Biodiesel and Renewable Diesel Emissions Study and Biodiesel Multimedia Evaluation

Real-Time Particulate Matter Emissions

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INSTRUMENTS AND PARAMETERS MEASURED

1. Differential Mobility Spectrometer (DMS 500, Cambustion Ltd)
   • Size distribution and number concentration for C15 Caterpillar and MBE 4000 vehicles
   • Classifies particles (4.5 nm-1000nm) according to their electrical mobility

2. Engine Exhaust Particle Sizer (EEPS 3090, TSI Inc)
   • Size distribution and number concentration for 2006 Cummins ISM
   • Electrical mobility analyzer (6.04 nm-523nm)

3. Electrical Aerosol Detector (EAD 3070A, TSI Inc)
   • Particle length/diameter concentration (the total length of all the particles if placed in a line) for 2006 Cummins ISM and MBE 4000 vehicles
   • Diffusion Charger (10-~1000nm)

   • Particle bound polycyclic aromatic hydrocarbons (pPAH) for 2006 Cummins ISM and MBE 4000 vehicles
   • Photoionization of particle-bound PAH
Table 1 Number of driving runs used for data analysis

<table>
<thead>
<tr>
<th>Fuel</th>
<th>2000 C15 Caterpillar</th>
<th>2006 Cummins ISM</th>
<th>2007 MBE 4000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cruise</td>
<td>UDDS</td>
<td>Cruise</td>
</tr>
<tr>
<td>CARB</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Soy B20</td>
<td>NA</td>
<td>NA</td>
<td>3</td>
</tr>
<tr>
<td>Soy B10</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>An B100</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>R20</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>R50</td>
<td>1</td>
<td>NA</td>
<td>3</td>
</tr>
<tr>
<td>R100</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Renewable fuel was not tested for International and MBE 4000 trucks

*A few single UDDS were run for MBE 4000 while testing Animal based biodiesel. These are denoted by the numbers in brackets [1]. Rest of the UDDSs are composites of two single UDDS.
C15 Caterpillar:
- PN varied between $1.4 \times 10^{13}$- $4.2 \times 10^{15}$ \#/mile
- An B100 highest particle number (PN) ($4.2-4.4 \times 10^{15}$ \#/mile)
- Increase in PN with the progressive enrichment in fuel blends for Animal based biodiesel

Cummins ISM: Particle number concentration varied between $\sim 4.8 \times 10^{14}$-
$1.65 \times 10^{15}$ \#/mile for cruise and $6.52 \times 10^{14}$-
$1.19 \times 10^{16}$ \#/mile for UDDS cycle.

MBE 4000: Higher PN emissions for Cruise cycles ($1.76 \times 10^{13}$-$1.31 \times 10^{14}$
\#/mile) than UDDS ($1.76-6.41 \times 10^{12}$ \#/mile)

- Highest PN for C15 closely followed by Cummins ISM; MBE 4000 reduced PN significantly
• High concentrations of small particles (<20nm) were formed; distinct peak ~10nm for all fuel types and cycles
• Nucleation increased while accumulation mode decreased with increasing blend levels for Animal and Soy biodiesel.
• Renewable fuel, trimodal distributions with peaks of ~10, 60, 230nm.
• Larger particles (230nm) increased with increasing blends for Renewable fuels.

• Distinct peak at ~10 nm and a broad peak at ~50-60 nm
• No Particulate trap; second mode (~50 nm) likely generated from elemental carbon emissions
• With higher content of biodiesel (B50, B100) the size of larger mode (~50nm) has decreased (shift towards smaller modes), while the small nucleation mode (10-20nm) is increased especially for B100.
• Predominantly two modes: <10nm; ~50nm

• Cruise cycles were associated with high concentration of nucleation mode particles

• Pure biodiesels (animal and soy B100) showed the highest concentration in accumulation

**PARTICLE LENGTH (PL) / DIAMETER CONCENTRATION**
• Cummins ISM PL is approximately in the range of ~10^10 mm/mile and is consistent over the whole spectrum of fuel types and driving conditions.

- MBE 4000
  The PL did not change with higher blends of soy biodiesel during cruise operation.

- Slightly higher signals observed for B100 for UDDS cycle

- The Cummins ISM truck produced almost one to two magnitude higher PL than the MBE 4000

**Cruise: Particle Length**

**UDDS: Particle Length**
• Cummins ISM
• Higher pPAH in UDDS cycle (39-235 µg/mile) than Cruise (7.4-160 µg/mile) cycle
• Higher Blend level (B50 and B100): significant and progressive reduction in pPAH

MBE 4000
• pPAHs are low, varied between 1.7-24.4 µg/mile
• pPAH emissions (µg/mile) were more in cruise than UDDS runs for B100.
• B100 pPAH increased: higher accumulation mode
• Significant improvement (two order of magnitude) in eliminating pPAHs for CARB, B20 and B50

SUMMARY
• Highest Particle number observed for C15 caterpillar closely followed by Cummins ISM
• Equipped with DPF and DOC, MBE 4000 reduced PN significantly compared to C15 Caterpillar and Cummins ISM
• Particle number did not follow the same trends as that of PM mass for different blend levels
• Size distribution showed mono, bi and tri-modal distributions. Significant nucleation observed for C15, Cummins ISM and MBE 4000 cruise
• For C15 and Cummins increase in nucleation was accompanied by decrease in accumulation mode particles for Animal and Soy based bio-diesel
• Higher particle length/diameter concentration observed for Cummins ISM than MBE 4000
• Progressive reduction in pPAH observed for uncontrolled emissions of Cummins ISM with increasing blends of biofuels
• Higher pPAHs correspond to higher accumulation mode particles