FUDMA Journal of Engineering and Technology
ISSN: 3092-9385
https://fjet.fudutsinma.edu.ng/index.php/fjet/
Volume 2, Issue 2, 2026, 611-617

Formulation and Evaluation of Drilling Fluids from Waste Engine Oil and Algae-Based Surfactants

Amina N. IBRAHIM[1*], Petrus NZEREM[2], Mojeed O. OLOGUN[3]

Department of Petroleum and Gas Engineering, Faculty of Engineering, Nile University of Nigeria, Abuja, Nigeria

[1*]aminanasiribrahim41@gmail.com, [2]petrus.nzerem@nileuniversity.edu.ng, [3]moluogun.olawale@nileuniversity.edu.ng

Abstract

In this study, formulation and characterization of drilling muds based on treated waste engine oil and surfactants extracted from algae have been carried out as potential environmentally friendly substitute for conventional drilling fluid. Characteristics of waste engine oil and algae biomass were analyzed by Fourier Transform Infrared Spectroscopy (FTIR) and Energy Dispersive X-ray Spectroscopy (EDX). FTIR spectroscopy confirmed the presence of functional groups such as hydrocarbon, alcohol, and carbonyl in waste engine oil and lipids, proteins and carbohydrates in algae biomass. Elements found from EDX analysis were the necessary elements for extraction of surfactants. Surfactants were extracted from algae biomass and used in making four types of drilling muds which are conventional drilling mud (mineral oil and bentonite), algae-mineral oil mud, algae-waste engine oil mud and waste engine oil mud without surfactants. Characterization of these drilling muds was done based on their pH, density, viscosity, plastic viscosity, yield point and gel strength. On the other hand, waste engine oil mud lacking the surfactant did not perform well rheologically. Algae surfactants greatly improved viscosity, yield point, and gel strength, which improved cuttings carrying and suspension abilities of drilling muds. Graphically, non-Newtonian and shear thinning behavior were observed in the samples, which is an indication of the efficient drilling mud. Density and pH values differed between the samples but all values were still within acceptable limits. The results clearly indicate that algae surfactants are capable of greatly improving the rheological properties and performance of drilling mud.

Keywords: *Waste engine oil, algae-based surfactant, drilling fluid, filtration properties, oil-based mud.*

1.0 Introduction

As mentioned in [1] and [2], the drilling fluid plays an important role in petroleum drilling process and has many functions such as conveying the cuttings from the bottom of the hole to the surface, stabilizing the wellbore, cooling and lubricating the drilling tools, and balancing the pressure of the formation. As pointed out in [3], the oil-based muds (OBMs) have been widely applied due to their great lubricity, high thermal stability, shale inhibition, and good performance in harsh drilling conditions. However, traditional oil-based drilling fluids use diesel or mineral oils, which are expensive and have hazardous effects on the environment due to their toxic nature and difficulties associated with their disposal. As stated in [4], there has been an increase in the production of waste engine oil (WEO) due to activities of cars and industries. Improper disposal of waste engine oil will lead to contamination of both soil and groundwater, causing harmful consequences to the environment and human beings. This is why the possibility of utilizing waste engine oil in various industrial processes has been studied to minimize environmental pollution and conserve hydrocarbons.

Other than the selection of appropriate base fluids, the efficiency of drilling muds depends on how well the emulsifiers and surfactants used perform, as mentioned in [3]. The function of surfactants in lowering the interfacial tension and stabilization of emulsions and rheological behaviour of drilling muds has been highlighted in [5]. In [6] it has been stated that algae-based surfactants have received a lot of interest owing to their degradability, non-toxicity, renewability, and environmental-friendly character. The lipids, proteins, and carbohydrates found in the algae can act as biosurfactants for stabilizing oil-water emulsions. Algae-based biosurfactants have been applied successfully in wastewater treatment and other industrial purposes, as mentioned in [7]. In past researches, it has been found that the treated waste engine oil provides an excellent rheology and filtration behaviour of the drilling fluid system [8]. Likewise, biosurfactants prepared from biological resources are known to provide improved emulsion stability for drilling fluid systems [9]. Nevertheless, there is very little research done regarding the application of waste engine oil and algal biosurfactant in drilling fluid system.

For this reason, the current research focuses on the formulation and performance analysis of drilling fluids formed from the treated waste engine oil and the surfactants extracted from algae. Both the waste engine oil and the algae were characterized through the techniques of Fourier Transform Infrared Spectroscopy (FTIR) and Energy Dispersive X-ray Spectroscopy (EDX), whereas the drilling muds that were formulated were analyzed through their rheological and physical properties. The purpose of the current research is to explore the possibility of using waste engine oil and algae as environmentally friendly and inexpensive substitutes for other drilling fluid components.

Received: 09/06/2026; Revised: 06/07/2026; Accepted: 07/07/2026; Published: 17/09/2026

2.0 Materials and Methods

2.1 Materials

The materials used for the experiment include waste engine oil obtained from automobile workshops, algal biomass (Chlorella vulgaris), mineral oil, distilled water, bentonite clay, barite, and ethanol. Equipment that was used includes mud mixer, rotational viscometer, mud balance, pH meter, centrifuge, Soxhlet extractor, API filter press, thermometer, measuring cylinders, and FTIR equipment.

2.2 Method

Collection of WEO from the auto workshops and its treatment was done prior to using it as drilling fluid base. The algae biomass was collected, cleaned to remove any impurities, and then used for extraction of the surfactant. The process of extraction involved heating ethanol with algae biomass and centrifuging of the mixture to obtain the surfactant which was later separated for use in formulating drilling fluid. The characterization of WEO and algae biomass was done using FTIR and EDX to determine their respective functional groups and elemental composition. The characterization process was meant to determine whether they could be used for drilling fluid formulation. Four drilling mud samples namely; Sample A, Sample B, Sample C and Sample D were formulated for comparison purpose. Sample A was formulated from conventional drilling mud using mineral oil, water and bentonite clay. Sample B had mineral oil and algae-based surfactant while Sample C was formulated from waste engine oil and algae-based surfactant. Sample D comprised of waste engine oil and bentonite clay without using surfactant. The formulation of all these samples was carried out under the same laboratory conditions.

Drilling fluids prepared according to the formulations mentioned above were analyzed in accordance with API Recommended Practice 13B [10]. Rheological parameters were measured by means of rotational viscometer operating at various rotation rates. Plastic viscosity, yield point, apparent viscosity, and gel strength were calculated based on viscometric measurements. Density and pH were determined by means of mud balance and pH meter, respectively. The results of the experiment were recorded and compared in order to evaluate the effect of waste engine oil and algae-based surfactants on drilling fluids.

3.0 Results and Discussion

3.1 Characterization of Algae Biomass and Waste Engine Oil

FTIR and EDX analysis was conducted to ascertain the capability of algae biomass and waste engine oil in preparing drilling fluid. As indicated in Figure 1 above, FTIR analysis of algae biomass showed the presence of functional groups of protein, lipid, and carbohydrate. Some of the main peaks were seen at 2920 cm^{-1}, 1640 cm^{-1}, 1416 cm^{-1}, and 1029.7 cm^{-1}, showing the presence of organic groups that have capability of forming surfactants. This proves that there are chemicals in the algal biomass that could be used in the manufacture of biosurfactants to use in drilling fluids. This is evident in [11] in which the presence of functional groups related to algal biomass was confirmed through FTIR analysis.

The FTIR spectrum of the waste engine oil is shown in Figure 2. The peaks found in the range from 1690 to 1730 cm^{-1} are characteristic for the C=O group. Moreover, the peaks at 1460 cm^{-1} and 1375 cm^{-1} are characteristic for the C–H bending of alkanes. Moreover, the peaks found within the region of 1150-1050 cm^{-1} can be attributed to C-O vibrations, suggesting that there are oxygen-containing chemicals due to oil degradation, as stated in [12] and [13]. Moreover, the peaks shown in Figure 2 clearly show that there are suitable chemical components in waste engine oil for the preparation of drilling fluid, according to [13] and [14].

In addition, the Energy Dispersive X-ray Spectroscopy (EDX) analysis (Figure 3) revealed that carbon, oxygen, and nitrogen were the predominant elements present in the algal biomass, while phosphorus, calcium, and magnesium were detected as trace elements. The high carbon and oxygen contents confirm the organic nature of the biomass, whereas the presence of nitrogen and other trace elements suggests its potential for biosurfactant production. These findings further support the suitability of algal biomass as a sustainable source of surfactants for drilling fluid applications. Similar observations have been reported in [15], where EDX analysis was used to determine the elemental composition of algal biomass and evaluate its potential for industrial applications.

Received: 09/06/2026; Revised: 06/07/2026; Accepted: 07/07/2026; Published: 17/09/2026

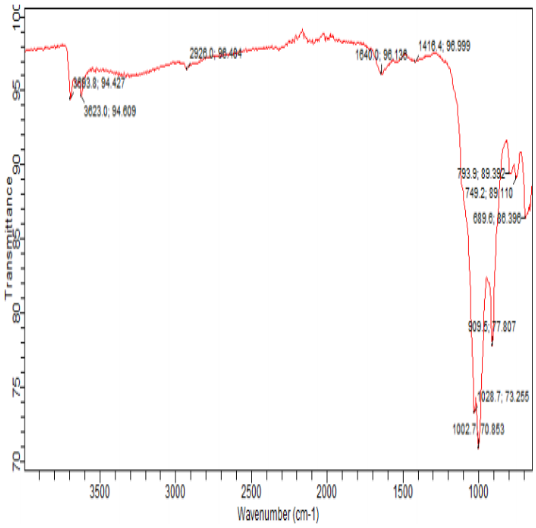

Figure 1: FTIR Spectrum of Algae Biomass Oil

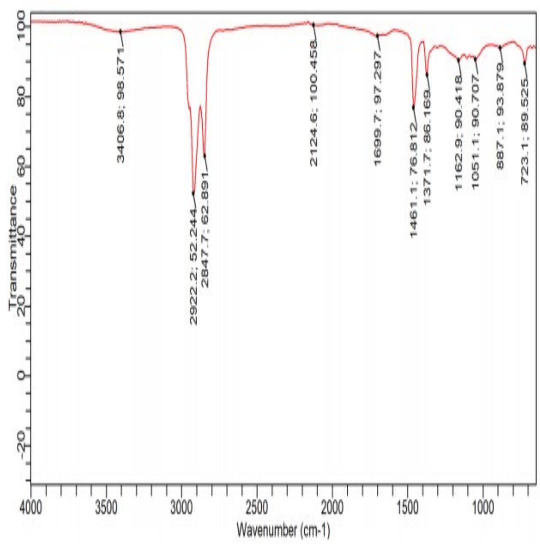

Figure 2: FTIR Spectrum of Waste Engine

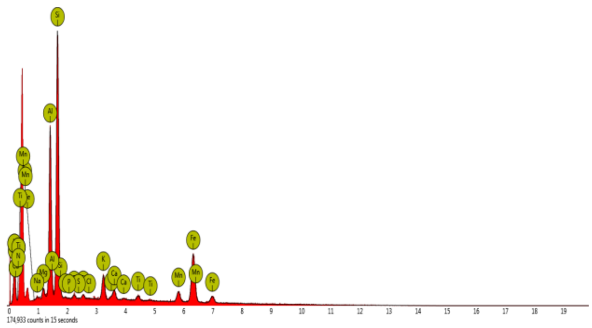

Figure 3: Elemental Analysis of Algae Biomass Sample

3.2 Formulation of Drilling Mud Samples

Four drilling muds have been successfully formulated and are presented for evaluation as shown on plate 1 below.

Plate 1: Mud Samples Prepared

Plate 2: Algae Based Surfactant

These include conventional drilling mud (mineral oil + bentonite), algae-drilling mud (algae + mineral oil), algae-waste engine oil drilling mud, and waste engine oil drilling mud without surfactants. The formulated drilling mud systems seemed uniform and stable in laboratory experiments. The extracted algae-based surfactant exhibited good solubility and emulsifying ability, which contributed significantly to the stability of the drilling mud systems as shown in plate 2. Reduced phase separation was observed in the surfactant-containing formulations, indicating the effectiveness of the algae-derived surfactant in enhancing drilling mud stability, as reported in [16].

3.3 Rheological Properties of the Formulated Drilling Fluids

For comparative analysis, Table 1 (Typical Properties of a Standard Conventional Oil-Based Mud) and Table 2 (Typical Rheological Properties of Conventional OBM) were used from various sources available in the industry and online. These tables were used as reference values for assessing the drilling muds prepared in the study.The waste engine oil drilling mud prepared without surfactant was characterized by poor rheological properties, poor gel formation, and poor suspension capacity. Lack of surfactant prevented formation of a stable structure within the system, hence poor drilling muds properties. Data extracted from the algae–mineral oil mud results section of the report. As per the gel strength results, drilling muds with surfactants extracted from algae had better suspension properties. The algae mineral oil mud had a 10-min gel strength of approximately 18.9 Pa, showing its good solid suspending ability under static condition.

Table 1: Typical properties of a standard conventional oil-based mud

S/N	Property	Typical Value/Range
1.	Density (Mud Weight)	9.0 – 14.0 ppg ()
2.	pH (Water Phase)	9.0 -11.0 (Alkaline, often adjusted with lime)
3.	Plastic Viscosity (PV)	10 – 30 cP (Highly dependent on temperature and oil type)
4.	Yield Point (YP)	10 – 25 lb/100
5.	Emulsion Type	Invert Emulsion (Oil external, Brine internal)
6.	Surfactant Content	1% – 5% (Main Emulsifier/Wetting Agent)

Source: European Journal of Sustainable Development Research [16]

Table 2: Typical rheological properties of conventional OBM

S/N	RPM (Speed)	Shear Rate (SR)	Shear Stress, (SS)	Apparent Viscosity (AV)
1.	600	1022	40 - 60	20 - 30
2.	300	511	25 - 40	25 - 40
3.	200	340	20 - 32	30 - 48
4.	100	170	12 - 22	36 - 66
5.	6	10.2	4 - 8	200 - 400
6.	3	5.1	3 - 6	300 - 600

Source: European Journal of Sustainable Development Research [16]

According to the results obtained from the rheology test and indicated in Table 3, the traditional drilling fluid had good drilling fluid characteristics. The rheological properties of the algae-mineral oil drilling mud are similar to the conventional mud, meaning that the surfactant produced by algae works well as an emulsifier. Furthermore, the rheological properties of the algae-waste engine oil drilling mud are higher compared to the waste engine oil drilling mud without the surfactant. The improved rheological properties are due to the effective emulsion of the oil and water, according to [17] and [5]. These results clearly show the effectiveness of the surfactant obtained from algae in improving the stability of the drilling fluid as reported earlier in [18] and [19]. Moreover, the improvement in the gel strength is due to better interaction between the molecules of the surfactant and the dispersed phases in the drilling fluid. Improvements in the suspension properties and performance of the drilling fluid by using biosurfactants have been observed in [18], [20].

Table 3: Summary of measured properties of formulated drilling fluids

S/N	Property	Conventional Mud	Algae + Mineral Oil Mud	Engine Oil Mud	Engine Oil + Algae Mud
1.	pH	9.50	9.78	7.87	9.30
2.	Density (ppg)	9.00	9.30	8.10	9.00
3.	Plastic Viscosity (cP)	12.0	18.0*	0.1	10.0
4.	Yield Point	12.0	16.9*	296.1	12.7
5.	10 sec Gel Strength	5.0	16.0*	7.4	12.7

Received: 09/06/2026; Revised: 06/07/2026; Accepted: 07/07/2026; Published: 17/09/2026

S/N	Property	Conventional Mud	Algae + Mineral Oil Mud	Engine Oil Mud	Engine Oil + Algae Mud
6.	10 min Gel Strength	7.0	18.9*	8.3	14.9
7.	Flow Behaviour	Non-Newtonian, Shear-Thinning	Non-Newtonian, Shear-Thinning	Poor Rheological Behaviour	Non-Newtonian, Shear-Thinning
8.	Drilling Performance	Good	Very Good	Poor	Good

Source: Author et al. (2026)

As can be seen from Figures 6 and 7, the viscosity of the drilling fluids decreased as the speed increased. It shows that the fluids were shear thinning or pseudoplastic. Pseudoplasticity is preferred during drilling because the fluid retains high viscosity required for cuttings suspension at low shear rates, while it decreases viscosity under high shear rate to decrease the resistance of flow. Both fluids had the same trends, but the fluid illustrated by Figure 7 showed higher viscosity values than that illustrated by Figure 6.

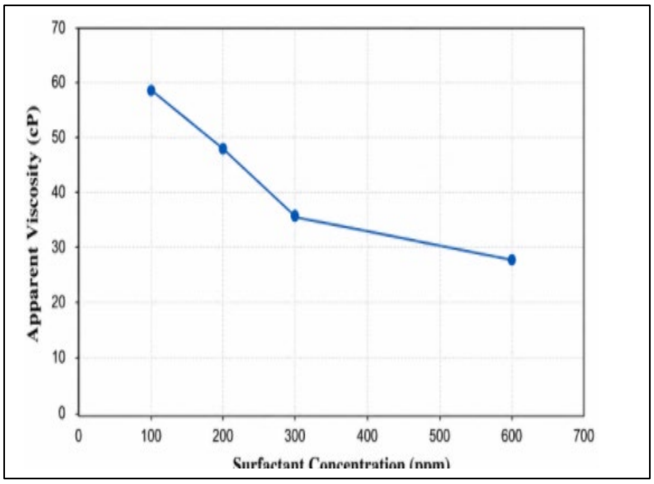

Figure 6: Effect of Surfactant Concentration on the Apparent Viscosity of Conventional Oil-Based Mud (OBM)

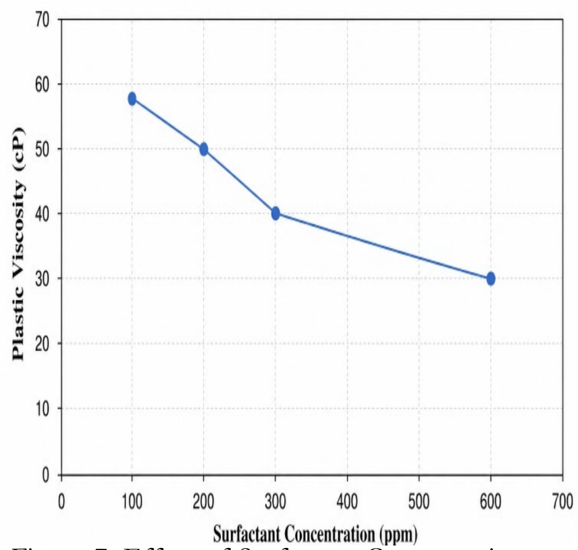

Figure 7: Effect of Surfactant Concentration on the Plastic Viscosity of Conventional Drilling Mud

From Figure 8, the viscosity reduces gradually with an increase in rotational speed, which is a demonstration of shear-thinning. This implies that the drilling fluid will move freely when circulating without compromising its viscosity level in suspending cuttings. Figure 9 depicts the reduction in mud viscosity from 57 cP at 100 rpm to 29 cP at 600 rpm. This indicates shear-thinning behaviour, which is desirable for effective drilling fluid circulation.

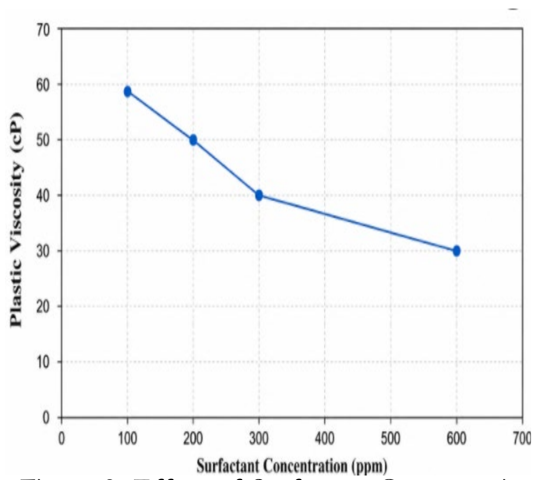

Figure 8: Effect of Surfactant Concentration on the Viscosity of Conventional Drilling Mud

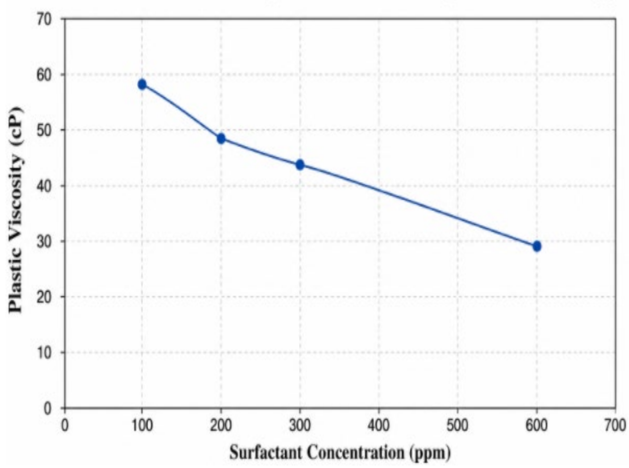

Figure 9: Effect of Surfactant Concentration on the Apparent Viscosity of Algae and Waste Engine Oil-Based Drilling Fluid

Received: 09/06/2026; Revised: 06/07/2026; Accepted: 07/07/2026; Published: 17/09/2026

From Fig. 10, it can be seen that the viscosity value was quite stable between 100 and 300 rpm, where the values were around 580 cP and then reduced suddenly to become 290 cP when the rotation speed reached 600 rpm. It implies that the fluid was highly resistant to flow when its shear rate was low but had shear-thinning properties when its shear rate was higher. From Fig. 11, it can be seen that viscosity firstly dropped slightly from 30 cP to 27 cP until 200 rpm, increased to be around 46 cP at 300 rpm and then dropped to become 30 cP at 600 rpm.

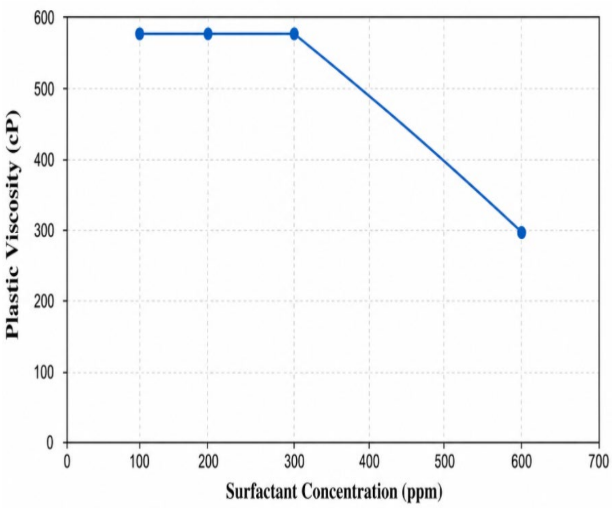

Figure 10: Effect of Surfactant Concentration on the Apparent Viscosity of Waste Engine

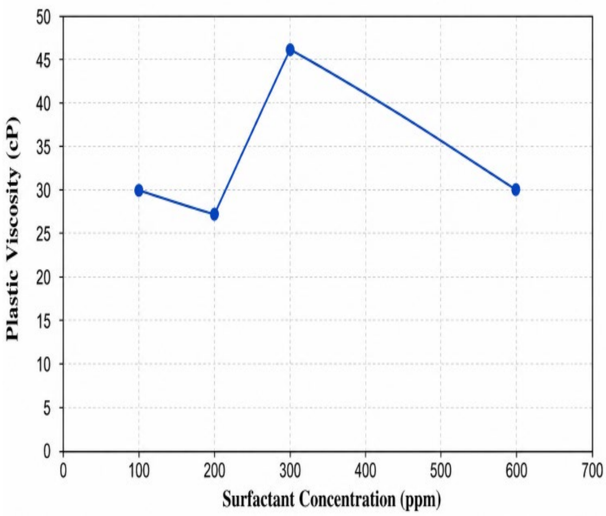

Figure 11: Effect of Surfactant Concentration on the Apparent Viscosity of Algae and Mineral Oil-Based Fluid

3.4 Flow Behaviour and Comparative Performance

From graphical analysis of the viscosity profile, it was observed that the developed drilling fluids possessed non-Newtonian shear-thinning behaviour. It means that viscosity of the drilling fluids decreases with an increase in shear rate. This feature is highly appreciated in drilling fluids. With such feature it is possible to circulate easily at high shear rate but also retain enough carrying capacity at low shear rate. Comparing the results, it can be seen that drilling fluids prepared with the use of algae-derived surfactants performed better than the waste engine oil mud without surfactant. The algae-added muds possess acceptable alkaline pH, optimal density, increased viscosity and gel strength, which is necessary for efficient transporting, cleaning and stability of drilling fluids. Thus, it can be stated that the addition of the algae-derived surfactants greatly improved rheological behaviour of waste engine oil mud. The performance of algae-waste engine oil mud was similar to that of conventional drilling mud.

4.0 Conclusion

The current study is about the development and performance evaluation of drilling fluids using treated waste engine oil and algal surfactants as greener options to traditional oil-based drilling fluids. From FTIR analysis, it was found that the treated waste engine oil and algal biomass possess hydrocarbon, alcohol, carbonyl, lipid, protein, and carbohydrate functional groups, whereas from EDX analysis, it was established that the essential elements for the formation of surfactants and drilling fluids were present. It was found that the addition of algal surfactants greatly enhanced the rheological behaviour of the waste engine oil-based drilling fluids compared to the waste engine oil mud without the surfactant. This suggests an improvement in cuttings transportation, suspension capability, emulsification ability, and performance of the drilling fluids. In addition, the designed drilling fluids had a desired non-Newtonian shear thinning property that is crucial in effective drilling. In summary, it can be noted that the study showed that the surfactants from algae can effectively improve the performance of drilling fluids containing waste engine oil in an economical and environmentally friendly way while at the same time ensuring its utilization in drilling. However, there is a need to conduct additional research on the long-term stability and performance of the designed drilling fluids under high temperature and high pressure drilling conditions as well as their filtration ability and lubricity.

5.0 Acknowledgment

The author expresses profound gratitude to Almighty Allah for His guidance, mercy, and blessings throughout the course of this research. Sincere appreciation is extended to my beloved parents, Mr. and Mrs. Nasir Ibrahim, for their unwavering love, encouragement, sacrifices, and steadfast support throughout my academic journey. The author also gratefully acknowledges Prof. Abdullahi Gimba, Head of the Department, for his leadership and support. Special appreciation is extended to Prof. Petrus Nzerem for his invaluable guidance, constructive criticism, mentorship, and continuous encouragement throughout this study. The author is also grateful to Dr. Mojeed Oluogun, Project Coordinator, for his assistance and coordination during the research. Appreciation is further extended to Engr. Khaleel Jakada and Prof. Ayuba for their guidance, teaching, encouragement, and valuable contributions to the author's academic development. Finally, the author sincerely thanks Ahmad Babale, Ruqayya Salihu, Aisha B. Usman, and Radia Iliyasu for their friendship, encouragement, and moral support throughout the research process.

References

[1] H. C. H. Darley and G. R. Gray, Composition and Properties of Drilling and Completion Fluids, 5th ed. Houston, TX, USA: Gulf Publishing Company, 1988.

[2] A. T. Bourgoyne Jr., K. K. Millheim, M. E. Chenevert, and F. S. Young Jr., Applied Drilling Engineering. Richardson, TX, USA: Society of Petroleum Engineers, 1986.

[3] ASME Shale Shaker Committee, Drilling Fluids Processing Handbook. Amsterdam, Netherlands: Elsevier, 2005.

[4] I. Hamawand, T. Yusaf, and S. Rafat, "Recycling of waste engine oils using a new washing agent," Energies, vol. 6, no. 2, pp. 1023–1049, 2013, doi: 10.3390/en6021023.

[5] I. M. Banat, A. Franzetti, I. Gandolfi, et al., "Microbial biosurfactants: Production, applications and future potential," Applied Microbiology and Biotechnology, vol. 87, no. 2, pp. 427–444, 2010, doi: 10.1007/s00253-010-2589-0.

[6] N. Kosaric, Ed., Biosurfactants: Production and Utilization—Processes, Technologies, and Economics. New York, NY, USA: Marcel Dekker, 1993.

[7] I. Mnif and D. Ghribi, "High molecular weight bioemulsifiers: Main properties and potential environmental and biomedical applications," World Journal of Microbiology and Biotechnology, vol. 31, no. 5, pp. 691–706, 2015, doi: 10.1007/s11274-015-1830-5.

[8] S. Ahmed, R. Khan, and M. Malik, "FTIR characterization of waste engine oil and its chemical transformations," Journal of Petroleum Science and Engineering, 2021.

[9] A. Kumar, S. Banerjee, and R. Sen, "Algae-derived biosurfactants: Renewable biomolecules for industrial applications," Bioresource Technology, 2021.

[10] American Petroleum Institute, API Recommended Practice 13B-2: Field Testing Oil-based Drilling Fluids, 6th ed. Washington, DC, USA: American Petroleum Institute, 2023.

[11] P. K. S. M. Rahman and E. Gakpe, "Production, characterisation and applications of biosurfactants—Review," Biotechnology, vol. 7, no. 2, pp. 360–370, 2008, doi: 10.3923/biotech.2008.360.370.

[12] J. Coates, "Interpretation of infrared spectra, a practical approach," in Encyclopedia of Analytical Chemistry, R. A. Meyers, Ed. Chichester, U.K.: John Wiley & Sons, 2006.

[13] B. H. Stuart, Infrared Spectroscopy: Fundamentals and Applications, 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, 2023.

[14] D. A. Kamel, S. A. El-Mekkawi, and I. A. Hussein, "Characterization and recycling potential of waste lubricating oils using FTIR spectroscopy," Journal of Petroleum Science and Engineering, vol. 205, Art. no. 108796, 2021.

[15] J. J. Mayers, K. J. Flynn, and R. J. Shields, "Rapid determination of bulk microalgal biochemical composition by Fourier-Transform Infrared spectroscopy," Bioresource Technology, vol. 148, pp. 215–220, 2013, doi: 10.1016/j.biortech.2013.08.133.

[16] S. O. Eze and C. J. Chukwu, "Formulation of drilling fluids using local materials," European Journal of Sustainable Development Research, vol. 9, no. 3, Art. no. em0308, 2025.

[17] S. S. Cameotra and R. S. Makkar, "Recent applications of biosurfactants as biological and immunological molecules," Current Opinion in Microbiology, vol. 7, no. 3, pp. 262–266, 2004, doi: 10.1016/j.mib.2004.04.006.

[18] R. Caenn, H. C. H. Darley, and G. R. Gray, Composition and Properties of Drilling and Completion Fluids, 7th ed. Oxford, U.K.: Gulf Professional Publishing, 2017.

[19] C. N. Mulligan, "Environmental applications for biosurfactants," Environmental Pollution, vol. 133, no. 2, pp. 183–198, 2005, doi: 10.1016/j.envpol.2004.06.009.

[20] A. Tabzar, A. Sadatshojaie, and D. A. Wood, "Effectiveness of colloidal gas aphron fluids formulated with a biosurfactant enhanced by silica nanoparticles," ChemRxiv, 2020, doi: 10.26434/chemrxiv.12764708.v1.