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>
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<tbody>
<tr>
<td>Particle Number/Size Dist.</td>
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<td>pPAH (PAS) Particle Length</td>
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* A few single UDDS runs are for MBE 4000 while testing animal based biodiesel. These are denoted by the numbers in brackets [ ].

**Note:** All of the UDDSs are compounded of two single UDDS.
PARTICLE EMISSIONS IN TERMS OF NUMBER

- 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 $4.8 \times 10^{14}$ - $1.65 \times 10^{15}$#/mile for cruise
  - $6.52 \times 10^{14}$ - $1.19 \times 10^{15}$#/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

PARTICLE SIZE DISTRIBUTION
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, multi-modal distributions with peaks of ~10, 60, 230nm.

Larger particles (230nm) increased with increasing blends for Renewable fuels.

*Distinct peak at ~10nm and a broad peak at ~50-60nm.

No Particulate trap; second mode (~50nm) 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 constant 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
two magnitude
higher PL than the
MBE 4000.

PARTICLE SURFACE BOUND PAH
• 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
  • 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