

## Research Article

# Re-refining Used Engine Oil in Ghana Using Solvent Extraction and Acid-Clay Treatment

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Despite having detrimental impacts on the environment and human health, used engine oil is not properly disposed of in Ghana. However, used engine oil can be a valuable resource when recycled. This study investigates the recovery of base oils from used engine oils collected in one Ghanaian municipality. The used engine oils are re-refined either through acid-clay treatment or solvent extraction. Pour point, density, viscosity index, and total acid number of used engine oil and re-refined oils were measured in order to evaluate the two re-refining processes used and assess whether it is appropriate to reuse the re-refined oils as base oils. The pour point, total acid number, and viscosity index of the re-refined oils were significantly different from those of the used engine oils. The density of the re-refined oils varied little from that of the used engine oils (by 0.83% to 6.65%). These changes indicate the separation of some components, primarily impurities, from used engine oil as a result of re-refining. Compared to solvent extraction, acid-clay treatment was found to be less selective. When nitric acid or sulphuric acid was used, acid-clay treatment often produced group I and II base oils, whereas hydrochloric acid typically produced group III base oils. Also, the solvent extraction process frequently yielded oils with very high viscosity indices comparable to group III base oils. It is recommended that the type of base oil preferred for the production of new lubricants should be taken into account when deciding on a specific method for re-refining used engine oil.

## 1. Introduction

Changing the engine oil in cars has numerous advantages, but in places where the used oil is not properly managed, the oil being changed could cause environmental and public health issues. Lubricants are generally used to reduce friction, heat, and wear between mechanical components that are in contact. Engine oil, also known as motor oil, is a type of lubricant that is commonly used in automobiles. They are mainly petroleum-based or synthetic oils with various additives to improve their performance. The used engine oil (UEO), which has become contaminated with physical and/or chemical contaminants as a result of its use over time, must be replaced with fresh engine oil (FEO), as it can no longer perform its intended functions. Metallic particles from engine wear, carbonaceous particles from incomplete

fuel combustion, metallic oxides, water, fuel or fuel additives or their by-products, sludge, lacquer, oil-soluble products, and others are only a few examples of possible pollutants [1].

Open dumping of UEO on land, streams, rivers, and public sewer and drainage systems, as well as uncontrolled burning, are examples of improper disposal. Since waste oil contains lead, zinc, arsenic, chromium, cadmium, and sulphur, contamination of natural resources such as soil, surface water, and ground water as well as damaging atmospheric emissions are some of the potential environmental effects of such disposal practices [2, 3]. Therefore, proper management is necessary, particularly to turn the used engine oil into a profitable product.

Despite the presence of impurities, UEO contains a significant amount of base oil that has not been depleted. Because of the high stability of the base oils, the chemical

composition of the base oils is typically maintained to a substantial extent. In other words, the base oil of UEO actually becomes contaminated; therefore, removing the impurities helps save a valuable resource [4]. Re-refining essentially involves treating used lubricating oils to get rid of the impurities, which include dust, moisture, combustion products such as unburned fuel, corrosion products, and metallic particles for the purpose of recovering the base oil to be blended with additives to produce new lubricants [5, 6]. By re-refining UEO, the amount of UEO that is likely to pollute the environment will be reduced. As a result, waste oil recycling can be a practical and affordable substitute for waste oil incineration because it reduces pollution, protects natural resources, and has positive economic effects [4].

Re-refining used lubricating oil is not a novel concept because recycling used lubricants has been a common practice since the 1930s [7]. Several recycling techniques have been developed as a result of the long-standing interest in re-refining used lubricating oil. The re-refining techniques may include acid treatment, solvent extraction, clay treatment, vacuum distillation, hydrotreating, and others [8–19]. Most often, the re-refining process may involve a combination of the techniques and a pretreatment step to separate solids and water in the used oil prior to the re-refining process [1].

Re-refining used engine oil has the following benefits: lowers reliance on imported base oil; saves foreign exchange; does not contribute to contamination and degradation of surface and ground water; reduces the cost of sewage treatment; minimizes the use of waste oil as a source of fuel, which produces poisonous fumes and pollutes the environment [20]. Currently, there are no used engine oil treatment systems available in Ghana, and general awareness of the environmental implications of used engine oil is extremely poor. The garage floors, for instance, at the Suame Magazine (a very popular garage within Kumasi, Ghana), are mostly stained with large volumes of UEO and have been attributed to some level of contamination of the groundwater in the area. A study conducted by Appiah-Adjei et al. [21] showed significant lead contamination of the underground water in the mapped area with very high levels of UEO disposal.

Large factories, railways, and large vehicle fleets generate huge amounts of waste oil, although there are only a few such sources. The remaining sources, though numerous, generate UEO in usually small amounts, and they include garages, filling stations, small factories, and various residences. Often, the UEO is left at the filling stations after changing the engine oil of several vehicles without any proper means of disposal. In some parts of the country, UEO is normally collected and used for wood board coating as it acts as a pest repellent in order to prolong the lifespan of these wood boards. In some fishing communities within Ghana, the UEO is used for waterproofing purposes by coating canoes during the production of these local canoes.

The objective of this research was to treat UEO to recover base oils that could be reused in the production of new lubricants. To treat the UEO, two conventional re-refining processes, acid-clay treatment and solvent extraction, were

used. Furthermore, used engine oil and re-refined oils obtained through acid-clay treatment or solvent extraction were analysed in order to determine the suitability of re-refined oils as base oils and to compare the efficacy of the various re-refining processes described in this work. These properties included pour point, density, viscosity index, and total acid number.

## 2. Materials and Methods

**2.1. Materials.** The apparatuses used in this study were accessed or obtained from the Process Development Laboratory of the Department of Chemical Engineering, the Core Rock and the Fluid Properties Laboratories of the Department of Petroleum Engineering, both at Kwame Nkrumah University of Science and Technology (KNUST). The apparatuses included analytical balance, pipette, burette, conical flask, Buchner funnel, vacuum pump, filter paper, viscometer, test sieves, mechanical sieve shaker, filtering flask, separating funnels, electric oven, temperature sensor, Erlenmeyer flasks, beakers, magnetic stirrers, measuring cylinders, and rotary evaporator. All chemicals used were of analytical grade. The chemicals used in this study included toluene, 1-butanol (90%), methanol (70%), ethanol (60%), isopropanol (65%), sulphuric acid (94%), nitric acid (65%), hydrochloric acid (90%), NaOH (10% w/v) and phenolphthalein. Kaolinite clays were obtained from three different locations in Ghana: Afiemya in the Greater Accra Region; Nkroful in the Western Region; and Mfensi in the Ashanti Region. Used engine oil was collected from garages and local filling stations within the Oforikrom Municipality (Kumasi, Ghana) for this research.

**2.2. Pretreatment of Used Engine Oil.** With the aid of a vacuum pump, a Buchner funnel, and filter paper, impurities such as sand, metal chips, and other solid particles that polluted the used engine oil were removed. The Buchner funnel was attached to the filtering flask with a rubber stopper, and the vacuum pump was connected to the filtering flask. Samples of the used oil were filtered. The filtrate was preheated at about 50°C while stirring for an hour. The two different treatment processes used in this study are acid-clay treatment and solvent extraction treatment. Each of the treatment processes was followed after the pretreatment.

**2.3. Acid-Clay Treatment.** This treatment method entails contacting acid-treated used engine oil with activated clay for better adsorption of impurities and pollutants in the used oil. Three different acids (sulphuric acid, nitric acid, and hydrochloric acid) were used for treating the used engine oil, followed by clay treatment. The clays (kaolinites) used were obtained from three different locations in Ghana, as indicated previously. The different acid-clay combinations used in re-refining UEO are presented in Table 1. The procedures followed in the acid-clay treatment process are briefly described next.

TABLE 1: Acid-clay combinations employed in this study for re-refining used engine oil.

Acid	Activated clay	Acid-clay combination	Re-refined oil label
Sulphuric acid ( $H_2SO_4$ )	Kaolinite from Mfensi (KM)	$H_2SO_4 + KM$	SM
	Kaolinite from Nkroful (KN)	$H_2SO_4 + KN$	SN
	Kaolinite from Afienya (KA)	$H_2SO_4 + KA$	SA
Nitric acid ( $HNO_3$ )	Kaolinite from Mfensi (KM)	$HNO_3 + KM$	NM
	Kaolinite from Nkroful (KN)	$HNO_3 + KN$	NN
	Kaolinite from Afienya (KA)	$HNO_3 + KA$	NA
Hydrochloric acid (HCl)	Kaolinite from Mfensi (KM)	HCl + KM	CM
	Kaolinite from Nkroful (KN)	HCl + KN	CN
	Kaolinite from Afienya (KA)	HCl + KA	CA

**2.3.1. Acid Treatment.** 100 ml of pretreated used engine oil was measured and poured into a beaker. Also, 10 ml of sulphuric acid was measured and poured into a separate beaker. The pretreated UEO sample in the beaker was placed on the hot plate and heated to 50°C. The temperature was maintained at 50°C while adding the sulphuric acid to the heated UEO and stirring the mixture for 30 minutes. The same steps were repeated using nitric acid and hydrochloric acid.

**2.3.2. Sedimentation, Decantation, and Neutralization.** At the end of the acid treatment step, the acid-UEO mixtures were allowed to settle for 24 hours while sediments formed at the bottom of the beaker. After this period, the mixture was properly decanted into another beaker for further processing, leaving behind the sediments (acidic sludge) at the bottom of the beaker. The raffinate was neutralized by adding 100 ml solution of 10% NaOH and the resulting solutions were allowed to stand for 12 hours, after which they were decanted.

**2.3.3. Clay Activation.** Although the clay has a high adsorption efficiency at room temperature and relative humidity, it was activated because activated clay retains its structure when saturated and is simple to reactivate for reuse by heating. To begin with, the kaolinite clay sample from Mfensi (KM) was ground and made into a slurry with distilled water. Then, impurities such as sand and stones were allowed to settle at the bottom and then decanted. The slurry free from impurities was dried in an oven at a temperature of 110°C. The dried clay was ground into very fine particles and screened using a mesh size of 0.5  $\mu m$ . Lastly, the clay was activated by calcining it in a furnace at 800°C for 5 hours. The same steps were repeated using kaolinite clay samples from Afienya (KA) and Nkroful (KN).

**2.3.4. Purification and Filtration.** The activated clay samples were mixed for 15 minutes with the respective acid-treated used engine oil according to Table 1. The mixture was thoroughly mixed using a stirrer. The mixture was then kept for 24 hours to allow the efficient adsorption of impurities from the acid-treated UEO by the activated clay. After this, the mixtures were decanted to be filtered afterwards, leaving behind the residues at the bottom of the beaker. The

decanted oils were filtered using filter papers; the filtrates were collected in filtration flasks.

**2.4. Solvent Extraction Treatment.** The solvent extraction treatment method was also used beside the acid-clay treatment method. This method makes use of solvent for re-refining UEO. In this study, three different solvent mixtures were used. The first solvent mixture was made up of equal volumes of toluene, 1-butanol and methanol and was labelled as TBM. Similarly, the second solvent mixture was made up of equal volumes of toluene, 1-butanol and ethanol and was labelled as TBE. The third solvent mixture was made up of equal volumes of toluene, 1-butanol and isopropanol and thus labelled as TBI. A brief description of this treatment method follows next. The solvent mixture labelled TBM was mixed with the pretreated used engine oil in a closed vessel. The solvent to oil ratio was 3:1. The whole mixture was then stirred for one hour using a magnetic stirrer. Afterwards, the mixture was allowed to stand for 24 hrs and decanted to obtain the clear surface oily layer containing the solvent and the oil, which was later transferred into a rotary evaporator to separate the solvents from the re-refined oil. The same steps were repeated using TBE and TBI. The re-refined oil obtained through solvent extraction was labelled according to the solvent mixture used. As a result, the re-refined oil produced using the TBE solvent mixture was given the TBE label. The re-refined oil made with the TBI and TBM solvent mixtures was given the TBI and TBM labels, respectively.

## 2.5. Characterization

**2.5.1. Density.** Density is a physical property that must be determined because oils are often formulated by weight but measured by volume [22]. The density of a substance is equal to its mass divided by its volume. As a result, 50 ml of oil samples were measured, weighed, and recorded. The density of the oil samples was calculated by dividing the mass of the oil recorded by its volume.

**2.5.2. Pour Point.** For the proper operation of lubrication systems, flow parameters such as pour point are important. Pour point is an indicator of the lowest temperature at which the oils can be used for specific applications. In brief, each oil sample was poured into a beaker and then refrigerated. The beaker was inspected within a 5-minute interval by holding

it in a horizontal position. The temperature of the cooled oil was taken using a thermometer when the oil surface does not sag for five seconds. The pour point is 3°C higher than the thermometer reading.

**2.5.3. Total Acid Number.** The amount of acidic and basic elements in the oil is determined by the total acid number (TAN). TAN is a useful indicator of the degree of oxidation in used lubricating oil [1]. The steps taken to determine TAN are mentioned below. A few drops of phenolphthalein were added to 10 ml of lubricant already measured into a conical flask. The burette was filled with KOH solution and titrated against the lubricant until a pink solution formed. The acid value was calculated using the following equations.

$$\text{Acid value} = \frac{\text{Volume of KOH in ml} \times \text{normality of KOH} \times 56}{\text{Mass of oil in grams}}, \quad (1)$$

where mass of oil = volume of oil  $\times$  density of oil.

**2.5.4. Viscosity and Viscosity Index.** Viscosity is one of the important characteristics of lubricating oil. The viscosity was determined in the following manner: the viscometer was filled with 10 mL of distilled water, and an air-sucking rubber ball was used to suck air. When the liquid reached the required level in the viscometer, the air suction was stopped and the rubber ball was withdrawn. The time it took for the sample to travel the distance (A–B) on the viscometer was measured in seconds. The viscosity was estimated using the following equation:

$$\text{viscosity } (n_s) = \frac{(n_w \times \rho_s \times t_s)}{(\rho_w \times t_w)}, \quad (2)$$

$n_s$  = viscosity of the given sample,  $n_w$  = viscosity of distilled water at a given temperature,  $\rho_s$  = density of the given sample at a given temperature,  $t_s$  = time required by the given sample to cover a distance on the viscometer,  $\rho_w$  = density of water at a given temperature, and  $t_w$  = time required by water to cover a distance on the viscometer.

A viscosity index is a measurement of a lubricant's resistance to viscosity change with temperature. Because it shows whether an oil will be able to properly lubricate at a high engine temperature, the viscosity index is very significant [1]. In brief, the kinematic viscosity of a given oil was measured at 40°C and 100°C (i.e.,  $Y_{X40}$  and  $Y_{X100}$ ). For the value of  $Y_{X100}$ , the values of  $Y_{A40}$  and  $Y_{B40}$  are taken from the ASTM D2270 table. The formula below was used to determine the viscosity index.

$$VI_X = \left( \frac{Y_A - Y_X}{Y_A - Y_B} \right)_{\text{at } 40^\circ\text{C}} \times 100. \quad (3)$$

### 3. Results and Discussion

**3.1. Analytical Characterization.** Although two different treatment techniques, solvent extraction and acid-clay treatment, were employed for the re-refining process, a total of twelve distinct re-refined oils were produced as a result of

the variations in each technique. Table 2 lists four significant characteristics of these re-refined oils along with the used engine oil. Also, Table 3 shows the specifications of two classes of engine oil provided by some renowned engine oil manufacturers. It is important to note that none of the re-refined oils exhibited foaming properties.

**3.1.1. Density.** Density is a term used to describe how much matter is present in a volume. As a result, the higher the density of a substance, the heavier it is. According to Figure 1, the density of UEO examined in this work is 0.842 g/cm<sup>3</sup>. However, the re-refined oils had densities ranging from 0.849 to 0.898 g/cm<sup>3</sup>, which is 0.83% to 6.65% higher than the density of UEO. This shows that all the refined oils were heavier, albeit slightly, than the UEO. This contradicts observations in other works of literature. Usually, UEO has a higher density than fresh engine oil (FEO), but after re-refining, the density of UEO reduces and gets closer to that of the fresh oil. The presence of more aromatic compounds and solids in UEOs than in FEOs explains why the density of a UEO is usually higher than that of its FEO. And that re-refining a UEO to remove the aromatic compounds and/or solids causes the density of the re-refined oil to decrease and approach that of its FEO. However, in this study, this was not the case; the re-refined oils reported densities that were higher than the UEO. The density of oil decreases as the number of saturated hydrocarbons increases. Therefore, the re-refined oils have higher densities than UEO because UEO contains a little bit more saturated compounds than re-refined oils. Along with the removal of solids and/or aromatic compounds, the refining also removed some saturated compounds from the UEO.

**3.1.2. Total Acid Number.** A used engine oil (UEO) with a high total acid number (TAN) may have undergone oxidation, additive depletion, or a change in the operating environment. The total acid number for UEO and all the refined oils is all displayed in Figure 2 in relation to each other. As shown in Figure 2, the TAN of the used engine oil is measured to be 8.783 mg (KOH)/g (sample), which is much higher. This points to the potential presence of organic, inorganic, heavy metal salts, glue, water, and corrosive substances, the majority of which were the end result of oxidation, which occurred at high temperatures. The total acid number of all the re-refined oils is fairly lower than that of the UEO. This suggests that the aforementioned contaminants or undesirable constituents of UEO were decreased to some extent. The re-refined oil, TBM, had the lowest reduction of around 46.76%, while the re-refined oil, SN, had the maximum reduction of about 89.97%.

**3.1.3. Pour Point.** The lowest temperature at which oil will stop flowing is known as the pour point. The pour point measures how well oil flows at low operating temperatures. The pour point is a key factor to consider, particularly when starting the engine in cold weather. Figure 3 contrasts the pour point of SAE 30 oil class with the pour points of UEO

TABLE 2: Properties of the used engine oil and re-refined oils from this work.

Oil	Properties			
	*Density (g/cm <sup>3</sup> )	Pour point (°C)	TAN (mg KOH/g)	Viscosity index
UEO	0.842	-27	8.783	129.61
CA	0.868	-8.5	2.259	129.94
CM	0.855	-7.4	1.801	115.21
CN	0.849	-8.0	2.145	138.03
NA	0.884	-9.1	3.961	123.37
NM	0.880	-9.4	2.228	106.26
NN	0.869	-9.0	1.531	102.8
SA	0.854	-7.0	1.311	97.266
SM	0.881	-6.1	2.066	94.045
SN	0.867	-7.2	0.969	93.105
TBE	0.882	-7.1	3.176	168.01
TBI	0.871	-8.2	1.608	119.8
TBM	0.898	-9.0	4.676	148.06

\*Density measurements were taken at 25°C.

TABLE 3: Typical specification of different classes of engine oil according to the Society of Automotive Engineers (SAE) classification.

Specification	Unit	SAE 30	SAE 40
Viscosity index (VI)	—	95	97
Density at 15°C	g/cm <sup>3</sup>	0.895	0.898
Pour point	°C	-18	-15

The above values may vary within commercially acceptable tolerances.

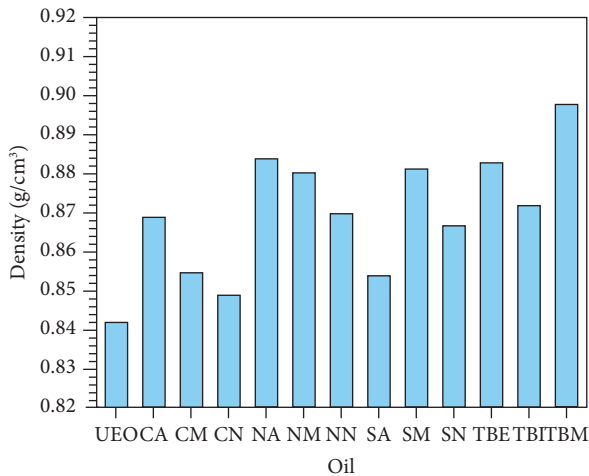


FIGURE 1: Densities of used engine oil and re-refined oils.

and all re-refined oils. As can be seen from Figure 3, the pour points of all the re-refined oils were higher than those of UEO and SAE 30 oil. The re-refined oils had pour points ranging from -6.1 to -9.4°C. Usually, low paraffin content and high aromatics are the reasons for low pour points. Thus, higher pour points are associated with oils that contain more wax and paraffin. This means that re-refined oils have fewer aromatics than UEO since the aromatics along with the other impurities are separated from UEO to get the re-refined oils during the refining process. Therefore, the re-

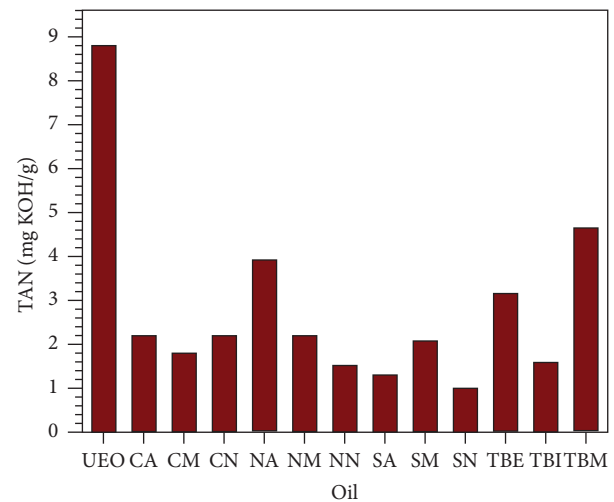


FIGURE 2: Total acid number of the used engine oil and re-refined oils compared to SAE 30 oil class.

refined oils had higher pour points than UEO due to this tendency to contain more wax and paraffin.

**3.1.4. Viscosity Index.** In hot, high-severity service, lubricants are frequently designed to have a viscosity that is high enough to offer acceptable film thickness and lubricity while still being low enough to allow for effective cold weather starting. Because of this, when hot and cold performance is required, a small response to variations in temperature is preferred, which is measured by the viscosity index; a higher viscosity index indicates a smaller, more favourable response to temperature. Figure 4 shows the viscosity index of used engine oil and all the refined oils relative to the viscosity index of the SAE 30 oil class. With the exception of SN re-refined oil, all the refined oils as well as UEO had VI equal to or greater than SAE 30 oil. Also, all the refined oils had a VI less than 120, except CA, CN, NA, TBE, and TBM, which reported a VI greater than 120. Thus, CA, CN, NA, TBE, and TBM oils compare favourably with group III base oils, while the remaining oils compare favourably with either group I or

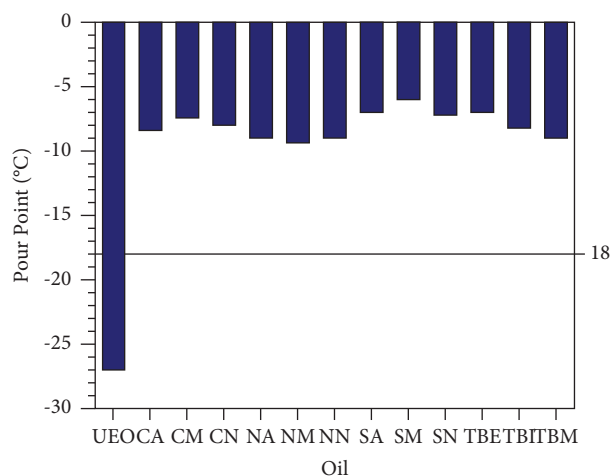


FIGURE 3: Pour points of used engine oil and refined oils compared to the pour point of SAE 30 oil class.

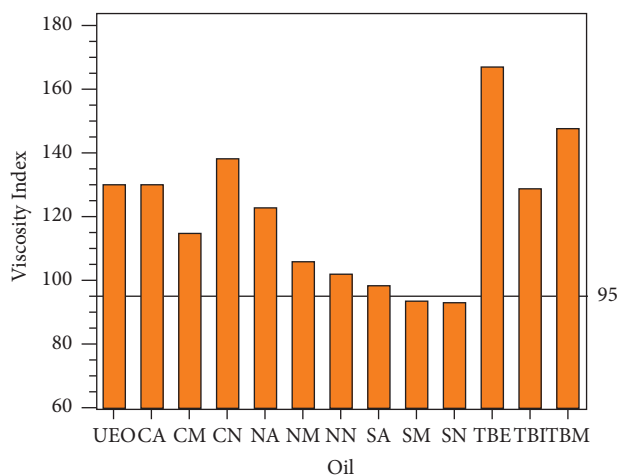


FIGURE 4: Viscosity index of used engine oil and refined oils compared to that of SAE 30 oil class.

group II base oils. It is important to remember that the classification of refined oils into various base oil groups was exclusively based on VI and not on the proportion of saturated compounds or sulphur content.

### 3.2. Effect of Different Re-refining Techniques and Operating Conditions.

In general, the oils produced by the acid-clay treatment and solvent extraction had pour points that were nearly identical. This means that each of the re-refining processes removed or separated the same number of aromatic components from UEO. Additionally, compared to oils produced by solvent extraction, oils produced by the acid-clay treatment were less dense and had a relatively lower TAN and VI. This suggests that acid-clay treatment eliminates more components in the UEO than solvent extraction, yet these components may not only be undesirable contaminants but also a considerable quantity of desired saturated components. Acid-clay treatment is a multi-step process that separates or removes more components than

solvent extraction, which is a single-step process. In contrast to solvent extraction, which is a more selective process, acid-clay treatment is less selective, particularly during the acid treating step. All of the components of the oil, including saturated and aromatic hydrocarbons, sulphur, nitrogen, oxygen, and other undesirable chemicals, are attacked by strong acid. Data on the amounts of saturates, sulphur, and other heavy metals in UEO and re-refined oils could help to clarify this point.

The different re-refining techniques had an impact on the different properties under investigation, but so did the different operating conditions, such as the use of different acids and kaolin clay from different sources for the acid-clay treatment technique and different solvent mixtures for the solvent extraction treatment technique. For instance, among the three solvent mixtures examined, the oil generated with the TBI combination had the least dense oil, the lowest TAN, and the lowest VI. The oil generated by the TBM combination had the highest density and TAN, whereas the oil produced by the TBE combination had the highest VI. The third constituent that makes up the ternary system distinguishes the three solvent mixtures employed in this investigation. The third constituents were alcohols with varying numbers of carbon atoms; for the TBM, TBE, and TBI combinations, the alcohols were methanol (one carbon atom), ethanol (two carbon atoms), and isopropanol (three carbon atoms). In this study, it was discovered that increasing the number of carbons in the solvent mixtures reduces the acidic components of the oils. This means that the alcoholic solvents with fewer carbons had a high affinity for the acidic components and hence dissolved them alongside the base oil.

When the same acid was employed for the acid-clay treatment, the usage of clay from different sources influenced the various properties studied. However, because the trend changed with each acid used, no clear patterns emerged. Furthermore, the use of different strong acids during the acid treatment stage has an effect on the attributes being evaluated. Two separate trends emerge when the acid is changed but the clay remains unchanged. Nitric acid had a higher VI than hydrochloric acid, while nitric acid had a higher VI than sulphuric acid. Also, the oils obtained with nitric acid had a lower pour point than those obtained with hydrochloric acid, and hydrochloric acid had a lower pour point than sulphuric acid. It is worth noting that all the acids used are strong acids. As previously stated, these strong acids attack all components of the oil, including saturated and aromatic hydrocarbons, sulphur, nitrogen, oxygen, and other unwanted compounds. However, the extent to which each acid removed a specific component cannot be identified in this study because some properties such as proportions of saturates, sulphur, and other heavy metals were not evaluated. However, the trends in the viscosity index indicate that, of the three acids, sulphuric acid removes the most saturated components, followed by nitric acid and hydrochloric acid. Nitric acid was also more effective at dewaxing than hydrochloric acid, which is better than sulphuric acid, and this helps to explain the trend in the pour points.

## 4. Conclusions

With more vehicles on the roads in Ghana, the consumption of engine oil is increasing, and it is important that after changing the oil, the used engine oil be managed properly because it is hazardous. This study set out to look at the possibility of recovering base oils from UEO collected in one Ghanaian municipality using conventional techniques. After treating the UEO using either acid-clay or solvent extraction treatment techniques, the examined properties of the re-refined oils differed significantly from those of the UEO but were comparable to base oils. Generally, the re-refined oils produced by the acid-clay treatment were less dense, had lower TAN and VI, but almost the same pour point values as those produced by the solvent extraction technique. Furthermore, when each treatment method was modified, such as the use of different acids in the acid-clay treatment method, the examined properties of the re-refined oils differed from one another. As a result, this study demonstrates that acid-clay treatment is a less selective process compared to solvent extraction, though both techniques are suitable for recovering base oils from UEO and that modifying certain process parameters may lead to recovering a particular type of base oil. However, further investigation is needed to assess the physiochemical properties of used engine oils from different regions of the country as well as re-refined oils produced using other treatment techniques not covered in this study in order to gain more understanding that will guide the development of a sustainable re-refining process for recovering base oils from used engine oils generated in Ghana. Future studies should also cover the formulation of re-refined engine oils, that is, engine oils that incorporate re-refined base oils, as well as the field evaluation of the re-refined engine oils. Furthermore, as the economic viability of the treatment techniques was outside the scope of this study, additional research works, such as technoeconomic assessment studies, are required to better understand the financial benefits of each technique.

## Nomenclature

API: American petroleum institute  
SAE: Society of automotive engineers  
TAN: Total acid number  
UEO: Used engine oil  
VI: Viscosity index

## Data Availability

The Society of Automotive Engineers (SAE 30) Oil Specifications for engine data used to support the findings of this study are included within the article. All other data needed for reproducibility of this research are adequately provided within the article. However, if any one requires any further data to aid in any other research based on our research findings, the person can contact the corresponding author of this manuscript.

## Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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## References

- [1] J. G. Speight and D. I. Exall, "Refining used lubricating oils," 2014. Refining used lubricating oils.
- [2] M. El-Fadel and R. Khoury, "Strategies for vehicle waste-oil management: a case study," *Resources, Conservation and Recycling*, vol. 33, no. 2, pp. 75–91, 2001.
- [3] B. Kwakye-Awuah, R. Kwakye, B. Sefa-Ntiri, I. Nkrumah, E. Von-Kiti, and C. Williams, "Comparison of the recycling efficiency of metakaolin and laboratory-synthesized zeolite types LTA and LSX on used lubricant engine oil," *Applied physics research*, vol. 10, no. 4, 11 pages, 2018.
- [4] D. I. Osman, S. K. Attia, and A. R. Taman, "Recycling of used engine oil by different solvent," *Egyptian Journal of Petroleum*, vol. 27, no. 2, pp. 221–225, 2018.
- [5] G. S. Dang, "Rerefining of used oils - a review of commercial processes," *Tribotest*, vol. 3, no. 4, pp. 445–457, 1997.
- [6] N. Zgheib and H. Takache, "Recycling of used lubricating oil by solvent extraction: experimental results, Aspen Plus simulation and feasibility study," *Clean Technologies and Environmental Policy*, vol. 23, no. 1, pp. 65–76, 2021.
- [7] J. D. Udonne, "A comparative study of recycling of used lubrication Oils using distillation, acid and activated charcoal with clay methods," *Journal of Petroleum and Gas Engineering*, vol. 2, no. 2, pp. 12–19, 2011.
- [8] G. R. Daham, A. A. J. AbdulRazak, A. S. Hamadi, and A. A. Mohammed, "Re-refining of used lubricant oil by solvent extraction using central composite design method," *Korean Journal of Chemical Engineering*, vol. 34, no. 9, pp. 2435–2444, 2017.
- [9] M. A. dos Reis and M. S. Jerónimo, "Waste lubricating oil rerefining by extraction-flocculation 1. A scientific basis to design efficient solvents," *Industrial & Engineering Chemistry Research*, vol. 27, no. 7, pp. 1222–1228, 1988.
- [10] H. A. Durrani, "Re-refining recovery methods of used lubricating oil," *International Journal of Engineering Sciences and Research Technology*, vol. 3, no. 3, pp. 1216–1220, 2014.
- [11] E. A. Emam and A. M. Shoaib, "Re-refining of used lube oil, i-by solvent extraction and vacuum distillation followed by hydrotreating," *Petroleum and Coal*, vol. 55, no. 3, pp. 179–187, 2013.
- [12] E. A. Emam and A. M. Shoaib, "Re-Refining of used lube oil, II- by solvent/clay and acid/clay-percolation processes," *ARPN Journal of Science and Technology*, vol. 2, no. 11, pp. 1034–1041, 2012.
- [13] A. Hamad, E. Al-Zubaidy, and M. E. Fayed, "Used lubricating oil recycling using hydrocarbon solvents," *Journal of Environmental Management*, vol. 74, no. 2, pp. 153–159, 2005.

- [14] M. Hussein, A. A. Amer, and A. S. Gaberah, "Used lubricating oils re-refining by solvent extraction," *American Journal of Environmental Engineering and Science*, vol. 1, no. 3, pp. 44–50, 2014.
- [15] J. P. Martins, "The Extraction–Flocculation Re-refining lubricating oil process using ternary organic solvents," *Industrial & Engineering Chemistry Research*, vol. 36, no. 9, pp. 3854–3858, 1997.
- [16] H. Mensah-Brown, "Re-refining and recycling of used lubricating oil: an option for foreign exchange and natural resource conservation in Ghana," *ARPJ Journal of Engineering and Applied Sciences*, vol. 10, no. 2, pp. 797–801, 2015.
- [17] R. R. Mohammed, I. A. R. Ibrahim, A. H. Taha, and G. McKay, "Waste lubricating oil treatment by extraction and adsorption," *Chemical Engineering Journal*, vol. 220, pp. 343–351, 2013.
- [18] S. Thorat, J. Arekar, and S. Dhokpande, "Re-refining of used lubricating oil and to determine rheological characteristics: a literature review," *International Research Journal of Engineering and Technology*, vol. 8, no. 4, pp. 3567–3572, 2021.
- [19] P. K. Wong and J. Wang, "The accumulation of polycyclic aromatic hydrocarbons in lubricating oil over time - a comparison of supercritical fluid and liquid-liquid extraction methods," *Environmental Pollution*, vol. 112, no. 3, pp. 407–415, 2001.
- [20] F. B. Hani and H. Al-Wedyan, "Regeneration of base-oil from waste-oil under different conditions and variables," *African Journal of Biotechnology*, vol. 10, no. 7, pp. 1150–1153, 2011.
- [21] E. K. Appiah-Adjei, N. F. Appiah, and K. A. Adjei, "Potential groundwater pollution from improper oil and metal waste disposal in Suame, Ghana," *Journal of Science and Technology*, vol. 36, no. 3, pp. 20–33, 2016.
- [22] R. J. Prince, "Base oils from petroleum," in *Chemistry and Technology of Lubricants* pp. 3–33, Springer, 3rd edition, 2010.