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Original article

GREEN DRILLING: SUBSTITUTING TIGER NUT OIL FOR DIESEL AS BASE OIL IN DRILLING MUD FORMULATION

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ABSTRACT

Due to the cost and environmental impacts associated with traditional diesel oil-based muds, the utilization of alternative oils serving as a continuous phase in the formulation of drilling muds has been at the forefront for mud engineers. To this end, this research work was embarked on to compare the existing diesel oil-based muds with a newly formulated mud using tiger nut oil. To achieve this aim, extracted tiger nut oil was used to formulate the drilling mud in line with the American Petroleum Institute (API) standard of 25 g bentonite to 350 mL base fluid for nontreated bentonite. The oil extraction method used was the Soxhlet extraction method. 245 mL of tiger nut oil (which was the required volume for formulation) was extracted from 1100 grams of tiger nut powder at the consumption of 1.5 L of n-hexane. The rheological properties that were deduced from the formulated mud were in line with the Bingham plastic model of fluids. The formulated drilling fluid also displayed great gel strength with respect to other types of base oils used in drilling mud formulation. Also, with the addition of barite – a weighing substance, the mud density of the tiger nut OBM (8.15 lb/gal) was higher relative to that of the diesel OBM (7.98 lb/gal) which is an advantageous quality of drilling fluid, especially in less stable formations. Other properties like pH, 8.5, CCI, and 2.03, were also in favour of the tiger nut OBM. Hence, the formulated mud possesses a greater advantage both in technology utilization and environmental viability.

Keywords: Drilling, Oil and gas, Tiger nut oil, Oil-based mud, Rheological tests, CCI, pH test, Soxhlet Extraction Method.

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INTRODUCTION

For decades, oil drillers and industry administrators have looked to drill into a useful solid opening with insignificant ecological effects and a minimal expense footprint [1]. The drilling/boring fluid is a significant part of the oil well drilling activity that is regularly alluded to as "the soul of the drilling system." The drilling mud makes any drilling activity a reality or an impossibility [2]. This is inferable from the truth that fluid gives numerous fundamental capacities. These functions incorporate, yet are not restricted to, moving drill cuttings from the lower part of the opening to the surface, cooling and lubricating the boring piece and drill string to decrease wear and tear [3]. Others include, shutting off porous formations by making an impermeable, slight mud cake at the borehole surface of the penetrable formations, making an overbalanced penetrating condition to control arrangement pressure, suspending drill cuttings during dissemination, and transferring downhole information to the surface to allow adequate knowledge of boring conditions, etc. [4]. Therefore, the greatness of any rotational penetrating cycle is subject to the viability of the drilling liquid utilized. The exhibition of these boring liquids is not entirely settled by the rheological attributes of the mud being used [5]. Drilling mud costs are projected to consume around 20% of the total penetrating cost of a well owing to the fact that these drilling conditions require fluids that perform excellently in execution [6]. Subsequently, estimating fluid performance requires an appraisal of all crucial boring indicators and the expenses in question [7]. Generally, two kinds of penetrating liquids are utilized: water-based muds (WBMs) and oil-based boring muds (OBMs). On one hand, water-based mud is the most commonly used drilling fluid with relatively low cost and convenience of synthesis [8]. Oil-based muds, on the other hand, despite being more expensive than their water-based equivalents, are used due to the excellent rheological behaviour at temperatures reaching 500 ^{0}F, their viability against a wide range of corrosion, and fantastic lubricating ascribes. Oil-based muds have the additional advantage of having the option to penetrate through structures that typically contain water-swellable strata. [8]. Diesel oil is usually utilized as the base liquid in the preparation of these oil-based muds because of its availability, viscosity, low elastic dissolvability, and low combustibility [9]. All such petrol-based oils utilized for drilling mud contain somewhat undeniable degrees of aromatics and something like a critical grouping of n-olefins, the two of which can be unsafe to flora and fauna [10] Therefore, over the long run, the drilling business has been creating various types of oil-based muds referred to as synthetic-based muds (SBMs) [11].

MATERIALS AND METHODS

Materials/Equipment

Brown tiger nut seeds/powder, Distilled water, n-Hexane, Diesel oil, Primary and Secondary emulsifier, Hydroxyl Ethyl Cellulose, Bentonite, Barite, Caustic soda (NaOH), Weigh balance, Filter paper, Beakers, Measuring cylinder, Soxhlet extractor, Heating mantle, Sieve, Distillation flask, Thermometer, Stopwatch, Mud balance, Rotary viscometer, pH paper, Hand gloves.

Extraction of tiger nut oil

Tiger nuts seeds were acquired from the Kure market in Minna, Niger State, North Central district of Nigeria. This location was chosen because it's a source of cheap and large volumes of tiger nut seeds (Cyperus esculentus L.) The seeds were washed to eliminate the presence of soil contaminants and afterwards left to dry under atmospheric conditions. The dry seeds were grounded to fine particles of 200 µm utilizing a manual pulverizer before initiating extraction.

1100 grams of the powdered tiger nut in separate bits of 60g were measured and put into the extraction thimble. 200 mL of n-hexane was poured intermittently into the extraction flask before commencing the extraction process. The extraction duration for each cycle was in an average of 5hours,

Formulation of mud

For viable examination, tiger nut oil was utilized as the base oil in setting up the drilling mud. The experiment was based on the American Petroleum Institute (API) standard. This approved standard stipulates a 25 g bentonite to 350 mL base liquid for nontreated bentonite. Subsequently, the mud tests were set up concerning keeping up a similar part extent in each example. The oil-water ratio utilized was 70:30 [14]. The materials were manually mixed (in a bowl with a spatula), the deliberate materials were completely mixed until a homogenous combination was gotten. By standard, the mixed muds were left to age for 24 hours before initiating the trial of different mud properties. Blending direction and timeframe are highlighted in Table 1.

Table 1: Composition of Formulated Muds

Mud component	Tiger nut oil	Mixing Duration (mins)	Mixing order
Oil (mL)	245	--	1
Primary emulsifier (mL)	6	5	2
Secondary emulsifier (mL)	4	5	3
Filter loss agent HEC (g)	0.35	5	4
Water (mL)	105	15	5
Bentonite (g)	25	5	6
NaOH (g)	0.25	5	7
Barite (g)	10	10	8

Mud Rheological Properties Test

Mud viscosity test

The revolving viscometer was turned on and left to settle, after which the integrity trial of the hardware was done by utilizing water as the sample. After this, the cup was purged and cleaned. The viscometer cup was filled with the tiger nut oil mud and the rotational sleeve was submerged precisely to the top line by lifting off the stage. The power switch at the viscometer's back was switched on. To mix the mud for a couple of moments, the speed selector handle was changed by the "stir" setting. After, it was set at 600 RPM. At the point when a consistent dial perusing was reached, the worth demonstrated was recorded. Steps (ii) to (iv) were repeated for 300, 200, 100, 6, and 3 RPMs respectively. Afterwards, the plastic viscosity (PV), yield point (YP), and apparent viscosity (AV) of the mud samples were evaluated based on the resulting figures from viscometer dial readings as presented in Table 5.

$$PV = \theta 600 - \theta 300, \quad (1)$$

$$YP = \theta_{300} - PV, \quad (2)$$

$$AV = ½ * \theta_{600}, \quad (3)$$

Where;

AV is apparent viscosity, PV is plastic viscosity, θ_{600} is dial reading at 600 revolutions per minute, θ_{300} is dial reading at 300 revolutions per minute, and YP is yield point.

Mud gel strength test
The speed selector knob was turned to mix the TNO mud for ten seconds, and a short time later, it was tuned to gel setting. Next, power was promptly stopped. After the sleeve quit rotating, at 3 RPM, the power was switched on after 10 seconds and 10 minutes, respectively. The greatest dial reading was recorded for each case.

Mud Density Test
The integrity test and adjustment of the mud balance was done by testing for the density of refined water. The TNO mud sample was poured into the mud balance cup till it filled to the brim. The cover was set on the cup and went clockwise to guarantee it was immovably shut. Overabundant mud that spilt through the opening on the cover was cleared off from the top and body of the cup. The balance was placed on a knife-edge while the rider moved laterally until the cup and arm were balanced as exhibited by the air pocket. The mud weight was examined at the edge of the rider towards the mud cup as exhibited by the bolt on the rider and was noted.10g of barite was added and blended in with the readied mud until a homogenous combination was accomplished and steps (ii) to (v) were repeated for the mud new sample. The TNO mud's density with and without barite of 10 g was measured and documented as introduced in Table 7.

Cuttings Carrying Index (CCI) Evaluation
The CCI is a numerical relationship gotten from genuine information. The relationship between annular velocity (AV), power law constant (K), and mud weight (MW), and is represented by equation (4).

$$CCI = \left(\frac{K \times AV \times MW}{400{,}000}\right) \quad (4)$$

$$K = (511)^{1-n} (PV+YP) \quad (5)$$

$$n = 3.322\log\left(\frac{2PV+YP}{PV+YP}\right) \quad (6)$$

Where;

AV is the annular velocity (ft/min); MW is mud weight (lb/gal); K is a Power Law Constant and can be calculated as shown in equation (5); PV is plastic viscosity (cp); YP is the yield point (lb/100ft^2); n is the flow behaviour index calculated using equation (6)

Hydrogen Ion Potential (pH Value) Test
A piece of pH paper was put on the upside of the tiger nut oil mud sample. After finding out that the shade of the test paper had settled, the shade of the upper side of the paper, which had no prior contact with the mud, was matched against the standard shading outline. The gotten estimation was recorded.

RESULTS AND DISCUSSION

Results

Table 2: Viscometer readings of the TNO mud

Viscometer speed (RPM)	Dial Readings (lb/100ft^2)	Viscosity (mPa.s)
600	38	5315.3
300	28	2657.4
200	25	2054.5
100	17	1063.1
6	11	531.7
3	11	531.5

Table 3: Rheological values of the tiger nut oil mud

Mud properties	Values
Plastic viscosity, cp	10
Yield point, lb/100 ft^2	18
Apparent viscosity, cp	19
Gel strength 10 sec, lb/100 ft^2	7.9
Gel strength 10 min, lb/100 ft^2	10.1

Table 4: Mud density values TNO mud

Barite (g)	Mud density (lb/gal)
0	7.34
10	8.15

Table 5: pH value of the tiger nut oil mud

pH Value
8.5

Discussion

Comparison of diesel oil mud and tiger nut oil mud

Rheological properties:

The focal objective for concentrating on the rheological properties, plastic viscosity, yield point, and gel strength, of the two oils as the establishment for correlation, is the importance these properties deal with the all-out drilling mud execution. Yield point (YP) is utilized to evaluate the capacity of mud to exit cuttings out of the well annulus. A high yield point would suggest a non-Newtonian liquid; one that has better rock-cuttings carrying ability more than a fluid of comparable compactness but of lesser yield point. Additionally, it should be noted that frictional pressure loss is linearly connected to the yield point. A significant variable to consider is the yield point. Excessively high yield point causes pressure losses despite the fact the drilling mud is being dispersed in and from the wellbore. To get the shear stress and shear rate values, the dial readings and viscometer speeds were directly converted to give the needed parameters, respectively.

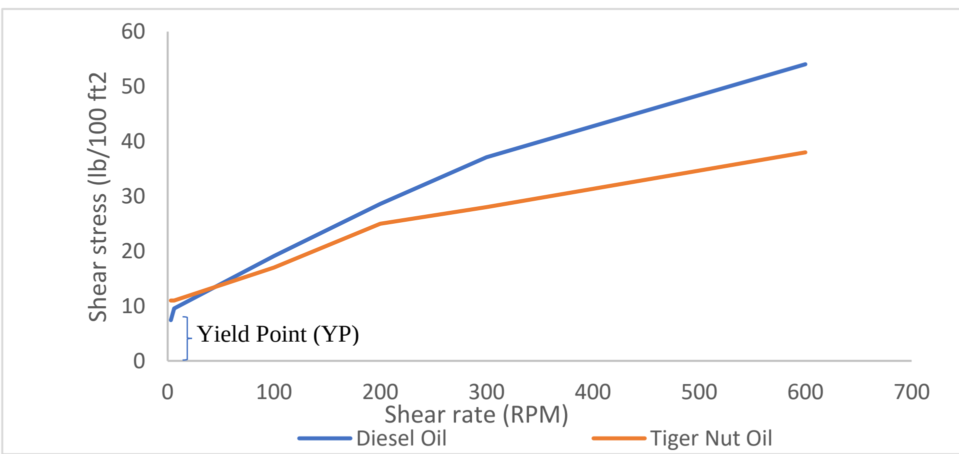

Figure 1: Profile of the prepared tiger nut and diesel OBMs

Figure 1 presents the shear stress-shear rate profile (rheogram) of the prepared TNO mud sample from the values gotten in the experiment and the literature values for diesel oil mud. This figure addresses the rheological model of the two muds in review. As portrayed in the figure, the rheology of both mud tests is analogous (i.e., increasing from left to right with an intercept on the vertical axis). This coordinates that the mud tests are comparable in their rheological execution. Given that, it very well may be seen that the two oil-based muds (OBMs) show a rheological prototypical which is almost similar to the Bingham plastic model. This performance was clarified by Bourgoyne et al., [9] as follows:

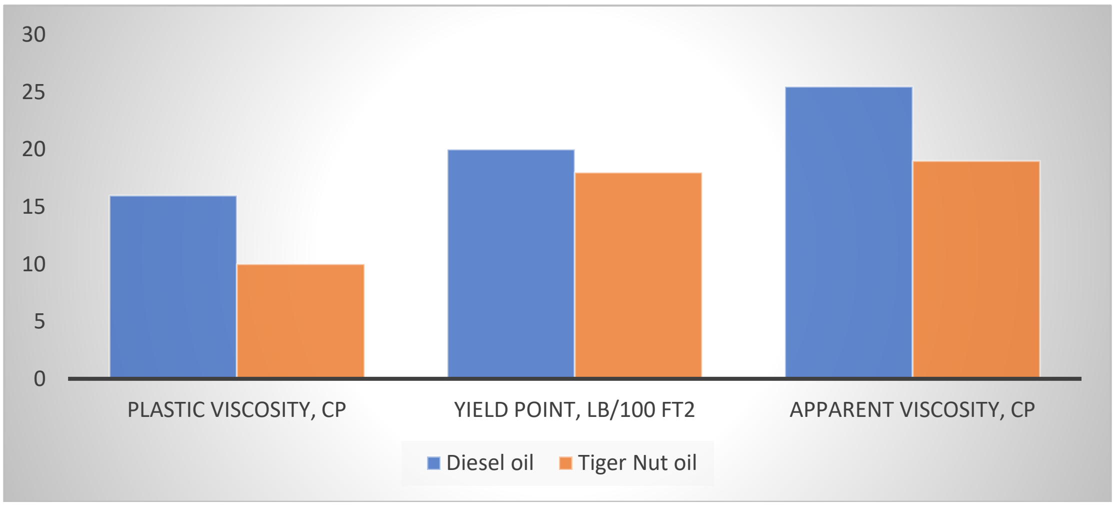

Figure 2: PV, YP, AV profile of the tiger nut OBM and diesel OBMs

Bingham plastic liquid will not stream except if the shear pressure (τ) outperforms the minutest worth distinguished as the yield point, YP. They reasoned that the yield point (YP) cannot be outperformed until the variations in shear pressure and stress are proportionate to variations in shear rate wherein the steady of proportionality is known as the plastic viscosity (PV). From Figure 2, it can be seen that diesel OBM exhibits a higher plastic viscosity in comparison to tiger nut OBM. This means diesel OBM has a higher viscosity, which is not a benefit since it would offer a bigger resistance from the liquid stream which could prompt an increment in coursing pressures which at last causes loss of dissemination and expanded costs for pumping activities. Hence, TNO mud with a lower viscous value is a superior option for drilling in the rationale that its little thickness will offer less resistance from the progression of liquid and along these lines would give a turbulent stream at low pump pressure which is invaluable for quality downhole cleaning.

Gel strength

Gel strength is another fundamental drilling liquid resource. It approves the limit of the drilling liquid to suspend bored stone cuttings and suspend strongly when the liquid stream is temporarily halted.

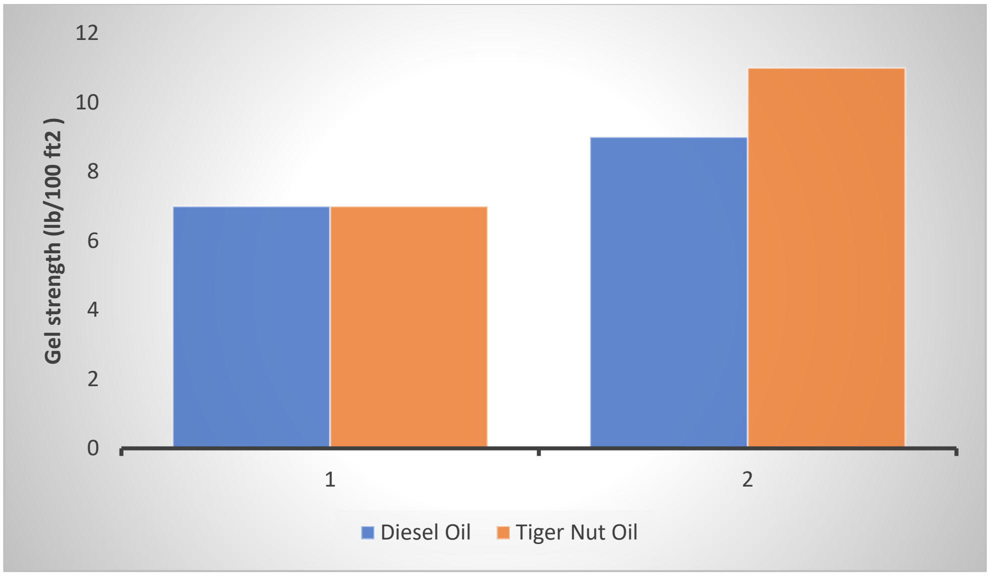

Figure 3: Gel strength profile of the tiger nut OBM and diesel OBMs

Figure 3 above, shows that tiger nut OBM has comparable gel strength with diesel OBM at 10 seconds. At 10 minutes, it can be seen that tiger nut OBM has a better gel strength than diesel OBM. In this way, the gel strength graph of the tiger nut oil-based mud shows that the mud displays a level gel structure, implying that the mud will stay pumpable with time whenever left static in the wellbore. Alternately, the gel strength upsides of the two muds at 10-minute gel esteem were higher than the 10-second gel esteem, connoting that the diesel mud shows a high-level gel structure. This means that the gelation of the diesel mud is great yet that of the tiger nut oil is better. It further clarifies the soundness benefits that tiger nut OBM has with time. Consequently, the ideal gel property of the tiger nut OBM is alluring during boring activity as the gel can likewise be broken effectively with lower siphon strain to make flow. Then again, assuming that the OBM gel strength is excessively high, it would cause high dissemination breakdown tension and augmentation in pumping costs as high siphon power would then be expected to defeat this gelling challenge of the OBMs.

Mud density

Mud density (mud weight) is also an integral parameter of any drilling mud. It possesses numerous functions like stabilizing wellbore pressure, formation stability, as well as adequate gel strength. The mud density is mostly characterized with and without the inclusion of barite which is the weighting material.

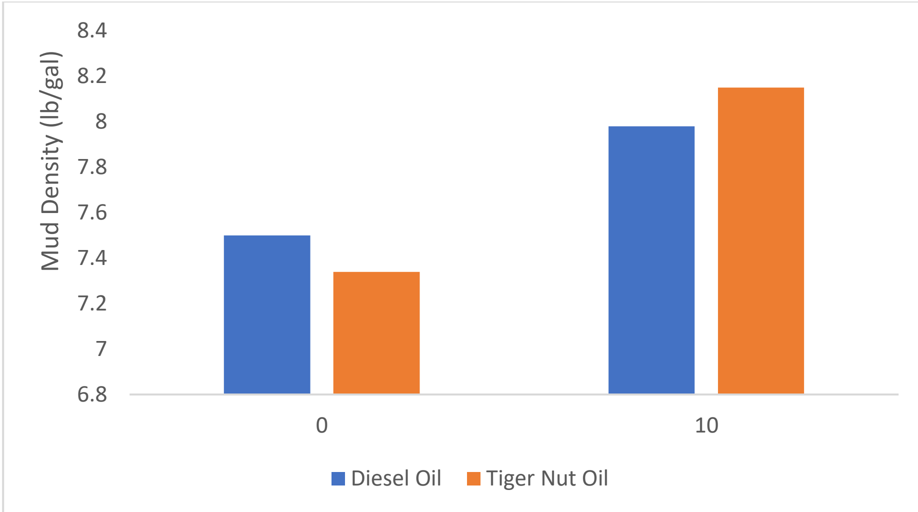

Figure 4: Mud density profile of the tiger nut OBM and diesel OBMs

With the absence of barite (weighing material), the diesel oil-based mud has more density than the tiger nut oil-based mud as shown in Figure 4. This is not a significant consideration as it is always advised that drilling mud be mixed with a weighting additive such as barite. After the addition of barite, it can be seen from Figure 4 that the tiger nut OBM now performed better than the diesel OBMs. This added advantage is of vital interest to mud and drilling engineers because it would be of a tremendous application when drilling in less stable formations to help avoid cavitation. This statement demonstrates that the density of tiger nut oil-based mud can be increased with barite to suit the required drilling operation, particularly in operations where muds with high density are required. e.g. high-temperature high-pressure formations. A methodology that is significant in case of drilling issues and when gas cut developments are experienced.

Cuttings Carrying Index

Figure 5 depicts the cuttings carrying index (CCI) of both the formulated tiger nut oil-based mud and the literature value of diesel oil-based mud. As shown, the tiger nut OBM exhibits a better CCI than the diesel OBMs. It increases the minimum requirement for an average by twofold. The annular velocity of 100ft/min. the diesel OBM is also good but the tiger nut OBM has shown that it can perform the task better and even help in minor cementing properties.

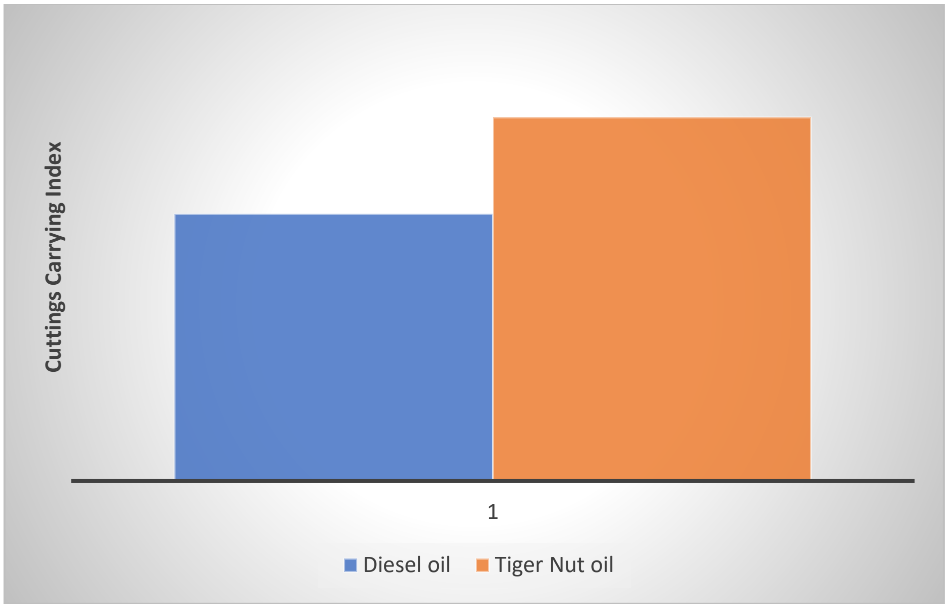

Figure 5: CCI outline of TNO and diesel OBM

pH value

Noting that the alkalinity of drilling mud is very vital, the tiger nut oil-based mud indicated a better value. It is closer to the maximum (optimum) alkalinity value required for drilling mud.

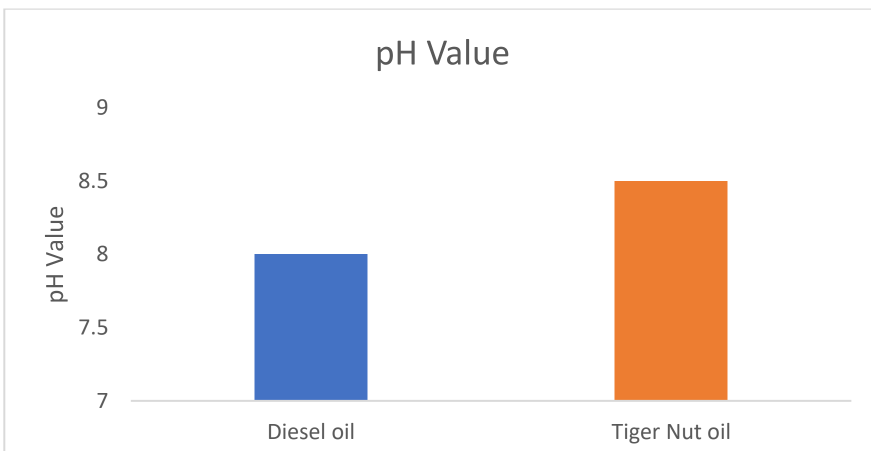

Figure 6: pH relationship between tiger nut OBM and diesel OBMs

The alkalinity of a diesel oil-based mud (8.0 lb/gal) is smaller compared to that of the tiger nut OBM (8.5 lb/gal). This shows that tiger nut OBM would perform better irrespective of the formation encountered. Also, tiger nut oil-based mud, by the virtue of its alkalinity, possesses the capability of lesser harm to equipment and personnel likewise. It would also aid in disposal advantages.

Comparison of TNO mud with previous works on muds using varied biomasses

Plastic viscosity, cp, apparent viscosity, cp, yield point, lb/100 ft^2, Gel strength 10 sec, lb/100 ft^2 of some past works are compared with that of tiger nut OBM. The results in the review are from the work of Paul et al., [15]. They worked on the viability of groundnut oils and jatropha oils in the formulation of oil-based muds. Also, in comparison is the drilling mud formulated with moringa oil by Adesina et al., [16].

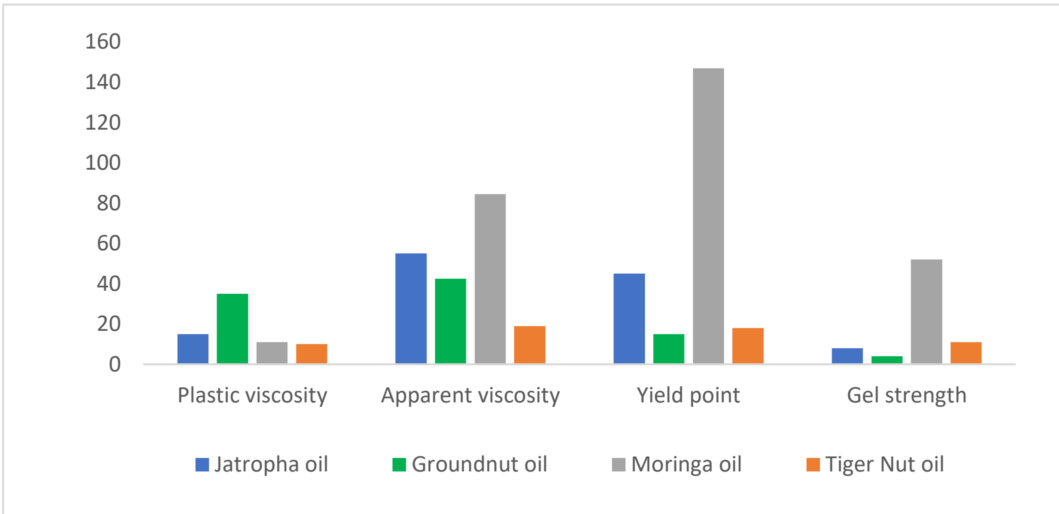

Figure 7: PV, YP, AV profile of the tiger nut OBM and other vegetable oils

From the visual representation in Figure 7, the, tiger nut OBM also demonstrated that it is a better alternative not just in comparison with diesel OBMs but also with other oil-based muds sourced from other common locally sourced biomasses. Considering plastic viscosity and apparent viscosity, it can be deduced that tiger nut OBM exhibited the optimum properties for applications. the other vegetable oils displayed either values that are too low or too high. When too low, the handling becomes a challenge and wellbore stability seems impossible. Also, more pumping power is required to circulate the fluid when too high, hence, increment in operating costs. In terms of gel strength, jatropha oil and groundnut oil would not be able to maintain wellbore stability optimally as such values. Moringa oil's gel strength shows it is on the high side and hence requires a very high amount of pumping power which is an undesirable factor in drilling. Therefore, tiger nut oil is the best among these four.

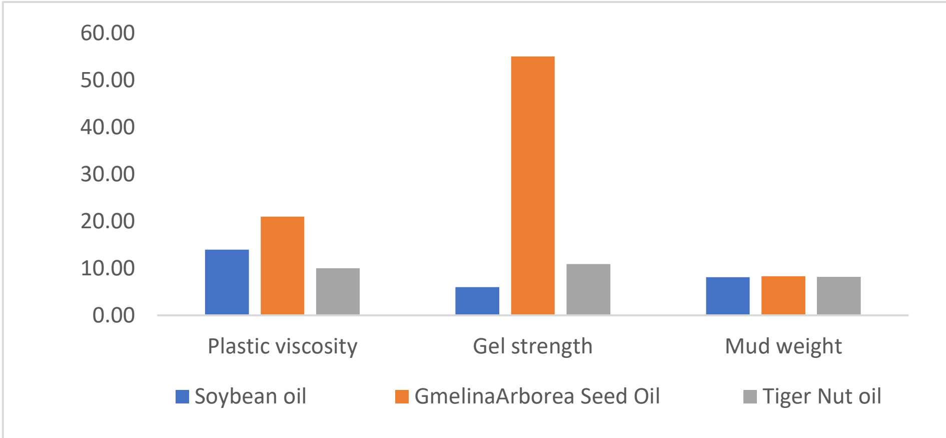

Figure 8: Rheological property profile of the tiger nut OBM in comparison to Soybean and Gmelina OBMs.

The profile shown in Figure 8 shows how tiger nut OBM compares with Soybean and Gmelina in terms of plastic viscosity, gel strength, and mud weight. Concerning the mentioned characteristics, tiger nut OBM fared best. The gel strength of Gmelina is on the high side, whilst that of Soybean oil was too low in line with the API standard for oil-based muds. For plastic velocity and mud weight, their characteristics were closely associated. Therefore, tiger nut OBM possessed the inclusive required properties for oil-based drilling muds.

However, comparing previously published works on various vegetable oils with tiger nut oil as the continuous phase in mud formulation becomes difficult as different authors such as Adesina et al., [16] and Paul et al., [15] used differing mud formulation standards: API and OCMA standard. Whereas Paul et al., used the API standard of 20 g bentonite to 350 mL liquid phase: oil-water ratio of 70:30, with the addition of 106 g of barite to the formulated mud, Adesina et al., [16] did not highlight their drilling mud formulation standard.

CONCLUSION

The experiment on a comparative study of tiger nut oil-based drilling mud with diesel oil-based drilling mud was carried out successfully. The tiger nut oil extraction took approximately 30 hours. The rheological properties tests carried out include the viscosity, gel strength (at 10 seconds and 10 minutes, correspondingly), plastic viscosity (PV), yield point (YP), and apparent viscosity (AV). From the result obtained, the mud density test carried out showed that tiger nut OBM is 8.15 lb/gal and has a better and higher advantage than that of diesel OBM at 7.95 lb/gal, both with the presence of the weighting material - barite. The cuttings carrying index (CCI) of the drilling mud was evaluated which also has a higher value of 2.03, comparing it with that of diesel OBM, 1.49, at the same angular velocity of 100 ft/min. The pH of diesel OBM, 8.0, falls within the acceptable range for a drilling mud's pH but is lower compared to tiger nut OBM, 8.5, which displays an optimum value and is more suitable for diverse formations. Considering costing, the chief challenge comes across in the oil extraction phase. If cheaper methods are employed, there is a very high possibility that tiger nut OBM could also be cheaper than diesel OBM.

It was inferred that tiger nut oil-based mud proved to be more effective than the diesel oil mud as well as being in line with environmental requirements. It was recommended that cheaper and alternative methods of extracting plant seed oils should be encouraged to reduce the cost of extraction which was a major downside in the course of this research work. Also, in tackling challenges of sustainability of tiger nut oil, the mixture of edible and inedible oils should be experimented with as base oil for mud formulation. Lastly, more work should be done on using as many local materials as a substitute in the formulation of drilling muds.

Abbreviations

TNO: Tiger nut oil
OBM: Oil-based mud
RPM: Revolutions per minute
CCI: Cuttings carrying index

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