CHEMICAL CHARACTERIZATION OF PARTICULATE MATTER EMISSIONS FROM A CATALYZED TRAP EQUIPPED NATURAL GAS FUELED TRANSIT BUS

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Project Objectives

• Reduction of exhaust emissions from current (2001 ULEV compliant) natural gas fueled vehicles
  – Recognize the problem (PM/gaseous; regulated/unregulated)
    • Natural gas engine designs need to focus more on cylinder materials, design of ring packs, valve stem seals, etc., to minimize oil consumption.
  – Identify the nature of the problem by conducting a detailed speciation of the exhaust (Round 1)
  – Design an exhaust aftertreatment system to tackle specific pollutants
  – Install exhaust aftertreatment system on the vehicle and conduct another speciation study (Round 2)
  – Operate the vehicle in the field for 6 months and monitor performance.
  – Conduct speciation study after 6 months (Round 3)
Project Objectives

• Engine
  – Cummins C8.3G+ (6-cylinder, 8.3 liter, 280 hp@2400 rpm)
  – Certified with a catalyst for California ULEV levels
    • NOx: 1.53 g/bhp-hr
    • NMHC: 0.21 g/bhp-hr
    • Total PM: 0.008 g/bhp-hr
    • CO: 0.8 g/bhp-hr

• Vehicle
  – Orion, standard 40-foot, high-floor design

• Laboratory
  – WVU Transportable Laboratory with a dedicated “Clean Tunnel” with on-site GC
Chemical Characterization

– Particulate Matter
  • TPM, PM$_{10}$, PM$_{2.5}$, PM$_{1}$
– Volatile Organic Compounds
  • Low molecular weight alkanes and olefins (C$_2$ – C$_5$)
  • Low molecular weight aromatics (BTEX)
– Elemental & Organic Carbon
– PAHs and n-PAHs
– Hopanes and Stearanes
– Elemental Compounds
– Ionic Species
– Carbonyls
– PM Size Concentration and Distributions
Test Vehicle Installed On The Chassis Dynamometer
“Clean Tunnel” With Sampling Ports/Trains

PM$_1$ Cyclone

PM$_{2.5}$ Cyclone

PM$_{2.5}$ Cyclone (EC/OC)

PM$_{10}$ Cyclone

Total PM
PM Filter followed by an Oxidation Catalyst in the Transit Bus Exhaust System
WVU/Lubrizol-ECS
Catalyzed Filter and Oxidation Catalyst

• Diesel Particulate Filter
  – Silicon Carbide segmented honeycomb (11.25 in x 12 in)
  – 200 square CPI cell density
  – Pt coated on proprietary wash-coat for passive regeneration over duty cycles producing exhaust temperature 280°C - 320°C for >25% of the time

• Oxidation Catalyst
  – Cordierite monolith (10.5 in x 6 in)
  – 400 square CPI cell density
  – Pd coated on proprietary wash-coat
Tunnel Background (Round 1)

- **Data:** BG2_B
- **Model:** Gauss
- **Chi^2/DoF:** 101079652.46189
- **R^2:** 0.53704
- **y0:** 809.40262 ± 3129.09373
- **xc:** 65.20498 ± 2.48241
- **w:** 52.22772 ± 8.15302
- **A:** 2206882.03511 ± 467990.75733

**Particle concentration dN/dlogDp (#/cm^3)**

**Particle diameter (nm)**
Sunline Transit Bus Steady State Operation
20 Mph With Oxidation Catalyst (Round 1)

**Data: SS 20mph with cat hot**
Model: Gauss

- $\chi^2/\text{DoF} = 294888399.39383$
- $R^2 = 0.74812$
- $y_0 = 5318.76959 \pm 3234.95684$
- $x_c = 42.91572 \pm 0.95994$
- $w = 28.99202 \pm 2.35115$
- $A = 3266736.64037 \pm 313992.14651$

**Data: SS 20mph with cat cold**
Model: Gauss

- $\chi^2/\text{DoF} = 14102545157.70303$
- $R^2 = 0.86379$
- $y_0 = -3741.47652 \pm 26882.40612$
- $x_c = 47.34166 \pm 0.76992$
- $w = 36.18543 \pm 2.0348$
- $A = 41264889.31164 \pm 2966796.1965$
Tunnel Background (Round 2)

Particle Concentration $dN/d\log D_p$ (#/cm$^3$)

Particle diameter (nm)

- Background 1
Sunline Transit Bus Steady State Operation 25 Mph with PM Filter Only – No Oxidation Catalyst (Round 2)

**Steady State 25Mph Cold**

Data: Steady State Cold
Model: Gauss

- \( \chi^2/\text{DoF} = 3572981174.48617 \)
- \( R^2 = 0.94352 \)
- \( y_0 = 12292.20008 \pm 7627.46749 \)
- \( x_c = 57.19985 \pm 0.39402 \)
- \( w = 25.32478 \pm 0.8411 \)
- \( A = 26114214.0915 \pm 875462.32399 \)

**Steady State 25Mph Hot**

Data: Steady State Hot
Model: Gauss

- \( \chi^2/\text{DoF} = 45250324274.3747 \)
- \( R^2 = 0.97051 \)
- \( y_0 = 124246.57048 \pm 25723.0407 \)
- \( x_c = 13.34646 \pm 0.05907 \)
- \( w = 5.24218 \pm 0.12387 \)
- \( A = 28190677.16038 \pm 655746.44917 \)
Sunline Transit Bus Steady State Operation 25 Mph with PM Filter and Oxidation Catalyst (Round 2)

Particle concentration $dN/d\log D_p$ (#/cm$^3$)

Particle diameter (nm)

- Steady state 25Mph with Oxidation Catalyst and Trap
Comparison of Particle Size Distributions 
LNG-fueled and Diesel-fueled Transit Buses

1999 Study

- Diesel fueled M11-1
- Diesel fueled M11-2
- LNG fueled L-10 -1
- LNG fueled L-10 -2
- LNG fueled L-10 -3

GMD ~ 30 nm (LNG)

GMD ~ 49 nm (Diesel)

M. Gautam and S. Mehta, West Virginia University

1999 Study
Sunline Transit Bus Transient Operation
Quad CBD; PM Filter Only (Round 2)

Normalized particle concentration N/dlog Dp (#/cm^3)

Time (sec)
Transit Bus Transient Operation Quad CBD; PM Filter and Oxidation Catalyst (Round 2)

Normalized concentration dN/dlog Dp (#/cc)

Time (sec)

18.8 nm
Transit Bus Transient Operation
Quad CBD; PM Filter Only (Round 2)

Normalized particle concentration dN/dlog

Dp (#/cm^3)

- 53.3 nm
Transit Bus Transient Operation
Quad CBD; PM Filter and Oxidation
Catalyst (Round 2)

Normalized particle concentration dN/dlog

Time (sec)

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Regulated Emissions

Bars are Average of 3 Replicate Runs
Total PM Emissions

Bars are Average of 3 Replicate Runs

- C8.3G+ (Without Oxy Cat)
- C8.3G+ (With Oxy Cat)
- C8.3G+ (WVU-Lubrizol Trap & Oxy Cat)
Methane and Non-Methane Hydrocarbons

<table>
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<tr>
<th></th>
<th>FIDHC</th>
<th>CH4</th>
<th>NMHC</th>
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<tbody>
<tr>
<td>C8.3G+ (No Cat)</td>
<td>21.90</td>
<td>20.56</td>
<td>0.54</td>
</tr>
<tr>
<td>C8.3G+ (With Cat)</td>
<td>15.80</td>
<td>14.94</td>
<td>0.13</td>
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<tr>
<td>C8.3G+ (With WVU-Lubrizol Trap &amp; Cat)</td>
<td>11.80</td>
<td>10.00</td>
<td>1.14</td>
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<tr>
<td>C8.3G+ (WVU-Lubrizol Trap Only)</td>
<td>23.80</td>
<td>20.91</td>
<td>1.67</td>
</tr>
</tbody>
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Bars are Average of 3 Replicate Runs.
Carbonyls

Formaldehyde acetaldehyde acetone propionaldehyde

Emissions, g/mile

C8.3G+ (Baseline)
C8.3G+ (With OEM Cat)
C8.3G+ (WVU-Lubrizol Trap & Cat)X100

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XRF Chemical Elements

C8.3G+ (with WVU-Lubrizol Trap & OC: Non-Detectable)

Bars are Average of 3 Replicate Runs

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