Development and Field Demonstrations of the Low NO₂ ACCRT™ System for Retrofit Applications

Ajay Joshi, Mojghan Naseri, Abhilash Nigam, Jason Stimmel

Johnson Matthey

DEER 2009
Outline

• Introduction
• System Description
• System Performance
• Field Demonstrations
• Summary
Outline

• Introduction
• System Description
• System Performance
• Field Demonstrations
• Summary
• Passive PM retrofits rely on NO₂ generation for low temperature combustion of soot

• NO₂ is classified as a criteria pollutant with both federal and state ambient air quality standards and is known to contribute to formation of ozone and particulate nitrates

  • In Jan 2009, CARB and EPA enforced a limit to the amount of allowable NO₂ increase from diesel retrofit technologies to 20% above engine baseline

  • Many retrofit technologies have been deverified due to non-compliance with the NO₂ limit
JM’s solution – The ACCRT™ System

ACCRT = Advanced Catalyzed Continuously Regenerating Technology
ACCRT System Technology Highlights

• EPA and CARB Level 3 Verified Technology
  • >90% PM reduction
  • Complies with 2009 NO₂ Regulations
    • Does not increase NO₂ by over 20% of engine baseline

• For challenging applications
  • MY 2002-2006, includes both EGR and non-EGR engines
  • Fully passive regeneration
    • No high temperature regenerations
    • Minimal maintenance

Only EPA+ CARB verified passive DPF for EGR engines
ACCRT System Application Requirements

• Exhaust gas temperature must exceed 240°C for greater than 40% of operating time
• Can be applied to engine with and without EGR systems
• Engines may have a pre-existing DOC, must be removed prior to installation
• Engines manufactured between 2002-2006, certified to NOx standard of 2.5 g/bhp-hr and PM below 0.1 g/bhp-hr
• Currently available sizes allow application on engines with displacements between 5.9 liters – 15 liters, and horsepower ratings between 150 hp – 500 hp
Outline

• Introduction

• System Description

• System Performance

• Field Demonstrations

• Summary
### ACCRT System Principle of Operation

#### 1. DOC
- CO + $\frac{1}{2}$ O$_2$ $\rightarrow$ CO$_2$
- [HC] + O$_2$ $\rightarrow$ CO$_2$ + H$_2$O
- NO + $\frac{1}{2}$ O$_2$ $\rightarrow$ NO$_2$

#### 2. CSF
- PM (C) trapped
  - $[C] + 2$NO$_2$ $\rightarrow$ CO$_2$ + 2NO

#### 3. NO$_2$ Decomposition catalyst
- [HC] + xNO$_2$ $\rightarrow$ CO$_2$ + H$_2$O + NO

Highly efficient DOC+CSF followed by NO$_2$ decomposition
ACCRT System Major Components

• CCRT Section
  • Diesel Oxidation Catalyst (DOC) + Catalyzed Soot Filter (CSF)
• Decomposition Catalyst
• Fuel Dosing System
  • Doser
  • Fuel Pump Module
• Proven PM reduction technology for on-road, off-road and stationary applications for over 10 years
• Millions of miles of durability experience
• Previously CARB and EPA verified technology
CCRT Section – Operating Principle
Decomposition Catalyst Function

- Decomposes NO₂ to NO in a lean exhaust gas environment
- This is achieved by adjusting C1 HC:NO₂ ratio of exhaust gas and contacting the exhaust gas with a proprietary catalyst
- Amount of HC dosed is very low
- The proprietary catalyst promotes the decomposition of NO₂ to NO via reaction with HC. The catalyst is also designed to be a reservoir for the HC reductant

\[
[\text{HC}] + x\text{NO}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{NO}
\]
NO₂ reduction achieved by controlling HC: NO₂ ratios
ACCRT System NO$_2$ Reduction
Hot Start FTP on Engine Dyno

40% NO$_2$ reduced from CCRT out levels
**NO₂ Reduction Impact of Decomposition System**

Avg of 3 Hot FTPs on Cummins ISM 330 HP
ACCRT System Doser

- Contains
  - Controller with datalogger
  - Fuel manifold
  - Fuel injector
  - Fuel pressure sensor for leak detection

- Features
  - Airless injection system
  - Over 1 year data logging
  - Rated for -20°C to 100°C
ACCRT System Fuel Pump Module

• Contains
  • Fuel Pump
  • Fuel filter
  • Pressure Regulator

• Features
  • 3 bar fuel pressure
  • 10 micron fuel filtering
  • Can be integrated into existing vehicle fuel system
Controls Overview

Inputs:
- Engine Parameters
- ACCRT_inlet Temp
- ACCRT_Inter Temp
- ACCRT_Out Temp
- Exhaust Backpressure

Input Calculations
- NOx Estimate
- Catalyst NO₂ Maps
- Catalyst Decomposition Maps
- Warm-up and Light-off Requirements
- Transient Performance Requirements
- HC slip limits

Output Calculations
- HC·NO₂
- Catalyst Protections
- System Protections

Outputs:
- Injector Control Diagnostics Alarms
Outline

• Introduction
• System Description
• System Performance
• Field Demonstrations
• Summary
Performance validated on multiple test engines

All test engines meet applicable emissions standards
- NOx+NMHC: 2.5 g/bhp-hr
- PM: 0.1 g/bhp-hr

Test Fuel: 2007 Certification Diesel (ULSD)

Test Cycle: FTP per 40 CFR Part 86

Emissions Measurements: HC, CO, NOx, NO, PM
PM reduction meets Level 3 Targets
Avg of 3 Hot FTP cycles
Tailpipe NO₂ maintained well below CARB 20% limit 3 Hot FTP cycles
Durability demonstrated after 1000-hr aging

- Performance of 1000-hour field aged system was compared to a fresh degreened system
- 1 Cold+ 3 Hot FTP test cycles in accordance with methods described in CFR Title 40, Part 86, Subpart N
- Field - aged system from the following application:

<table>
<thead>
<tr>
<th>Application</th>
<th>Vehicle Model</th>
<th>Engine</th>
<th>HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-Haul Truck</td>
<td>Volvo VN Series Tractor</td>
<td>My 2006 Cummins ISX</td>
<td>400</td>
</tr>
</tbody>
</table>
Fresh vs. Aged System Performance Comparison
MY2003 DDC Series 60 500 HP – Composite FTP Cycle

Baseline 0.089 0.589 2.11 0.092 0.234
Fresh Degreened 0.080 0.023 1.87 0.003 0.268
1000-hr Aged 0.070 0.043 1.90 0.005 0.166

<table>
<thead>
<tr>
<th></th>
<th>HC (g/bhp-hr)</th>
<th>CO (g/bhp-hr)</th>
<th>NOx (g/bhp-hr)</th>
<th>PM (g/bhp-hr)</th>
<th>NO2 (g/bhp-hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0.089</td>
<td>0.589</td>
<td>2.11</td>
<td>0.092</td>
<td>0.234</td>
</tr>
<tr>
<td>Fresh Degreened</td>
<td>0.080</td>
<td>0.023</td>
<td>1.87</td>
<td>0.003</td>
<td>0.268</td>
</tr>
<tr>
<td>1000-hr Aged</td>
<td>0.070</td>
<td>0.043</td>
<td>1.90</td>
<td>0.005</td>
<td>0.166</td>
</tr>
</tbody>
</table>

>90% Reduction
>94% Reduction
<4% Increase
Field Demonstrations

- Retrofits successfully demonstrated on a variety of engines and applications types
- Applications
  - OTR trucks
  - Refuse trucks
  - Transit buses
  - School buses
  - Municipal vehicles
- \( \text{NO}_2 \) measurements are not possible on-board, PM regeneration indicated by stable backpressure
ACCRT System Installations

- Transit
- Municipal
- Long Haul
- Refuse
Transit Bus Application
MY 2004 DDC Series 60 385 hp, 12.7 liter EGR engine

- Exhaust Temp is 290°C for over 40% of time
- Stable backpressure observed over 900 hours of operation on a single DPF

**Exh Backpressure on time-basis**

**Backpressure Histogram**

- DPF service

- Frequency
- Time Over
- Backpressure Bins ("Hg"

- Percentage time over

- Peak Exh Backpress ("Hg"

- Time-stamp

- 9/1/08 11/1/08 1/1/09 3/1/09 5/1/09 7/1/09
School Bus Application
MY 2006 Cummins ISB 245 hp 5.9 liter EGR

- School buses with low temperature (<220°C)
- Stable backpressure over 9 months of operation (including a winter in the North Western US)
Municipal Vehicle Application
MY 2005 International DT 570 9.3 liter EGR

- High temperature application over 300°C
- Backpressure is stable for over 4 months of operation

![Exh Backpressure on time-basis](image1)

![Backpressure Histogram](image2)
Summary

- The CARB and EPA verified ACCRT System is the only passively regenerating Level 3 PM device for 2.5g NOx engines
- The ACCRT reduces PM emissions by over 90% while controlling increase of NO$_2$ below CARB and EPA regulatory limits
- The system reduces PM using a passively regenerating DPF and reduces NO$_2$ by dosing a small quantity of fuel over a decomposition catalyst
- Emissions performance has been proven on multiple test engines including both EGR and non-EGR engines
- Emissions durability has been demonstrated by showing that the system maintains performance after 1000 hours of field aging
- Field trials conducted on a diverse set of applications that include school buses, refuse trucks, transit buses, municipal vehicles and long haul trucks
- Commercialization of the technology is in progress