DPF for EMD Switcher Locomotives

by

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CEP = California Emissions Program

* Part of CARB diesel toxics reduction program
* CARB looked for voluntary participation from the railroad industry
  » BNSF & UP railroads
  » Scope:
    - PM reduction
    - Switchers
    - California
“The Bottom Line”

* CARB wants to see a DPF installed and functioning on a switcher locomotive in California

* Railroads are now included on the CARB list of programs for diesel toxics reduction

CEP Administration

* R&D work for the Association of American Railroads (AAR) performed by the Transportation Technology Center, Inc (TTCI) in Pueblo, Colorado

* TTCI is program manager of CEP for BNSF & UP
* SwRI under contract with TTCI
* CEP participation includes AAR, CSX, and NS
  » These issues will ultimately affect the eastern railroads (and the OEMs!)
General Technical Approach

* Task 1: Install & baseline EMD locomotive engine

* Task 2: Reduce lubricating oil consumption
  » cylinder kits (pistons, rings, cylinder liners) (ASME ICES2003-549), CIMAC 2004
  » assess role of recirculated crankcase blowby (ASME ICEF2003-707)
  » currently rebuilding engine with lowest oil consumption parts

* Task 3: Apply and validate DPF on test engine

Test Engine Installed at SwRI

- Electro-Motive Division (EMD) 16-645-E
- Two-stroke Diesel engine
- Roots-blown
- 1969 model
- 950 hrs since rebuild
- About 3,400 of these in Class 1 railroad switcher operation

<table>
<thead>
<tr>
<th>EMD 16-645-E Engine Specifications</th>
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</thead>
<tbody>
<tr>
<td>Engine Model</td>
</tr>
<tr>
<td>Cylinder Arrangement</td>
</tr>
<tr>
<td>Bore</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Displacement/Cylinder</td>
</tr>
<tr>
<td>Compression Ratio</td>
</tr>
<tr>
<td>BMEP</td>
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<tr>
<td>BSFC @ Rated Power</td>
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<tr>
<td>Air Charging</td>
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<tr>
<td>Fuel Injection</td>
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<tr>
<td>Crankcase Ventilation</td>
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<tr>
<td>Emissions Level</td>
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</table>
EMD 645E PM Composition

* Baseline tests to assess PM composition and oil consumption rate
* SOF expected to be relatively high (70-85%)
* Aftertreatment approach needs to be engineered to the PM characteristics

Oil Consumption

* Oil consumption level of roots-blown EMD engines reported to be relatively high
* Could affect aftertreatment performance & durability:
  » Ash loading
  » Sulfur
  » “Souping”
Reduced Oil Consumption Cylinder Kits

* Evaluated 7 cylinder kits or kit components to assess relative oil consumption
* Used SwRI-developed RTOC-III™ technique to measure oil consumption

3 candidate kits evaluated simultaneously

Reducing Oil Consumption

"C3" selected for DPF testing
Crankcase Blowby

* 645-E engine routes crankcase blowby into the intake air, downstream of the air filters, but upstream and into the roots blowers (i.e., closed crankcase)

* SwRI experimental results reported in ASME ICEF2003-707:
  * Blowby flow is < 1% of the intake air drawn into the blowers
  * Blowby contribution to exhaust PM likely < 2%
  * If you assume that 100% of blowby PM mass is engine lube oil aerosols,
  * Blowby PM mass represents only 1% to 2% of total lubricating oil consumption
    » Based on oil consumption measurements by RTOC technique (ASME Paper ICES2003-549)

Oil Consumption & Sulfur

<table>
<thead>
<tr>
<th>Fuel-Specific Oil Consumption (gal lube / gal fuel)</th>
<th>0.1%</th>
<th>0.5%</th>
<th>1.0%</th>
<th>1.5%</th>
<th>2.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>% sulfur in lube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.00%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.25%</td>
<td>3</td>
<td>13</td>
<td>25</td>
<td>38</td>
<td>50</td>
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<tr>
<td>0.50%</td>
<td>5</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
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<td>0.75%</td>
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<td>38</td>
<td>75</td>
<td>113</td>
<td>150</td>
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<tr>
<td>1.00%</td>
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<td>59</td>
<td>100</td>
<td>150</td>
<td>200</td>
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<tr>
<td>1.25%</td>
<td>13</td>
<td>63</td>
<td>125</td>
<td>188</td>
<td>250</td>
</tr>
<tr>
<td>1.50%</td>
<td>15</td>
<td>75</td>
<td>150</td>
<td>225</td>
<td>300</td>
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</tbody>
</table>

Fuel Sulfur Equivalent, ppm

Lube-oil derived sulfur will be an issue if a catalyzed trap is used.
**EMD 16-645-E Exhaust Temperatures**

2,000 hp @ 900 rpm

- **Low Idle**
- **DB4**
- **N1**
- **N2**
- **N3**
- **N4**
- **N5**
- **N6**
- **N7**
- **N8**

- **Exhaust temperatures are too low**
  - Compounded by switcher duty cycles
    - 60% of the time at Idle
    - Automatic Idle shutdown system will likely be required
  - This application will likely require active regeneration
    - Most likely electrical heating
    - Cost & complexity
    - Fuel consumption penalty

- **Soot ignition temp. = 600 °C**
- **Oxy Cat (HC, CO, 50% of SOF)**
- **29.9% 29.9% 0.0% 12.4% 12.3% 5.8% 3.6% 3.6% 1.5% 0.2% 0.8%**
- **94% of operating time <250°C**
Backpressure Sensitivity

EMD 16-645-E at 2,000 hp rated power, Notch 8

DPF Design

* Preliminary trap design work has started

* SwRI will likely screen traps from “truck size” samples

* 135 hp / cyl
* 100 kW/cyl
Locomotive Space Limitations

MECA’s Role In CEP?

* RR’s are responding to CARB’s need for PM reductions
* RR funded program
* Many elements of CEP have Tier 2 and beyond synergy
  » Oil consumption
  » Aftertreatment
* Seek MECA member interest/role in the CEP