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Alternate Formulation of Oil Based Mud Using Moringa Oil as the Based Fluid

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ABSTRACT

Drilling operations predominantly rely on synthetic-based muds that use mineral oil as the base fluid, leading to longstanding environmental concerns in the industry. The injection of non-biodegradable oil into the subsurface results in significant fluid infiltration into the formation, highlighting the need for a more sustainable alternative. Therefore, a mud system incorporating biodegradable oil from renewable sources is essential. This alternative must replicate the rheological properties of conventional mud systems while minimizing formation damage. This study investigates whether Moringa oil can serve as a substitute for diesel in oil-based mud by evaluating its rheological characteristics, including viscosity, yield point, gel strength and filtration properties, through laboratory testing to address environmental challenges.

Keywords: Annular flow; Sand particles; Shear stress; Wave velocity; Superficial velocity

Introduction

Over the years, the petroleum industry has successfully drilled and produced hydrocarbons for various applications. Since its inception, the industry has continuously sought efficient methods to extract oil from the pore spaces of reservoir rocks and bring it to the surface. The processes involved in hydrocarbon production fall under petroleum engineering, a specialized field of engineering with several subdivisions, including drilling engineering, reservoir engineering, production engineering, petroleum economics and natural gas engineering.

A drilling engineer's primary responsibility is to ensure that wells are drilled safely and efficiently. One critical factor in achieving this is the selection and management of drilling fluid, often referred to as "the blood of the drilling process". The drilling engineer is responsible for choosing and maintaining the most suitable drilling fluid for the operation. However, other key aspects must also be considered, including bit penetration, bit face cleaning, cuttings transportation and borehole stability, to ensure successful well construction (Mitchell and Miska, 2012).

The choice of drilling fluid is critical to the success of drilling operations, as it aids in cuttings removal, maintains wellbore stability and serves as the primary well control mechanism to prevent kicks and blowouts[1]. Drilling fluids are generally categorized into three types: synthetic-based mud (SBM), oil-based mud (OBM) and water-based mud (WBM), with oil-based mud being the most widely used. OBM plays a crucial role in drilling by cooling and lubricating the drill bit, transporting cuttings to the surface, maintaining borehole stability, controlling formation pressures and enhancing the efficiency of downhole equipment.

The use of OBM in drilling operations has grown significantly due to its advantages, including excellent shale inhibition, lubricity, thermal stability, corrosion resistance, contaminant tolerance and ease of maintenance. Since its introduction, diesel oil has primarily been used as the base oil in OBM. However, research from the early 1980s revealed that diesel oil poses environmental and health risks due to its high toxicity and aromatic content[2].

Stricter environmental regulations have led to significant restrictions on the use and disposal of oil-based mud, particularly due to concerns over diesel oil contamination. Even newer, more environmentally friendly mineral and synthetic oils are sometimes deemed unsuitable for offshore applications due to their non-biodegradability. As a result, many countries, including the USA, UK, Netherlands, Norway, Nigeria and Australia, have imposed strict limitations or outright bans on diesel and mineral oil-based drilling fluids for offshore operations.

A single well can generate between 1,000 and 1,500 tonnes of drill cuttings, with an estimated oil retention rate of 15%, meaning that each well releases approximately 150 to 225 tonnes of drilling fluid into the ocean. The disposal process requires costly cleaning methods before cuttings can be discharged into the sea, while the used oil mud itself must be transported to land for proper disposal. In environmentally sensitive areas, the use of OBM is completely prohibited. In response to these challenges, vegetable oil-based drilling fluids and synthetic muds have been developed as safer, more sustainable alternatives that minimize risks to oilfield workers and surrounding communities[3].

Moringa seed oil is a promising plant-based alternative to diesel in oil-based drilling fluids, offering comparable performance while adhering to Health, Safety and Environmental (HSE) standards. Moringa is a highly beneficial, fast-growing and drought-resistant tree, widely cultivated in Northern and Western Nigeria. Once established, it requires minimal water and soil nutrients, making it a sustainable resource.

In this study, moringa oil serves as the base fluid for the candidate oil-based mud. The research focuses on evaluating whether moringa oil can effectively replace diesel oil in oil-based mud by analyzing its physical and chemical properties. Diesel oil-based mud, which is commonly used and proven effective, will serve as the benchmark. To determine its suitability as a diesel substitute, this study will assess and describe the characteristics of moringa oil-based mud.

Drilling fluid

Drilling fluid, often referred to as "the blood of the drilling process," accounts for approximately 5% to 15% of the total well drilling cost (Boyl et al., 1994). It is typically a mixture of liquid, solid and gas, circulated within the wellbore to enhance efficiency and reduce overall drilling expenses (Gandhi and Sarkar, 2016). Throughout the drilling process, the fluid plays a critical role in ensuring smooth operations (Agwu et al., 2017).

Key functions of drilling fluid include transporting drill cuttings to the surface, cooling and lubricating the drill bit and string to minimize wear, forming a thin, impermeable mud cake on borehole walls to prevent fluid invasion, maintaining an overbalanced pressure to control formation pressures, providing buoyancy to support the weight of the drill and casing strings, minimizing formation damage, delivering hydraulic horsepower to optimize penetration rates and transmitting downhole data to the surface for analysis.

The effectiveness of drilling fluid is crucial to the success of any drilling operation (Wedman, Ahmed and Kalkan, 2019). When designing a drilling fluid, factors such as well design, rock mechanics, anticipated formation pressures, formation chemistry, temperature, environmental regulations, logistics and economic considerations must be taken into account. The fluid's efficiency in the wellbore is largely determined by its rheological properties.

Type of drilling fluid

Drilling mud is classified into three main types: pneumatic/gas-based mud, water-based mud (WBM) and oil-based mud (OBM). Since the 1930s, OBM has been recognized as more effective than WBM, making it the preferred choice in upstream petroleum operations. The efficiency and performance of drilling fluids are largely influenced by their rheological properties, which determine their deformation and flow behavior (Figura and Teixeira, 2007). Key rheological parameters include apparent viscosity, gel strength, yield point and plastic viscosity (Elkatatny et al., 2016).

As oil and gas exploration expands into challenging environments such as arctic regions, deep-water offshore fields and reservoirs with extreme temperature and pressure conditions, drilling costs continue to rise. In such demanding conditions, achieving high-performance circulation of drilling fluids is critical to the success of drilling operations[4].

Water Based Mud (WBM)

Water-based mud (WBM) primarily consists of water and bentonite, with common weighting agents such as calcium carbonate and barium sulfate. WBM is the most widely used drilling mud due to its cost-effectiveness and ease of application. However, a major drawback is the thermal degradation of chemical additives when drilling in high-temperature wells. This deterioration can lead to significant fluctuations in rheological and filtration properties, ultimately affecting fluid performance[5]. Additionally, even in the absence of chemical breakdown, elevated temperatures can drastically reduce the viscosity of hydro-soluble polymer solutions commonly used in drilling fluid formulations. Improperly designed and maintained drilling fluid systems can cause severe damage to wellbore formations and lead to blockages in screens and slotted liners, further complicating drilling operations (Pitoni et al., 1999).

Oil Based Mud (OBM)

Oil-based mud (OBM) is primarily composed of a surfactant, water or brine and oil, with base oils including mineral oil, low-toxicity mineral oil or diesel oil (Caenn et al., 2011). OBMs outperform water-based muds (WBMs) when drilling into shale formations due to their superior stability and resistance to filtration losses. They are commonly used in complex drilling environments, such as horizontal wells, deep wells and reactive shale formations. Despite their effectiveness, OBMs present environmental and economic challenges. They are costly to dispose of and contain harmful components like mineral oil, making them less suitable for modern environmental regulations. The primary disadvantage of OBMs is their low or nonexistent biodegradability. Their poor aerobic biodegradability is a significant concern, particularly because they degrade very slowly in anaerobic conditions, such as those found on the seafloor and in drill cuttings discharged from offshore platforms. These environmental concerns have driven extensive research into the development of synthetic drilling fluids as more sustainable alternatives (Salleh et al., 2011).

Pneumatic/Gas Based Mud (GBM)

Pneumatic (gas) drilling fluids, including dry gas (such as natural gas, nitrogen and air), foam, gasified muds and mist, are commonly used in low-reservoir pressure zones, potential loss circulation zones and underbalanced drilling operations (Azar and Samuel, 2007). These fluids are particularly effective for drilling through poorly consolidated or fractured formations and are often referred to as underbalanced fluids due to their frequent application in underbalanced drilling[6].

Drilling fluid selection

Selecting the appropriate drilling fluid involves evaluating the characteristics of the rock formation while considering financial implications and environmental impacts (Nwaiche, 2015). To strike an "economic-ecological" balance, companies aim to develop drilling-fluid systems and additives that meet industry standards while maintaining efficiency, despite their high costs[7].

Several key factors influence the choice of drilling fluid, including formation pressure, well design, formation chemistry, rock physics, potential formation damage, logistics, cost and environmental regulations. Traditionally, the industry has relied on two main types of drilling fluids: water-based and oil-based. While water-based fluids are more cost-effective and easier to produce, oil-based fluids are preferred in certain applications due to their superior lubricating properties, corrosion control and rheological stability at high temperatures, up to 500°F. Oil-based fluids are particularly effective for drilling through water-sensitive clays. Diesel oil, known for its high viscosity, low rubber solubility and low flammability, has commonly been used as the base fluid in oil-based mud formulations (Agwu et al., 2015).

However, oil-based muds come with significant cost and environmental challenges, particularly concerning proper disposal of drill cuttings to prevent contamination. As a result, selecting an appropriate base oil is crucial. The petroleum industry has been tasked with developing improved drilling fluids that minimize handling costs and environmental impact compared to conventional diesel-based muds[8].

Recent research has focused on identifying alternative oils that address environmental concerns. This has led to the development of synthetic oil-based muds with enhanced biodegradability and lower toxicity. Using biodegradable oils as base fluids can reduce costs, ensure environmental safety and preserve essential drilling functions such as maintaining hydrostatic pressure, removing cuttings, cooling and lubricating the drill string and stabilizing boreholes before cementing[2].

Due to growing environmental concerns, the use of oil-based mud is increasingly restricted or prohibited. Diesel oil, the most commonly used commercial base oil, offers various advantages in drilling operations but also poses significant environmental risks due to its high aromatic content and toxicity (Setyawan et al., 2011). Drill cuttings from diesel oil-based muds require special treatment before disposal to prevent water contamination and the additional cost of transporting cuttings to onshore disposal sites further increases drilling expenses (Veil, 1998).

To develop a sustainable drilling fluid, a systematic and quantitative approach is necessary, balancing performance with cost-effectiveness. This has led to a shift toward biodegradable oil-based muds that retain the properties of conventional oil-based muds while significantly reducing environmental impact and costs (Gbadebo et al., 2010).

One promising alternative is moringa oil, a locally available vegetable oil that has been proposed as a substitute for diesel oil in drilling fluids. Moringa oil possesses key characteristics that make it a viable replacement, including high viscosity, high density, local availability and environmental friendliness. This study aims to assess the feasibility of moringa oil as a cost-effective and eco-friendly alternative to diesel oil in drilling fluids by evaluating its rheological properties through various testing methods.

Literature Review

Drill cuttings or fragments of rock from subsurface formations, are typically removed using drilling fluids, also known as drilling mud[9]. These fluids, essential in petroleum drilling operations, consist of a mixture of oils, water, chemicals and clays. Water-based muds are the most commonly used drilling fluids worldwide, with water making up approximately 90% of the continuous phase (Meinhold, 1999). They are preferred over oil-based muds due to their cost-effectiveness and environmental benefits (Ogugbue et al., 2010). These fluids primarily consist of aqueous solutions of polymers and clays, along with various additives that enhance their performance[6].

Oil-based muds have oil as their continuous phase and are specifically formulated for conditions where water-based muds prove insufficient (Bol et al., 1994). Common base oils in OBM formulations include diesel, kerosene, mineral oil, gasoline and crude oil. Despite their superior performance in challenging drilling environments, oil-based muds pose environmental concerns due to their toxicity and disposal challenges. Pneumatic drilling fluids consist of gases or gas-liquid mixtures as their continuous phase. These fluids operate at pressures lower than the formation pressure of petroleum within the rock pores, making them classified as underbalanced fluids. They are primarily used in drilling formations that are weakly cemented or naturally fractured[6].

Drilling fluid selection

The selection of a drilling fluid system starts with identifying the appropriate category of drilling fluids based on the characteristics of the rock formation while also considering environmental and financial factors (Nwaiche, 2015). Oil-based drilling fluids offer several advantages over traditional water-based drilling fluids due to their superior rheological properties. According to Fadairo, et al[10], some key benefits of oil-based drilling fluids include:

Shale stability: Oil-based mud is effective in drilling water-sensitive shales. Proper salinization prevents water invasion, maintaining shale integrity. Optimized penetration rate typically allows for higher penetration rates compared to water-based muds. High-temperature tolerance is suitable for drilling formations where water-based muds may degrade due to extreme downhole temperatures and contaminants. Excellent lubricating properties make oil-based mud ideal for horizontal and highly deviated wells. The external oil phase coats the pipe, reducing corrosion risks. Oils are thermally stable, non-conductive and resistant to microbial growth. Oil-based muds can be reused and stored for extended periods due to reduced microbial activity.

Properties of drilling fluid

Density

Mud weight, also known as fluid density, is a critical parameter in drilling operations. To prevent formation fluids from entering the wellbore during conventional drilling, the drilling fluid density must be higher than the formation fluid pressure density. However, it should not be excessively high, as this can lead to lost circulation, reduced drilling efficiency or potential formation damage (Cleveland & Ayres, 2004).

Viscosity

Viscosity is a term used to describe the internal friction a fluid generates when subjected to an external force that induces flow. This internal friction arises due to the molecular attraction within the liquid and is directly related to shear stress. The greater the resistance to shear stress, the higher the viscosity. In drilling operations, the viscosity of a drilling fluid must be adequately balanced-it should be high enough to effectively transport cuttings to the surface and suspend the weighting agent but not excessively high to avoid unnecessary friction pressure loss (Boyl et al., 1994)

Yield point

Yield point refers to the flow resistance caused by attractive interactions between particles within a fluid. It is measured in pounds per 100 square feet and represents the initial resistance to flow due to electrostatic forces acting on or near particle surfaces (Azzar and Samuel, 2007). Several factors influence yield point, including the type and concentration of solids, their surface charges and the ions present in the fluid phases (Baker, 1995).

Gel strength

Gel strength is a measure of a mud's thixotropic capacity, representing its ability to develop a gel structure and suspend drill cuttings when circulation is stopped, such as during connections or tripping operations. Thixotropy refers to the fluid's ability to transition from a gelled state to a flowing state when shear is applied. The stress required to break this gel structure under static conditions depends on the attractive forces between particles in the mud, which are quantified as gel strength (Annudeep, 2013).

Gel strength is time-dependent, typically measured at 10 seconds and 10 minutes. Excessively high gel strength can lead to pipe sticking, increased pump pressure to restart circulation and even formation fracture, particularly in high-angle wells (Azzar and Samuel, 2007).

Fluid loss

Fluid loss refers to the amount of drilling fluid that infiltrates the formation after passing through the filter cake formed during drilling. To minimize or control fluid loss, drilling fluids are often treated with additives. Several factors influence fluid loss, including time, temperature, cake compressibility and the type, quantity and size of particles in the drilling fluid. Optimizing these parameters is crucial for maintaining wellbore stability, especially when drilling into shale formations under high-pressure and high-temperature (HPHT) conditions (Chilingar et al., 1981).

Drilling fluid additives

The characteristics of drilling fluids are altered using a variety of drilling additives to meet the needs of varied depth intervals. Throughout the drilling process, parameters including density, flow characteristics or rheology, filtration, solid content, as well as chemical properties, must be precisely monitored, regulated and maintained at pre-selected levels.

Methodology

Apparatus used

Measuring/weighing Balance, Mixer/Blender, Soxhlet extractor, Mud balance, pH meter, Thermomete, Fann viscometer, Measuring cylinder, N-hexane, Filter paper, Stopwatch, Mud cup, Beaker(s), Oil (diesel and moringa).

Method

Extraction

Moringa plant seeds were sourced from Mile One Market in Port Harcourt and subsequently dried in an oven at approximately 55°C for 70 minutes. Once dried, the seeds were dehulled to extract the kernels, which were then blended into a fine consistency.

In this study, solvent extraction was employed as the oil extraction method. Unlike mechanical pressing techniques (such as expellers or hydraulic presses), solvent extraction involves treating oil-bearing materials with a low boiling point solvent, maximizing oil recovery. This method ensures that nearly all of the oil is extracted, leaving only about 0.5% to 0.7% residual oil in the raw material[9]. The Soxhlet extractor was used for the extraction process. Originally designed by Franz von Soxhlet in 1879, this laboratory apparatus is specifically intended for extracting soluble compounds from solid materials.

Extraction procedure

The extraction of moringa seed oil using the Soxhlet extraction method was carried out as follows:

Sample preparation: 50g of crushed moringa plant seeds were wrapped in filter sheets.

Loading the soxhlet extractor: The prepared sample was placed inside the main chamber of the Soxhlet extractor. Approximately 300 ml of n-Hexane was added to the chamber. The main chamber was then positioned inside a flask containing an additional 300 ml of n-Hexane.

Heating and extraction: The heating mantle was switched on and the system was heated to 70°C. The solvent was reflux-heated, causing its vapors to rise through the distillation arm into the chamber containing the sample wrapped in filter papers. The condenser facilitated the condensation of the solvent vapor, which then trickled back into the chamber containing the solid sample.

Continuous solvent cycling: This process was repeated until the sample in the chamber significantly changed color, indicating maximum oil extraction. At this point, the siphon transferred the liquid phase into the flask, where the mixture of oil and solvent was collected in glass reagent bottles.

Separation of oil and solvent: Simple distillation was used to separate the oil from the solvent. The mixture was heated at 70°C, allowing the n-Hexane to evaporate and be recovered for reuse.

Mud formulation process

Procedures for mud formulation

The preparation of both diesel-based and moringa-based drilling muds was conducted using a Hamilton Beach mixer with the following steps:

Table 1: Constituent of the Moringa Based Mud.

ADDITIVES	MASS / VOLUME	FUNCTION
Moringa oil	210ml	Based fluid
Organophilic clay	6g	Viscosifier. They are used to provide thixotropic properties to drilling mud.
Primary emulsifier	4ml	To emulsify water into oil-based fluid
Secondary emulsifier	8ml	Dispersant
Lime	5g	pH regulator
Brine ($CaCl_2$+H_2O)	3.4g+5ml	To reduce foaming tendency of mud
Gypsonite	3g	Fluid loss agent
Barite	30g	Weighting/density control
Water	90ml	Discontinuous phase

Table 2: Constituent of the Diesel Based Mud.

ADDITIVES	MASS / VOLUME	FUNCTION
Diesel oil	210ml	Based fluid
Organophilic clay	6g	Viscosifier. They are used to provide thixotropic properties to drilling mud.
Primary emulsifier	4ml	To emulsify water into oil-based fluid
Secondary emulsifier	8ml	Dispersant
Lime	5g	pH regulator
Brine ($CaCl_2$+H_2O)	3.4g+5ml	To reduce foaming tendency of mud
Gypsonite	3g	Fluid loss agent
Barite	30g	Weighting/density control
Water	90ml	Discontinuous phase

Liquid additives, such as emulsifiers and distilled water, were measured using a calibrated syringe and measuring cylinder. Solid mud additives were accurately weighed using a weighing balance. The Hamilton Beach mixer was plugged into a power source **(Tables 1 and 2)**. Moringa oil and diesel oil (for their respective muds) were added to the mixer cup. The required quantity of organophilic clay was weighed and added to the mixer. The mixture was stirred for two minutes to ensure even dispersion. Primary and secondary emulsifiers were introduced into the liquid using a syringe. The mixture was agitated for five minutes to ensure proper emulsification. A measured amount of lime was added to the mixture. Stirring continued for two minutes to ensure even distribution. Brine was added to the mixture. The solution was stirred for two minutes. Gypsonite was introduced into the mixture. Stirring was carried out for two minutes. The mud was agitated for five minutes to achieve uniform dispersion. Once the mixing process was complete, the prepared mud was poured into a cup. The mixer was turned off and the mud was stored for further testing.

Rheology test

The tests conducted under rheology were the viscosity and the gel strength tests respectively.

Viscosity

The viscometer was properly set up. The power supply was plugged in and the device was turned on. The rotor sleeve was lifted and test fluids were added to a sample cup. The rotor sleeve was submerged up to the fill line on the sleeve. The platform was stabilized by tightening the lock nut. The power switch on the rear panel and the mains switch were turned on. The sample was stirred for a few seconds using the STIR setting on the knob. The knob was turned to 600 RPM and the dial reading was allowed to stabilize before recording the 600-RPM value. The procedure was repeated for RPMs of 300, 200, 100, 6 and 3, recording the stabilized dial readings for each speed.

Gel strength

Gel strength measurement procedure

The viscometer was connected to the power supply. The platform was lift and the rotor was submerged to sleeve up to the fill line. The test fluid added to the sample cup. The platform was by tightening the locknut. The mains were turned and the power switch was located on the rear panel. The sample was stirred for a few seconds using the STIR setting on the knob. The knob was turned to the GEL position. The power was then switched off and start timing started once the rotor stopped revolving. After 10 seconds, the power was switched back on and recorded the highest deflection reading. The procedure was repeated for the 10-minute gel strength measurement, following the same steps.

Density

Mud density measurement using a mud balance

First, calibration of the mud balance was done using fresh water. The mud balance was placed on a level surface. It was ensured that the cup was thoroughly dried before adding the mud sample.

The cup was filled with the mud sample up to the top. The hole was closed and cleaned any excess mud from the exterior and dried the surroundings. The lid was secured onto the cup, twisting it to expel excess mud and remove trapped gases. The filled cup was placed on the knife-edge of the balance. The rider was adjusted along the arm until equilibrium was reached. The mud weigh was read and recorded from the balance arm.

pH test

The pH meter will be used to determine if the mud is acidic or alkaline. While acidic muds would corrode the metal fittings in the borehole, such as the strings and harm subsurface formations, drilling muds are often anticipated to be on the basic side. The following techniques were employed in this experiment:

- For homogeneity of qualities, the mud was placed in a cup and the electrode was dipped into the sample and the glass electrode while softly mixing the fluid.

Filtration test

The top cap of the filtration unit was removed. A filter paper was placed at the bottom of the test cell. A graduated cylinder was positioned beneath the filtrate exit tube to collect the fluid, thereby filling the Cell.

The mud sample was poured into the test cell, leaving approximately 10 mm of empty space at the top.

The test celled were sealed and assembled. The top of the cap of the cell was secured. The assembly was fastened to the frame using a T-screw. The pressure was regulated to ensure the safety bleeder valve on the regulator was safe. The T-screw was rotated counterclockwise until it is freely rotating, ensuring the diaphragm pressure is released.

The pressure source's valve was opened to pressurize the air hose once the airline was attached to it.

The regulator was set such that 40 psi was applied to the cell in 35 seconds by rotating the T screw in a clockwise direction. The test started after this pressure was reached, lasted for 30 minutes and was then halted. The volume of filtrate was then measured, the air flow was stopped by twisting the regulator counterclockwise and the pressure source valve was closed while the relief valve was gently opened.

Toxicity test

The mud will be tested on plants using bean seed once it has been created to evaluate how it affects plant development. The number of days that the bean seed survived after being planted and exposed to 100ml of the mud samples was noted.

Results and Discussions

Result of density measurement

Table 3: Mud density value.

SAMPLE	MEASURED DENSITY (ppg)
DIESEL BASED MUD	8.1
MORINGA BASED MUD	8.4

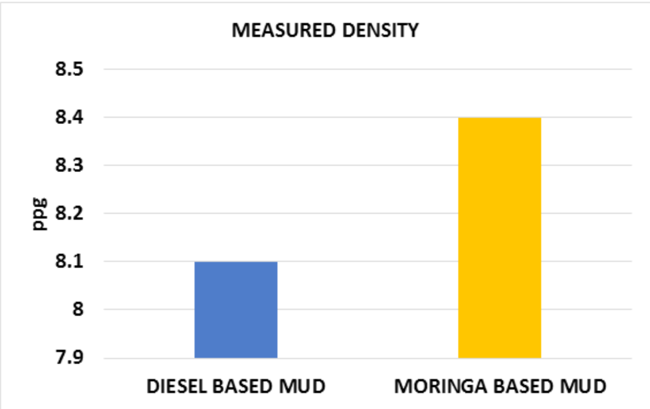

Figure 1: Density Plot for Moringa and Diesel oil-based mud.

Mud density is a crucial factor in limiting formation fluid pressure **(Table 3).** Because the mud density of moringa-based mud is larger than that of diesel by 0.3ppg, less weighting agent (barite) would be required to be added to moringa-based mud to reach the same mud weight as diesel-based mud **(Figure 1)**.

Viscosity and gel strength result

Rheological characteristics are crucial for understanding drilling fluid development **(Figure 2)**. The removal of cuttings from well drilling, whether deviated drilling or horizontal drilling technique, is aided by increasing the viscosity of a drilling mud[8]. **(Tables 4 and 5)** contains the viscosity readings from the experiment performed on the rotating viscometer. The viscometer speeds in RPM are recorded against the dial reading values (in lb/100ft2).

Table 4: Viscometer Readings.

Dial speed (RPM)	Diesel oil-based mud	Moringa oil-based mud
600	165	230
300	144	204
200	137	160
100	118	125
6	40	55
3	25	50

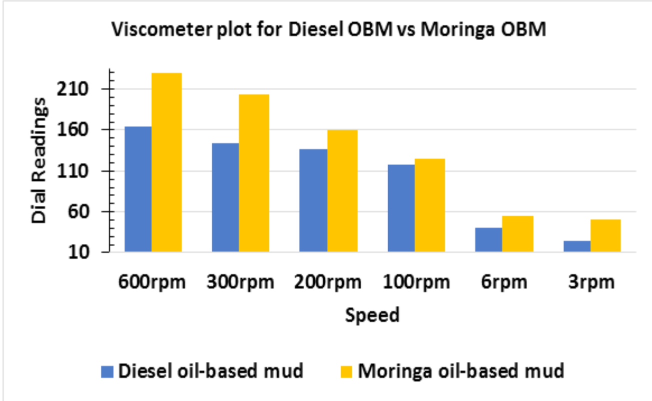

Figure 2: viscometer plot for Diesel OBM vs Moringa OBM.

Table 5: Plastic Viscosities, Apparent Viscosities, Yield Point and Gel Strength values.

Rheological Properties	Diesel oil-based mud	Moringa oil-based mud
Plastic Viscosity	21	26
Apparent Viscosity	82.5	115
Yield Point	123	178
Gel Strength (10 seconds)	37	45
Gel Strength (10 minutes)	41	51

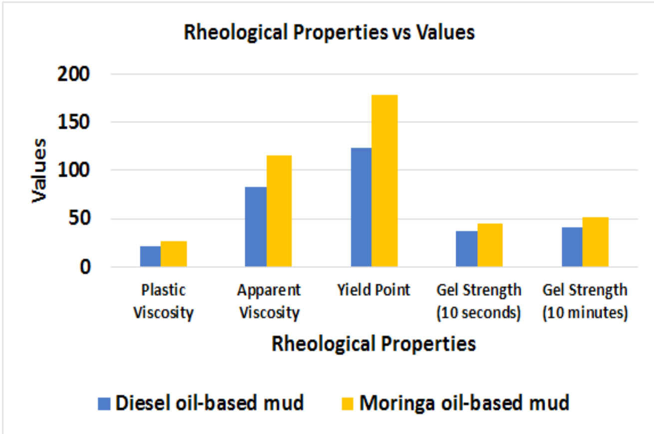

Figure 3: Plot of Rheological properties vs values of Diesel OBM and Moringa OBM.

Moringa oil-based mud has the maximum viscosity, as seen in **(Table 5)**. As a result, moringa oil-based mud has the highest fluid flow resistance, which contributes to its high plastic viscosity value. Diesel oil-based mud offers greater chances because it will flow more freely due to its lower viscosities. The drill string will thus endure less wear as a result **(Figure 3)**.

A satisfactory cutting suspension in the drilling fluid is ensured by a high gel strength. According to **(Table 5)**, moringa oil-based mud offers a better cutting suspension than diesel oil-based mud because it has a greater gel strength value.

Hydrogen ION result

Table 6: pH Values.

SAMPLE	pH VALUE
Diesel oil-based mud	8.5
Moringa oil-based mud	9.0

Drilling muds are always made to have an alkaline pH (a value greater than 7). A pH of 8.5 to 9.5 seems to provide the optimum hole stability and control over mud qualities for reducing shale concerns (Fadairo et al., 2012). Shale issues seem to be brought on by an elevated pH (10+) **(Table 6)** and **(Figure 4)**. When metal encounters an acidic solution, corrosion is accelerated. As a result, both samples' pH values are within acceptable bounds.

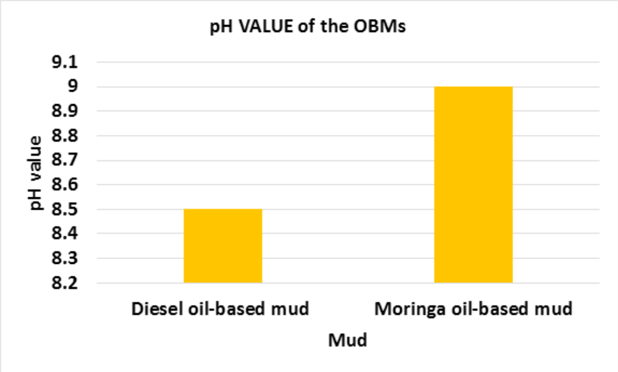

Figure 4: Plot of pH value of the OBMs.

Mud filtration result

Table 7: Mud Filtration Results.

Filtration properties	Diesel oil-based mud	Moringa oil-based mud
Filtrate loss	2.6ml	2.4ml
Mud cake thickness	2.4mm	2.0mm

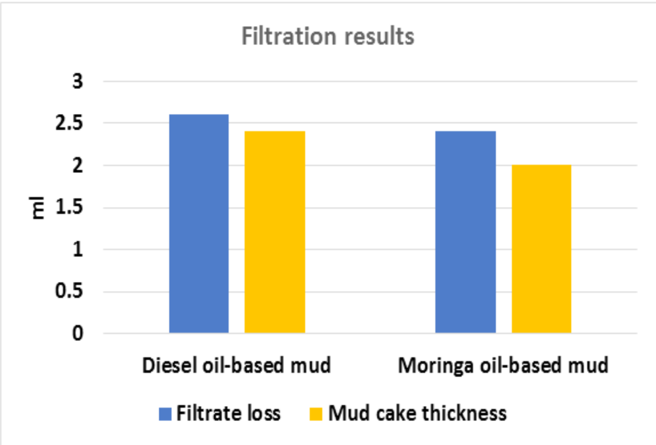

Figure 5: Plot of Filtration results of the OBMs.

The most crucial characteristic of a drilling fluid is frequently filtration rate, especially when drilling permeable formations when the hydrostatic pressure is higher than the formation pressure[4]. Filtration may be effectively controlled to decrease borehole instability and, in some cases, eliminate wall adhering and drag **(Table 7)**.

Table 5 displays the filtering characteristics of the oil-based mud formulations that were collected after 30 minutes. According to the figure, diesel oil-based mud exhibits higher filtrate loss capabilities than moringa oil-based mud **(Figure 5)**. High filtrate volumes are typically linked with thick filter cakes because the cake is created when clay particles are deposited on the hole's walls during filtrate loss to the development of the cake[5].

Toxicity test result

Table 8: Toxicity text result

SAMPLE	DIESEL OIL BASED MUD	MORINGA OIL BASED MUD
Days of survival	5	8

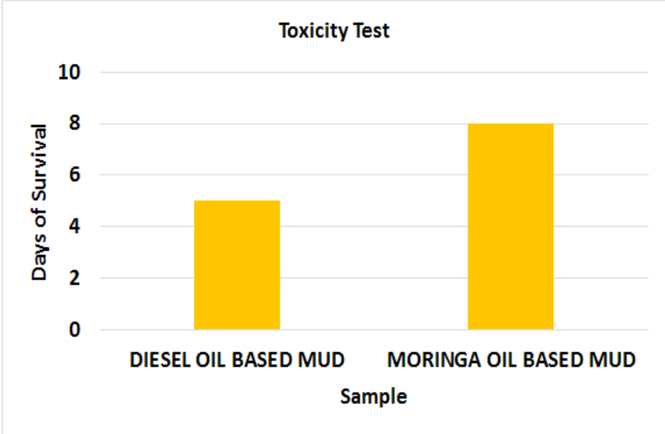

Figure 6: Plot of Toxicity Test of the OBMs.

Moringa oil has a less detrimental effect on plant development than diesel oil, according to the data shown in **(Table 8)**. Thus, mud made with moringa oil is better for the environment than mud made from diesel oil **(Figure 6)**.

Conclusion

During the well drilling phase, drilling activities produce wastes related to rock cuttings and used drilling fluids. Chemicals are necessary for the procedure to be completed successfully. Also, the wastes and drilling fluids include harmful compounds that, either directly or indirectly, endanger the environment and the public's health[7]. Drilling fluid wastes are often dumped into the sea or the land during the drilling operation or when the well is finished[9]. Drilling fluid wastes and associated compounds have the potential to contaminate all geosphere components. Many authorities throughout the world are developing discharge restrictions and recommendations. The creation of a drilling fluid that is ecologically friendly is thus necessary. In this work moringa oil was chosen as the based fluid.

The results of the test show that, despite diesel-based mud having a little superior rheologic quality than moringa oil, moringa oil-based mud has a good possibility of being one of the technically feasible alternatives. The findings also indicate that, in order to make the mud formulation more technically possible, additional chemistry must be used. Also, due to moringa oil's high level of biodegradability, the toxicity test results show that diesel oil-based mud is more harmful to the environment than moringa oil. The following conclusions may be inferred from the main findings of the experiment done with the moringa-based mud: based on the results of the viscosity tests, it can be concluded that a sufficient concentration of thinner can further reduce the plastic viscosity of mud made from moringa oil. The higher pH value of moringa oil-based mud inhibits corrosion rates, resulting in an increase of the lifespan of drilling equipment.

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