Research Article

Characterization of Metakaolin from Wassa Kaolin and Its Potential as Adsorbent for the Regeneration of Used Engine Lubrication Oil

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1. Introduction

Metakaolin is an anhydrous clayey material obtained by the calcination of kaolin. This material has been utilized as a valuable substitute or additive for concrete/cement mixtures and many other applications. The current study is on the production and characterization of metakaolin together with its adsorbent properties for the purification and regeneration of spent lubrication oil. Metakaolin was produced from the calcination of kaolin from Wassa in the Western region of Ghana. The metakaolin was characterized by using X-ray fluorescence (XRF), X-ray diffractometry (XRD), scanning electron microscopy (SEM) coupled with energy dispersive X-ray (EDX), and Fourier transform infra-red (FT-IR). The metakaolin was then used as an adsorbent in the regeneration of the engine lubrication oil, mimicking the acid-clay percolation process. The test results show that the efficiency of metakaolin in removing heavy metals from the used oil using an atomic absorption spectrometer (AAS) was 13.25% for Fe, 25.37% for Cr, 94.36% for Zn, and 33.33% for Cu. The viscosity index of the regenerated oil was 118 compared to that of the virgin oil, which was 115. The regenerated oil had 79% saturates, 6% carbon residues, and 18% aromatics compared to the commercial virgin oil, which contained 84% saturates, 5% carbon residue, and 11% aromatics. This indicated that metakaolin is a better adsorbent for regenerating the used lubrication oil.
As these transformations occur, there is an accumulation of
dirt, heavy metals, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) in the lubricant [7, 8]. The oil loses its lubricating properties after some time due to the accumulation of these materials and must be replaced. At this point, we termed the lubricant as used engine lubricating oil [9]. If not well disposed of, these used lubricants can have severe effects on our health [10]. Disposing of these lubricants by burning them contributes to the environment’s aerosols or greenhouse gases. The air pollutants generated from the burning of these used lubricants are not concentrated at one point. They diffuse from one place to another, as reported by the authors of [11]. Used oils are one of the most significant amounts of liquid, nonaqueous hazardous waste on Earth [9]. Therefore, we need to regenerate these used lubricants to preserve our natural resources and protect our environment from these dangerous wastes [10].

One of the most popular treatment methods for the regeneration of used lubricants is the acid-clay process [12]. In the work of [11], acetic acid was used in the regeneration process. The acid-clay process is comparatively cheap and an excellent procedure depending on the variation of the acid and clay compositions. The authors regenerated used engine lubricating oil using sulphuric acid and metakaolin as adsorbents in this work. The results obtained in this work show a high-quality recycled engine lubricating oil. The use of metakaolin as an adsorbent in restoring used lubricating oils is a novel and very cheap process as compared to many other advanced technologies being used. The metakaolin was obtained from the calcination of kaolin from Wassa in the Western region of Ghana. This method proved to be very practical and cost-effective compared to many conventional technologies.

2. Materials and Methods

Kaolin was obtained from Wassa with geographical coordinates 5.7823°N, 2.0883°W in the Western region of Ghana. Sulphuric acid, Sigma Aldrich (Merck) Chemical Company, Inc. UK with 99% purity was obtained from MES Chemical Limited in Achimota, Accra, with geographical coordinates 5.6128°N, 0.2343°W. The used lubricating engine oil (GOIL SAE 20W—50) was collected from a Goil service station in Ho with geographical coordinates 6.6101°N, 0.4785°E, in the Volta region of Ghana. Ten (10) litres of used lubricating engine oil were collected from one service station and 350 samples were prepared.

2.1. Characterization of Kaolin and Metakaolin. Kaolin powder was sieved under dry conditions with a mesh to obtain a uniform particle size of $<0.75 \mu m$. The dried kaolin powder was then calcined at a temperature of 600°C for 2 hours to form metakaolin. Nearly complete dehydroxylation of the kaolin was complete at this temperature and time. The chemical composition of the kaolin and the formed metakaolin were first determined using a Malvern Panalytical X-ray fluorescence spectrometer (XRF) on dispersed particles in deionised water. A glass slab was placed on both the kaolin and metakaolin powder on the sample holder’s flat surface and compressed. This was done to achieve a smooth, levelled surface. They were then characterized using a Panalytical Empyrean powder X-ray diffractometer (XRD) operated at 40 mA and 40 kV. Phase identification scans were taken from $2\theta = 5$ to 80 with a step size of 0.013 and a scan step time of 8.67 S. Rietveld analysis was performed using Xpert HighScore Plus software. A ZEISS EVO50 scanning electron microscope (SEM) attached with an energy dispersive X-ray analyzer (EDX) was used to investigate the morphology of the kaolin and metakaolin. The SEM was operated with an accelerating voltage of EHT = 20.00 kV, Signal A = SEI, and WD = 4.0–5.5 mm. The kaolin and metakaolin powders were dry sprayed onto aluminium stubs using double-sided adhesive carbon discs. They were then coated with gold to decrease static charging when under observation. A Mattson Fourier transform infra-red spectrometer (FT-IR) (Mattson Instruments, UK) equipped with a ZnSe crystal plate attached to the spectrometer with a mercury cadmium telluride A, (MCTA) detector and KBr as a beam splitter was used to analyze the kaolin and metakaolin. The analysis was conducted using 100 scans at 4 cm$^{-1}$ resolution over the mid-IR region of 1200–400 cm$^{-1}$. A small sample of both the kaolin and metakaolin were separately centred on the ZnSe plate to ensure that they covered the entire crystal surface. A pressure clamp was used to apply pressure on the filter. The results were analyzed using MATLAB. The kaolin and metakaolin samples were analyzed three times per sample characterization.

2.2. Regeneration of the Used Oil. The used oil samples (GOIL 50 W—SAE 40) were collected from the Goil service station at Ho in the Volta region of Ghana. Ten litres of used oil were collected. The collected oil samples were initially filtered using a Buchner funnel and filter paper. A vacuum pump was then used to remove sand, metal chips, and microimpurities. The filtered oil was further filtered using a centrifuge set at 1000 rpm for 30 minutes. The collected and filtered oil was allowed to settle for twenty-four hours [10]. The filtered used oil was then preheated to reduce the effect of some of the additives that were initially contained in it. 800 mL of the preheated oil was treated with 80 mL of sulphuric acid. This mixture was thoroughly stirred to ensure a uniform mixture between acid and oil at a temperature of $50^\circ C$. The mixture was then allowed to settle and kept for 24 hours in a container. The preserved mixture was finally decanted into a separate beaker. 5, 10, 15, and 20 g masses of metakaolin were mixed with 100 mL of the acid-treated oil in separate beakers. The mixtures were well stirred on a hot-plate magnetic stirrer for 20 minutes [11]. The above procedure yielded refined oils with some dark and other bright colours. The process was repeated three times using the same oil in the container. The 20 g of metakaolin treated with 100 mL of the treated acid-oil mixture gave the maximum yield with the brightest colour from observation, as shown in Figure 1. A Physicochemical analysis was then
carried out on the mixture with the best colour and product. The analysis was repeated three times.

3. Results and Discussion

The chemical composition of the Wassa kaolin is \( \text{Al}_2\text{Si}_2\text{O}_5 \) (OH)\(_4\). This is a clay that typically forms from intense weathering and leaching of the source rock. This then leaves predominantly relatively white Kaolin. The kaolin was calcined for 2 hours, and metakaolin was formed with a chemical composition of \( \text{Al}_2\text{Si}_2\text{O}_7 \)\(_3\).

3.1. XRF Analysis of Kaolin and Metakaolin. From Table 1, we have the XRF results of the chemical composition of both the kaolin and the metakaolin as determined. The results show that the silicate SiO\(_2\) to aluminate Al\(_2\)O\(_3\) ratio was 1.23 with a loss of ignition (LOI) of 11.74 on the kaolin.

Table 1 shows the results (mean ± SD) of the oxide composition for kaolin and metakaolin using an ANOVA test. The ANOVA test revealed that kaolin had a SiO\(_2\) composition of 48.69 ± 0.10 while metakaolin had 51.70 ± 1.00. However, there was no significant difference (\( P = 0.34 \)) between the kaolin and metakaolin SiO\(_2\) compositions. Kaolin had an Al\(_2\)O\(_3\) composition of 39.70 ± 0.10 while metakaolin had 44.60 ± 0.10. Interestingly, we observed a significant difference (\( P = 0.036 \)) between the Al\(_2\)O\(_3\) composition of kaolin and metakaolin.

3.2. XRD of Kaolin and Metakaolin. The XRD (Figure 2) shows the phases present in the kaolin powder. The XRD indicates 45.2% quartz# (ICSD 96-900-9667, JCPDS 46-10450), and 54.8% kaolinite# (ICSD 98-008-7771, JCPDS 14-0164). Quartz was identified from the XRD peak at 2\( \Theta \) = 20.83°, 26.62°, and 36.53°, followed by the kaolinite with XRD peaks at 2\( \Theta \) = 12.36°, 28.79°, and 36.49° as reported by the authors of [13].

When kaolin was calcined at 600°C for 2 hours to form metakaolin, the crystalline phases were quartz 74.3% and sodalite (JCPDS 89-9099) 25.7%, with the kaolinite phase disappearing. In the conversion of kaolin to metakaolin, sodalite was the main new crystalline phase present after the decomposition of the kaolinite phase [14]. Higher-order reflections of this mineral lost their intensity and merged into the XRD background, as shown by the XRD peaks, which led to the opinion that metakaolin is amorphous. However, the short-range order crystalline structure metakaolin predominates [15]. Therefore, the activation of kaolin produced structural changes, which promoted its reactivity.

3.3. SEM EDX of Kaolin and Metakaolin. The SEM image of Wassa kaolin and metakaolin are shown in (Figure 3(a)). The SEM of kaolin shows a crystalline sample with a slightly hexagonal outline. The platelet structure of the kaolinite mineral sheets was loosely packed as reported in [1], with an average particle size estimated to be 2.0 \( \mu \)m (Figure 3(a) left).
Figure 3(a) (right) shows the SEM image of metakaolin. The morphology of the kaolin was completely lost as compared to that of the metakaolin. The metakaolin’s morphology was largely lumplike, with a small platelet morphology. The observed lumplike morphology of the metakaolin was due to the amorphous nature of a new material produced as a result of the dehydroxylation of the kaolin after calcination, as earlier shown in the XRD. The metakaolin exhibited an amorphous spherical aggregate interspersed with a few silica crystalline materials present in the metakaolin. The average particle size of metakaolin is 70 μm.

The EDX spectra (Figure 3(b)) show the elemental compositions of both kaolin and metakaolin. The analysis of the kaolinite shows the presence of Si, Al, Na, K, and O as distinct peaks. That of the metakaolin also shows K, O, Na, Al, and Si as the distinct peaks present. The elemental compositions of both kaolin and metakaolin were the same but varied in the ratios of the silica to alumina compositions.

3.4. FT-IR Kaolin and Metakaolin. Figure 4 shows the FT-IR spectrum, ranging from 400–3900 cm\(^{-1}\) for both kaolin and metakaolin. The conversion of kaolin to metakaolin was complete due to the disappearance of some characteristic bands in the FT-IR spectrum of kaolin.

The disappearance of these bands at 3300–3650 cm\(^{-1}\) related to the OH functional group was due to the conversion of kaolin to metakaolin. These changes were similar to those reported in other studies [16–18]. The characteristic
bands observed in the metakaolin were 1000, 945, 639, 539, and 442 cm$^{-1}$, with three broad bands centred at 1945 and 442 cm$^{-1}$. A significant shift of the Si–O vibration bands at 1084 and 1023 cm$^{-1}$ in kaolin to a higher frequency band at 1000 cm$^{-1}$ in metakaolin is assigned to amorphous SiO$_2$. This was reported by the authors of [14, 19–21]. The stretching vibration of Al (OH)$_6$ octahedra in kaolin was observed at 539 cm$^{-1}$. This was substituted by a peak at 960 cm$^{-1}$ corresponding to the vibration band of the Al$_2$O$_3$ tetrahedron in metakaolin. These peaks indicate the formation of the disordered metakaolin phase.

### 4. Physical and Chemical Properties of Recycled Lubricant

#### 4.1. Physical Properties

**4.1.1. Flashpoint.** The flashpoint of an engine lubricant oil is the lowest temperature at which the oil can radiate adequate vapour. When this vapour blends with air, it can be ignited. The importance of the flashpoint of an engine oil indicates how the oil is tinted. A low flash point of engine oil is a solid indicator because the oil is contaminated with volatile items, such as gasoline [10].

Figure 5 shows the average values for flashpoints of the recycled, virgin, and used oil samples. They were repeated three times and were compared with those of the virgin oil [22]. The used oil’s lowest average flashpoint is 231°C compared to that of the metakaolin-treated oil, which is 233°C, and virgin oil, which is 264°C. The flash point values of all the oils were within an acceptable range. The flashpoint of the kaolin recycled oil was highly affected by the addition of sulphuric acid, which reacted with the additives in the oil [23]. In the presence of 3.5% fuel or greater in used engine lubricant oils, the flashpoint will potentially reduce to below 55°C [23].

![Flashpoint of oil samples (n = 3).](image)

**4.1.2. Kinematic Viscosity.** The bar chart (Figure 6) shows the kinematic viscosity for the different oil samples at two temperature ranges [24].

The average kinematic viscosity at 100°C for the used oil was affected by the metakaolin. It reduced from 169.9 cSt to 129.2 cSt. Comparing this value to virgin oil, the average kinematic viscosity recorded at 100°C was 149.91 cSt. At 40°C, the average viscosity values for the recycled oil differ slightly from those of the virgin and used oils. However, the kinematic viscosity of the used oil was significantly affected at 100°C. It lost more than 25% of its value at 100°C but this was not the case at 40°C. It would appear that recycling the used oil with metakaolin gave very comparable results at both temperatures (40°C and 100°C) to that of virgin oil. This means that metakaolin effectively removed the oxidized products, deposits, and varnishes from the spent oil [25].

Table 2 shows physical properties of oil samples ($n = 3$).

<table>
<thead>
<tr>
<th></th>
<th>Virgin lubricant oil</th>
<th>Used lubricant oil</th>
<th>Metakaolin lubricant oil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Viscosity (cSt)</strong></td>
<td>149.91</td>
<td>169.9</td>
<td>129.2</td>
</tr>
<tr>
<td><strong>Refractive Index</strong></td>
<td>1.5912</td>
<td>1.5833</td>
<td>1.572</td>
</tr>
<tr>
<td><strong>Pour Point</strong></td>
<td>$-1°C$</td>
<td>$-2°C$</td>
<td>$-3°C$</td>
</tr>
<tr>
<td><strong>Viscosity Index</strong></td>
<td>101</td>
<td>102</td>
<td>103</td>
</tr>
</tbody>
</table>

![Kinematic viscosity of oil samples (n = 3).](image)

The viscosity index demonstrates the impact of changes in temperature on the viscosity of lubricating oils. When the viscosity index is high, there will be a slight change in thickness with temperature. This is better and ensures the safety of an engine that works under unfathomable temperature varieties [10]. Table 2 shows various viscosity indexes of the oil samples using [27]. The average viscosity index of the recycled lubricating oil with metakaolin was 118. This was higher than that of the used lubricant oil, which was 94. The viscosity index of the recycled oil had a better value than even virgin oil. The viscosity index of the recycled oil was high; hence, there would be no need to add additives to improve the viscosity.

The refractive index of an engine oil gives the composition of the oil. When the refractive index of the oil is low, it indicates the presence of paraffin materials, but when it is high, this also suggests the presence of aromatic compounds [28]. This also estimates other physical properties, such as molecular mass [28]. Table 2 shows that the virgin lubricant oil had an average refractive index value of 1.4923 using [29]. The used oil had an average refractive index of 1.5912. This
was due to additives like polymers, polar organic compounds, organic compounds, different metals, copolymers of olefins, and hydrogenated diene styrene copolymers accumulating in the used lubricant oil [28]. These components increased the molecular mass of the used oil and consequently its refractive index [28]. The results also show that by recycling the used oil with metakaolin, the average refractive index of the used oil was reduced by 11.22%. The chemical composition of the oil mainly influences the specific gravity of lubricating oil. An increase in the number of aromatic compounds in the oil increases its specific gravity [28]. Results also show that by recycling the used oil with metakaolin, the average refractive index of the used oil was reduced by 11.22%. The chemical composition of the oil mainly influences the specific gravity of lubricating oil. An increase in the number of aromatic compounds in the oil increases its specific gravity [28]. Table 2 shows that the average specific gravity was determined by using [30]. The specific gravity of the used oil increased due to the increasing amounts of solids that accumulated in it. One percent of the weight of solids in the sample can raise the specific gravity by 0.007 [31]. Used engine oils were contaminated with oxidized and condensed products rich in carbon [23]. The recycled oil with metakaolin had a specific gravity of 0.721 at room temperature. This value is low compared to the used engine oil, with an average specific gravity of 0.831. The high value of the average specific gravity of the used engine oil was due to oxidation products, metals, and contamination. The average specific gravity value of the recycled oil was close to that of the virgin oil, which was 0.697.

The means with different letters are significantly different (supplementary material). The Student’s t-test was performed at 95% CI for comparison of means. Microsoft Excel 2016 and IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA) were used for all data analyses. Data were subjected to a one-way analysis of variance for comparison of means where appropriate, and differences were tested for significance at P < 0.05. For the post hoc test, a two-sample (unpaired) Student’s t-test was used to determine if there were any differences between treatments, and differences in interaction terms were examined with Bonferroni corrections.

The pour points of the virgin and the metakaolin-treated lubricant oils were significantly different, but the two in comparison to the used lubricant oil were not significantly different. In terms of the viscosity index, there was no significant difference between the virgin and the metakaolin lubricant oils. There was a significant difference in the viscosity index of the used lubricant oil as compared to that of the virgin and metakaolin lubricant oils. For the refractive index and specific gravity, there was a significant difference between all the lubricating oils.

### 4.1.3. Chemical Properties

After the used oil was recycled using the acid-metakaolin process, the average concentrations of iron and chromium in the oil reduced from 0.0083 ppm to 0.0072 ppm and 0.0067 to 0.0050 ppm, respectively, as shown in Table 3.

The average zinc concentration was highly reduced from 0.0556 to 0.0028 ppm, and the average copper concentration was also reduced from 0.0021 to 0.0014 ppm. The percentage reduction of both iron and chromium was relatively small. This was because the concentrations of these metals were already high in the metakaolin.

The acid number is utilized as an aide and part of quality control for lubricating oils. It is also used as a measure of oil contamination in administration. Petroleum products contain acidic constituents present as additives or as degradation products. From Table 3, the used oil was found to have an average acid number of 10.3138 mgKOH/g using [32]. After recycling the used oil with metakaolin, this dropped to an average value of 4.2041 mgKOH/g. These results showed that the organic and inorganic acids, esters, phenolic compounds, water, and corrosive materials generated as a result of the oxidation process occurring in the engine at high temperatures had been successfully reduced. These results are similar to the findings of [9].

#### 4.1.4. Lubricants Composition

Figure 7 shows that the number of saturated compounds left in the used oil was not more than 42%, and the rest were aromatics and carbon residual compounds [33–35].

After recycling the spent oil with metakaolin, the saturation compounds increased from 41.8% to 76% per the acid/clay method. The saturated compounds increased after the recycling process because most aromatic hydrocarbons were left behind in the metakaolin.

#### 4.1.5. FT-IR Analysis

Generally, the FT-IR spectra of engine oils are marked by intense bands within the region of 2950–3000 cm$^{-1}$. This indicates the hydrocarbon nature of such oils. Spent or used oils are normally marked by the appearance of IR signals, which consist of their combustive and oxidative natures during the combustive-automobile transmission processes [36].

The hydrocarbon nature of all three oils was confirmed by the presence of IR bands in the regions of 2950–3000 cm$^{-1}$ (Figure 8) for the C-H stretching vibrations in the oils. The observation is further corroborated by their C-H bending vibrations at 1400–1495 and 1250–1000 cm$^{-1}$ consistent with the major hydrocarbon structural features of engine oils as the oil goes through cracking, oxidation, peroxidation, carboxylation, sulfation, and hydration. The hydrocarbon nature of these substances goes through transformations into other organic products such as peroxides, acids, alcohols, nitrates, and sulphates. The transformations lead to major changes in its viscosity and

### Table 2: Shows the pour point values of the virgin lubricant oil, the used lubricant oil, and the metakaolin lubricant oils using [26].

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pour point (C)</th>
<th>Viscosity index</th>
<th>Refractive index</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin lubricant oil</td>
<td>−19 ± 1 (a)</td>
<td>115 ± 1 (a)</td>
<td>1.493 ± 0.001 (a)</td>
<td>0.697 ± 0.016 (a)</td>
</tr>
<tr>
<td>Used lubricant oil</td>
<td>−18 ± 1 (ab)</td>
<td>94 ± 1 (b)</td>
<td>1.591 ± 0.001 (b)</td>
<td>0.831 ± 0.001 (b)</td>
</tr>
<tr>
<td>Metakaolin treated lubricant oil</td>
<td>−15 ± 1 (b)</td>
<td>118 ± 1 (a)</td>
<td>1.413 ± 0.001 (c)</td>
<td>0.721 ± 0.000 (c)</td>
</tr>
</tbody>
</table>
Lubricating abilities [37, 38]. Such transformations are characterized by the presence of IR bands at 3300–3600 cm\(^{-1}\) (acids, alcohols), 1600–1800 cm\(^{-1}\) (carbonyls), and 1300–1000 cm\(^{-1}\) (alcohols, sulphates) [38].

The FT-IR of the used engine oil (Figure 8) showed medium to new bands at 1704 and 1458 cm\(^{-1}\), indicating the presence of short-chained compounds with carbonyl groups from esters, ketones, or acids [9]. The formation of these compounds in engine oils was mainly due to the oxidation processes in the oil as it was in use. The used engine oil has bands at 1140 cm\(^{-1}\), which indicates the presence of peroxide compounds. The unsaturated additives have bands located at 722 cm\(^{-1}\) and 2850 cm\(^{-1}\) [9]. These bands, 1470 and 1356 cm\(^{-1}\) were due to the hydrocarbon compounds mixing with small chain lengths and C-H vibrations within C-H groups contained in the used oil. The presence of aromatics and PAHs in the used oil was detected by new bands that occurred at 978, 471, and 450 cm\(^{-1}\), representing the hydrocarbons in the aromatic ring [23]. There was also degradation of the oils due to absorption of water at the bands at 900 cm\(^{-1}\) and fuel from the engine at 1200 cm\(^{-1}\). The FT-IR spectrum of the recycled oil in Figure 8 showed no degradation peaks compared to that of the used oil. The FT-IR range of the recycled oil offers no oxidation, nitration, or sulfation components. Hence, the absorbent metakaolin was able to remove most of the degraded compounds from the spent engine oil.

The FT-IR spectrum of the recycled oil (Figure 8) showed no degradation peaks compared to that of the used oil. The FT-IR range of the recycled oil offers no oxidation, nitration, or sulfation components. Hence, the absorbent metakaolin was able to remove most of the degraded compounds from the spent engine oil, as shown in Figure 8. The FT-IR results of the virgin oil showed no oxidation peaks that generally occur around 1730 cm\(^{-1}\) and nitration at 1630 cm\(^{-1}\). All these peaks indicate the degradation of engine oil. No bands were also observed at 3400, 1150, and 960 cm\(^{-1}\), respectively, which means engine oil degrades due to sulfation, water, and additive wear [10]. The absence of all these bands confirms the virginity of this engine oil. These results are similar to the findings of [10].

### 5. Conclusion

The impact of recycling used lubricant engine oil with metakaolin as an adsorbent, mimicking the acid/clay percolation procedure, was conducted. The results obtained from the test values of the used lubricant oil and the regenerated lubricant oil using metakaolin were compared to those of the virgin lubricant oil. The test results showed that the acid-metakaolin-permeation process gave good qualities to an engine lubrication oil as compared to virgin oil. There was a reduction in all the metal content initially contained in the used oil. Zinc content in the recycled oil with metakaolin had a 94.36% expulsion. After the recycled processes, the saturated compounds increased from 43% in the spent oil to a maximum of 79%. Clearly, the acid-metakaolin percolation procedure is a decent system for the expulsion of organic pollutants and heavy metals from used engine lubricant oil, which upgrades the qualities of the regenerated lubricant engine oil to be similar to those of the base virgin lubricant oil.
Data Availability

All the Data in the study is obtain in the manuscript will be included in the supplementary data files.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Supplementary Materials

The bar charts show the differences in the means of the pour point, viscosity index, refractive index, and specific gravity of the various lubricating engine oils. (Supplementary Materials)

References


