Full Useful Life (120,000 miles) Exhaust Emission Performance of a NOx Adsorber and Diesel Particle Filter Equipped Passenger Car and Medium-duty Engine in Conjunction with Ultra Low Sulfur Fuel

Diesel Engine Emissions Reduction Conference
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Outline

- Project Overview
- Program goals and objectives
- Hardware overview
- Test procedures
- Test results
- Summary and outlook
## APBF-DEC Projects

<table>
<thead>
<tr>
<th>NOx Adsorber/DPF</th>
<th>SCR/DPF</th>
<th>Lubes</th>
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<tbody>
<tr>
<td><img src="image1" alt="Car" /></td>
<td><img src="image2" alt="Engine" /></td>
<td><img src="image3" alt="Engine" /></td>
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<tr>
<td>FEV</td>
<td>SwRI</td>
<td>Ricardo</td>
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<tr>
<td>1.9L TDI</td>
<td>6.6L Isuzu Duramax</td>
<td>15L Cummins ISX</td>
</tr>
<tr>
<td>Audi A4 Avant</td>
<td>Chevrolet Silverado</td>
<td>No vehicle</td>
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*Note: Images of Car, Engine, and Lubricant are placeholders for actual images.*
Project Objectives for LD NOx Adsorber Projects: Examine fuel property effects on NAC/DPF systems

Approach:
• Demonstrate low emissions potential of diesel engines equipped with advanced fuel, NOx adsorbers, DPFs, EGR, double-wall exhaust
  - Goal: Tier 2 Bin 5 (0.07 g/mi NOx 0.01 g/mi PM)
• Age systems with Ultra Low S fuel for up to 2200 hrs
  - Periodic emissions evaluations during aging (before and after NOx adsorber desulfation)
  - Periodic unregulated emissions measurement with 15-ppm S refinery product
  - NOx adsorber desulfation performed on time based schedule
Project Outline

Project divided into three Tasks:

• Hardware procurement and operational strategy development
• System integration and optimization
• Performance and aging evaluation
  – Age ECS to 2000-2200 hours with 15-ppm S Fuel
  – 2,200 hours equal full useful lifetime of 120,000 miles
  – Emissions evaluation procedures performed every 100-200 hrs
  – Desulfations performed every 150-200 hours to start then 100 hours (and every 50 hours at the end for the Passenger Car platform)
Project Hardware Overview

Passenger Car

**Engine Specification**
- Arrangement: In-Line 4-Cylinder
- Displacement: 1.9 L
- Rated Power: 100 kW @ 4000 rpm
- Max. Torque: 330 Nm @ 2000 rpm

Medium-Duty Engine

**Engine Specification**
- Arrangement: 8-Cylinder V
- Displacement: 6.6 L
- Rated Power: 224 kW @ 3100 rpm
- Max. Torque: 705 Nm @ 1800 rpm
Passenger Car Project In-Line Emission Control System

Engine → Pre-Catalyst → Underbody NAC → CDPF → Exhaust

**ECS-A:** DOC + NAC
- Cell Density: 400 cpsi
- Volume: 1.34 L
- Diameter: 4.16 inch
- Length: 6 inch
- Wall Thickness: 4.5 mil

**ECS-B:** NAC

**All ECS:** NAC
- Cell Density: 350 cpsi
- Wall Thickness: 5.5 mil
- Volume: 2.5 L
- Diameter: 5.66 inch
- Length: 6 inch

**Substrate Material:** Cordierite
- Cell Geometry: Square

**All ECS:** CDPF
- Cell Density: 200 cpsi
- Wall Thickness: 14 mil
- Substrate Material: SiC
- Volume: 2.5 L
- Diameter: 5.66 inch
- Length: 6 inch
- Cell Geometry: Square
## Test Procedures

### Engine Dynamometer Test Cell:

**Pre-Desulfation Procedure**

1. Run 3x
   - 1 test cycle = 1 gas sample = 30 gas samples
   - 1 set of cycles = 1 PM sample = 10 PM samples

<table>
<thead>
<tr>
<th>Run</th>
<th>CLA4</th>
<th>HLA4</th>
<th>US06</th>
<th>HFET</th>
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<thead>
<tr>
<th>Pre-samples</th>
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</thead>
<tbody>
<tr>
<td>1/3 PM sample</td>
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</table>

| Post-Desulfation Procedure** |

1. Run 2x
   - 1 test cycle = 1 gas sample = 20 samples
   - 1 set of cycles = 1 PM sample = 7 PM samples

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<tr>
<th>Run 2x</th>
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<th>Pre-samples</th>
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<tbody>
<tr>
<td>1/2 PM sample</td>
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</table>

1 test cycle = 1 gas sample = 30 gas samples
1 set of cycles = 1 PM sample = 10 PM samples

1 test cycle = 1 gas sample = 20 samples
1 set of cycles = 1 PM sample = 7 PM samples

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NREL National Renewable Energy Laboratory
Engine Change

1300-hour post-desulfurization tests were run without the regeneration strategy.
Passenger Car Project Test Results

NOx Adsorber Conversion Efficiency

Engine Change

1300-hour post-desulfurization tests were run without the regeneration strategy.

79%
Passenger Car Project Test Results

NOx Adsorber Deterioration

Change in NOx Conversion (% of Engine Out NOx) Between Desulfations

Difference

Difference Trend
Passenger Car Project Test Results

Desulfation Effectiveness

Increase in NO\textsubscript{X} Conversion (% of Engine Out NO\textsubscript{X}) at Each Desulfation

- Difference (Post-Pre)
- Difference Trend

NO\textsubscript{X} Conversion

Age (hours)
Passenger Car Project Test Results

PM Emission Trends

![Graph showing PM emission trends over age (hours)]
Medium-Duty Engine Project Test Results

NOx Emission Trends

The graph shows the NOx emissions over time for the medium-duty engine project test results. The x-axis represents the age of the engine in hours, ranging from 0 to 2000 hours. The y-axis represents the NOx emissions in grams per mile (g/mi), ranging from 0.0 to 1.0 g/mi. The data points indicate a trend of increasing NOx emissions with age, with error bars showing the variability in emissions. The graph also includes a line for desulfation and a line for NOx mean emissions.
Medium-Duty Engine Project Test Results

NOx Adsorber Conversion Efficiency

NOx Conversion vs. Age (hours)

- Desulfation
- NOx Mean
- Standard-D 15

NOx Mean 98.4%
Medium-Duty Engine Project Test Results

NOx Adsorber Deterioration

Change in NOx Conversion (% of Engine Out NOx) Between Desulfations

-14.0%  -12.0%  -10.0%  -8.0%  -6.0%  -4.0%  -2.0%  0.0%

300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000

Age (hours)

NOx Conversion

Difference  Difference Trend
Medium-Duty Engine Project Test Results

Desulfation Effectiveness

Increase in NO\textsubscript{X} Conversion (% of Engine Out NO\textsubscript{X}) at Each Desulfation
Medium-Duty Engine Project Test Results

PM Emission Trends

![Graph showing PM emission trends over age (hours)](image)

- Desulfation
- PM Mean
Summary

• Fresh NOx adsorber system in conjunction with 15ppm sulfur fuel can achieve Tier 2 Bin 5 NOx emission levels for both platforms
• Desulfation strategies are effective in recovering NOx adsorber performance with some deterioration through 2000 hours for both platforms
• Aged and desulfurized NOx adsorber system in conjunction with 15ppm sulfur fuel achieved Tier 2 Bin 5 NOx emission levels for the passenger car platform, achieved 85-90% NOx conversion for the MD Engine platform
• DPF in conjunction with 15ppm sulfur fuel can achieve Tier 2 Bin 5 PM emission levels throughout aging for both platforms
• Detailed emissions information (e.g. CO, HC, and Unregulated species) are included in final report
Program Participants

Automobile:
- DaimlerChrysler
- Ford
- GM
- Toyota

Government:
- CARB/SCAQMD
- DOE
- EPA
- NREL
- ORNL

Emission Control:
- Argillon
- ArvinMeritor
- Benteler
- Clean Diesel Tech.
- Corning
- Delphi
- Donaldson Co.
- Engelhard
- Johnson Matthey
- MECA
- NGK
- Rhodia
- Robert Bosch Corp.
- STT Emtec AB
- Tenneco Automotive
- 3M
- Umicore

Energy/ Additives:
- American Chemistry Council
- API
- BP
- Castrol
- Chevron Oronite
- Chevron
- Ciba
- Conoco-Phillips
- Crompton
- Ergon
- Ethyl
- ExxonMobil
- Infineum
- Lubrizol
- Marathon Ashland
- Motiva
- NPRA
- Pennzoil-Quaker State
- Shell Global Solutions
- Valvoline

Engines:
- Caterpillar
- Cummins
- Detroit Diesel
- EMA
- International Truck & Engine
- John Deere
- Mack Trucks

Technology:
- Battelle
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