Effect of Exhaust Gas Recirculation (EGR) on Diesel Engine Oil – impact on wear

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Background

- Exhaust gas recirculation (EGR) is an effective means to reduce NOx emission from diesel engine

- EGR will contaminate engine oil
  - Increase of oil soot loading
  - Increase in oil total acid number (TAN)

- EGR will result in durability problem for many lubricated engine components due to accelerated wear

- Goal: Mitigate detrimental impact of EGR on engine components through materials, surface and lubricant technologies.
Approach

- Characterize and quantify effect of EGR on lubricant degradation
  - Physical, chemical, etc.

- Evaluate impact of lubricant degradation on friction and wear behavior

- Develop and evaluate material and surface technologies for improved friction and wear performance in EGR environment

- Develop and evaluate advanced lubricant formulation for EGR
  - Impact of regulation
**Oil Degradation – physical**

- Used oils from Cummins M-11 engine tests were characterized

<table>
<thead>
<tr>
<th></th>
<th>A (New oil)</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 100 °C (cSt) (start of engine test)</td>
<td>14.40</td>
<td>14.39</td>
<td>14.55</td>
<td>14.86</td>
</tr>
<tr>
<td>Viscosity at 100 °C (cSt) (end of engine test)</td>
<td>-</td>
<td>24.95</td>
<td>42.91</td>
<td>120.52</td>
</tr>
<tr>
<td>Total Acid Number (TAN)</td>
<td>1.1</td>
<td>3.81</td>
<td>2.08</td>
<td>2.36</td>
</tr>
<tr>
<td>Total Base Number (TBN)</td>
<td>10.43</td>
<td>8.42</td>
<td>6.11</td>
<td>5.33</td>
</tr>
<tr>
<td>Soot Content (%)</td>
<td>0</td>
<td>6.9</td>
<td>9.0</td>
<td>12.0</td>
</tr>
</tbody>
</table>
Oil Degradation

- Oil viscosity increases as 4\textsuperscript{th} power of soot content.
- Oxidation may also contribute to oil thickening.
- Soot content of 4.5% limit in engine tests.

- TAN and TBN variation as expected.
- None of used oils reached cross over point.
## Oil Degradation – Additives

- Used oils from Cummins M-11 engine tests chemical composition (ppm) characterized by standard spectrochemical analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>A (New oil)</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>1</td>
<td>119</td>
<td>147</td>
<td>58</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>&lt; 1</td>
<td>18</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>&lt; 5</td>
<td>6</td>
<td>&lt; 5</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>1247</td>
<td>750</td>
<td>756</td>
<td>304</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>1356</td>
<td>1111</td>
<td>945</td>
<td>843</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>3992</td>
<td>1096</td>
<td>3058</td>
<td>999</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>14</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

- Increase iron content from wear
- Decrease in additive content – additive depletion
Soot (Solid) Particles

- Insoluble solid particles in used oil consist of many components.
  - Carbon, iron oxide, metallic wear debris

- Variety of sizes and shapes
**Preliminary Friction and Wear Test**

Test configuration:  
Four-ball (ASTM D 4172)

**Balls:** ½” diameter M50 steel  
**Load:** 73 N  
**Speed:** 1200 rpm  
**Lubricant:** New and used oil from Cummins M-11 engine test  
**Duration:** 1 hour
Friction Results

- Friction coefficient nearly constant for duration of test for all oils
- Periodic spike in friction for all the used oils
Friction Results

- Average friction for used oil slightly lower than for clean oil
  - Effect of viscosity increase on fluid film
  - Carbon soot acting as solid lubricant
Wear Results

Substantial increase in wear in tests with used oils

- Oil degradation leads to less protection of rubbing surfaces
  - Change in chemistry
  - Presence of solid particles
Wear Results

For the limited data points in the present study:
- Wear volume not dependent on soot content
- Wear appears linearly dependent on TAN

\[ y = -3.752 + 3.6301x \quad R^2 = 0.9858 \]
Wear Mechanism – clean oil

- Evidence of abrasive and oxidative wear
- Formation of surface films – reaction with lubricant additive
Wear Mechanisms – used oil

- For used oils B and C, wear similar – primarily abrasive, with less surface films
- For used oil D, in addition to abrasion, evidence of corrosion and scuffing
  - Higher TAN (corrosion) and soot content (scuffing).
  - Soot interferes with lubricant entrainment into the contact
Conclusions

- Exposure of oil to EGR during diesel engine testing resulted in accelerated degradation of oil
  - Increase in soot content resulting in significant increase in oil viscosity
  - Increase TAN and more rapid decrease in TBN
  - Oil additive depletion

- Although the used oil reduced the average friction during a four-ball bench-top test, wear was increased by about two orders of magnitude compared to new oil.

- In the tests with used oils, predominant wear mode is abrasion, aided by corrosion.
  - Scuffing was also observed in test with 12% soot content.

- No clear trend correlation can be established between bench-top friction and wear testing and wear during engine test.
The End

Thank you!

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