diesel oil. However, OBM are often based on crude oil produced from the production facility and drilling mud. OBMs are generally considered as having the most negative effect on the environment (especially diesel) and subsequently, they are no longer in use in the North Sea (Kjeilen, 1997). Industry efforts as well as research and development efforts has recently been focused on the development of novel drilling muds as a result of the need to comply with the strong environmental protection legislation being enacted in various oil producing countries. These novel samples of drilling muds possess less damaging impact to the environment, as part of their design, that is, they possess bio-degradable characteristics as well as less toxicity potentials when being compared with natural oil-based drilling mud (Cripps et al., 1998). Several research works on understanding the effect of oil-based drilling mud cuttings have shown an important negative effect on the benthic fauna and flora organisms (Gray et al., 1990). Relatively high presence of toxins in the OBMs being used today constitutes a detrimental effect on the environment. Diesel oil are not bio-degradable; thereby leading to a possibility of toxins persisting for several years within the environment and giving rise to an accumulated toxin concentration over a period of time with subsequent harsh impacts on the environment, including:

(1) Reduction in animal and plant growth
(2) Disruptions of reproductive cycles
(3) Death of animals and plants within the locality the mud is disposed.

Hence, the need for a more environmentally friendly OBM cannot be over-emphasized; as the current ones available in the petroleum industry, present huge negative effects on the environment. Associated cost for the OBMs currently in use in the industry is relatively high. There is an urgent need to develop more cost-effective oil for the formulation of oil based drilling fluid, in order to moderate the associated relatively huge cost of drilling, especially on offshore oil fields. Consequently, a higher commitment in this respect, will lead to generation of less expensive and environmentally friendly drilling muds that could replace diesel in the oil industry as the major oil based mud. There is a huge focus in recent times on development of new oil based muds that are environmentally friendly (Sáchez et al., 1999).

Bio-degradable non-edible castor oil has numerous industry applications such as lubricant production, polish manufacturing and wax production, paint production and the production of biodiesel (Mistri et al., 2011). The residue of the *Ricinus cummunis* seed after crushing, serves as a fertilizer once the inherent toxin has been removed. An average of 46 to 55% oil by weight, is contained in a typical castor oil seed; even though there are several species of the *R. cummunis* seeds. About 90% (18:1) recinuleic acid is contained in the new castor oil; which is special among vegetable oils and possess the hydroxyl group near the double bond; thereby improving the viscosity in comparison to some other sample oils (Ogunniyi, 2006; Scholz and Da Silva, 2008). Oil from *R. cummunis* has other special characteristics which include: great affinity for metal surfaces and highly polar (Ogunniyi, 2006).

There are numerous environmentally associated challenges with complex drilling muds in general, and oil-based mud (OBM) in particular. Generally, an optimum drilling mud is one that has capacity to move drilling cuttings to the topsides, from the bottom section of the borehole, keep drill cuttings and weight materials suspended when circulation is stopped, and also ensure pressure maintenance. An efficient drilling mud also performs these functions at minimum operational costs, considering the Health, Safety, and Environment (HSE) policy. Previous research in this area is focused on generating oil from plants to enable to formulation of

Table 1. List of experimental materials and equipment.

Materials	Key equipment
Bentonite	Weighing balance
Barite	Hamilton Beach Mixer
Castor oil	Methylene blue kit
Diesel oil	Mud Balance
Sodium carbonate	API Filter press
Bean plants	-
Laboratory glass wares	-

Figure 2. Bentonite.

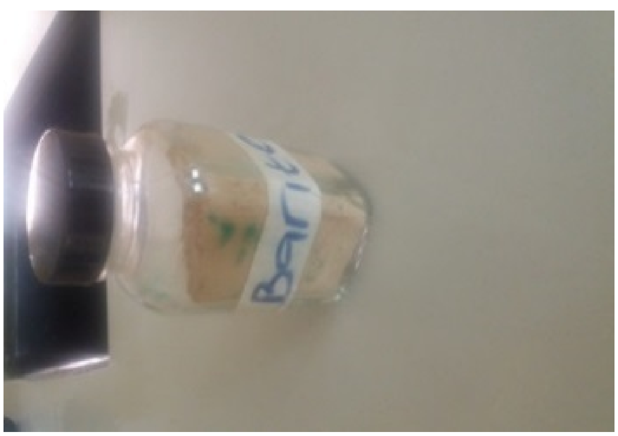

Figure 3. Barite.

more environmentally friendly and effective OBMs. Popular seeds considered so far include: *Jatropha* oil, Mahua oil, Rapseed oil, palm oil, soya bean, etc. This captures the significance of agro-allied contribution towards the energy industry. Therefore, the significant contribution of oils such as castor oil, which are non-edible will be relevant as a plant oil source substitute for diesel oil in the development of OBMs.

Figure 4. Diesel oil.

METHODOLOGY

This aspect of the study analyses the apparatus and procedures used in carrying out the formulation of the mud samples. It details the type of tests that were performed on the oil base drilling fluid formulated with castor oil and diesel oil (standard for oil based muds) with the aim of assessing the effectiveness of using castor oil as an alternative to diesel oil in formulating oil based mud. The corresponding tabulated data for each experiment is also available. The experiments are as follows: density and specific gravity measurements, rheology tests, filtration test, pH test, test for solid and oil volume, methylene blue test, and toxicity test. Two mud samples were formulated in the laboratory as part of this study. Castor oil and diesel oil were used in preparing two drilling mud samples.

Materials and equipment

Key equipment and materials deployed in this research study are presented in Table 1. Figures 1 to 4 show respectively illustrations of bentonite, barite, diesel oil and castor oil used in formulating diesel oil based mud (Diesel OBM) and castor oil based mud (Castor OBM) used in conducting the experiments.

Experimental procedure

The method utilized in this study involved the deployment of oil derived from *R. cummunis* to formulate a drilling mud which captured the numerous properties of oil based mud with respect to rheology and their importance during drilling operations and well completion operations. Key properties such as viscosity, density, gel strength, pH, cation exchange capacity, etc., were all measured in the laboratory with the appropriate equipment as presented in Table 2.

Mud preparation

(1) The same quantity of bentonite, barite, and sodium carbonate were measured using the weighing balance shown in Figure 6 for formulating each of diesel and castor oil based muds.
(2) Measuring beakers were used in measuring of the volume of brine and oil. The volume of diesel oil and castor oil were fixed at 185 ml and their densities were found to be 850 and 956 g/l, respectively. The volume and mass of other components for each drilling mud formulation were also kept constant and are all presented in Table 2.

Table 2. Constituent of the castor oil and diesel based mud.

Mud	Diesel oil (ml)	Diesel oil density (g/L)	Castor oil (ml)	Castor oil density (g/L)	Barite (g)	Clay (g)	Brine (ml)	Na_2Co_3 (g)
Oil based mud	185	850	185	956	10	5	82	2

Figure 5. Castor oil mud sample.

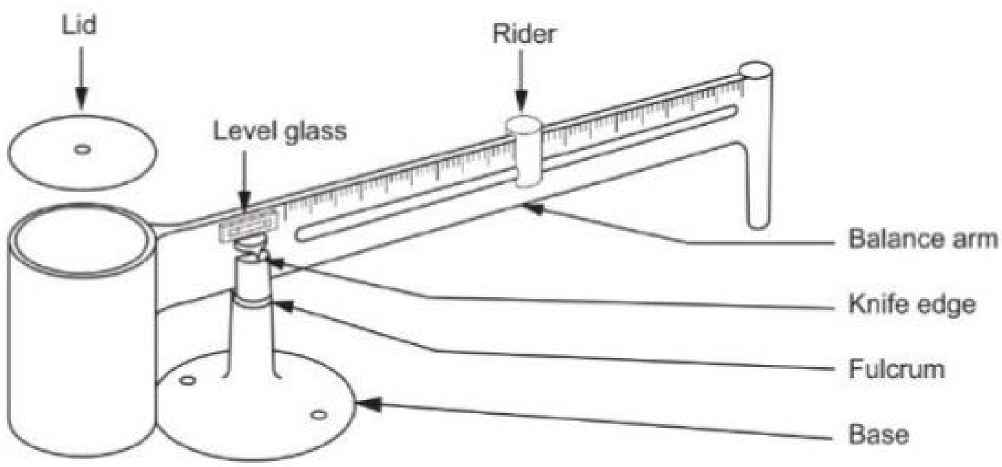

Figure 6. Mud balance.
Source: Bourgoyne et al. (1991).

(3) There was a thorough mixing of the measured materials using the Hamilton Beach Mixer leading to the formation a homogenous mixture after mixing.

Density measurement

The drilling mud density of each of the formulated mud samples was measured using the Baroid Mud Balance as shown in Figure 5. The equipment consists of a volume cup component that is in constant with an adjoining lever arm and a calibrated rider which directly reads the density of the fluid in Ibm/gal (ppg), specific gravity, and pressure gradient.

Test procedure

(1) There was agitation of the mud sample for approximately 2 minutes with the Mixer.
(2) The mud cup was cleaned and dried and the agitated mud was filled to the top of the cup.
(3) The cover was then placed on the cup and the mud balance

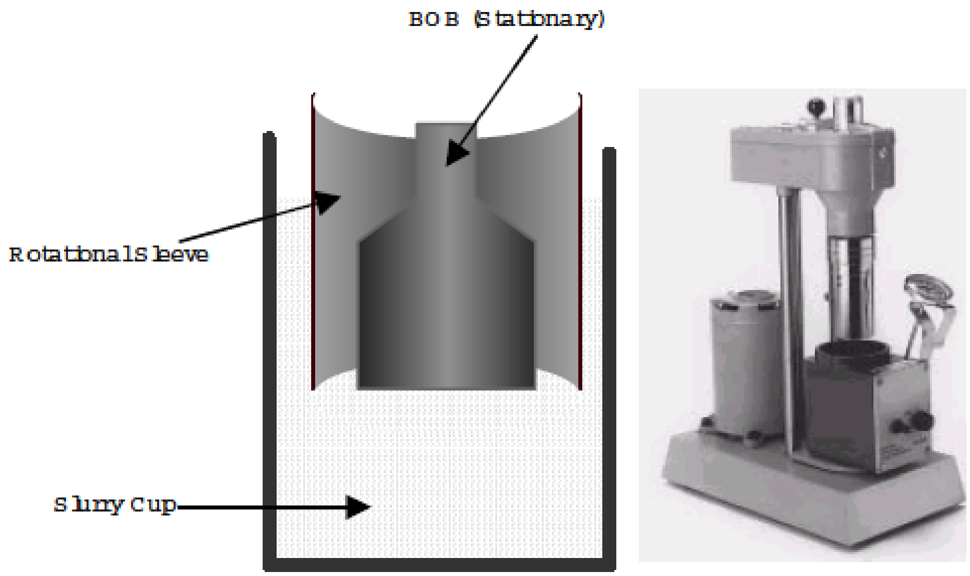

Figure 7. Fann Viscometer.
Source: Fann (n.d.-b)

was washed and dried.
(4) The mud balance was placed on a knife edge and consequently, the rider was positioned along the arm until there was a balance between the cup and the arm.
(5) The weight of the mud and the specific gravity were read off at the edge of the rider and recorded.

Viscosity measurement

The resistance to flow of a fluid is known as the viscosity of the fluid. Typically, the viscosity obtained by any equipment is valid for a specific shear rate. Field measurement for viscosity was done via the marsh funnel as a standard equipment. In the laboratory, the Fann V-G meter (Figure 7), is the standard viscosity measuring equipment, enabling the measurements of plastic viscosity, yield point, and gel strength.

Test procedure

(1) The formulated oil based drilling muds (Diesel OBM and Castor OBM) were firstly poured into the rotary viscometer mud cup, with the rotor sleeve inserted up to the fill line on the sleeve.
(2) Subsequently, the power switch of the viscometer was turned on
(3) The speed selector knob was rotated to the stir setting for a few seconds, to revolve it at 600 rpm.
(4) The processes highlighted in No. 1 to 3 were repeated for 6, 30, 60, 100 and 300 rpm, respectively and viscosity measurements recorded.

Gel strength test

The mud gel strength was determined using the Rheometer.

Test procedure

(1) The speed selector knob was rotated to stir the mud sample for a few seconds, and the gel setting was subsequently rotated and the power turned off.
(2) The power was turned on after the sleeve stopped rotating in 10 s and 10 min, respectively.

Mud filtration property test

Drilling fluid loss as a result of filtration is basically controlled by the mud cake thickness formed from the solid components in the drilling mud. In the filtration test, the focus was on measuring the liquid volume pushed through the mud cake, into the formation being drilled. This is done using the API filter press as shown in Figure 8.

Test procedure

(1) Parts of the test cell were dried and cleaned, and subsequently the gaskets were checked.
(2) The test set-up was assembled in the following order: top cap, gasket, screen, filter paper, gasket, and test cell.
(3) A mud sample was prepared and poured into the test cell to 13 mm to the top.
(4) A dry and clean cylindrical glass was fixed under the exit tube of the filtrate.
(5) The T-screw regulator was subsequently turned anti-clockwise to position the screw in the right position where there was a reduction in the diaphragm pressure.
(6) The pressure valve of the test cell source was opened to activate pressurization into the air hose. Subsequently, the regulator was adjusted by ensuring that the T-screw was turned clockwise to pressurize the cell for 30 s.
(7) The volume of filtrate obtained was measured, after 30 min. Subsequently, flow of air via the pressure regulator was then shut-off by rotating the T-screw in an anti-clockwise direction.
(8) The set-up was subsequently dismantled, and the drilling mud removed.
(9) The mud cake thickness was subsequently measured and recorded.

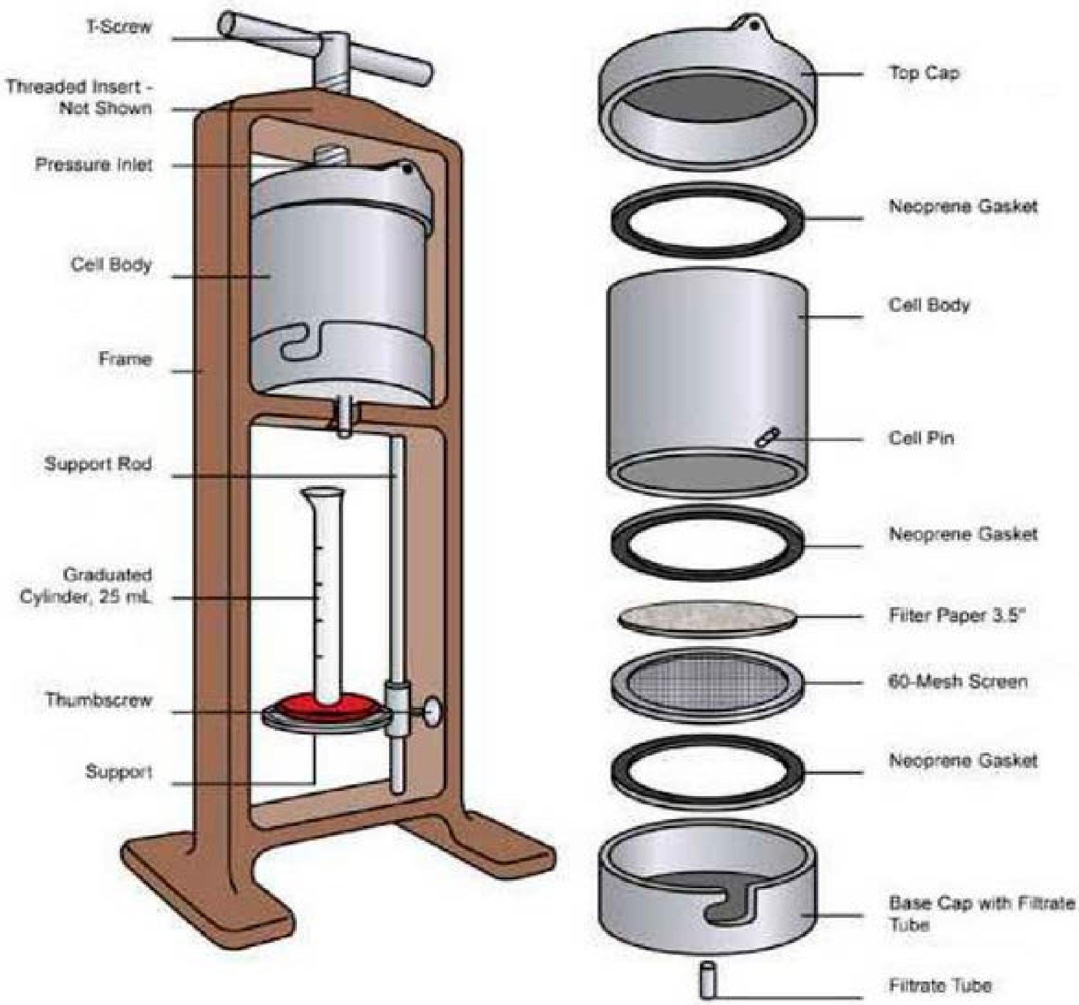

Figure 8. API Filter Press.
Source: Fann (n.d.-a).

Methylene blue test

The cation exchange capacity of the clay solids were measured via methylene blue test. This test involved the measurement of cation-exchange capacity of a clay mineral.

Test procedure

(1) 2 ml of drilling mud was added via a syringe into the flask. Entrained gas within the drilling mud was removed prior to injection.
(2) 10 ml of water that was deionized was added to the flask.
(3) 15 ml of hydrogen peroxide (3%) was added to the flask.
(4) 0.5 ml of 5N sulfuric acid was subsequently inputted into the mud mixture.
(5) The mud mixture was subsequently boiled for 10 min using the hot plate.
(6) The mixture was subsequently diluted to about 50 ml with water that has been deionized.
(7) Within the flask, a methylene blue solution was added in increments of 0.5 ml and stirred for about 30 s.
(8) A drop of liquid was subsequently removed from the suspended solids, via a stirring rod and was positioned on the filter paper.
(9) The blue spot halo spreading from the equipment was detected; subsequently the flask was shook for an extra 2 min, until another blue tint drop was detected on the filter paper.

Toxicity test

The diesel and castor oil based mud sample formulated were subsequently tested on bean seedlings. The beans seedlings were exposed to a 100 ml of each mud sample prepared from castor oil and diesel oil and their growth and survival rates measured and tabulated.

RESULTS

Drilling mud density

Table 3 shows the density and specific gravity obtained for the two drilling mud formulations when 185 ml of each

Table 3. Comparison of mud density of formulated oil based muds.

Sample	Density (ppg)	Specific gravity	Barite (g)
Castor oil	9.2	1.10	10
Diesel mud	8.9	1.07	10

Figure 9. Methylene blue kit.

Table 4. Viscosity readings of diesel and castor oil OBMs at room temperature.

Dial speed (RPM)	Diesel oil based mud	Castor oil based mud
600	188	170
300	173	168
200	170	161
100	160	153
60	155	147
30	140	136
6	124	114
3	93	77

type of oil was mixed with 10 g of Barite. The results are illustrated in Figure 9.

Rheology

Dial reading values ($Ib/100ft^2$) of the two mud samples against the viscometer speeds at room temperature (30°C) are shown in Table 4 and illustrated by Figure 11. A further comparison was made for both drilling mud formulations at varying temperatures to investigate the effect of temperature on shear rate and the results are presented in Table 5 and Figure 12 for diesel oil based mud and Table 6 and Figure 13 for castor oil based mud.

Table 5. Viscosity variations with temperature at RPM readings for diesel oil mud.

Dial speed (RPM)	Dial readings		
	40°C	60°C	80°C
600	144	130	119
300	55	51	48
200	46	41	36
100	33	30	27
60	26	24	20
30	21	19	16
6	18	16	12
3	11	10	10

Viscosity values such as apparent and plastic viscosities were also calculated and the results are presented in Table 7.

$$\text{Apparent viscosity} = \frac{\text{Dial reading at 600RPM}}{2}$$

Filtration property test

Results from the mud filtration test conducted on the diesel and castor oil based muds are presented in Table 8 and illustrated in Figure 14.

Hydrogen ion potential

The hydrogen ion pH value for castor oil formulated mud was measured and compared with diesel oil formulated mud (Table 9).

Methylene blue

$$\text{Methylene blue capacity} = \frac{\text{Methylene Blue (ml)}}{\text{Drilling fluid (ml)}} \frac{4\text{ ml}}{2\text{ ml}} = 2$$

$$\text{Bentonite Equivalent} = \frac{5 \times \text{Methylene Blue (ml)}}{\text{Drilling fluid (ml)}} = \frac{5 \times 4\text{ ml}}{2\text{ ml}} = 10\text{ lb/bbl}$$

Based on the methylene blue test captured in Figure 9 and 10, 4 ml of the methylene blue solution was needed to get to the end point of the mud mixture, hydrogen peroxide and sulphuric acid. The calculations suggested that the ratio of methylene blue to drilling mud was 2. Based on the result, the low gravity solids obtained were 10%; which is subsequently equivalent to 10 pounds of bentonite in one barrel of drilling mud. This indicated that the drilling mud had low gravity solids of 10% and that the ion exchange could occur but would have little impact on the clays within the formation. Hence, it would be preferable for drilling fluids to possess a lower cation exchange capacity, which could further reduce the

Table 6. Viscosity variations with temperature at RPM readings for castor oil mud.

Dial speed (RPM)	Dial readings		
	40°C	60°C	80°C
600	122	91	84
300	87	76	70
200	69	62	57
100	43	35	31
60	26	24	20
30	19	19	17
6	15	11	10
3	8	8	6

Table 7. Comparison of gel strength, plastic viscosity and yield point for the two mud formulations at room temperature (30°C).

Rheological property	Castor oil mud	Diesel oil mud
Gel strength (lb/100 ft^2)	2	4
Plastic viscosity (cp)	2	15
Apparent viscosity (cp)	85	94
Bingham Yield (lb/100 ft^2)	166	158

Table 8. Mud filtration readings.

Filtration property	Diesel oil mud	Castor oil mud
Total fluid volume (ml)	6	6
Oil volume (ml)	2.83	2.35
Water volume (ml)	3.17	3.65
Mud thickness (mm)	1.01	0.85

Table 9. pH values of mud samples.

Mud type	Castor oil mud	Diesel oil mud
pH value	8	6

reactivity within the shale formations. During drilling operations, it is quite relevant to be conscious of the solids content of the drilling mud so as to prevent any unanticipated sloughing that may occur if the cation exchange is too high. The Bentonite content of the castor OBM was 10 lb/bbl indicating the total cation-exchange capacity of all the clay minerals present in the drilling mud.

Toxicity

Bean seeds were planted within Afe Babalola University premises and after seven (7 days), the bean seeds were then exposed to 50 ml of both castor oil formulated drilling mud and diesel oil formulated drilling mud and the number of days which the crops survived was recorded. The rate of growth was also measured by considering the new height of the plant measured at regular time intervals. The results are shown in Table 10.

DISCUSSION

Results show that drilling mud formulated with castor oil resulted to a mud density of 9.2 ppg, which was greater than the density of 8.9 ppg obtained with diesel oil as depicted in Table 3 and Figure 9 indicating the suitability

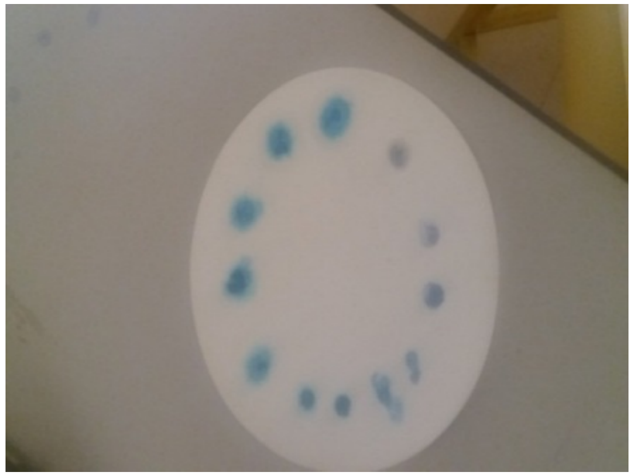

Figure 10. Filter paper.

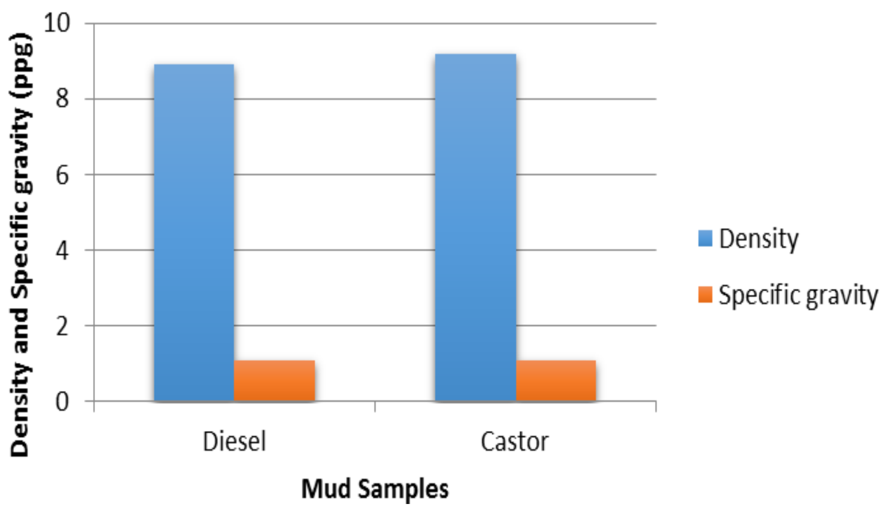

Figure 11. Density and specific gravity of mud samples.

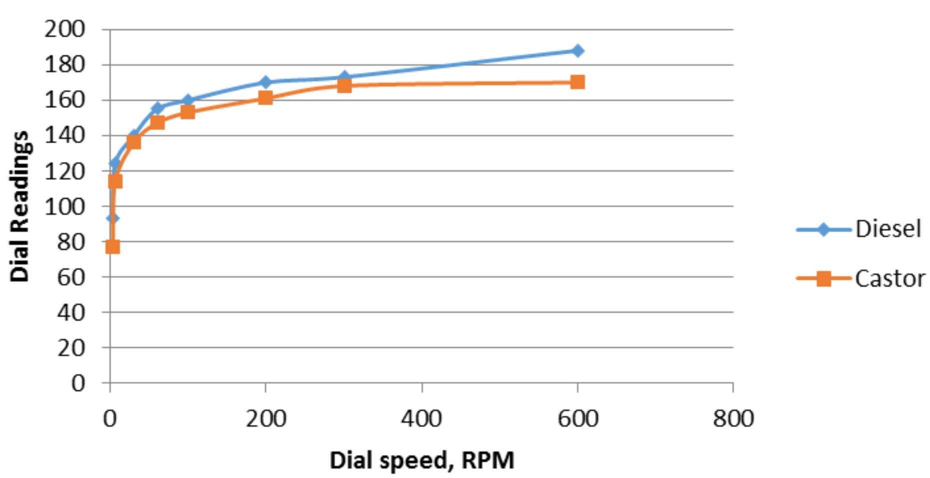

Figure 12. Viscosity readings of diesel and castor oil mud samples.

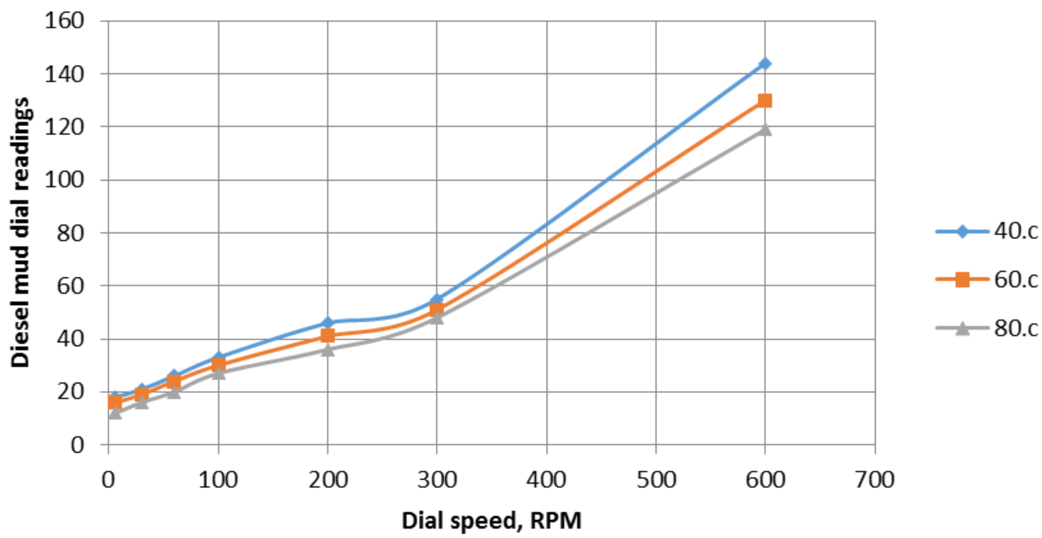

Figure 13. Viscosity of diesel OBM at different temperatures.

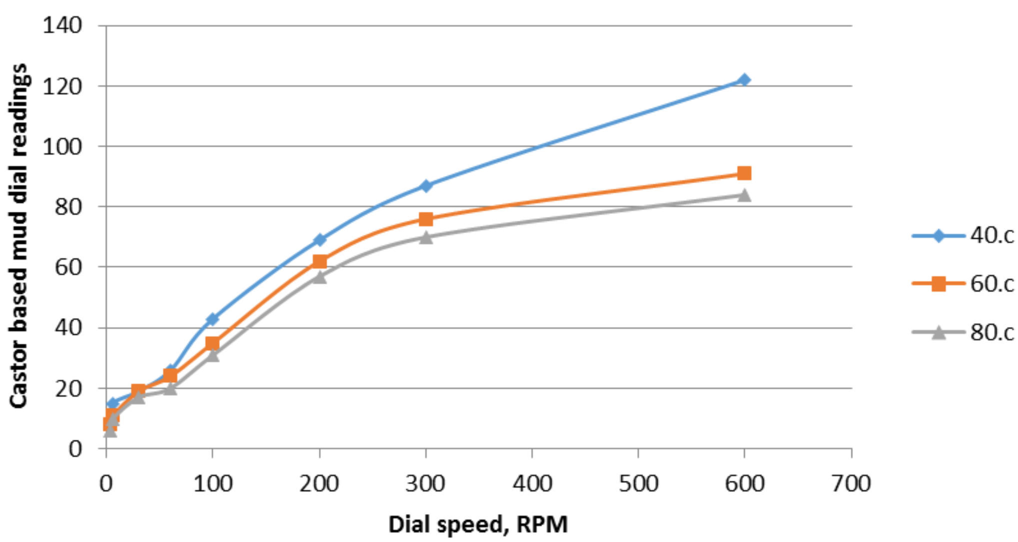

Figure 14. Viscosity of castor oil OBM at different temperatures.

Table 10. Growth values of bean plant.

Mud type	Castor oil mud	Diesel oil mud
No. of days	24	9

of drilling mud formulated with castor oil in controlling formation pressure during drilling operations and may serve as a substitute for diesel in oil based mud formulations.

The shear viscosity of the two mud formulations increased with a rise in dial speed but the shear viscosity of castor oil based drilling fluid was found to be smaller than that of diesel oil based drilling fluid at the same dial speed (Table 4 and Figure 11) indicating that drilling mud formulated with castor oil can effectively suspend drilling mud cuttings when circulation is stopped in comparison with diesel oil mud. Figures 12 and 13 show a plot of

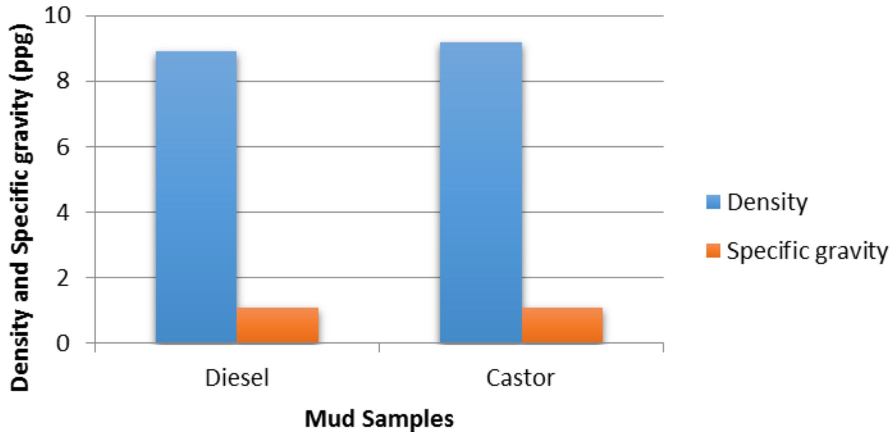

Figure 15. Density and specific gravity of mud samples.

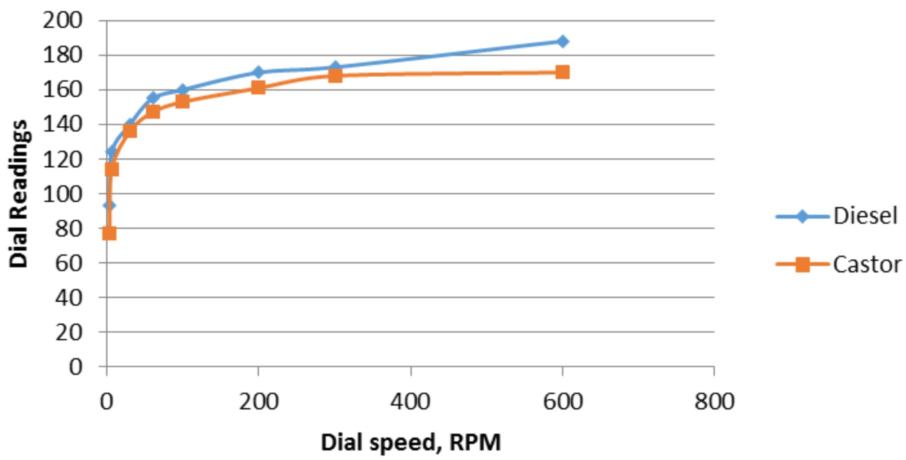

Figure 16. Viscosity readings of diesel and castor oil mud samples.

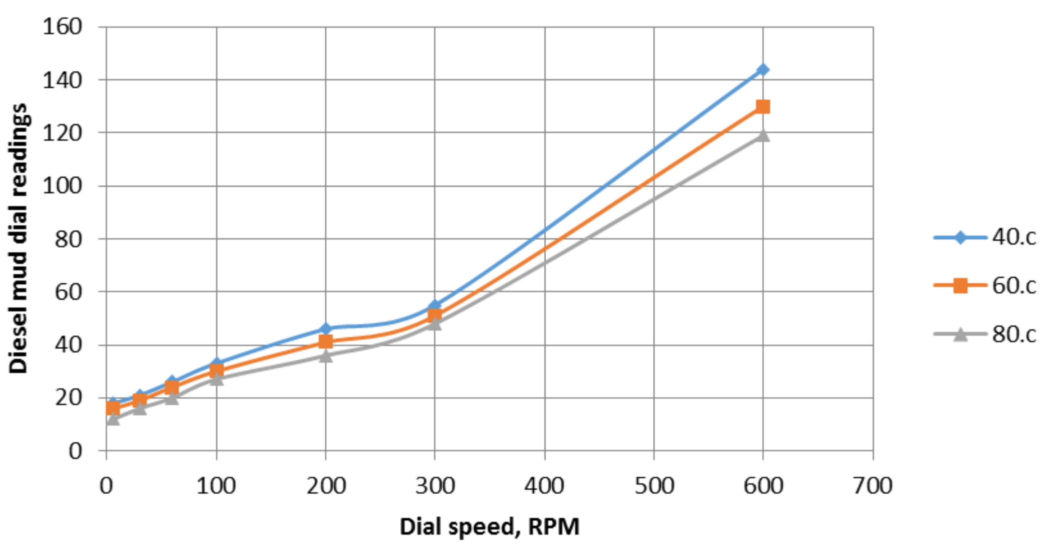

Figure 17. Viscosity of diesel OBM at different temperatures.

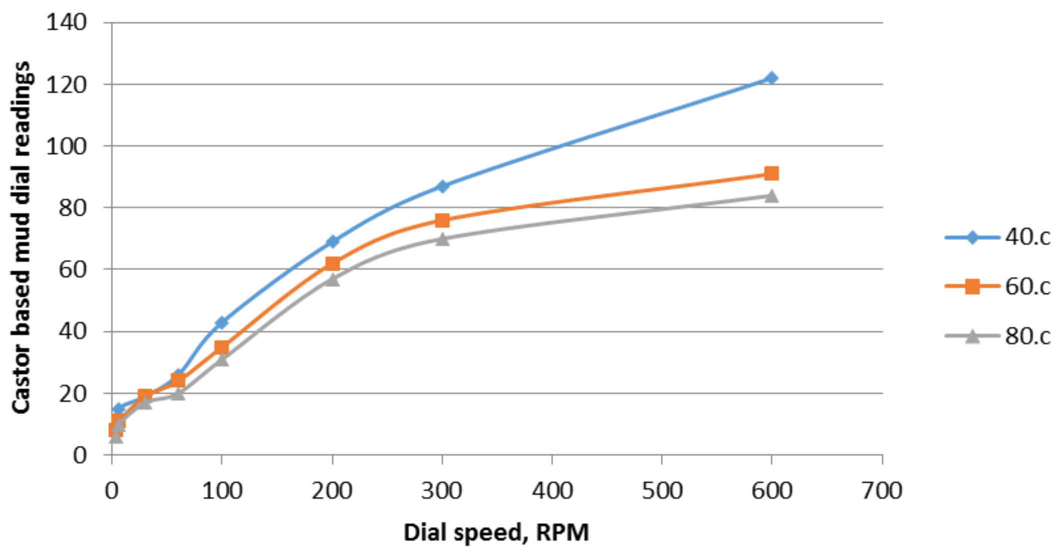

Figure 18. Viscosity of castor oil OBM at different temperatures.

shear viscosity against dial speeds at different temperatures for diesel oil and castor oil based muds, respectively and it can be depicted from the graphs that that the viscosity increases as the dial speed increased from 1 to 600 rpm for both cases but for each dial speed, the shear viscosity decreased gradually with increasing temperature and lower values were obtained for castor oil in comparison with diesel oil. The viscosity variation was due to the heat being lower in the diesel OBM than in the castor OBM. It can be seen from the plots of viscosity against the dial readings, the shape of the graphs in Figures 12 and 13 are similar to the power law model showing similar rheological behavior of drilling fluids. However, not all the lines of the plot are as straight as the power law model. This could be explained by a number of factors such as availability of contaminants, causing it to behave in a different manner when compared to standard model such as the Herschel Buckley model.

Table 7 shows a comparison between rheological properties of the two types of drilling muds and results show that plastic viscosity of the castor oil based mud was less than that of diesel mud (2 cp < 15 cp) which indicates that castor oil will enhance rate of penetration during drilling operation because there will be a lower shear rate viscosity occurring at the bit. It is also important to note that a lower shear rate allows the drill bit to crush the sub-surface easily. Furthermore, increase in plastic viscosity has a negative effect on hole cleaning, as it is associated with increased pressure drop of the drilling mud; thereby affecting the lifting of drill cuttings; hence castor oil drilling mud with its associated relatively lower plastic viscosity under similar condition performs better.

Yield point is basically affected by two key functions of mud: hole cleaning capability and the ability of the mud to control pressure of a drilling fluid. A higher yield point often increases the mud carrying capacity and also leads to increase in the pressure drop circulating within the annulus. Table 7 also shows that the Bingham yield for castor oil was 166 lbm/ft in comparison to a lower Bingham yield of 158 Ibm/ft for diesel oil indicating that castor oil is efficient in hole cleaning than diesel oil and can thus be used in place of diesel oil in formulating an OBM. The disadvantage of a high yield point is that it makes the well vulnerable to loss circulation and swabbing. Adjustments of the yield point may be required depending on the formation evaluation data or rock properties. The weighted castor oil OBM and diesel oil OBM had gel strengths of 2 and 4 lb/100 ft^2, respectively (Table 7) and hence for a weighted mud to suspend barite, it should have a gel strength of about 2 to 4 lb/100 ft^2 indicating that the gel strength of castor oil based mud will be capable of suspending barite when circulation is stopped.

Results show that the oil volume lost when the castor oil OBM was subjected to pressure in an API Filter press (2.35 ml) was lower than that of the diesel based mud (2.83 ml) indicating that in a pressurized permeable formation, the castor oil OBM will lose a lesser amount of oil to the formation than diesel OBM. However, this is not the case for the water volume of the castor oil based mud.

The difference in water volume between the two muds as shown in Figure 13 indicates that a larger volume of water was lost in comparison with Diesel oil mud. A thin filter cake of 0.85 mm was deposited by the castor oil based mud in comparison with a filter cake thickness of 1.01 mm by diesel oil mud. A thin filter cake is essential for drilling operations because a thick mud cake would lead to several problems such as differential sticking, loss

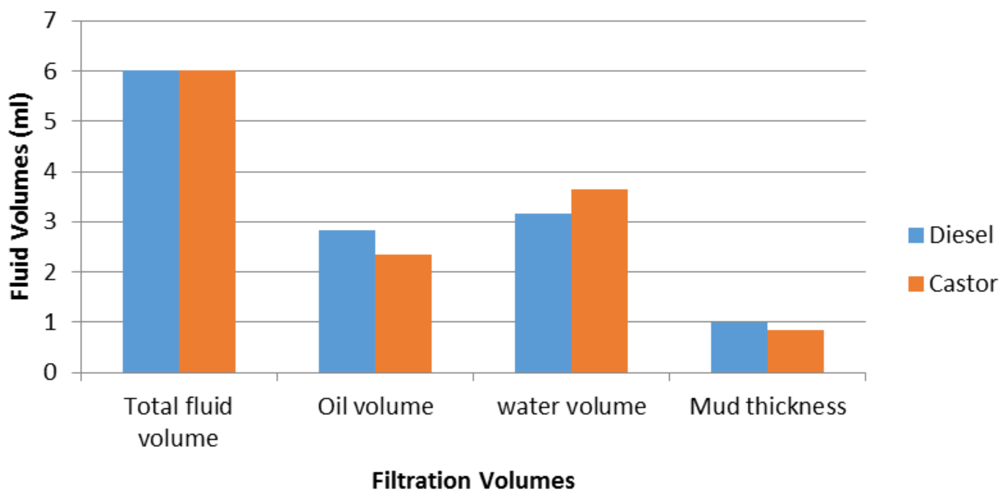

Figure 19. Filtration volumes of castor and diesel mud.

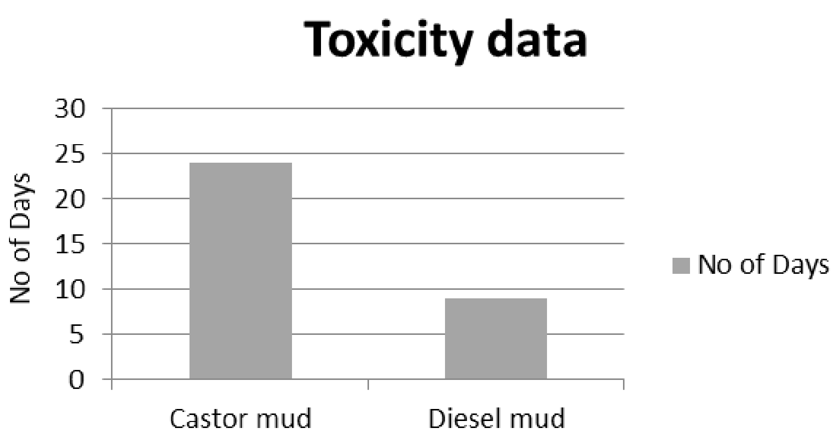

Figure 20. Graph of bean plant growth.

circulation and poor primary cement jobs. Other challenges associated with excessive thickness include high surge and swab based on reduced annular clearance, tight spots in the wellbore that could give rise to excess drag and primary cementing job challenges as a result of insufficient displacement of filter cake.

Results on Table 9 show that the pH values obtained for the mud formulated from castor oil was less acidic (pH = 8) than a diesel based mud (pH = 6) indicating that the formulated castor oil based drilling mud has met the alkalinity requirements of drilling fluids as it will least affect bentonite (if the pH of mud is within the range of 7 to 9.5). pH values above this range will lead to an increase in mud viscosity unsuitable for good drilling practices. With regards to the minimizing of shale problems, a pH of 8.5 to 9.5 appears to provide the best borehole stability and improved mud properties; thereby making drilling mud formulated with castor oil more suitable in achieving good borehole stability conditions which aids in minimizing hole related problems.

From the results presented in Table 10 and illustrated in Figure 15 and Figure 16, castor oil based mud showed a less toxic effect on the growth of the bean seeds as compared to diesel oil drilling mud; considering that the bean seeds survived for 24 days as compared bean seeds exposed to diesel oil based mud, which survived after only 9 days and subsequently withered. Also, when check was done on the soil, no evidence of any living organisms was found within the diesel oil based mud sample; while that of the castor oil based mud showed some living organisms such as earth worms, indicating that castor oil based mud is environmentally friendly.

Conclusion

Based on key results derived from the experiment carried out on the castor oil OBM sample, the following conclusions could be drawn:

(1) The hydrostatic pressure of the castor oil based

drilling mud made the wellbore protected from potential ingress of formation fluid.

(2) The test of temperature effect on mud viscosity indicated a smaller reduction in the castor oil OBM viscosity; as it encounters a higher operating temperature.

(3) Oil based mud formulated with castor oil gave rise to lower fluid loss depicted by a thinner filter cake in comparison with diesel oil based which gave rise to a thicker filter cake.

(4) The total cation-exchange capacity of the clay minerals present in the castor oil OBM is suitable for drilling processes.

(5) Corrosion rates are suppressed in castor oil based mud due to a higher pH value which will consequently lead to an ectension of life of drilling equipment.

(6) Disposal of the castor oil based mud is more economical and environmentally friendly because less amount of money is spent in treating the mud after it has been exhausted its life cycle in exploratory activities.

As part of further development of this research, the following key recommendations are made:

(7) The temperature effect should be checked on other properties of the mud. This is to further strengthen the theory that castor oil based mud could be used at different downhole operating conditions.

(8) There were contaminants present in the castor oil based mud which led to variations in some of the results obtained, therefore, removal of these contaminants should be considered.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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