Wear and thermal conductivity studies on nano copper particle suspended soya bean lubricant

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This study presents lubrication, wear and thermal conductivity of transesterified soya bean oil (SBO). Nano copper particle was added to soya bean methyl ester (SBME) to improve wear resistance and heat transfer characteristics. Various SBO formulations (Crude SBO, SBME, SBME + 1.5% nano copper) and commercial mineral oil based 4T oil were tested for tribological and thermal conductivity. Wear results of SBME+1.5% Cu showed reduction in wear scar diameter by 12% compared to SBME, and 9.5% compared to 4T oil. Thermal conductivity of SBME+1.5% Cu was 1.66 times more than that of SBME, and 1.83 times more than that of 4T mineral oil.

Keywords: Lubricants, Nano copper particle, Soya bean oil (SBO), Thermal conductivity, Wear

Introduction

Soya bean oil (SBO) ranks first in worldwide production of vegetable oils (29%). Crude SBO has viscosity close to that of mineral oil (29 cSt at 40°C), a high flash point (325°C) and a high viscosity index (246). However, high polyunsaturation (C18:2 & C18:3) of SBO leads to auto-oxidation at room temperature itself. Though, chemical modification of vegetable oil increases its suitability to lubricant application, but oxidation, low temperature and extreme pressure capabilities of SBO fails to provide effective lubrication in automotive engines. Also, wear resistance, corrosion and heat transfer of bio-lubricants are not equivalent to mineral oil lubricants. Bio-based fats, oils, and their derivatives had better lubricities than diesel fuel. Rapeseed oil has been studied as additive with base oil. Masjuki et al observed better performance of palm oil based lubricating oil in terms of wear, and that of mineral oil based lubricating oil in terms of friction. Stefanescu et al compared lubricating capacity of rapeseed oil to that of usual mineral oil. Chemical and physical modifications, as well as additives, change SBO characteristics and properties, thereby broadening potential industrial applications. Sunflower oil as lubricant showed that viscosities increase with increase in oxidation time and peroxide index reduces (2%); additive ascorbic acid has a positive effect on oxidation while hydroquinone doesn’t have a positive effect. Esters of SBO yield better results compared to crude SBO as a lubricant in diesel engine. Though copper ions are capable of catalyzing oxidative reactions, oil soluble Cu compounds (Cu salt, cuprous or cupric) are effective antioxidants/ supplementary antioxidants for triglycerides. But Cu when added as micro particles settles in the oil. Compared with micron-sized particles, nano phase powders have larger relative surface areas and a great potential for heat transfer enhancement. Also, nano Cu particles can easily enter the surface asperity contact area, morphology (spherical or cylindrical) allows them either to roll or to slip between two contacting surfaces, which minimize friction. With such characteristics, nano Cu particles can have better tribological properties in vegetable oils.

This study presents tribological, thermal, and field studies on SBO formulations including nano Cu particle as additive to soya bean methyl ester (SBME) in order to improve wear resistance and heat transfer capabilities of SBO. SBO formulations were analyzed as crankcase lubricants by ASTM tests.

Experimental Section

Production of Soybean Methyl Esters (SBMEs)

For SBME production, crude SBO (1000 ml) was preheated to 50-55°C for 1 h to increase reaction capacity of crude SBO with alcohol. Then methanol...
(200 ml) was taken in beaker and sodium hydroxide (NaOH) (3.5 g) as a base catalyst was added and stirred vigorously for 30 min. Crude SBO and oxides of sodium and methanol were mixed in beaker to form esters. Entire mixture was stirred for 1 h at different stages, poured into separating funnel and kept for 12-18 h when glycerol got settled at bottom of separating funnel leaving ester at the top. Ester was separated from glycerol and product obtained was heated to 70°C to remove untreated methanol. A bubble wash was taken by mixing methyl ester with distilled water to remove excess alcohol, NaOH and soap (glycerol). Lubricant properties of crude SBO and SBME, respectively, were found as follows: Kinematic viscosity 40°C (ASTM D88), 29.19 cSt, 9.058 cSt; Kinematic viscosity 100°C (ASTM D2983), 9.14 cSt, 2.954 cSt; Viscosity index (ASTM D2270), 192.45, 208.18; Flash point (ASTM D 92), 310°C [COC], 182°C [COC]; Fire point (ASTM D 92), 320°C [COC], 196°C [COC]; Pour point (ASTM D97), < -5°C, < -5°C; Water content (ASTM D4006), 0.14%, 0.57%; Sediment (ASTM D2273), 0.04%, 0.001%; and Iodine value (ASTM D1541), 127, 110.

Production of Nano Copper Particle

Electrolysis method was used for nano Cu particle synthesis. Copper sulphate (CuSO4.5H2O) salt (5 g) was kept in an electrolytic cell [consists of a cleaned glass vessel, two copper electrodes and direct current (DC) power supply unit], 500 ml distilled water was poured, stirred well and a homogenous aqueous CuSO4 solution was made. Surface-cleaned copper electrodes were connected with anode and cathode of DC power supply unit (15 V & 6 A) separately on one end, inserted in CuSO4 solution on another end. Electrolysis of this solution was done by passing constant current inside solution. After electrolyzing process, nano Cu particles, deposited on cathode surface, were removed carefully and collected. XRD pattern of Cu nanoparticles (Fig. 1) showed three peaks at 2θ values of 43.64, 50.80, and 74.42 degree corresponding to (111), (200) and (220) planes of Cu and compared with standard powder diffraction card of Joint Committee on Powder Diffraction Standards (JCPDS), copper file No. 04-0836. XRD study indicates that resultant particles were FCC Cu nano powder. From this study, average particle size was estimated as 24 nm by using Debye-Scherrer formula.

Experimental Setup

Four Ball Wear Test (FBWT)

Transesterification process that converts crude SBO into SBME and addition of nano Cu particles increases anti-wear property. Wear properties of oil samples were tested as per ASTM D 4172 and ASTM D 2783 standard test method using a FBWT apparatus, which includes a motor and adjustable weight assembly supported by upper test ball on lower test balls positioned in a test cup. Lower three balls were immersed in lubricating oil to be tested and upper ball was made to rotate at 600 rpm at various loads (50 kg, 100 kg and so on) up to welding of balls. Then, scar diameter of ball was found by repeating and stopping experiment before welding of balls. Weld load and scar diameter indicated extreme pressure and wear resistance of lubricating oil respectively.

Thermal Conductivity Apparatus (TCA)

TCA contains a cylinder (ht 15 cm; diam 13.5 cm), fully insulated in three sides and bottom side, exposed to cooling surface. A heater (20 W) is placed at a height of 13.5 cm from bottom of the cylinder, at the top of apparatus for better conduction. Thermocouples (6) were provided at the top for measuring temperature at three different locations at height of 10 cm and 9.5 cm from bottom surface. Cylinder was filled with oil and power supply was provided to heat the oil for 30 min to reach steady state condition. Thermal conductivity (TC) of various oil forms including SBME with 1.5% nano Cu particles (by wt) was calculated based on Fourier heat conduction equation. Before that, measurement setup was validated by determining TC of water by filling
cylinder with water. TC is estimated with an error bar of ± 0.5%.

Results and Discussion

Wear patterns on testing balls with various oil forms were obtained from ball wear test (Fig. 2). Wear scar (diam) was observed visually on top ball of all the samples. Decreasing order of wear pattern for different oil samples was: SBME > 4T oil > SBME + 1.5% Cu > Crude SBO. Oil form containing 1.5% of nano Cu particle created minimum scar on both top and bottom balls, mainly due to availability of nano Cu particles in peaks and valleys at the interaction surface zones between top and bottom balls. Linear friction between the contact areas were converted into rolling friction, which reduces direct contact between top and bottom balls. A reduction was found in wear scar (diam) by SBME + 1.5% Cu to an extent of 12% when compared to SBME, and 9.5% when compared to 4T oil. However, crude SBO has got minimum wear in top and bottom three balls, may be due to high oil viscosity, which is not suitable for lubricant application. When nano Cu increased beyond 1.5% (by wt), wear scar (diam) increased, may be due to increase in density of nano Cu particles in the contact areas of top and bottom balls.

Decreasing order of TC of various oil samples was: SBME + 1.5% Cu > SBME > 4T oil > CSBO. Addition of nano Cu particles increased TC of oil samples (Table 1), which in turn increased heat transfer characteristics of base oil, may be due to increase in surface area by nano particles for heat transfer. Increased value of TC was 1.66 times in the case of

Fig. 2—Wear patterns on top and bottom ball lubricated with various oil forms: a) Crude soya bean oil (SBO); b) Soyabean methyl ester (SBME); c) Soyabean methyl ester (SBME) with copper nano particles; and d) SAE40
when added with nano Cu particle (Fig. 3). When comparing TC of mineral oils with SBME +1.5% Cu, TC of nano fluid was 1.83 times more than the value of mineral oil. Though nano Cu additive increases TC of oil samples, copper oxide (CuO) formation by oxidation of nano Cu particle with O$_2$ molecules available in oil sample changes the colour of sample. However, CuO was in nano level, there was no significant change in oil viscosity and CuO also acted as a wear preventive element to reduce friction between contact areas.

**Conclusions**

Wear and thermal conductivity studies on different forms of SBOs indicated that by addition of 1.5% nano Cu particle with SBME, low wear rate as well as high TC were observed in base stock. Tribological and thermal properties were better than commercial 4T oil in most of the cases. However, optimum level of nano Cu additive should be decided for a particular lubricant application.

**References**


### Table 1—Thermal conductivity of oil samples

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Crude SBO</th>
<th>SBME</th>
<th>4T oil</th>
<th>SBME + 1.5% Cu</th>
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</thead>
<tbody>
<tr>
<td>Average temp. (T1), °C</td>
<td>83</td>
<td>82</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Average temp. (T2), °C</td>
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<td>50</td>
<td>48</td>
<td>70</td>
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<td>Area, m$^2$</td>
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<td>0.01431</td>
<td>0.01431</td>
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<td>Heat supplied, W</td>
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<td>20</td>
<td>20</td>
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<td>Gap, m</td>
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<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Thermal conductivity (TC), W/m°C</td>
<td>0.1625</td>
<td>0.2183</td>
<td>0.2055</td>
<td>0.5823</td>
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**Fig. 3**—Thermal conductivity values of various oil forms with error bars