Some Studies on the Use of Vegetable Oils as Environmentally-Friendly Lubricants

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Environmentally friendly lubricants have been gaining importance worldwide for different technical applications because of the growing concern for the environments. In this respect vegetable oils have immense potential to replace polluting mineral oil based lubricants due to their biodegradability, renewability, low toxicity and excellent lubrication performance. In this paper tribological property of two vegetable oils, namely, rapeseed oil and sunflower oil, were evaluated at different temperatures. The influence of stearic acid as an additive on the tribological properties of these vegetable oils was also investigated using four-ball tribometer. The viscosity, acid value, peroxide value and iodine value of the selected oils were determined experimentally following AOCS methods. It has been observed that stearic acid improved the antitrust properties of the vegetable oils based on formulation under boundary conditions of lubricants at different temperatures.

Keywords: vegetable oils, lubricants, tribological properties, stearic acid, friction coefficient

1. Introduction

Vegetable oil, as a renewable resource is a good alternative to mineral oil as lubricant because of its environmentally friendly, non toxic and readily biodegradable nature[1,2]. The triacylglycerol structure of vegetable oils makes them an excellent candidate as lubricants and functional fluids for industrial applications and imparts them good potential for avoiding environmental hazards associated with traditional mineral oil based lubricants, like contamination of the environment through accidental leakage, dripping or generation of large quantities of after-use waste materials requiring costly disposal etc[3-7]. In addition double bonds present in triacylglycerol structure offer sites for additional functionalization of the structure to improve the technical properties such as thermo-oxidative, low temperature stability and lubricity of the vegetable oils[8]. The tribological properties of saturated stearic acid (n-octadecanoic acid) are attracting a considerable amount of research effort. It is a saturated fatty acid having one carboxyl group in its structural formula. As stearic acid contains no double bonds its molecules align itself as a straight chain and this suggests a close packing of stearic acid molecules on the surface, providing a strong protective layer[9,10]. It has been reported that stearic acid improve the antitrust and extreme pressure properties of vegetable oils as environmentally friendly lubricants considerably due to its long carbon chain and stable structure[12,13].

In this paper the antitrust and properties of vegetable oils such as sunflower and rapeseed oil are evaluated with and without stearic acid as additive at different temperature conditions.

2. Experimental

2.1. Materials

2.1.1. Chemicals

All the chemicals such as stearic acid, sodium hydroxide, sodium thiosulphate, acetone etc used in this research project were purchased from MERCK and were used without any further purification.

2.1.2. Test oils

Sunflower oil and rapeseed oil were used as test oils in this work. These oils were extracted by conventional machines, from the unprocessed locally produced seeds.

2.1.3. Stainless steel balls

Stainless steel balls (diameter 12.5 mm) were employed for wear assessment of the test lubricating oils. The stainless steel balls were purchased from FAG ball bearing, Rawalpindi, Pakistan.
2.1.4. Apparatus

Four-ball, Optical microscope, Ostwald viscometer temperature controlled viscometric bath, Sonicator was used as testing and processing equipment for this work.

2.2. Measurements and procedures

Acid value of both the sunflower and rapeseed oils was determined following the American Oil Chemists Society (AOCS) official method (Ca 5a-40)\(^\text{14}\). Peroxide value of the sunflower and rapeseed oil was determined according to AOCS standard method (Cd 8b-90)\(^\text{15}\) for the given vegetable oil samples. Iodine value of the sunflower oil and rapeseed oil was determined by AOCS standard method (Cd 1-25)\(^\text{16}\). Viscosity of the sunflower oil, and rapeseed oil was determined with a Ostwald viscometer, having a viscometer constant 0.091 cSt/s. Four-ball machine was used for measurement of wear on the steel balls in the presence of sunflower and rapeseed oils under the applied load of 64 N at 30 °C and 80 °C. For this purpose, the steel balls (diameter 12 mm) and appropriate parts of four-ball machine were washed in the ultrasonic bath with toluene and then dried at 50 °C before use. Four balls were then adjusted in the machine, in which one ball in the upper rotating spindle and three in the lower oil cup. About 50 cm\(^3\) of the test oil was poured in the oil cup and its temperature was adjusted to the desired value by circulating water from the thermostatic water bath. When temperature of the oil cup reached steady state, the upper rotating ball was allowed to come in contact with the lower stationary balls under the applied load of 64 N. The machine was allowed to run for known interval of time. Friction force at the sliding contacts was continuously monitored by the load sensor and the obtained data was recorded in the computer. After the end of the each experiment, the steel balls were collected from the four-ball tribometer, washed in an ultrasonic bath with toluene, and then dried. The wear scar diameter on each of the three lower balls was measured with optical microscope and recorded in millimeter. Similarly, the recorded friction force data was converted into friction coefficient by the following formula:

\[
\text{Friction coefficient} = \frac{F}{P} \quad (1)
\]

Where

\(F\) = Frictional force (N); \(P\) = Applied load (N)

3. Results and discussion

3.1. Effect of vegetable oil structure on wear

Both the sunflower and rapeseed oils were tested for their antiwear performance at 30 and 85 °C by using four ball tribometer. In this case, the average diameter of the wear scars on the test steel balls immersed in the oil cup during the wear experiment, was measured under definite applied load, temperature and sliding distances. The diameter of the wear scar is considered as a measure of the wear protection properties of the test lubricating oils\(^\text{13}\). The larger diameter of the wear scar is an indication of the poor lubrication behavior of the test oils.

From the results of the wear experiments (Figs. 1 and 2) it is apparent that the diameter of the wear scar increased almost linearly with the increase in the sliding distance for the oils at both 30 and 80 °C. It is also evident that both the lubricating oils continuously lost their wear protection properties with the increase in the sliding distance. The results also indicated that the mechanism of generation of wear at the contacting surfaces was identical in both the cases and the frictional heat at the contacting surfaces did not result in the formation of any anti- or pro-wear compounds (compound which may form as a result of some chemical reaction at the sliding surface) form which could have affected the wear mechanism. The observed loss in the antiwear properties at elevated temperatures for both the oils at the given sliding distance may be related to the decrease in the viscosity of the oil blend at
higher temperature. Again at high temperature the adsorption of the triglyceride molecules present in these oils might have been affected resulting in the generation of weaker wear resistant adsorption layer at the sliding contacts. It was further noted from Figs. 1 and 2 that sunflower oil exhibited better antiwear performance compared to the rapeseed oil at both the temperatures under the experimental condition. It can be related to the difference in chemical composition of the oils. Vegetable oils are generally composed of triglycerides of fatty acids. The fatty acids may be mono or polysaturated and usually have straight chains containing 8 - 22 carbon atoms which make them suitable for lubrication8). Generally, sunflower oil contains relatively higher quantity of stearic and oleic acid and therefore possesses good anti-wear properties as compared to rapeseed oil at the same applied load and temperature. Moreover, acid value and peroxide value was found to be higher whereas iodine value was found to be smaller for the sunflower oil than that of the rapeseed oil as shown in the Table 1. Vegetable oils with high acid value and peroxide value exhibit good anti-wear properties17).

Table 1 Some parameters of the tested vegetable oils

<table>
<thead>
<tr>
<th>Oils</th>
<th>Viscosity (m²/s)</th>
<th>Acid value (mg KOH/g)</th>
<th>Peroxide value (meq/kg)</th>
<th>Iodine value</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 °C</td>
<td>80 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO</td>
<td>4.56 × 10⁻⁵</td>
<td>3.04 × 10⁻⁵</td>
<td>1.17</td>
<td>9.1</td>
</tr>
<tr>
<td>RO</td>
<td>5.654 × 10⁻⁵</td>
<td>4.11 × 10⁻⁵</td>
<td>1.11</td>
<td>7.5</td>
</tr>
</tbody>
</table>

SO = Sunflower Oil  
RO = Rapeseed Oil

3.2. Effect of stearic acid on wear behavior

The sunflower and rapeseed oils blends with stearic acid were tested for their antiwear performance, using the tribometer and the wear data obtained has been presented in Figs. 3 - 5. From Fig. 3 and 4 it can be seen that both at 30 and 80 °C, WSD decreased with the increase in stearic acid concentration in the oil blend and passed through minima at the stearic acid concentration of 0.00015 mol/L. This minima formation in the WSD with additive in lubricating oils agreed with the results reported by other workers18,19). With the increase in stearic acid concentration in the sunflower oil, its adsorption on the surface of the test steel balls increased resulting in the increase in the wear protection properties. When the concentration of stearic acid in the bulk of the oil was more than that corresponding to the minima in WSD, the adsorbed layer started to get desorbed causing in the increase in size of the wear scar indicating a reduction in wear protection properties for the oil blends.

The minima in the WSD occurred at the same concentration of stearic acid for both the oils at both the temperatures (Figures 3 and 4) indicating that the adsorption mechanism and adsorbed layer formation of stearic acid was independent of temperature. At 80 °C, the values of WSD were larger than those obtained at 30 °C in the whole range of stearic acid concentration. It indicated that the adsorption of stearic acid on the steel balls surfaces was exothermic in nature. Moreover decrease in viscosity of the oil blends at high temperature could also contribute to the loss in the antiwear properties. The minima in WSD at lower concentration of stearic acid for sunflower oil might be related to its comparatively less viscosity than the rapeseed oil, as a result of which the adsorption process of stearic acid reached saturation at a smaller concentration. The minima in the WSD was smaller for sunflower oil than rapeseed oil indicating better
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3.3. Friction

The frictional coefficient was recorded in all the wear experiments with the help of tribometer. Figure 5 represents typical traces of the friction coefficient obtained for the virgin oils and oils containing stearic acid, corresponding to the minima in the WSD versus stearic acid concentration at 30 °C. It is evident from the figure that the presence of stearic acid in the oil matrix significantly reduced the friction coefficient at the sliding contacts. It was observed that stearic acid is most effective in sunflower oil as compared to rapeseed oil under similar conditions to reduce the friction coefficient and wear. The lower values of the friction coefficient were obtained for the sunflower oil, containing $1.5 \times 10^{-2}$ mol dm$^{-3}$ stearic acid. This sort of behavior of stearic acid in sunflower oil and rapeseed oil may be attributed to the different oil composition and to the strength of intermolecular interactions and the ability of stearic acid molecules to form protective film on the sliding surface in two different oil matrices. Therefore this oil blend may prove to be an alternative environmentally friendly energy saving lubricant.

4. Conclusion

The wear resistance behavior of sunflower and rapeseed oils as alternative lubricants have been studied. Sunflower oil provided better protection to the sliding contacts against wear as compared to the rapeseed oil due to the compositional differences. Stearic acid proved to be an effective antiwear additive for both the sunflower and rapeseed oils. However, stearic acid was more effective as antiwear additive blended with sunflower oil. This may be attributed to the high solubility of stearic acid and formation of protective layer on the sliding surface in the sunflower oil.

The friction coefficient recorded in sunflower oil was lower than that in the rapeseed oil both in the absence and presence of the optimum amounts of the stearic acid in these oils. Both the oils therefore may be considered as environmentally friendly lubricants for use in various applications.

5. References


