EFFECT OF LONG-CHAIN ALKYLAMINE ON THE DISPERSIBILITY AND TRIBOLOGICAL PROPERTIES OF ALKYL-GRAFHEINE IN LUBRICANT OIL

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ABSTRACT

We report on the preparation of Alkyl-Graphene by hydrothermal method, and their dispersion in lubrication oil. The alkylated graphenes with variable alkyl chain lengths ($C_n = 8, 12, 18$) are prepared by coupling of alkylamine with carboxylic groups of graphene oxide (GO). FTIR, XPS, TGA methods were used to analyze and assess the GO modified ability by amine. The morphology and microstructure of prepared GO and alkyl-graphene were examined using field emission scanning electron microscopy (FESEM), transmission electron microscopy (HRTEM), X-ray diffraction (XRD). The experiments confirmed the formation of GO and alkyl-graphene. Stably distributed system of alkyl-graphene in SN500 reached 13.2 g/l with octylamine and 9.5 g/l with decylamine and 6.0 g/l with dodecylamine. The lubricating characteristics of lubrication oil containing alkyl-graphene was determined according to ASTM D2783. Evaluation of the reduction performance of SN500 oil when adding with alkyl-graphene: modified GO by octylamine gave the best performance compared to decylamine, dodecylamine. The reduction of abrasion reached 11.3% at 0.3 g/l and 12.5% at 0.4 g/l of octyl-graphene.

Keywords: graphene oxide, tribology, alkylamine.

1. INTRODUCTION

Graphene materials have a layer structure [1], the weak van der Waals interactions between these layers make them can easily slide over each other, so graphene can greatly reduce the abrasion [2, 3]. Based on this characteristic, graphene has been studied as an anti-wear additive in lubricating oils [3, 4]. However, to improve this property for lubricants, graphene needs to be dispersed in a hydrocarbon environment, which is a major component of lubricants. There are many methods of dispersing graphene in the oil: using surfactants [5] or modifying graphene oxide with amine, fatty acid [6-8].

Graphene oxide synthesized by graphite oxidation is well-dispersible in water because of the presence of hydroxyl (-OH), epoxy (-COC-) and carboxyl (-COOH) functional groups [9].
Hydroxyl and epoxy functional groups are usually located on the surface of graphene oxide, while the carboxyl group is on the boundary of oxide graphene (Fig.1) [10].

The reaction between the COOH-functional groups on graphene oxide with amines based on amidation which form alkyl-graphene is a way to increase the dispersibility of graphene in lubricating oils [2]. Amines with a long carbon chain with a carbon number ≥8 will allow graphene to be more compatible with the lubricant (non-polar environment), which increase graphene dispersion in the lubricant [2, 11].

![Figure 1. Functional groups distribution on graphene oxide and alkyl-graphene [9, 10].](image)

Amine modification of graphene oxide will form long chains of alkyl, at the edges of the GO, facilitating the stable dispersion of the additive in the lubricating oil. The dispersion of the alkylated graphene in the non-polar hydrocarbon solvent changes as the chain length of the alkyl groups attached to the graphene increase [12, 13]. The effects of alkyl chains attached to graphene oxide have been investigated by examining their dispersion in mineral-based lubricants.

Graphene oxide was synthesized using Tour's method [13]. It was then modified by alkyl amines to increase the dispersion of graphene in the oil and the dispersion and abrasion ability of alkyl-graphene additives in mineral-based lubricants (SN500 and HD50) was investigated. The alkyl-graphene containing oil lubricity was tested by determining the adhesive bond strength according to the ASTM D 2783-03 Abrasion Method.

2. EXPERIMENTS

**Chemicals:** Powder graphite 99.5 % (China); H$_2$SO$_4$ (China) 98 %; H$_3$PO$_4$ (China) 98 %; HCl 5 %; KMnO$_4$ (China); H$_2$O$_2$ 30 % (China); Octyl Amine (C$_8$H$_{17}$NH$_2$) (Merk-Germany);
Dodecyl Amine (C\textsubscript{12}H\textsubscript{25}NH\textsubscript{2}) (Merk-Germany); Octyl Decyl Amine (C\textsubscript{18}H\textsubscript{37}NH\textsubscript{2}) (Merk-Germany); 99 % acetone (China), Ethanol 99 %; petroleum ether; Toluene; SN500 oil; HD50.

**Graphite oxidation:** Graphene oxide was synthesized by Tour's method. Graphite powder (5 grams) were dispersed by ultrasonication in 200 ml mixture of H\textsubscript{2}SO\textsubscript{4} and H\textsubscript{3}PO\textsubscript{4} with volume fraction 1:9. KMnO\textsubscript{4} was added before stirring the mixture well and cooling to maintain temperature not over 15 °C. The mixture of acid, graphite and KMnO\textsubscript{4} was stirred for 5 hours at 65-70 °C. After that, the mixture was poured into 1000 ml of cold H\textsubscript{2}O. When the mixture reached room temperature, 10 ml of 30 % H\textsubscript{2}O\textsubscript{2} were added to the reaction solution. At the end of the oxidation process the product was washed with distilled water, 5 % HCl solution, centrifuged, dried at 60 °C for 24 hours to obtain GO graphite oxide sample.

**Amine modification:** Disperse 0.5 g of GO in 50 ml of H\textsubscript{2}O + 50 ml of C\textsubscript{2}H\textsubscript{5}OH by ultrasonic bath for 1 hour. Add 0.2 ml of amine (C\textsubscript{8}, C\textsubscript{12}, C\textsubscript{18}) to the GO dispersion solution, stirring for 2 hours at 90 °C. Amidations were performed in autoclave with time (1, 2, 3) hours at temperatures (115, 130, 145, 160) °C. At the end of the reaction, the product was washed off excess amine with alcohol, centrifuged and dried at 60 °C for 12 hr to obtain alkyl-graphene product:

\[ \text{G-COOH} + \text{H}_2\text{N-R} \rightarrow \text{G-CONH-R} + \text{H}_2\text{O} \]

**Preparation of dispersed sample:** Selection of oils: HD50, SN500 to disperse OA-G. Dispersion of 2 g of Alkyl-G in 5ml of SN500 oil by grinding method for 4 hours. 20 ml of oil was added and ultrasonicated to disperse in ultrasonic tank for 30 minutes. Centrifuge to separate undispersed precipitation. Dispersed additive content in oil was determined, from which blends of different content graphene-alkyl additives containing oil.

**Research methods**

X-ray diffraction (XRD) analysis on X'Pert Pro; Infrared absorption spectrometry (FT-IR) analysis and TGA thermal analysis (on NETZSCH STA 409 PC/PG) were done at Institute of Chemistry - Materials. Transmission Electron Microscopy (TEM) images on Tecnai G2 20S-TWIN were recorded at University of Natural Sciences, Vietnam National University, Hanoi.

Scanning electron microscope scanning (SEM) images were recorded at Material Laboratory, Vietnam Academy of Science and Technology. X-ray photoelectron spectroscopy (XPS) analysis was performed at RMIT University (Australia).

Adhesion strength of lubricating oil according to ASTM D2783-03 was determined at Institute of Industrial Chemistry.

### 3. RESULTS AND DISCUSSION

#### 3.1. Synthesis graphene oxide

Thermogravimetric analysis of graphene oxide GO is shown in Fig. 2. The mass reduction of the sample during the TGA thermal analysis in Fig. 2 is attributed to the thermal decomposition of GO functional groups. GO sample’s mass reduced by 15 % at < 100 °C, due to water absorption in the material. A significant reduction in mass (45 %) in the range of 100-300 °C is due to the decomposition of functional groups on the GO surface.

The morphological analysis of GO by SEM and TEM (Fig. 3) allows for a clearer view of the stacked layers structure at random with numerous wrinkles and dents, which is overlapped. This is explained by the fact that oxidation of graphite widens the gap between
layers of GO. At high resolution (TEM), thin layers with folded areas of GO were observed more clearly.

The infrared spectrum of the GO model is shown in Fig. 4. High intensity peak appearing at 3324.8 cm\(^{-1}\) is the oscillation of the O-H bond. Peak at 1620.4 cm\(^{-1}\) is overlapped by water adsorption and carbon fraction which is not oxidized. The oscillating peaks at 1716.9, 1226.1, 1070.8 cm\(^{-1}\) are of the (C=O) group in the carboxylic group, the C-OH group and the C-O group (epoxy), respectively. Vibrations with strong intensity show the presence of many carboxyl groups, hydroxyl groups, epoxies on GO. Functional groups on GO have the ability to react chemically with amine as the basis for GO's modification using amine as a lubricant additive.

Results of infrared analysis, TGA analysis, XPS spectra of graphene oxide samples demonstrated the formation of functional groups on graphene oxide samples obtained from graphene oxide oxidation with KMnO\(_4\). This explains the GO's ability to disperse in water because polarized groups such as -COOH, -COH, -C=O.

### 3.2. Modification of graphene oxide by amine

GO sample from graphite oxidation with KMnO\(_4\) is used in amine modification. The authors investigated factors affecting the modification process including: modifier, temperature and reaction time. Various modifiers were used: \(\text{C}_8\text{H}_{17}\text{NH}_2\), \(\text{C}_{12}\text{H}_{25}\text{NH}_2\), \(\text{C}_{18}\text{H}_{37}\text{NH}_2\) and reaction temperatures were investigated at 115, 130, 145, 160 °C for 1, 2, 3 and 5 hours. Samples were
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labeled as in Table 1 and analyzed by infrared, SEM, TEM, XPS, and the ability to disperse in SN-500 base oil.

Infrared spectrum of GO, Alkyl-GO is also shown in Fig. 4. The combination of octyl amine with GO leads to the amide bond formation (-CO-NH-), which appear as a new peak in the range 1630-1640 cm\(^{-1}\), due to the C = O of the amide. The oscillation peaks at 1530-1580 cm\(^{-1}\) are results of carbon sp2 and N-H bonds [14, 15]. Fluctuations in the 1190 -1220 cm\(^{-1}\) range are attributed to the \(\nu\) motion of the C-N amide bond [16]. Vibrations in the 2800-3000 cm\(^{-1}\) range characterize the C-H bond (-CH\(_2\)- and -CH\(_3\)) in the alkyl chain from the amine [16].

Table 1. Amine modified GO when changing temperature, time.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Experimental conditions</th>
<th>Sample</th>
<th>Experimental conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>C(<em>8)H(</em>{17})NH(_2); 3 hr; 115 °C</td>
<td>M6</td>
<td>C(<em>8)H(</em>{17})NH(_2); 2 hr; 160 °C</td>
</tr>
<tr>
<td>M2</td>
<td>C(<em>8)H(</em>{17})NH(_2); 3 hr; 130 °C</td>
<td>M7</td>
<td>C(<em>8)H(</em>{17})NH(_2); 5 hr; 160 °C</td>
</tr>
<tr>
<td>M3</td>
<td>C(<em>8)H(</em>{17})NH(_2); 3 hr; 145 °C</td>
<td>M8</td>
<td>C(<em>8)H(</em>{17})NH(_2); 5 hr; 160 °C</td>
</tr>
<tr>
<td>M4</td>
<td>C(<em>8)H(</em>{17})NH(_2); 3 hr; 160 °C</td>
<td>M9</td>
<td>C(<em>8)H(</em>{17})NH(_2); 5 hr; 160 °C</td>
</tr>
<tr>
<td>M5</td>
<td>C(<em>8)H(</em>{17})NH(_2); 1 hr; 160 °C</td>
<td>M10</td>
<td>C(<em>8)H(</em>{17})NH(_2); 4 hr; 160 °C</td>
</tr>
</tbody>
</table>

Figure 4. Infrared spectrum of GO and Alkyl-GO (M4).

Figure 5 shows the high resolution of the C1S spectra of alkyl-graphene (M7) at 290-282 eV. The C1S spectra of M7 showed the only peak with smaller tail at higher linking energies. A clear sign of the amine molecule associated with GO is expressed by a peak at 284.68 eV, related to C = C/C-C bond. The long alkyl chain of the amine molecule contributes C1s peak at 284.68 eV, contributing to a significant increase in peak intensity. Alkyl-Graphene C1s spectral

XPS spectral analysis compares the chemical change of the GO sample and the alkyl-graphene sample after the amine modification (Fig. 5, 6).

Figure 5. XPS C1s spectroscopy of M7. Figure 6. XPS-Survey spectroscopy of samples.
analyses showed that the three conversion components with higher binding energies were 286.38, 287.78 and 288.68 eV, corresponding to the bonds in the amine/hydroxyl (CN/CO) groups ether (COC) and amide / carboxyl (CONH-R/C = O) [17]. The presence of the amide group in alkyl-graphene was confirmed by the appearance of the XPS N1s spectrum at ~ 400 eV for all alkyl-graphene samples as shown in Fig. 6. Elemental analysis spectra of all samples showed the presence of nitrogen on the alkyl-graphene after modification, which is not observed in the GO elemental analysis spectrum. The nitrogen content in alkyl-graphene asserts the association of GO with the amine molecule. This confirms the presence of the amide group in alkyl-graphene after the amine modification. The nitrogen content of the prepared samples is shown in Table 2.

Table 2. Nitrogen content from XPS analysis results of samples.

<table>
<thead>
<tr>
<th>No</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen content, At %</td>
<td>3.54</td>
<td>4.19</td>
<td>3.81</td>
</tr>
<tr>
<td>No</td>
<td>M7</td>
<td>M8</td>
<td>M9</td>
</tr>
<tr>
<td>Nitrogen content, At %</td>
<td>2.56</td>
<td>2.16</td>
<td>1.53</td>
</tr>
</tbody>
</table>

The thermal stability of the GO after amine modification is an important parameter for tribological applications. Therefore, the thermal decomposition properties of alkyl-graphene were analyzed by TGA. The mass reduction of the sample during TGA analysis in Fig. 7 is due to the thermal decomposition of GO and alkyl-graphene groups. Through the diagram, heat resistance was found to increase on all alkyl-graphene models compared to GO's. The alkyl-graphene lost 6 % of its weight up to 250 °C (M4, M7, M8, M9) and 20 % (M2, M3) afterwards, a significant reduction in weight (40-50 %) was observed in 250-530 °C. This may be mainly due to the thermal decomposition of the alkyl chains on the amide bond attached to the GO and partly contributed from the thermal decomposition of the alkyl-graphene graphene together with the remaining oxygen function groups. These results suggest that alkyl-graphene has highest thermal stability of 250 °C, and is quite good for use as a lubricant additive.

Also from the TGA diagram shown in Fig. 7a, the heat stability of the alkyl-graphene changes with the temperature change. When the temperature increases to 250 °C, M4 's weight decreases by 10 % and M2, M3 's weight decreases by 25 %. When the temperature increased ~500 °C, the M4 's weight decreases by 84.75 % and M2, M3 's weight decreases by 58.63 %, and 63.22 %, respectively. This can prove that the content of the alkyl groups attached to the GO decrease as M4>M3>M2. Increasing the content of alkyl groups means increasing the dispersibility and stability of alkyl-graphene in lubricating oils. Therefore, the increase in temperature during modification is important and the authors chose a modification temperature of 160 °C when investigating the influence of the alkyl chain length of the amine to the modification process.
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Figure 7. TGA Analysis of Alkyl-Graphene: a- TGA thermal analysis of GO-9, M2, M3, M4; - Thermal Analysis of GO-9, M7, M8, M9.

Alkyl-Graphene's SEM image showed that material has thin layers with wrinkles and folded areas (Fig. 8a). This is explained by the fact that the addition of alkyl groups to GO has widened the gap between the GO layers. At high resolution TEM images (Fig. 8.b), thin layers with folded areas of alkyl-graphene were observed more clearly.

Figure 8. FESEM (a) and HRTEM (b) images of alkyl-graphene (M7).

3.3. The dispersibility of the additive in mineral oil

Figure 9 shows the digital images of the GO and alkyl-graphene dispersions in SN500 and 20W-50 base oils. Fig. 9a, b shows that unmodified GOs, which are not dispersed in both SN500 and 20W50 oils. In contrast, Fig. 9c shows that all three samples of M7, M8, M9 modified by amine with carbon number (8, 12, 18) are well dispersed and stable in SN500, 20W50 base oil for several hours to 10 days (Fig. 9a*, b*, c*). Alkyl-Graphene's stable dispersion systems are due to the Van der Waals interaction between the long alkyl chains of the alkyl-graphene with the alkyl group in the lubricant, allowing the additives to be dispersed in the lubricating oil.

The post-modification alkyl-graphene samples were dispersed in SN500 mineral oil, investigate the dispersibility of the additives shown in Table 3.
Figure 9. SN500, GO dispersed in 20W5 oil, Alkyl-Graphene (M7, M8, M9) in SN500 oil.
Where: a, b, c - after ultrasound; a*, b*, c* - samples after 10 days.

Table 3. The dispersibility of Alkyl-Graphene samples in SN500 oil.

<table>
<thead>
<tr>
<th>Sample</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disperse g/l</td>
<td>3.2</td>
<td>6.7</td>
<td>10.4</td>
</tr>
<tr>
<td>Sample</td>
<td>M7</td>
<td>M8</td>
<td>M9</td>
</tr>
<tr>
<td>Disperse g/l</td>
<td>13.2</td>
<td>9.5</td>
<td>6.0</td>
</tr>
</tbody>
</table>

In Table 3, it was found that when increasing the synthesis temperature from 130 to 145-160 °C, the alkyl-graphene dispersibility increased. This is explained that when temperature increase, the alkyl content from the amine on alkyl-graphene should increase, and so the ability to disperse in the oil.

It can also be seen from Table 3 that the alkyl-graphene dispersibility in mineral oil decreased by 16.2, 9.8, 5.6 g/l when increasing alkyl chain length (carbon number) from C₈, C₁₂, C₁₈. This is explained by the increase in the length of the alkyl chain leading to an increase in alkyl-graphene mass and an increase in the extraction interaction between alkyl-graphene molecules leading to increased aggregates, to the extent that they are separated from the dispersion system, reducing the dispersibility and stabilization of the additive in the oil. Therefore, the authors selected the GO modified substance is C₈H₁₇NH₂ to synthesize additive samples and investigate the properties of lubricating oil with alkyl-graphene additive.

3.4. Evaluation of additives on lubricating oil
For the purpose of manufacturing amine modified graphene additive to reduce abrasion on lubricants, the authors selected the SN500 base oil and 20W50 commercial engine oil for study. A snapshot of the dispersed oil samples for both SN500 and 20W50 oils is also shown in Fig. 9.

Table 4 shows the effect of abrasion reduction on all samples. But when increasing the alkyl chain length of the amine molecule, the abrasive efficiency of the additive phase with the same concentration decreases as the concentration increases. This may be due to the low graphene content in the modified amine molecule increases (M9) resulting in reduced graphene coverage on the friction surface. Compare to C_{12}H_{25}NH_{2} and C_{18}H_{37}NH_{2} modified samples, modifying by C_{6}H_{13}NH_{2} was found to be different: with two concentration of 0.1 g/l and 0.2 g/l, the abrasion reduction was unchanged using C_{12}H_{25}NH_{2} and decreased using C_{18}H_{37}NH_{2}, while C_{6}H_{13}NH_{2} samples increased from 0.0 % to 12.5 % when concentration increase from 0.1 to 0.4 g/l. This can be explained that when the concentration exceeds the limitation, alkyl-graphene aggregated and lost layer structure, and the degree of agglomeration increases as the length of the carbon chain of the amine molecule increases from C_{8} to C_{18} thus reducing the abrasion resistance (adhesion load) of the additive, as indicated in the reference [2].

The abrasion-reducing performance of the additive is shown by the increased adhesion load value compared to the non-additive oil. This is explained that the alkyl-graphene molecules covering the surface of the friction material, which avoids direct contact between the two metal surfaces and the weak bonding layers of the alkyl-graphene slip on surface leads to reduced abrasion and friction. Moreover, the continuous supply of nanosheets on the contact surface, due to the steady dispersion of alkyl-graphene in the lubricating oil, also help decrease friction. Table 4 shows the effect of abrasion reduction on all samples. But when increasing the alkyl chain length of the amine molecule, the abrasive efficiency of the additive phase with the same concentration decreases as the concentration increases. This may be due to the low graphene content in the modified C_{18}H_{37}NH_{2} (M9) resulting in reduced graphene coverage on the friction surface. Compare to C_{12}H_{25}NH_{2} and C_{18}H_{37}NH_{2} modified samples, modifying by C_{6}H_{13}NH_{2} was found to be different: with two concentration of 0.1 g/l and 0.2 g/l, the abrasion reduction was unchanged using C_{12}H_{25}NH_{2} and decreased using C_{18}H_{37}NH_{2}, while C_{6}H_{13}NH_{2} samples increased from 0.0 % to 12.5 % when concentration increase from 0.1 to 0.4 g/l. This can be explained that when the concentration exceeds the limitation, alkyl-graphene aggregated and lost layer structure, and the degree of agglomeration increases as the length of the carbon chain of the amine molecule increases from C_{8} to C_{18} thus reducing the abrasion resistance (adhesion load) of the additive, as indicated in the reference [2].
Abrasion reduction is also carried out on 20W50 and HD50 oil samples with the additive alkyl-graphene (M7) is shown in Tables 5 and 6. The abrasion reduction performance is 10.3% on a 20W50 sample supplemented with 0.3g/l additive. With the HD50 oil, the maximum reduction in abrasion is 10.86 % when increasing the additive content from 0 g/l to 0.25 g/l and abrasion reduction decline when additive content increase to 0.3 g/l. This is explained by the fact that when the concentration is low, the coatings of graphene on the surface of the metal and sliding on each other increase the efficiency of reducing abrasion, while increasing the additive content exceed limitation, the additive aggregate and increase in size and causes the opposite effect that reduce the lubrication effect of the oil.

Table 6. Adhesion load of HD50 oil with additive alkyl-graphene (M7).

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Additive</th>
<th>Additive content, g/l</th>
<th>Kinematic viscosity, cSt</th>
<th>Adhesion load, kg</th>
<th>Abrasive reduction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V.00HD</td>
<td>-</td>
<td>0.0</td>
<td>78.9 16.6</td>
<td>230</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>V-8-006 HD50</td>
<td>GO-C₈H₁₇NH₂</td>
<td>0.06</td>
<td>79.2 15.9</td>
<td>235</td>
<td>2.17</td>
</tr>
<tr>
<td>3</td>
<td>V-8-015 HD50</td>
<td>GO-C₈H₁₇NH₂</td>
<td>0.15</td>
<td>80.1 16.4</td>
<td>240</td>
<td>4.34</td>
</tr>
<tr>
<td>4</td>
<td>V-8-020 HD50</td>
<td>GO-C₈H₁₇NH₂</td>
<td>0.20</td>
<td>85.6 17.3</td>
<td>250</td>
<td>8.69</td>
</tr>
<tr>
<td>5</td>
<td>V-8-025 HD50</td>
<td>GO-C₈H₁₇NH₂</td>
<td>0.25</td>
<td>91.5 18.1</td>
<td>255</td>
<td>10.86</td>
</tr>
<tr>
<td>6</td>
<td>V-8-030 HD50</td>
<td>GO-C₈H₁₇NH₂</td>
<td>0.30</td>
<td>94.3 18.5</td>
<td>220</td>
<td>-4.34</td>
</tr>
</tbody>
</table>

4. CONCLUSION

Alkylated graphene was successfully synthesized by modifying GO with various long chained amines using hydrothermal method. Synthesis at 160 °C, reaction time 5 hours gave the best results. Samples were used as additive for SN500 oil showing good dispersibility: 13.2 g/l with modified amine C₈H₁₇NH₂; 9.5 g/l with modified amine C₁₂H₂₄NH₂; 6.0 g/l with the modified amine C₁₈H₃₇NH₂.

Evaluation of the abrasive reduction effect of SN500 oil when added alkyl-graphene additive showed that using the modifier C₈H₁₇NH₂ gave the best performance compared to C₁₂H₂₄NH₂, C₁₈H₃₇NH₂. Abrasive reduction was 11.3 % at 0.3 g/l and 12.5 % at 0.4 g/l.

The abrasive reduction effect of HD50 oil was 10.86 % with 0.25 g/l additives, and 20W50 oil was 10.3 % with 0.3 g/l additives.

Evaluating the change of the characteristics of 20W50 commercial engine oils when adding additives deduced that all the main indicators of the oil after adding the additives are in the allowed limits. This opens up the possibility of applying graphene in the manufacture of additives to improve the abrasive properties of engine oils without altering the original nature of the oil.

REFERENCES


