INVESTIGATION OF SOME LIQUID LUBRICANTS FOR POTENTIAL AEROSPACE APPLICATION

Weimin Liu  Lijun Weng  Dapeng Feng  Haizhong Wang
State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, China

ABSTRACT
Some liquid lubricants for potential aerospace application were prepared. The lubricity of lubricants including silicon oil with and without chlorobenzene group, cyclotriphosphazene derivative X-1P and perfluoropolyether (PFPE) for both steel/steel and steel/bronze sliding pairs were investigated. Gel percolation chromatography (GPC) was used to detect the tribo-polymerization of the tested silicone oil.

Materials related to friction pairs is essential, silicon oil and PFPE are not quite effective for lubrication of a steel/steel pair, but be able to reduce both friction and wear of a steel/bronze pair. Chemical reactive elemental such as chlorine, which is substituted into silicon oil, is helpful to improve the antwear and load-carrying capacity of liquid lubricant. X-1P is also an effective liquid lubricant for both steel/steel and steel/bronze sliding pairs.

Keywords: liquid lubricant; aerospace; friction and wear; CuSn alloy

1. INTRODUCTION
Spacecraft contain a variety of instruments and mechanisms that require lubrication. Devices used for aerospace include solar drives, filter wheels, tracking antennas, scanning devices, and sensors. Lubrication of these devices plays a key role regarding the durance and reliability of the space program. In aerospace, lubricants must have low vapour pressure, low pour point, good anti-irradiation, good thermal stability and good lubrication properties. Particularly, good boundary lubrication performance and long wear-endurance is expected.

2. EXPERIMENTAL DETAILS
Domestic regular PFPE and PSO were commercially available from the markets, another kind of PFPE with trademark of Krytox 143 was from Dupont. X-1P was synthesized using our patent method (4), CPSO was also prepared at State Key Laboratory of Solid Lubrication. The chemical structures of X-1P, PSO and CPSO are shown in Figure 1.

![Molecular structures of X-1P, PSO and CPSO](image)

The tribological properties of the above mentioned lubricants of PSO, CPSO, X-1P, PFPE and Krytox143 were evaluated on an Optimol SRV oscillating friction and wear tester. The upper ball (diameter 10mm) slides reciprocally at amplitude of 1mm against the stationary lower disc.

Thermogravimetric analysis (TGA) was conducted in nitrogen with Perkin-Elmer 7 series apparatus at a scanning rate of 10 °C/min to study the volatility of the lubricants.

3. RESULT AND DISCUSSIONS
The results of the TGA studies with four lubricants are given in Figure 2. It can be clearly seen that chlorinated-phenyl and methyl terminated silicone oil -- CPSO has no weight loss below 320 °C, whereas X-1P and regular PFPE show weight loss of 65.9 wt% and 13.2% respectively. Compared with Krytox 143, CPSO shows better performance in TG test.

![TGA curves of the four tested lubricants](image)

Table 1 gives the evaporation weight loss of the four lubricants at 204°C for 30h under normal air atmosphere. Results clearly demonstrate that PSO and CPSO exhibit smallest evaporation loss, while X-1P shows better performance compared with a fine mineral oil.

<table>
<thead>
<tr>
<th>Lubricants</th>
<th>Evaporation Loss (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-1P</td>
<td>0.21</td>
</tr>
<tr>
<td>PSO</td>
<td>0.05</td>
</tr>
<tr>
<td>CPSO</td>
<td>0.05</td>
</tr>
<tr>
<td>Krytox 143</td>
<td>0.14</td>
</tr>
<tr>
<td>PFPE (regular)</td>
<td>0.15</td>
</tr>
<tr>
<td>Fine Mineral Oil</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Table 2 gives some typically physical properties of the prepared CPSO. Results show that CPSO has excellent low temperature behavior with the pour point lower than -75 °C.
The SRV test results of SAE 52100 steel against CuSn alloy at 100 N load for 2 h test duration under the lubrication of four types of lubricants are presented in Table 2. It can be seen that phosphazene (X-1P) exhibits smallest wear, while chlorinated-phenyl and methyl terminated silicone oil -- CPSO shows lowest friction coefficient. Compared to commercially regular PSO, PFPE and Krytox 143, CPSO gives much lower friction and wear both for steel ball and CuSn alloy disc. Such a result indicates that CPSO could be a good lubricant for steel/CuSn alloy sliding pair. In combination with other physical properties, it can be anticipated that CPSO might be a promising versatile lubricant for space application.

Table 2 The physical properties of CPSO

<table>
<thead>
<tr>
<th>Lubricants</th>
<th>Saturated Vapour Pressure (Torr, 25°C)</th>
<th>Kinetic Viscosity (mm²·s⁻¹)</th>
<th>Density (Kg·m⁻³)</th>
<th>Pour Point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPSO</td>
<td>1.1×10⁻⁸</td>
<td>120.4</td>
<td>48.6</td>
<td>1014</td>
</tr>
</tbody>
</table>

The SRV test results of SAE 52100 steel against CuSn alloy at 100 N load for 2 h test duration under the lubrication of four types of lubricants are presented in Table 2. It can be seen that phosphazene (X-1P) exhibits smallest wear, while chlorinated-phenyl and methyl terminated silicone oil -- CPSO shows lowest friction coefficient. Compared to commercially regular PSO, PFPE and Krytox 143, CPSO gives much lower friction and wear both for steel ball and CuSn alloy disc. Such a result indicates that CPSO could be a good lubricant for steel/CuSn alloy sliding pair. In combination with other physical properties, it can be anticipated that CPSO might be a promising versatile lubricant for space application.

Table 3 Friction and wear behavior of Steel/CuSn alloy under lubrication various lubricants

<table>
<thead>
<tr>
<th>Sample</th>
<th>Load (N)</th>
<th>Time (min)</th>
<th>Wear Volume Loss (&gt;10⁻⁶ mm³)</th>
<th>Upper Ball WSD (mm)</th>
<th>Fric.Coe.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO</td>
<td>100</td>
<td>60</td>
<td>2.57</td>
<td>0.92</td>
<td>0.12</td>
</tr>
<tr>
<td>CPSO</td>
<td>100</td>
<td>120</td>
<td>1.912</td>
<td>0.60</td>
<td>0.10</td>
</tr>
<tr>
<td>Krytox 143</td>
<td>100</td>
<td>120</td>
<td>4.750</td>
<td>0.68</td>
<td>0.16</td>
</tr>
<tr>
<td>PFPE (regular)</td>
<td>100</td>
<td>120</td>
<td>6.175</td>
<td>0.72</td>
<td>0.15</td>
</tr>
<tr>
<td>X-1P</td>
<td>100</td>
<td>120</td>
<td>1.306</td>
<td>0.38</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 4 gives the SRV test results of SAE 52100 steel against SAE 52100 steel or CuSn alloy at 100 N under the lubrication of CPSO. Both friction and wear results clearly indicate that CPSO is not effective for steel/steel pair, but is capable to lubricate steel/CuSn alloy.

Table 4 Lubricity of CPSO for sliding pairs of SAE52100/SAE 52100 or SAE 52100/CuSn alloy

<table>
<thead>
<tr>
<th>Sample</th>
<th>Load (N)</th>
<th>Time (min)</th>
<th>Wear Volume Loss (&gt;10⁻⁶ mm³)</th>
<th>Upper Ball WSD (mm)</th>
<th>Fric.Coe.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel/Steel</td>
<td>100</td>
<td>60</td>
<td>Not available</td>
<td>1.88</td>
<td>0.48–0.53</td>
</tr>
<tr>
<td>Steel/CuSn</td>
<td>100</td>
<td>120</td>
<td>1.912</td>
<td>0.60</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 5 gives the SRV test results of X-1P as additive for Krytox 143, lubricating of steel/CuSn alloy. No effect on friction reduction was observed, but X-1P can remarkably reduce wear of both SAE 52100 steel ball and CuSn alloy disc.

Table 5 Effect of X-1P on the friction and wear of SAE 52100/CuSu alloy with the lubrication of Krytox 143

<table>
<thead>
<tr>
<th>Sample</th>
<th>Load (N)</th>
<th>Time (min)</th>
<th>Wear Volume Loss (&gt;10⁻⁶ mm³)</th>
<th>Upper Ball WSD (mm)</th>
<th>Fric.Coe.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krytox 143</td>
<td>200</td>
<td>60</td>
<td>11.0</td>
<td>0.67</td>
<td>0.155</td>
</tr>
<tr>
<td>Krytox 143 + 5%X-1P</td>
<td>200</td>
<td>60</td>
<td>6.8</td>
<td>0.62</td>
<td>0.155</td>
</tr>
<tr>
<td>Krytox 143 + 10%X-1P</td>
<td>200</td>
<td>60</td>
<td>6.2</td>
<td>0.54</td>
<td>0.155</td>
</tr>
</tbody>
</table>

In order to improve the durability of CPSO, other trifluoropropyl group ended silicon oil is under developed, and results will be reported in future.

4. CONCLUSIONS

(1) Chlorinated-phenyl and methyl terminated silicone oil -- CPSO has excellent thermal stability, low temperature fluidity and very low saturated vapour pressure.

(2) CPSO shows excellent tribological behavior for sliding pair of SAE 52100 steel/CuSn alloy, and is superior to perfluoropolyether in terms of friction-reduction ability and load-carrying capacity.

(3) Tribo-polymerization was found after sliding of steel against CuSn alloy under lubrication of CPSO, with the formation of very high molecular weight polymer.

(4) Phosphazene (X-1P) as additive for PFPE is useful to reduce wear of steel/CuSn alloy sliding pair.

ACKNOWLEDGMENTS

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REFERENCES


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NASA has reported that silicone oils are liable to polymerize during sliding process (2). In our case, we have carried out a 60 h test of steel/CuSn alloy under lubrication of CPSO and collected the used CPSO for gel percolation chromatography (GPC) analyses. Figure 3 shows the results of GPC for CPSO before and after sliding tests. The curve of silicone oil after 60 h sliding shows the formation of polymer with molecular weight about 600000, proving the occurrence of tribo-polymerization of CPSO during sliding process. Inductively Coupled Plasma (ICP) detection to the used oil after 60 h sliding founded that 0.22% Fe and 0.19 % Cu existed in, indicating the wear occurrence of both steel and CuSn alloy. Results of SEM/EDAX of steel worn surface, as shown in Figure 4, also indicated that copper transferred to steel surface during sliding process.