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Utilization of Cow Fat-Derived Biodiesel as a Sustainable Base Fluid in Oil-Based Drilling Muds

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Abstract- Oil and gas production is capital-intensive, with drilling operations accounting for a significant portion of overall costs. Drilling fluids are essential to address downhole challenges such as hole cleaning, bit cooling, pressure control, and lubrication. Among these, drilling muds are classified into water-based and oil-based types. Oil-based muds (OBMs) typically use diesel or synthetic oils as the continuous phase, but the potential of waste-derived oils remains underexplored. This study investigates the feasibility of using biodiesel derived from cow fat as an alternative continuous phase in OBMs. Biodiesel was extracted through transesterification and used to formulate mud samples, alongside conventional diesel-based samples. Both mud types were evaluated for rheological properties plastic viscosity (PV), yield point (YP), and gel strength at temperatures of 80°F, 120°F, and 150°F, along with electrical stability (ES). At 80°F, the PV of diesel-based and biodiesel-based muds were 57.51 cP and 37.27 cP, respectively. As temperature increased, diesel-based PV dropped more sharply than the biodiesel-based mud, indicating better thermal stability in the latter. Biodiesel-based mud also exhibited superior yield point values, suggesting enhanced carrying capacity. However, its electrical stability (67.33 V) was significantly lower than that of the diesel-based mud (413 V), limiting its effectiveness in electrical stability performance. In conclusion, biodiesel-based drilling fluid shows promise as a rheological modifier with favorable thermal behavior but is not a suitable replacement for electrical stability enhancers in OBMs.

Keywords- Cybersecurity Awareness, Gamification, Phishing Simulation, Chatbot Assistance, Interactive Training.

I. INTRODUCTION

The oil and gas industry is characterized by its capital-intensive nature, with drilling operations constituting a significant portion of overall expenditures. These operations often encounter numerous challenges, many stemming from complex downhole conditions. Drilling fluids, particularly oil-based muds (OBMs), are engineered to address issues such as hole cleaning, bit lubrication, pressure control, and shale stabilization.

Traditionally, OBMs utilize diesel or synthetic oils as the continuous phase; however, environmental concerns and regulatory pressures have prompted the exploration of alternative, more sustainable feedstocks. Biodiesel, a renewable fuel produced through the transesterification of triglycerides from various feedstocks, including vegetable oils and animal fats, has garnered attention as a potential base fluid for OBMs. Animal fats, such as beef tallow, are particularly promising due to their high availability and suitability for biodiesel production. For instance, in Brazil, approximately 7.8% of

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biodiesel production in 2022 was derived from bovine tallow, resulting in a production of 509 million liters, contributing to a reduction in the carbon footprint compared to diesel derived from petroleum (Aboissa, n.d.).

Studies have demonstrated that biodiesel-based drilling fluids exhibit favorable properties, including high flash points, acceptable viscosity, low toxicity, and reliable storage stability. For example, biodiesel produced from waste cooking oil has been evaluated as an external phase in drilling fluids, showing promising rheological parameters and filtration properties suitable for drilling operations at temperatures up to 120°C (Zhang et al., 2015). Additionally, biodiesel-based fluids have been found to possess excellent lubricity, making them suitable for extended reach, directional, and horizontal drilling applications (Elkatatny, 2021).

Despite these advantages, the application of biodiesel derived from animal fats, such as cow fat, in OBMs remains underexplored. This study aims to bridge this gap by investigating the feasibility of utilizing cow fat-derived biodiesel as a sustainable base fluid in OBMs. The research focuses on evaluating the rheological properties, electrical stability, and environmental impact of cow fat-based drilling fluids, comparing them with conventional diesel-based systems. The findings are expected to contribute to the development of more sustainable and environmentally friendly drilling fluid formulations in the oil and gas industry.

The exploration and production of oil and gas are capital-intensive endeavors, with drilling operations accounting for a substantial portion of the overall costs. These operations often face challenges arising from complex downhole conditions, necessitating the use of specialized drilling fluids. Oil-based muds (OBMs) have been the traditional choice due to their superior lubricating properties, high-temperature stability, and effectiveness in inhibiting shale hydration. However, environmental concerns associated with the use of petroleum-based OBMs have prompted the exploration of alternative base fluids, such as biodiesel derived from animal fats.

Biodiesel from Animal Fats

Biodiesel is a renewable fuel produced through the transesterification of triglycerides found in vegetable oils and animal fats. Animal fats, such as beef tallow, are particularly promising due to their high availability and suitability for biodiesel production. For instance, in Brazil, approximately 7.8% of biodiesel production in 2022 was derived from bovine tallow, resulting in a production of 509 million liters, contributing to a reduction in the carbon footprint compared to diesel derived from petroleum (Aboissa, n.d.).

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Challenges and Considerations

Despite the advantages, the application of biodiesel derived from animal fats in OBMs presents certain challenges. One of the primary concerns is the higher viscosity of animal fat-based biodiesel, which can sometimes prevent it from passing the viscosity ASTM specification. This issue can be mitigated by blending the animal fat biodiesel with a lower-viscosity biodiesel (Farm Energy, n.d.).

Another consideration is the sulfur content in animal fat biodiesel. Some samples have been found to contain over 100 ppm of sulfur, which can be problematic for certain applications. The sulfur originates from sulfur-containing amino acids associated with proteins that carry over from the rendering process. While the sulfur level usually decreases by about half during the conversion, the remaining sulfur can be difficult to remove (Farm Energy, n.d.).

Environmental and Economic Implications

The environmental benefits of using biodiesel-based drilling fluids are significant. Biodiesel is biodegradable and non-toxic, reducing the environmental impact in case of spills. Additionally, the use of animal fats, which are often by-products of the meat industry, can contribute to waste reduction and promote sustainability.

Economically, while the initial cost of biodiesel-based drilling fluids may be higher than that of conventional diesel-based fluids, they offer advantages in terms of waste disposal and potential regulatory compliance. The economic evaluation of biodiesel-based drilling fluids suggests reduced formulation and waste management costs, implying lower waste disposal costs (ProQuest, n.d.).

The utilization of cow fat-derived biodiesel as a base fluid in oil-based drilling muds presents a promising alternative to traditional petroleum-based fluids. While challenges such as higher viscosity and sulfur content exist, these can be addressed through appropriate formulation strategies. The environmental and economic benefits further underscore the potential of this approach in promoting sustainable practices in the oil and gas industry.

II. METHODOLOGY

This study was designed to investigate the feasibility of using biodiesel derived from waste cow fat as a sustainable base fluid in oil-based drilling muds. The experimental procedure was divided into four major stages: biodiesel production, mud formulation, rheological evaluation, and electrical stability testing.

Biodiesel Production via Transesterification

Waste cow fat was collected and subjected to a transesterification process to produce biodiesel. Prior to transesterification, the raw fat was filtered and heated to remove impurities and moisture. The transesterification reaction was carried out using methanol and a potassium hydroxide (KOH) catalyst under controlled conditions. The resulting mixture was then allowed to separate into two layers—biodiesel and glycerol. The upper biodiesel layer was decanted, washed, and dried to obtain pure biodiesel suitable for drilling fluid formulation.

Formulation of Oil-Based Drilling Muds

Two sets of oil-based muds (OBMs) were formulated using standard American Petroleum Institute (API) procedures. The first set used conventional diesel as the continuous phase, while the second set used the extracted cow fat biodiesel. Identical weight percentages of emulsifiers, viscosifiers, lime, brine water (as the internal phase), and other additives were used to ensure consistency across samples, allowing for a comparative analysis of the base fluid performance.

Rheological Evaluation Under Simulated Downhole Conditions.

The rheological properties of both diesel-based and biodiesel-based OBMs were measured at varying temperatures (80 °F, 120 °F, and 150 °F) to simulate downhole reservoir conditions. Rheological parameters including plastic viscosity (PV), yield point (YP), and gel strengths (10-second and 10-minute readings) were obtained using a Fann 35 viscometer in accordance with API Recommended Practices (API RP 13B-2).

III. ELECTRICAL STABILITY TESTING

Electrical stability (ES) tests were performed to assess the emulsion stability of the formulated OBMs. ES readings were obtained using an API-recommended electrical stability meter at ambient temperature. This test provided insight into the compatibility and dispersion stability of the internal water phase within the oil-based systems, which is crucial for ensuring mud performance and wellbore integrity.

List of Materials/Apparatus

Beakers (250 ml), Conical flask (250 ml), Heat vessel, Separating funnel, Reflux condenser, Stop watch, Oven, Thermometer, Burette, Retort, Pipette, Magnetic stirrer, Electric heating mantle, water bath and Viscometer.

List of Reagents Used for Transesterification of Biodiesel (Waste Cow Fat)

Potassium hydroxide pellets, Methanol solution, Phenolphthalein indicator, Isopropanol solution and Distilled water.

Table 1: List of Materials Used in Formulation of Diesel and Biodiesel-Based Drilling Fluids

S/N	Materials	Functions
1	Diesel/Biodiesel	Base fluids
2	Organophilic Clay	Viscosifier
3	Soltex	Controls fluid loss, especially under high-temperature high-pressure (HTHP) conditions
4	Primary/Secondary Emulsifier	Provides stable emulsions and acts as an oil-wetting agent
5	Fresh Water	Provides viscosity, solid suspension, and fluid loss control
6	Calcium Chloride	Raises pH of make-up water; precipitates soluble calcium in bentonite/polymer fluids
7	Lime	pH enhancer
8	Rheological Modifier	Adjusts viscosity; prevents sagging; reduces pressure drop across the drill bit
9	Wetting Agent	Reduces surface tension
10	Barite	Weighing agent

Table 2: List of Equipment Used in Formulation of Diesel and Biodiesel-Based Drilling Fluids

S/N	Equipment/Apparatus	Type/Model	Functions
1	Hamilton Beach Mixer	HMD-200	Used for mixing drilling fluids in preparation for laboratory testing
2	Mud Balance	Ofite	Determines the density of drilling fluid and cement slurry
3	Viscometer	Chandler Model 3530	Measures the viscosity and gel strength of drilling fluids and cement slurries

S/N	Equipment/Apparatus	Type/Model	Functions
4	Electrical Stability Meter (ES Meter)	Ofite	Measures the electrical stability of emulsions and resistance to conductivity

Procurement and Extraction of Oil from Beef Tallow

Raw beef tallow was sourced from aluu laughter market, a Rivers state government approved and market as seen in Plate 1. The production of biodiesel was carried out by the transesterification process, where the oil was extracted from the fat, and reacted with potassium methoxide .The potassium methoxide was formed by dissolving potassium pellets (catalyst) in methanol. In order to determine the optimum alcohol to oil ratio for biodiesel production from beef tallow oil, molar ratios of 5:1, 6:1, and 9:1 of methanol to oil were used for three transesterification experiments as shown in equations 1 and 2 respectively. The stoichiometric amounts of the methanol, catalyst and oil needed for the reaction were calculated as shown in equations 1 and 2 .Tallow was rendered through the dry rendering process. A measured quantity of beef tallow was obtained, washed and placed on a sieve to drain off water. Afterwards, it was dried under sunlight, till it became stiff and moisture content was reduced. The dried beef tallow was cut into smaller chunks for better extraction of the oil. The cut pieces of tallow were put into a heating vessel and placed on medium heat to extract oil. The tallow was heated until all oil was extracted from the fat. Protein particles were then filtered out from the oil. The oil was heated further to dry out any water molecules presence.

Percentage Yield

Percentage Yield of Tallow Oil

Weight of tallow sample = 1000g

Weight of empty beaker = 250g

Weight of oil extracted = 930g

Weight of beaker and oil extracted = 1,180g

Percentage yield of Oil = (weight of oil extracted)/(weight of tallow sample) x 100/1 (1)

= 930/1000 x 100/1 = 93%

Percentage Yield of Biodiesel

Yield (%w/w) = mass of biodiesel/mass of oil =mi/M0

Where M0 = 50g

For;

Sample A

Mass of biodiesel produced = 21.831g

Yield == 21.83/50 x 100/1 = 43.66%

Sample B

Mass of biodiesel produced = 24.416g

Yield == 24.416/50 x 100/1 = 48.832%

Sample C

Mass of biodiesel produced = 32.21g

Yield == 32.21/50 x 100/1 = 61.94%

Stoichiometric Calculations

Methanol to Oil ratios

(gram of oil)/(molecular weight of oil) = (X gram of methanol)/(methanol ratio(molecular weight of methanol)) (2)

For 5:1 alcohol to oil ratio

(50 g)/(877 g/mol) = (X g)/(5(32.24) g/mol) = 9.19 g of methanol

For 6:1 alcohol to oil ratio

(50 g)/(877 g/mol) = (X g)/(6(32.24) g/mol) = 11.02 g of methanol

For 9:1 alcohol to oil ratio

(50 g)/(877 g/mol) = (X g)/(9(32.24) g/mol) = 16.62 g of methanol

Transesterification of Beef Tallow Oil

The Free Fatty Acid content of the oil was first determined by titration. The value was obtained to be 2.21%. The Production of Biodiesel by transesterification, was carried out in three experiments of varying methanol to alcohol ratios. Ratios of 5:1, 6:1 and 9:1, were evaluated as seen in Plates 2. All other parameters were kept constant. The experimental procedure was the same for all reactions. For the reaction of the 6:1 molar ratio; 50g of the oil was measured and heated at 120o c for 10 minutes to remove moisture. 0.5g of KOH pellets were weighed and dissolved completely in

11.02g of methanol using the heating mantle and magnetic stirrer, to form potassium methoxide solution. The potassium methoxide solution was added to the heated oil slowly and then mixed vigorously for 1 hour. The temperature was kept at 60 °C by carrying out the reaction on a heating mantle with a magnetic stirrer, and fitted with a reflux condenser to prevent escape of methanol. After the reaction, the mixture was poured into a separating funnel and allowed to separate by gravitational settling for 12 hours, after which the separation between biodiesel and the glycerin was complete. Glycerol layer was drained off from the bottom of the separating funnel leaving only crude biodiesel. The crude biodiesel was then purified by washing with warm distilled water, until the pH of the water was neutral; to remove residual catalyst and excess methanol. The same procedure was used to produce biodiesel for methanol to oil ratios of 5:1 and 9:1 where the methanol quantities used were 9.19g and 16.62g respectively. The Set up are presented in Plates 2, 3, and 4. Thereafter, the produced biodiesel was filtered is presented in Plate 5.

Plate 1: Unprocessed Beef Tallow as Feedstock for Transesterification Reaction

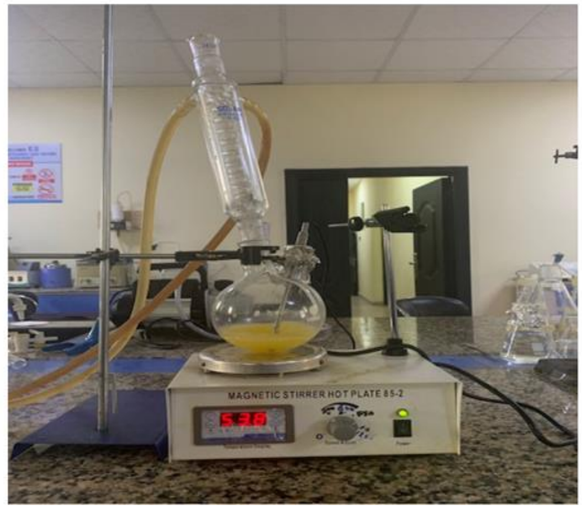

Plate 2: Transesterification of Beef Tallow for Biodiesel Production

Plate 3: Phase Separation of Biodiesel and Glycerin Post-Transesterification

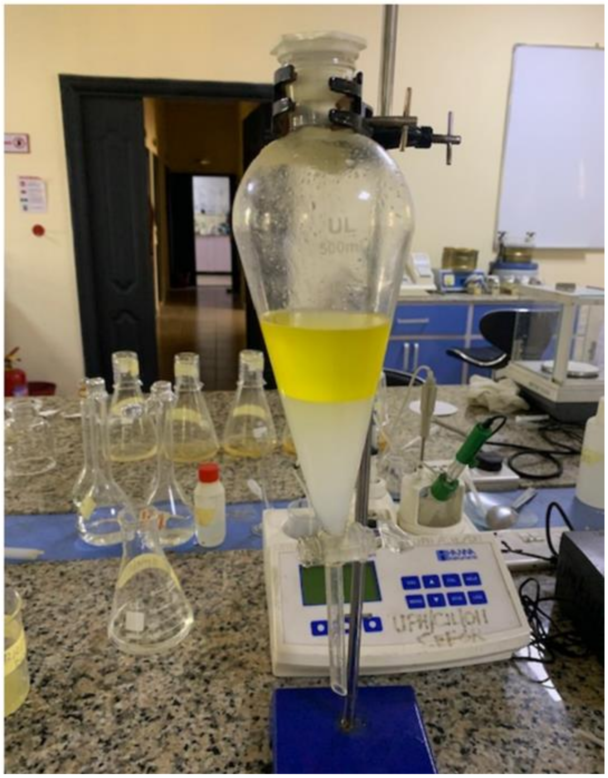

Plate 4: Purified Biodiesel After Washing Process

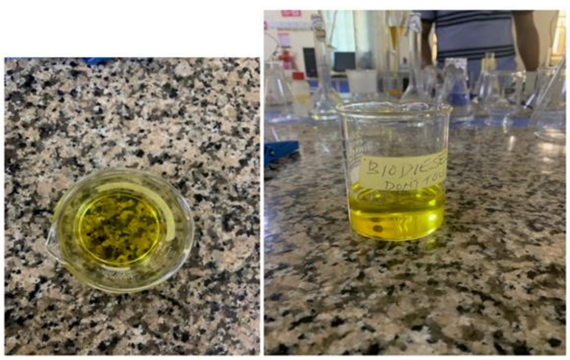

Plate 5: Biodiesel Post-Filtration Process

Diesel and Bio-diesel Based Drilling Fluids Preparation

Two different sets of 9.5 ppg of oil-based drilling fluids were formulated as indicated in Tables 1. Oil-based drilling fluid was formulated with diesel and biodiesel respectively, hard brine (brine with divalent ions) was prepared with 30.5 g of CaCl2 in 91.3 ml of fresh water, this was necessary for perfect dissolution in the drilling fluid design. 4 grams of organophilic clay was introduced into 209.5 millimeters of diesel and biodiesel, and it was mixed in the electric stirrer for 30 minutes to obtain excellent yielding performance. After 30 minutes other additives were such as 6 grams of lime, 1 ml of rheology modifier, 2 mls of wetting agent, 5 mls and 2.5 mls of primary and secondary emulsifier, 3 grams of soltex were added in accordance with the API specifications as seen in Table 3.3. Finally, 95.2 grams of barite was added to the stirring mixture. At the end of the last additive, a total of an hour was obtained for a homogenous mixture. The mud density is measured using mud balance, the pH of the mud is measured with the pH indicator, and the viscosity of the mud is also measured with the aid of a viscometer. The dial reading thereafter of the formulated mud will be recorded at 600, 300, 200, 100, 6, and 3rpm with the help of a rheometer. Rheological properties of the various water-based drilling fluids at temperatures between 800F to 1500F were obtained.

Drilling Fluid Preparation

Table 3: Formulation for Diesel and Biodiesel-Based Drilling Fluids

S/N	Additives	Quantities
1	Diesel/Biodiesel	209.5 ml
2	Organophilic Clay	4 g
3	Soltex	3 g
4	Primary Emulsifier	5 ml
5	Secondary Emulsifier	2.5 ml
6	Fresh Water	69 ml
7	Calcium Chloride	30 g
8	Lime	6 g
9	Rheological Modifier	1 ml
10	Wetting Agent	2 ml

S/N	Additives	Quantities
11	Barite	20 g

RESULTS AND DISCUSSION

This section presents a detailed discussion of the results obtained for oil-based drilling fluids. The analysis focuses on rheological properties and electrical stability, with all experiments conducted in alignment with the study's predefined objectives.

Effect of Rheological Properties of Diesel and Biodiesel Based Drilling fluids

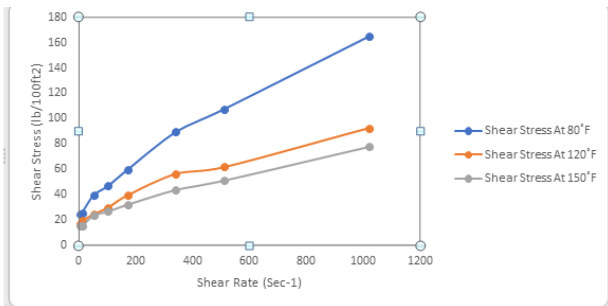

Figure 1: Shear Stress versus Shear Rate Relationship for Diesel-Based Drilling Fluid

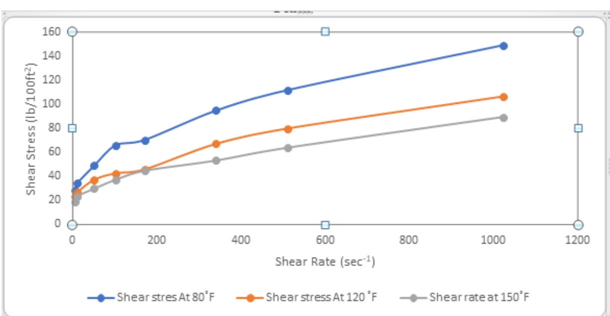

Figure 2: Shear Stress versus Shear Rate Relationship for Biodiesel-Based Drilling Fluid

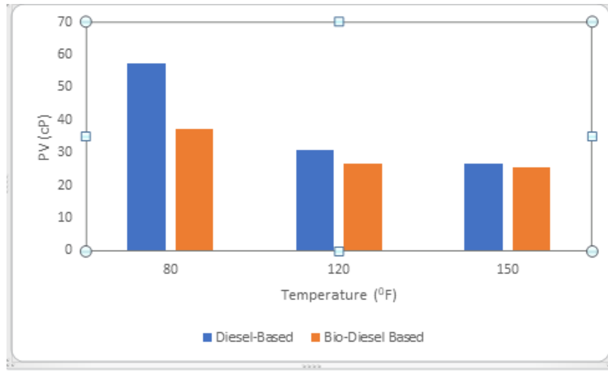

Figure 3: Plastic Viscosity as a Function of Temperature for Diesel and Biodiesel-Based Drilling Fluids

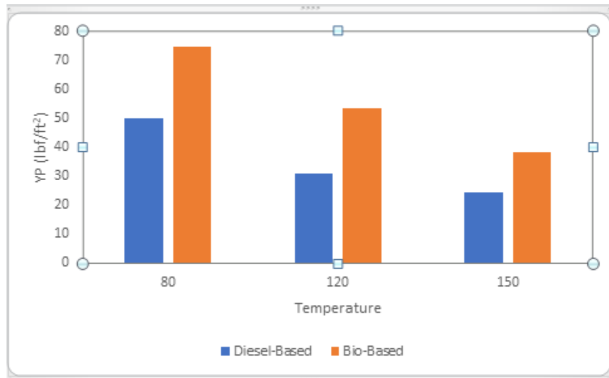

Figure 4: Yield Point as a Function of Temperature for Diesel and Biodiesel-Based Drilling Fluids

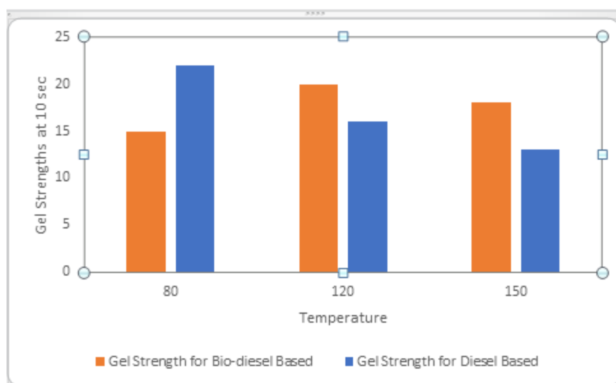

Figure 5: Gel Strength at 10 Seconds for Diesel and Biodiesel-Based Drilling Fluids Across Various Temperatures

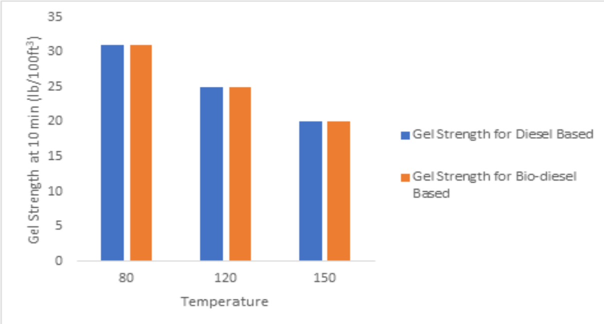

Figure 6: Gel Strength at 10 Minutes for Diesel and Biodiesel-Based Drilling Fluids Across Various Temperatures

This section presents the results and discussion of the rheological and electrical stability properties of diesel- and biodiesel-based drilling fluids, derived from laboratory experimentation. Figures 1 through 6 illustrate the evaluated properties, including shear stress, shear rate, plastic viscosity, yield point, and gel strength under varying temperature conditions. These properties are critical indicators of drilling fluid performance and were analyzed in accordance with the study's objectives.

The selection of rheological properties, such as plastic viscosity (PV), yield point (YP), and gel strength—as well as fluid loss and electrical stability—as the basis for comparing diesel and biodiesel-based drilling fluids, is driven by their established relevance in optimizing drilling operations. These parameters influence cuttings transport, hole cleaning efficiency, pressure management, and the overall circulation system performance (Caenn et al., 2017).

Both diesel and biodiesel-based drilling fluids were formulated to a standardized density of 9.5 ppg. The results (Figures 1 and 2) show the relationships between shear stress and shear rate at test temperatures of 80°F, 120°F, and 150°F. At maximum shear rate conditions, diesel-based fluids exhibited shear stress values of 165.08, 92.66, and 77.75 lb/100 ft² respectively, while biodiesel-based fluids recorded 149.10, 106.50, and 89.46 lb/100 ft² respectively. Conversely, at minimum shear rate conditions, diesel fluids showed shear stress values of 24.50, 17.04, and 14.91 lb/100 ft², while biodiesel fluids demonstrated slightly higher values: 28.78, 23.43, and 19.17 lb/100 ft² respectively.

The decrease in shear stress with increasing temperature for both fluids reflects the behavior of thixotropic fluids and aligns with the Bingham plastic model, where the fluid begins to flow only after surpassing a critical yield stress (Bilal et al., 2021). This behavior is advantageous for suspending solids while static and facilitating flow when agitated.

As shown in Figure 4, the yield point (YP) also declined with rising temperatures. Diesel-based fluids showed YP values of 50.06, 30.88, and 24.49 lb/100 ft² at 80°F, 120°F, and 150°F, respectively. Biodiesel-based fluids recorded higher YP values at the same temperatures: 74.56, 53.26, and 38.36 lb/100 ft². This suggests biodiesel-based fluids may have improved suspension and carrying capacity, which is beneficial for transporting cuttings from the wellbore. However, higher YP also contributes to increased frictional pressure losses and pumping requirements (Adewunmi et al., 2020).
Following the yield point, the linear region of the shear stress–shear rate plot provides the plastic viscosity (PV), a parameter indicative of the fluid's internal resistance to flow. Figure 3 illustrates this trend. Diesel-based fluids demonstrated PV values of 50.51, 30.89, and 26.63 cP across the temperature range, while biodiesel-based fluids showed lower values of 37.27, 26.63, and 25.54 cP respectively. Although diesel-based fluids exhibit higher viscosity—suggesting stronger internal friction—this may result in higher circulating pressures and energy costs. In contrast, the lower viscosity of biodiesel-based fluids offers potential advantages for turbulent flow and efficient hole cleaning at lower pump pressures (Okon et al., 2019).

Gel strength, representing the fluid's ability to suspend solids when static, is critical for evaluating the mud's performance during non-circulating intervals. Figures 5 and 6 show the 10-second and 10-minute gel strengths, respectively. At temperatures of 80°F, 120°F, and 150°F, the 10-second gel strength for diesel-based fluids decreased from 22 to 13 lb/100 ft², whereas biodiesel-based fluids fluctuated but remained lower overall (15, 20, and 18 lb/100 ft^2). The 10-minute gel strengths were more consistent across both fluids, with values of 31, 25, and 20 lb/100 ft^2.

These results suggest that biodiesel-based fluids maintain a flatter gel profile with increasing temperature—a favorable trait for field operations, as it ensures ease of restarting circulation with minimal pressure spikes. Diesel-based fluids, on the other hand, exhibit a progressive gel structure, where gel strength increases significantly over time. This may pose operational challenges such as increased start-up pressure requirements and higher energy costs (Kelessidis & Maglione, 2008).

In summary, while both fluids exhibit temperature-dependent rheological behavior consistent with Bingham plastic fluids, biodiesel-based drilling fluids demonstrate competitive, and in some cases superior, performance in terms of flowability, suspension capacity, and gel structure. These characteristics suggest that biodiesel-based muds can serve as effective and environmentally friendly alternatives to conventional diesel-based systems.

Effect of Electrical Stability of Diesel and Biodiesel - Based Drilling fluids

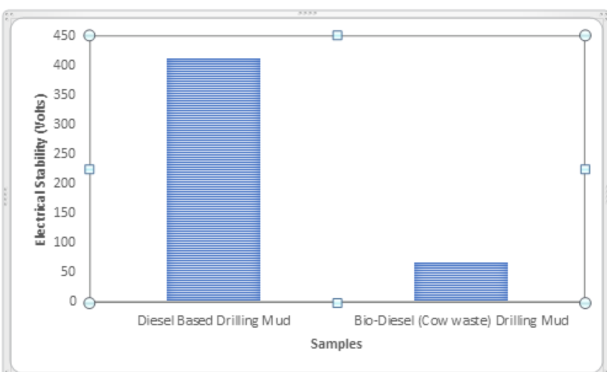

Figure 7: Electrical Stability of Diesel and Bio-diesel Based Drilling Fluid

The experimental results for the electrical stability (ES) of diesel- and biodiesel-based drilling fluids are presented in Figure 7. Electrical stability is a critical property of oil-based muds, as it measures the emulsion strength through the voltage required to cause a breakdown in the mud's dielectric strength. In water-in-oil emulsions—commonly used in oil-based drilling fluids—ES serves as an indicator of emulsion stability and overall fluid integrity during drilling operations (Caenn, Darley, & Gray, 2017).

A higher ES value reflects a more stable emulsion, which is essential for minimizing filtration losses, preventing emulsion breakage, and maintaining wellbore stability under high-pressure, high-temperature (HPHT) conditions. Additionally, electrical stability, when interpreted in conjunction with yield point and fluid loss, provides a comprehensive understanding of mud performance (Adewunmi et al., 2020).

The measured ES for the diesel-based drilling fluid was 413 volts, which is within the industry-accepted range for aged or conditioned oil-based muds (typically ≥400 volts). In contrast, the biodiesel-based drilling fluid exhibited a significantly lower ES value of 67.33 volts, which falls well below the acceptable threshold for fresh oil-based muds (generally ≥250 volts) (Okon, Etim, & Udoh, 2019). This result indicates that the biodiesel-based mud emulsion may be less stable and more susceptible to phase separation during downhole operations.

Numerous factors can contribute to reduced electrical stability, including oil-to-water ratio, presence of contaminants, solid content, temperature, pressure, and the specific type of emulsifying and weighting agents used (Kelessidis & Maglione, 2008). The observed poor ES performance in the biodiesel-based formulation could likely be attributed to one or more of these influences, especially the biodiesel's chemical composition or its interaction with emulsifiers at elevated temperatures.

Although biodiesel offers several environmental and performance advantages, its limited electrical stability under current formulation conditions may restrict its applicability without further optimization of emulsion additives or mud system parameters. As such, formulation adjustments are necessary to improve its emulsion resilience and bring its ES within operationally acceptable ranges.

IV. CONCLUSION

This study successfully achieved its primary objectives by formulating oil-based drilling fluids using conventional diesel and an alternative, cost-effective, and environmentally friendly source waste cow fat (biodiesel). The experimental analyses, including rheological and electrical stability evaluations, yielded the following key conclusions:
Rheological Performance: The rheological properties of both diesel- and biodiesel-based drilling fluids exhibited a consistent decrease with increasing temperature across the investigated range (80–150°F). This behavior confirms the thixotropic nature of both fluids and aligns with the Bingham plastic model. The biodiesel-based drilling fluid demonstrated rheological characteristics comparable to those of the diesel-based fluid, indicating its potential as an effective and sustainable rheological modifier in drilling operations.

Electrical Stability: Despite promising rheological performance, the biodiesel-based drilling fluid derived from waste cow fat did not achieve acceptable electrical stability levels required for field applications. The significantly lower ES values suggest limited emulsion stability, which may compromise the fluid's operational integrity. Therefore, without further optimization, waste cow fat–based fluids may not be suitable for use where high emulsion stability is critical.
These findings suggest that while biodiesel from cow fat is a viable alternative for enhancing rheological properties, additional research and formulation adjustments are required to improve its emulsion stability for broader application in oil-based drilling fluid systems.

Recommendations

Based on the experimental results and performance evaluation of diesel and biodiesel-based drilling fluids, the following recommendations are proposed for further study and industry application:
Fluid Selection for Specific Well Conditions:
Diesel-based drilling fluids should be prioritized in high-pressure, high-temperature (HPHT) environments and complex geological formations due to their superior rheological stability and emulsion strength. However, biodiesel-based fluids offer a viable alternative in environmentally sensitive or low-to-moderate depth drilling scenarios, where biodegradability and reduced toxicity are prioritized. Further development is required to enhance their field applicability.

Enhancement of Electrical Stability:
To address the lower electrical stability of biodiesel-based fluids, future studies should investigate advanced emulsifiers and surfactant systems compatible with biodiesel. The optimization of oil-to-water ratios, incorporation of stability enhancers, and evaluation of synergistic effects of additives under elevated temperature and pressure conditions are crucial to achieving acceptable ES values.

Long-Term Thermal Stability Testing:
Prolonged exposure to elevated temperatures typical of downhole conditions can alter fluid behavior. It is recommended to conduct thermal aging tests to assess the long-term performance and degradation tendencies of biodiesel-based muds, particularly their rheological and emulsion characteristics over time.

Compatibility with Drilling Equipment and Formations:
Further research should be conducted on the compatibility of biodiesel-based fluids with downhole tools, elastomers, and formation types (e.g., shale, sandstone, carbonates). Compatibility tests will ensure that the alternative fluid does not compromise equipment integrity or react unfavorably with specific lithologies.
Environmental Impact Assessment:
A detailed Life Cycle Assessment (LCA) of biodiesel-based drilling fluids should be undertaken to quantify their environmental advantages over conventional diesel-based systems. This includes assessments of biodegradability, toxicity to aquatic life, and greenhouse gas (GHG) emissions throughout production and application.

Economic Feasibility and Supply Chain Analysis:

While biodiesel offers environmental benefits, its economic viability needs thorough investigation. Cost analysis studies should evaluate the scalability of converting waste animal fat into usable drilling fluid components and assess market availability, logistics, and regional sourcing strategies.

Field Trials and Scale-Up Validation:

Laboratory results should be validated through pilot-scale or field trials under actual drilling conditions. Real-world testing will provide critical insights into fluid behavior, operational challenges, and the effectiveness of biodiesel-based muds in various drilling environments.

Formulation Standardization and Regulatory Compliance:

As biodiesel-based drilling fluids are developed, efforts should be made to standardize formulation practices and ensure compliance with environmental and operational regulations set by agencies such as the U.S. EPA, Nigerian DPR, or other regional authorities.

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Conflict of Interest

No conflict of interest.

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