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Development of a Process for the Production of Diesel Grade Engine Oil via Vacuum Distillation - Adsorption process

¹Epere Aworabhi

²Akuma Oji

²Obumneme Okwonna

¹Department of Chemical Engineering, Federal University Otuoke, Bayelsa State

²Department of Chemical Engineering, University of Port Harcourt, Rivers State

Corresponding Author's email: epereaworabhi@yahoo.com

Abstract

This study presents the development of an integrated vacuum distillation-adsorption process for the efficient production of diesel-grade engine oil from waste lubricating oil. This process aims to recover valuable base oils while meeting the stringent quality specifications of modern diesel engines. Initial vacuum distillation, conducted at a vacuum pressure of -0.032 to -0.062MPa and a temperature range of 275-300°C, yielded a distillate fraction constituting approximately 75 wt% of the input waste oil. This fraction, characterized by a kinematic viscosity of 8.5 cSt at 100°C, subsequently underwent an adsorption step utilizing activated clay. Adsorption parameters, specifically a clay dosage of 3 wt% and a contact time of 60 min at 80°C, resulted in a significant reduction in total acid number (TAN) from 5.7 mg KOH/g to 5.0 mg KOH/g and an improvement in color from ASTM D1500 7.0 to 2.5. The final refined oil exhibited properties consistent with those of commercial diesel-grade engine oils, including a flash point of 154°C and a viscosity index of 11. This integrated approach demonstrates a promising and environmentally sound method for producing high-quality base oils, contributing to resource sustainability and the principles of a circular economy.

Keywords: Environmental pollution; Vacuum distillation; Activated clay; Adsorption; Spent engine oil

1.0 Introduction

Energy production is vital for the development of any economy. Nigeria, a developing country, has relied on the oil and gas sector for economic growth. The oil and gas sector contributes significantly to Nigeria's Gross Domestic Product (GDP), with crude oil exports being the country's primary source of foreign exchange. With the highest size in Africa, Nigeria is a country rich in natural resources, both renewable and non-renewable energy sources. The International Monetary Fund estimates that oil accounts for over 95% of export revenues, 25% of GDP, and approximately 90% of government revenue, making it the primary source of economic dependence (Olayungbo, 2019).

Nigeria's oil reserves are estimated to be approximately 37 billion barrels, making it the largest oil producer in Africa and the sixth largest in the world. However, the increasing demand for energy sources and environmental challenges posed by the disposal of used engine oil have become growing concerns. It has been stated that in

underdeveloped nations such as Nigeria, the majority of used lubricating oils generated by the use of lubricating oil are not properly collected, processed, or recycled (Echiegu et al., 2021). Used engine oil is generated mainly as a result of servicing vehicles, industrial machinery, and equipment. Disposing of used engine oil in landfills or through open burning releases harmful pollutants such as sulfur and heavy metals into the atmosphere, contributing to air pollution. Waste lubricating oils (WLO), waste machinery oil (WMO), and waste oil from trains (WOT) are generic terms for several types of lubricating oils used in vehicles and machinery (Moses et al., 2023).

Waste lubricating oil (WLO) is one of the eight main forms of hazardous waste produced. Heavy metals, chlorine, and sulfur added during the manufacturing process or due to high temperature and oxidation during use form polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB), which are toxic to humans (Yu et al., 2012). A single automotive oil change generates four to five litres of spent oil, and only one litre of oil can cause contamination in one million gallons of water. Similarly, a single gallon of oil can contaminate millions of gallons of drinking water and create a thin oil coating on the water's surface that prevents oxygen from dissolving. Collecting and disposing of used engine oil in accordance with environmental rules frequently necessitates complex processes and incurs significant costs. Consequently, recycling and reusing spent motor oil can be both economically and environmentally responsible. Addressing the issues of diesel fuel production and used engine oil management simultaneously provides a chance for energy production and environmental sustainability to work together (Nwachukwu et al., 2012).

The worldwide expansion of transportation, industrialization, and other energy-dependent industries has been accompanied by a continuous increase in the need for energy resources, especially diesel fuel. Modern society cannot function without diesel fuel because it is essential for operating a vast range of machinery, generators, and cars. Consequently, governments, businesses, and researchers worldwide continue to place a high premium on the supply and accessibility of high-quality diesel oil. Waste oil management has garnered significant attention because of the significant amounts produced and their potential for processing back into valuable products, such as diesel oil. Reusing and collecting spent lubricating oils can supply up to 50% of the lubricating oil required in some wealthy nations (Sharma & Shrestha, 2023).

Used lubricant oil is constantly produced by industries, automobiles, and other machinery components. The majority of used motor oil contains dangerous materials, including heavy metals, and careless disposal pollutes the environment. Recycling used engine oil has economic benefits, and has gained importance. Recycling and reusing engine oil is a potential solution to the environmental challenges of managing waste oil in Nigeria. In addition to reducing environmental pollution, recycling used engine oil can provide a source of energy for the country, reduce the cost of importing crude oil, and create employment opportunities (Jock et al., 2023).

When used engine oil from automotive and industrial processes is not properly managed, it causes considerable issues. Improper disposal of engine oil can have serious environmental repercussions. They can contaminate soil and groundwater, alter ecosystems, and potentially harm human health. Furthermore, the dumping or incineration of used motor oil without sufficient treatment contributes to air pollution by emitting toxic pollutants and greenhouse gases into the atmosphere. Used engine oil disposal can be costly from an economic standpoint, particularly for the automotive industry and vehicle owners. Used motor oil recycling can address the environmental challenges associated with inappropriate disposal. Used engine oil is produced by various sources, including automotive maintenance, industrial machines, and marine engines. It is frequently polluted with contaminants such as heavy metals, chemicals, and combustion byproducts, making it difficult to manage. Improper disposal methods, such as illegal dumping or indiscriminate burning, not only pollute the soil and water but also endanger the health of humans and wildlife (Siddiqua et al., 2022).

The disposal of used motor oil has become an urgent environmental issue with serious implications for ecosystems, human health, and resource conservation. Improper waste engine oil disposal, frequently characterized by a lack of competent waste management methods, endangers soil and water quality and contributes to environmental degradation (Tian & Chen, 2014). Furthermore, used motor oil is a source of hazardous waste, necessitating long-term and efficient solutions to this environmental problem. In response to

this growing concern, vacuum distillation has gained interest as a potentially environmentally benign way of recycling spent engine oil into diesel-grade oil (Tomita et al., 1995; Guerin, 2008)

Used engine oil must be properly disposed of to prevent harmful pollutants from being released into the atmosphere and contaminating the land, water, and atmosphere. Reusing and recycling used motor oil helps reduce these environmental risks and promotes resource sustainability. Recycling used motor oil into valuable items, such as diesel-grade oil, is a more environmentally friendly option than disposal. This technique minimizes the demand for virgin crude oil, conserves precious natural resources, and contributes to circular economy principles. (Zitte et al., 2016). Within this framework, the investigation into utilizing vacuum distillation and modified clay treatment to produce diesel-grade oil from used engine oil is shown as a crucial line of inquiry. This strategy has a lot of potential to handle the two problems of reducing the environmental impact of used engine oil and satisfying the growing demand for diesel fuel.

Diesel fuel is a liquid fuel derived from hydrocarbons that is renowned for its energy density, efficiency, and adaptability. It is made from crude oil using several refining processes, using oil that is obtained from oil wells. For several crucial applications, including heavy-duty transportation (trucks, ships, trains), industrial machinery (generators, construction equipment), and agricultural equipment, it is the first choice. Furthermore, diesel fuel plays a crucial role in off-grid applications and remote power generation, helping to electrify rural areas across the globe (Beerge & Devarmani, 2024).

There are several environmental and resource-related issues with using conventional methods for refining crude oil. The limited nature of crude oil supplies, geopolitical issues, and the environmental impact of drilling and refining operations are pushing the quest for alternative diesel-grade oil sources. Because of the expansion of these industries, there has been an increasing need for diesel fuel, which has become an essential part of the world's energy consumption. Producing diesel fuel efficiently and sustainably is necessary to meet this demand. Given that the demand for petroleum products is increasing daily, it is anticipated that the supply of crude oil would eventually run out. Engine oil is used as lubrication to ensure that an engine runs smoothly. The used engine oil is removed after some time. About 20% of the lubricating oil is used during lubrication, leaving the remaining 80% partially contaminated. As a result, a significant quantity of used engine oil is wasted by various industrial sectors. There are not many studies on the subject of producing diesel fuel from used engine oil (Beg et al., 2010).

Several studies have been conducted on the subject of used oil vacuum distillation. A few existing studies have focused mainly on the characterization of the used engine oil and the comparison of the properties of diesel-grade oil with those of virgin diesel oil (Boadu et al., 2011). The vacuum distillation process is a technique that involves heating crude oil or used engine oil under low pressure to remove impurities, such as water, sulfur, and other contaminants. The process allows for the removal of impurities at a lower temperature, resulting in a higher yield of usable products. The vacuum distillation process has been used for many years in the refining of crude oil. The technology involved in the vacuum distillation process is complex and requires specialized equipment and expertise (Kannan et al., 2014). However, its application in Nigeria could provide a solution to the environmental challenges posed by the disposal of used engine oil while also contributing to the country's energy needs. The production of diesel-grade oil from used engine oil through vacuum distillation could potentially reduce the nation's dependence on imports of crude oil.

Vacuum distillation has emerged as a viable method for turning used motor oil into high-quality diesel-grade oil. Sometimes, this method is used for substances that decompose at atmospheric pressure or that typically boil at extremely high temperatures. Vacuum distillation is a process of separation that is based on the difference in boiling points of distinct components in a mixture. By lowering the pressure within the distillation column, high-boiling-point fractions, such as diesel fuel, can be distilled at lower temperatures. This method reduces the oil's heat deterioration, resulting in a higher-quality output (Al-Nidawi et al., 2024).

Clay minerals are found in nature and are known to be very effective sorbents that are also cost-effective and not harmful to the environment due to their high surface area, mechanical stability, and thermal inertness, among other physical and chemical characteristics. In the petroleum refining sector, clays are becoming increasingly popular to use in adsorption and separation processes, among other processes. Clay adsorption can

be used to remove a variety of substances, including colours, sulfur, heavy metals, and the separate of various hydrocarbon groups found in crude oil and petroleum fractions. (Emam, 2018). Many forms of clay are available and have various uses, including bentonite, attapulgite, hectorite, kaolin, and sepiolite (Pillon, 2010). The adsorption process is one of the most straightforward and effective separations because it may be done at room temperature, pressure, and without the need for costly materials. Also, it appears to be a very promising technology that reduces the consumption of energy (Ishaq et al., 2017).

This study aims to investigate the production of diesel-grade oil from used engine oil using a vacuum distillation process and modified clay treatment. The study will optimize the distillation process parameters to produce high-quality diesel-grade oil and evaluate its characteristics. The economic feasibility of producing diesel-grade oil from used engine oil was also assessed. This study is significant because it offers a sustainable solution for the disposal of used engine oil, which is a hazardous waste.

2.0 Materials and Methods

2.1 Materials

The used engine oil sample was purchased from a mechanic workshop on East West Road in Choba, whereas the local clay sample was obtained from Nenwe in the Animri Local Government Area, Enugu State.

2.2 Methods

To eliminate mechanical impurities and entrained particulates, 16 litres of spent engine oil was collected and filtered using a 32-mesh screen. To enable the free water to settle, the oil was moved to the distillation vessel and left there for a whole day.

A flow of two litres of cooling water per minute was set up through the condenser. Emulsified water and certain fuel diluents were boiled off the oil when the heater was turned on and heated to 130°C under atmospheric pressure. The condensate of the fuel diluent and water was collected in the receiver and stored.

The compressor was turned on to create and maintain a vacuum pressure of -0.032 to -0.062MPa. The used engine oil was then heated under vacuum pressure to 300°C. Diesel oil was collected in the range of 275°C to 300°C at an average vacuum pressure of -0.045Mpa.

Figure1: Fabricated vacuum distillation apparatus



2.3 Clay Activation

The raw Nenwe clay was weighed using a digital weighing scale. A weight of 5kg was recorded. Debris were removed by selection. The selected clay was placed in a container and completely immersed in water. The water was changed after 12 hours repeatedly for 3 days, in order to leach out unwanted disolvable or

soluble substances in the clay. Mashing/mixing was carried out in order to achieve a homogenous mixture in paste form. The clay was dried at 70-110°C to remove moisture content; this was done for 24 hours. The dried clay was crushed into tiny particles sizes, using a mortar and pestle. Sulphuric acid (H₂SO₄) activation of the clay was done using concentrations of 0.5M, 1M and 2M. 800g of the clay was measured into 3 different 1000ml beakers, and respective concentrations of 0.5M, 1M and 2M were used on each sample. The contact time was 24 hours.

By submerging the sample bottle in a hot water bath and using a pyrometer to measure the temperature, the recovered diesel oil was heated to 42°C indirectly. This was done in order to attain the ideal temperature for the contaminants of the raw diesel oil to be effectively absorbed. A 250ml filtration bed was filled with 250g of H₂SO₄ activated Nenwe clay in 0.5M, 1M, and 2M concentrations, unactivated Nenwe clay and commercial-grade clay (Bentonite). The recovered diesel oil was filtered through the clay bed in batches of 200ml each. A composite sample was sent to the lab for analysis after the volumetric yield and total volume of the regenerated diesel oil were determined.

3.0 Results and Analysis

3.1 Results

Table 1: Comparative analysis of Products and Standard commercial Diesel

Parameters	Test method	Diesel	Untreated product	Unactivated clay-treated product	0.5M activated clay-treated product	1M activated clay-treated product	2M activated clay-treated product	Commercial bentonite-treated product
Appearance	Visual	Clear and bright	Dark	Brown	Golden yellow	Golden yellow	Brown	Brown
Color	ASTMD1 500	3.0 max	7.4	5.3	3.5	3.2	4.8	3.8
Specific gravity @15°C	ASTMD1 298	0.820-0.870	0.879	0.874	0.868	0.826	0.834	0.841
Total acid Number mg KOH/g	ASTMD6 64	0.5 max	6.058	5.920	5.722	4.600	5.049	3.011
Pour point °C	ASTMD5 949	-8.1	-2	-3	-4	-4	-3	-1
Water content %vol	ASTMD9 5	0.05 max	0.600	0.093	0.035	0.020	0.010	0.091
Viscosity at 40°C, (cSt)	ASTMD4 445	2-5.5	28	21	11	6.8	11	8.2
Flash point °C	ASTMD9 3	52-96	176	173	163	155	154	155
Conradson carbon residue %wt	ASTMD1 89	0.5 max	1.28	1.04	0.81	0.48	0.64	0.46

Table 2: Yield of Diesel-grade Oil after Vacuum Distillation and Clay Treatment

S/N	Material	Volume (ml)
1	Initial Used oil	16,000
2	Final Used after distillation	14,320
	Total volume distilled	1,650

	Components	Volume (ml)	Yield (%)
1	Water	115	7%
2	Light ends	231	14%
3	Diesel	1,122	68%
4	Losses	182	11%
	Total volume distilled	1650	100%
	Initial diesel before clay treatment	1,122	68%
	Final diesel after clay treatment	1081	65.5%
	Loss due to clay treatment	41	2.5%

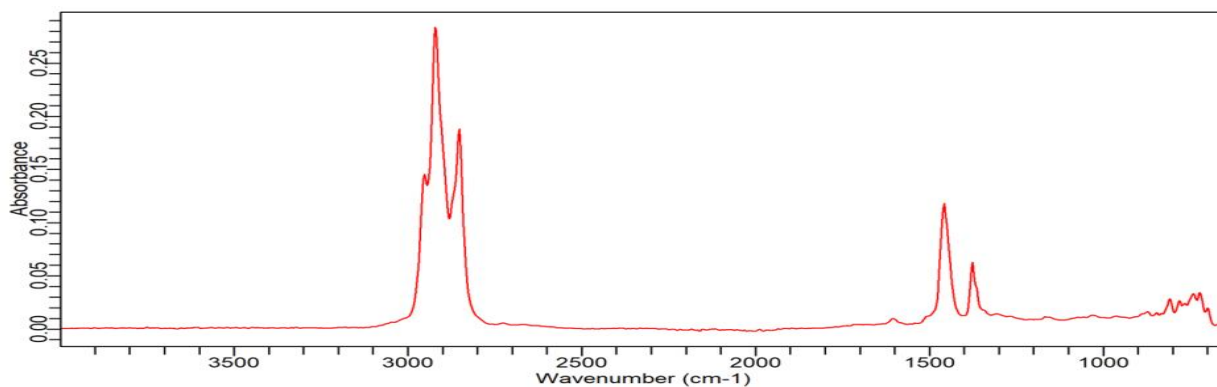
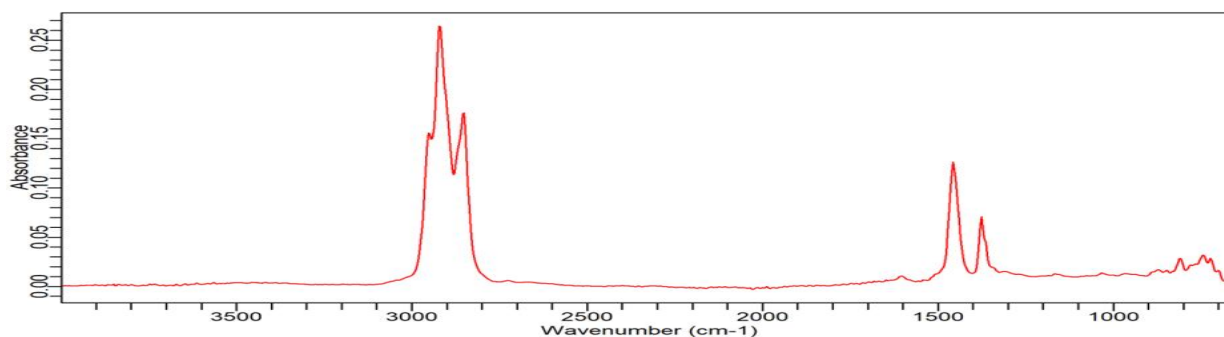
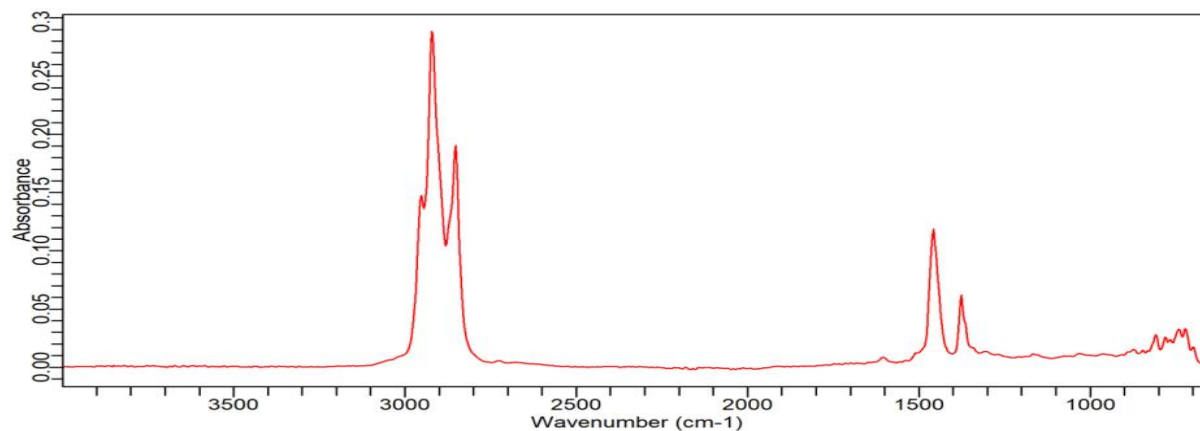
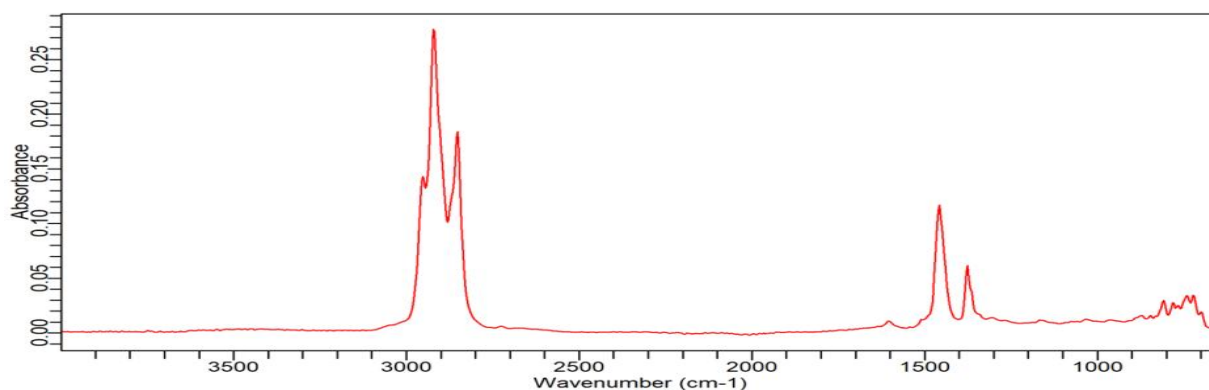
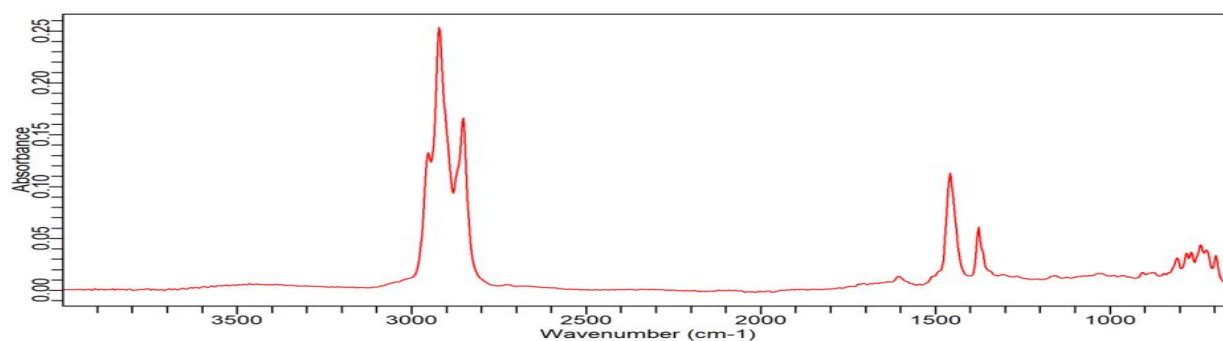
**Figure 2a: FTIR Analysis of Untreated Product**

Figure 2b: FTIR Analysis of Unactivated Clay Treated Product**Figure 2c: FTIR Analysis of 0.5M Activated Clay Treated Product****Figure 2d: FTIR Analysis of 1M Activated Clay Treated Product****Figure 2e: FTIR Analysis of 2M Activated Clay Treated Product**

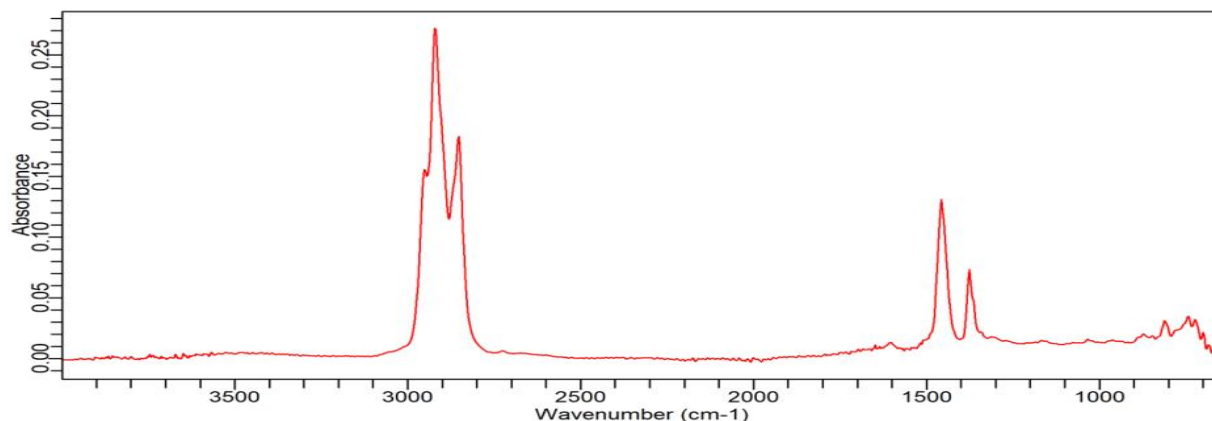


Figure 2f: FTIR Analysis of Commercial Diesel

3.2 Analysis

3.2.1 FTIR Analysis of Untreated Product

The frequency of the infrared light is represented by the X-axis (Wavenumber, cm^{-1}), where larger wavenumbers indicate more energetic vibrations. The Y-axis (Absorbance) shows how much light is absorbed at a given wavenumber. The spectrum's peaks represent distinctive vibrations of chemical bonds. From Figure 2a, the Region of High Absorbance corresponding to C-H stretching vibrations is approximately 3000 cm^{-1} . Unsaturated hydrocarbons or aromatic C-H bonds are usually present when peaks are located at or just above 3000 cm^{-1} . Alkane C-H bonds, or saturated hydrocarbons, are characterized by peaks that are just below 3000 cm^{-1} . The region between 1500 and 1600 cm^{-1} is linked to aromatic rings or alkenes' C=C stretching vibrations. The existence of aromatic or unsaturated chemicals is suggested by the sharp peaks in this region. The "fingerprint region," which is exclusive to particular molecular configurations, is the area below 1500 cm^{-1} . Bending vibrations and other more complex molecular reactions are linked to these peaks.

Examining this area aids in locating particular substances or structural elements within the specimen. Strong peaks about 1700 cm^{-1} are absent, indicating a paucity of carbonyl groups (C=O), which are common in esters, ketones and aldehydes. Peaks in the $1000\text{--}1200 \text{ cm}^{-1}$ region could be a sign of C-O stretching vibrations, which are often found in ethers, alcohols, or esters. These groups may not be prevalent in the sample, based on the comparatively low absorbance. The distilled product is represented by the spectrum, which demonstrates that hydrocarbons and impurities were effectively separated throughout the distillation process. Effective removal of oxygenated chemicals, additives or breakdown products from the original engine oil is suggested by the absence of polar groups like C=O or O-H. Diesel-range fuels should have aliphatic and aromatic hydrocarbon peaks that correspond to the spectrum.

3.2.2 FTIR Analysis of Unactivated Clay Treated Product

In Figure 2b, the Broad Peak typically O-H stretching vibrations (found in alcohols, phenols, or water) or N-H stretching vibrations (found in amines or amides) correspond to about $3000\text{--}3500 \text{ cm}^{-1}$. There may be less hydrogen bonding if broadness is absent. Sharp C-H stretching vibrations in alkanes are characterized by peaks that occur between 2900 and 3000 cm^{-1} . Since methyl ($-\text{CH}_3$) and methylene ($-\text{CH}_2-$) groups are frequently found in hydrocarbons, peaks in this area often signify their presence. Peaks in C=C stretching vibrations (alkenes or aromatic rings) or C=O stretching vibrations (carbonyl groups like acids, ketones, or esters) usually correlate to an area of $1500\text{--}1700 \text{ cm}^{-1}$. This depends on the precise wavenumber and peak form. Peaks below 1500 cm^{-1} are important for identifying particular chemicals since they are specific to each molecule and contain a complex mix of stretching and bending vibrations. Hydrocarbon chains are a significant component of diesel and lubricating oils, and their presence could be confirmed by the C-H stretching peaks about $2900\text{--}3000 \text{ cm}^{-1}$.

3.2.3 FTIR Analysis of 0.5M Activated Clay Treated Product

The FTIR analysis of the product treated with 0.5M activated Clay (Figure 2c) showed stretching of O–H/N–H (about 3500–3200 cm^{-1}) could indicate the existence of N–H (such as in amines or amides) or hydroxyl (O–H) groups (such as in alcohols or phenols). This peak's absence or broadening may be a sign of hydrogen bonding or other interactions. C–H stretching vibrations are characterized by peaks in the range of 3000 to 2800 cm^{-1} . Usually, the existence of aliphatic hydrocarbons (saturated C–H bonds in alkanes) is indicated by a significant absorption in this region. Slightly higher than 3000 cm^{-1} peaks indicate unsaturated C–H bonds (aromatics or alkenes). Carbonyl groups (C=O), which are often found in ketones, aldehydes, carboxylic acids or esters, are represented by a high peak in the C=O stretching area (around 1700–1600 cm^{-1}). Aromatic Ring Vibrations or C=C, occur at 1600–1500 cm^{-1} . C=C stretching in alkenes or aromatic compounds is often symbolised by peaks here. Bending vibrations of aliphatic or aromatic C–H bonds may be observed in the C–H Bending area, which is around 1450–1350 cm^{-1} . Stretching C–O or C–N (about 1300–1000 cm^{-1}), peaks here could represent C–N stretching (found in amines or amides) or C–O stretching (found in alcohols, ethers, or esters). The fingerprint area, which is located below 1500 cm^{-1} , is useful for identifying particular substances because of its intricate peak pattern, which is peculiar to the compound's molecular structure. This results in fewer oxygenated chemicals present in the distilled oil than in the original oil.

3.2.4 FTIR Analysis of 1M Activated Clay Treated Product

The O–H stretching vibrations represented by the broad peak at around 3500–3000 cm^{-1} are suggestive of alcohols, phenols, or water (if present in trace amounts) (Figure 2d). Overlapping peaks in this area may occasionally also be a sign of N–H stretching (amines or amides). Sharp Peaks at about 3000–2800 cm^{-1} are associated with alkyl groups' C–H stretching vibrations. Asymmetric CH_3 stretches are linked to peaks at 2950 cm^{-1} , whereas symmetric CH_2 stretches are responsible for peaks closer to 2850 cm^{-1} . C=O stretching vibrations in carbonyl groups (such as ketones, aldehydes, or carboxylic acids) are probably represented by an area between ~1700 and 1600 cm^{-1} . The carbonyl group's particular environment determines the precise wavenumber. There are aromatic C=C stretching vibrations or C–H bending vibrations (methyl or methylene groups) at about 1500–1300 cm^{-1} . This range's peaks could represent cyclic or aromatic structures. The fingerprint zone, which is complex and unique to each compound, is located below 1300 cm^{-1} and contains a variety of bending vibrations (such as C–O, C–N, or C–X bonds). Key components of diesel-grade oil are hydrocarbon chains, which are shown to be present by the C–H stretching peaks (~3000–2800 cm^{-1}). Oxygenated compounds, which could be impurities or oxidation products from used engine oil, could be indicated by the C=O peak (~1700 cm^{-1}). If there are O–H or N–H peaks (~3500–3000 cm^{-1}), they may be the result of processing-modified functional groups, additives, or residual moisture. Certain hydrocarbon structures and trace chemicals can be identified with the aid of fingerprint region analysis.

3.2.5 FTIR Analysis of 2M Activated Clay Treated Product

Broad Peak O–H stretching, which is frequently linked to alcohols, phenols, or water, is demonstrated by about 3000–3500 cm^{-1} . If amines or amides are present, N–H stretching may also contribute to this region. Sharp Peaks corresponding to C–H stretching vibrations occur between 2800 and 3000 cm^{-1} . Aliphatic C–H stretches from CH_2 and CH_3 groups, commonly found in hydrocarbons, are suggested by peaks close to 2850–2960 cm^{-1} . If carbonyl groups are present, the 1500–1800 cm^{-1} area frequently includes C=O stretching (1700–1750 cm^{-1}). Aromatic C=C stretching may occur between 1450 and 1600 cm^{-1} . Approximately 1000–1500 cm^{-1} , the "fingerprint region," as it is called, has intricate peaks that are indicative of the molecular makeup of the sample. Here, specific functional groups, such as C–O stretching (ethers, esters, etc.), can be identified (Figure 2e). The molecular structure's bending or skeletal vibrations are usually observed below 1000 cm^{-1} . The high concentration of aliphatic hydrocarbons, a significant component of diesel, is suggested by the strong C–H stretches at 2800–3000 cm^{-1} . The presence of carbonyl groups, possibly from oxidation products in used motor oil, could be indicated by peaks at about 1700 cm^{-1} . The absence of a broad O–H peak indicates low water content or fewer polar contaminants.

3.2.6 FTIR Analysis of Commercial Diesel

Broad peaks in the area of about $3500\text{--}3000\text{ cm}^{-1}$ signify the presence of O–H stretching (such as water, phenols, or alcohols). Nevertheless, the absence of a prominent wide peak indicates that there are either few or no hydroxyl groups present. The strong peaks in the range of about $3000\text{ to }2800\text{ cm}^{-1}$ are indicative of alkane C–H stretching. C–H stretching in sp^2 -hybridized carbons (alkenes or aromatics) can be detected by peaks over 3000 cm^{-1} , whereas sp^3 -hybridized carbons (alkanes) can be detected by peaks below 3000 cm^{-1} . Carbonyl groups (such as ketones, aldehydes, and esters) usually exhibit C=O stretching when they have a strong peak in the $\sim 1700\text{ cm}^{-1}$ range. Peaks in approximately $1600\text{--}1500\text{ cm}^{-1}$ indicate C=C stretching, which is frequently present in alkenes or aromatic compounds. Bending vibrations of C–H bonds, such as those of methyl and methylene groups, can be indicated by peaks in the range of around $1450\text{ to }1300\text{ cm}^{-1}$. The fingerprint area, which is between $1000\text{ and }700\text{ cm}^{-1}$, is where complex vibrations that are unique to a molecule take place. Certain molecular structures can be identified with the aid of these peaks. Alkanes, a significant component of diesel, can be identified by strong C–H stretching peaks in the $3000\text{--}2800\text{ cm}^{-1}$ region. If there are few or no peaks at about 1700 cm^{-1} (C=O stretching), it suggests that compounds containing oxygen were successfully removed or transformed during the distillation process (Figure 2f). The presence of aromatic compounds, which are present in engine oil and may persist in the finished product, may be indicated by peaks in the 1600 cm^{-1} range.

3.2.7 Comparison between Clay Treated Products and Commercial Diesel

Diesel fuel should have a clear, brilliant appearance (Table 1) since it denotes purity and the lack of impurities. Significant contaminants are indicated by the black appearance of untreated oil. Products treated with activated clays (0.5M and 1M) have a "golden yellow" look that is quite similar to diesel's clarity. Unactivated clay and commercial bentonite produce brown results, indicating less effective purification. Diesel has a very light colour with a maximum permissible value of 3.0. The untreated product has the darkest colour (7.4). The best improvement (3.2), which is close to the diesel standard, is obtained with the 1M activated clay treatment. Diesel typically has a specific gravity range of 0.820 to 0.870. The fact that untreated oil is over the range (0.879) indicates that contaminants have made it denser. The specific gravity decreases significantly to 0.826 by 1M activated clay treatment, which is in accordance with diesel standards. Untreated oil has a high acidity level (6.058), while diesel has a maximum TAN of 0.5.

Acidity is greatly reduced by the 1M activated clay and commercial bentonite treatments; commercial bentonite has the lowest TAN (3.011). Diesel is appropriate for cold climates because of its -8.1°C pour point. When compared to untreated oil (-2°C), all treated products increase the pour point; the greatest improvement is obtained with 0.5M and 1M activated clays (-4°C). The water content of diesel must be below 0.05 per cent. This threshold (0.600%) is exceeded by untreated oil. The best reduction (0.010%) is obtained with the 2M activated clay treatment, which is well below the standard. The viscosity range required for diesel is 2–5.5 cSt. Poor flow characteristics are shown by the high viscosity (28 cSt) of untreated oil. Viscosity is greatly reduced by activated clay treatments; the greatest result (6.8 cSt) is obtained with a 1M treatment, which approaches the upper limit of tolerance. Diesel requires temperatures between $52\text{ and }96^\circ\text{C}$, whereas treated oils have flash points exceeding 150°C , which suggests they may be handled safely but are less volatile than diesel. Untreated oil has a significant residue (1.28%), whereas diesel has a maximum of 0.5%. The residues are considerably reduced to less than 0.5% by treatments using 1M and 2M activated clays, as well as commercial bentonite; the best result is obtained with 1M activated clay (0.48%).

3.2.8 Diesel-grade Oil Yield

1,122 ml of diesel was recovered from 1,650 ml of distilled used engine oil after the used engine oil was subjected to vacuum distillation (Figure 2); this volume represents a 68% yield of the total volume of distilled used oil. Also, the initial and final volumes of produced diesel before and after clay treatment were 1,122ml (68% yield) and 1,081ml (65.5% yield), respectively, indicating a 41ml (2.5%) loss due to clay treatment. 68% of the distilled volume is diesel (Table 2), showing the effectiveness of the distillation process. Although some

diesel may also have been lost, the 2.5% loss following clay treatment shows that the clay successfully absorbed impurities.



Figure 2: Produced diesel samples

4.0 Conclusion

This study showed that used engine oil can be effectively refined into diesel-grade oil with qualities comparable to commercial diesel through the use of vacuum distillation and clay treatment. According to this study, the used engine oil emulsified water content was reduced from 5.8% to 0.600% by distilling it at 130°C while maintaining atmospheric pressure. Also, diesel oil was extracted from dehydrated used engine oil at temperatures ranging from 275 to 300°C by distilling it at an average vacuum pressure of -0.045MPa. In addition, the recovered diesel oil's appearance, colour, density, TBN, TAN, viscosity, pour point and flash point were effectively improved by adsorption treatment using H₂SO₄ acid-activated Nenwe clay, while the oil's moisture content was significantly reduced. Finally, it was revealed that utilizing vacuum distillation and the clay treatment process, used engine oil yielded 68% diesel oil with qualities similar to commercial diesel oil, and 1M activated clay treatment is the best option for producing diesel-grade oil because it removes a lot of impurities and achieves desirable physical and chemical properties. From these results, it can be seen that vacuum distillation in combination with clay treatment is an effective method for recovering diesel oil from used engine oil.

Declarations

Credit authorship contribution statement

E.A.O: Conceptualization. Wrote the original draft, Methodology, Validation, Resources, Project administration, and Review of manuscript.

Declaration of competing interest

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Consent for publication

Not applicable

Ethics and Consent to Participate

Not applicable

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