Mobile Off-Road Retrofit SCRT®
System Demonstration Program

Ray Conway and Mark Schmale
Johnson Matthey
July 29, 2010
Johnson Matthey Overview
Johnson Matthey Plc

- British Company - established in 1817, London.
- Incorporated as Limited Company in 1891.
- Member of the FTSE 100
- Comprised of three divisions.
- Employing 7,700 people in 38 countries.
- Sales revenue of $12 billion.
- Sole PGM marketing agent for Anglo Platinum formerly Rustenburg Platinum Mines Ltd.
Johnson Matthey is a specialty chemicals company focused on its core skills in precious metals, catalysts, and fine chemicals. It is organized into three global divisions:

- Precious Metal Products
- Fine Chemicals and Catalysts
- Environmental Technologies
Johnson Matthey Precious Metal Products Division

- Platinum Marketing
- PGM Refining
- Gold & Silver Refining
- Bullion Products
- Color Technologies
- Jewelry

*Sole Marketing Agent for The Largest Platinum Mines in South Africa – Anglo Platinum*
Johnson Matthey
Fine Chemicals & Catalysts Division

• Catalysts and Chemicals

• Pharmaceutical Materials and Services:
  • Anti-cancer drugs
  • Controlled substances
  • Non-Controlled Products
  • Contract R&D and Manufacturing Services

• Research Chemicals
• Emission Control Technologies
  • Mobile
  • SSEC

• Process Catalysts & Technologies
  • AMOG
  • Davy Process Technology

• Fuel Cells
Emission Control Technologies

• Comprises the autocatalyst, heavy duty diesel and stationary emissions control businesses

• Supply 35-40% of the world’s auto catalyst

• JM’s advanced NOx control technology, SCRT®, has been listed on EPA’s Emerging Technology List: in the process of being verified by the EPA and CARB

• The AdvCCRT® and CRT® Diesel Particulate Filter are EPA verified and CARB verified

• JM CRTs installed on over 5 million LDD vehicles and 1,000,000 HDD vehicles – OE & Retrofit

• JM DOC’s installed on millions of LDD vehicles, 400,000 HDD vehicles, 12,000 urban buses, and 25,000 off-road equipment – OE & Retrofit

• JM technology supplied for US’07 and US’10 and Euro 4/5
ICAT Grant No: 06-06
The purpose of the ICAT grant to JM was to demonstrate SCRT technology on two pieces of off-road diesel powered machines.
What is it?

CRT® + SCR = SCRT®

CRT® = Continuously Regenerating Technology, JM’s passively regenerating diesel PM filter technology

SCR = Selective Catalytic Reduction of NOx
Why the SCRT System?

- Demonstrated on dozens of on-road applications
- Being considered for on-road verification with EPA and CARB
- Proven NOx reduction
Selective Catalytic Reduction Technology (SCRT)

- A flow through SCR catalyst that uses ammonia for reduction of NOx by 50 – 90%+
- Currently all systems inject DEF (urea) which is converted to ammonia when injected into the exhaust stream
- SCR catalyst typically contains no precious metals
- SCR is a mature, commercial technology that has been used in stationary applications for over 30 years and has been implemented in the US, Japan, and Europe for on-road vehicles
- SCR technology is applicable to LHD, MHD and HHD new engines and is the solution for a number of MHD and HHD platforms to meet the US EPA 2010 regulations
- SCR only systems are in use for Euro 4 and Euro 5 engines
- SCRT is a retrofit solution and several systems are in verification with the EPA and CARB
Selective Catalytic Reduction Technology (SCRT)
SCRT

Ozark / Raley’s Truck 1555 (2.5g NOx engine)

<table>
<thead>
<tr>
<th>System Description</th>
<th>Vehicle</th>
<th>Engine</th>
<th>CRT</th>
<th>SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 Kenworth</td>
<td>2005 CUM ISX 400 Hp 14 l</td>
<td>8.5 l DOC</td>
<td>25.5 l Zeolite</td>
<td>4.2 l ASC</td>
</tr>
<tr>
<td>Grundfos</td>
<td>IFM Efector Kavlico</td>
<td>Performance evaluation/ Verification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grunfos</td>
<td>IFM Efector Kavlico</td>
<td>Performance evaluation/ Verification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection type</td>
<td>Sensors</td>
<td>Installed</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>22l 200 cpsi coated filter</td>
<td>Aug 2007</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>NOx Reduction</th>
<th>Hours run</th>
<th>Overall CRT P200</th>
<th>Overall SCR P200</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/16/2007 - 1/23/2008</td>
<td>80.6%</td>
<td>191.3</td>
<td>78.0%</td>
<td>81.1%</td>
</tr>
</tbody>
</table>
TECHNOLOGY DEMONSTRATION

SCRT
<table>
<thead>
<tr>
<th>Fleet Operator</th>
<th>Los Angeles Sanitation District (Carson)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator Identification Number</td>
<td>8231</td>
</tr>
<tr>
<td></td>
<td>8239</td>
</tr>
<tr>
<td>Machine Make</td>
<td>Hyundai</td>
</tr>
<tr>
<td></td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Machine Model</td>
<td>HL 740-7</td>
</tr>
<tr>
<td></td>
<td>966 GII</td>
</tr>
<tr>
<td>Model Year</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>2003</td>
</tr>
<tr>
<td>Machine Identification Number</td>
<td>LF0110523</td>
</tr>
<tr>
<td></td>
<td>0AXJ01440</td>
</tr>
<tr>
<td>Engine Make</td>
<td>Cummins</td>
</tr>
<tr>
<td></td>
<td>Caterpillar</td>
</tr>
<tr>
<td>Engine Model</td>
<td>ISC</td>
</tr>
<tr>
<td></td>
<td>3176C</td>
</tr>
<tr>
<td>Engine Displacement</td>
<td>8.3 L</td>
</tr>
<tr>
<td></td>
<td>10.3 L</td>
</tr>
<tr>
<td>Engine Emissions Family</td>
<td>5CEXL0359AAD</td>
</tr>
<tr>
<td></td>
<td>3CPXL10.3ESK</td>
</tr>
<tr>
<td>Engine Power</td>
<td>140 HP</td>
</tr>
<tr>
<td></td>
<td>327 HP</td>
</tr>
</tbody>
</table>
MACHINE SELECTION

Caterpillar 966 GII

Hyundai HL740-7
## Catalyst Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Hyundai</th>
<th>Caterpillar</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>1 - 10.5x6 DOC</td>
<td>1 – 11.25x5 DOC</td>
</tr>
<tr>
<td>DPF</td>
<td>1 – 10.5x12 CSF</td>
<td>1 – 12x12 Bare DPF</td>
</tr>
<tr>
<td>SCR</td>
<td>2 – 10.5x6 Fe Zeolite</td>
<td>2 – 12x6 Fe Zeolite</td>
</tr>
<tr>
<td>Slip Catalyst</td>
<td>1 – 10.5x3</td>
<td>1 – 12x4</td>
</tr>
</tbody>
</table>
# Dosing Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosing Pump</td>
<td>Grundfos Air Assisted</td>
</tr>
<tr>
<td>Dosing Nozzle</td>
<td>Grundfos</td>
</tr>
<tr>
<td>Controller</td>
<td>Custom ECU by STT Emtec with JM proprietary Dosing and Diagnostic Algorithm</td>
</tr>
<tr>
<td>Sensors</td>
<td>EO NOx Sensor (feed forward control)</td>
</tr>
<tr>
<td></td>
<td>TP NOx Sensor (Datalogging, NOx Reduction Monitoring)</td>
</tr>
<tr>
<td></td>
<td>Exhaust Backpressure</td>
</tr>
<tr>
<td></td>
<td>Nozzle Line pressure</td>
</tr>
<tr>
<td></td>
<td>CRT Temperature (inlet)</td>
</tr>
<tr>
<td></td>
<td>SCR Temperature (inlet)</td>
</tr>
<tr>
<td>Urea Tank</td>
<td>Custom Stainless Steel</td>
</tr>
<tr>
<td>Air System</td>
<td>Ready Air AAA 12V electric compressor with 6 gal air tank reservoir</td>
</tr>
</tbody>
</table>
Factors Contributing to Design:

- Minimize Engine Turbo-to-Exhaust system Distance
- Proximity to Structural mounting points on the machine
- Availability of 12V power
- Availability of Compressed Air
• Distance
  – Good – DPF mounted within 48 inches of the turbo outlet

• Proximity to Structural mounting
  – Good – Engine shroud made of structural members sufficient to support CCRT and SCR modules

• Availability of 12V Power
  – Ok – Machine operates on 24V, but uses two 12V batteries in series, so power was connected between ground and 12V terminal

• Compressed Air Availability
  – NO! – Procured a mobile air compressor system with a reservoir tank
• CCRT® filter mounted in Engine compartment
• SCR mounted on top of the engine compartment
• DEF Tank and Dosing System mounted adjacent to cab on Wheel Fender
• Distance  
  – Excellent – DPF mounted within 15 inches of the turbo outlet

• Proximity to Structural mounting  
  – OK – Engine shroud NOT made of structural members. Special mounting had to be designed to Engine Block/Head

• Availability of 12V Power  
  – Ok – Machine operates on 24V, but uses two 12V batteries in series, so power was connected between ground and 12V terminal

• Compressed Air Availability  
  – NO! – Procured a mobile air compressor system with a reservoir tank
Design Solution – Caterpillar 966 GII

- CRT® filter and SCR mounted in Engine compartment
- DEF Tank and Dosing System mounted adjacent to cab on Wheel Fender
- Air Tank and Reservoir mounted adjacent to Operator Entry on Railing
System Installation

- DPF installed on October 30, 2008
- SCR installed on August 14, 2009
- Hyundai Unit operated satisfactorily upon installation
- CAT Unit was not able to communicate with the SAE J1939 network with the engine
System Installation

- CAT J1939 Communication Problem
  - JM’s On-road experience with CAT Engines
  - CAT Wiring Diagram
    - showed only a CAT Data Link
    - NOT SAE J1939
    - CAT Proprietary use only
  - Contacted CAT Distributors for a solution
    - Solution not available
System Installation – Hyundai HL 740-7
Hyundai Unit
  • Backpressure stable
  • 93.5 hours of operation over 6 months
  • CCRT filter was operating properly
Caterpillar Unit

- Backpressure stable
- 43.5 hours of operation over 6 months
- Indicates CRT filter was operating properly
Hyundai Unit
• Backpressure stable
• 9 hours of operation
• CCRT filter was operating properly
• Average NOx Reduction = 74%
System Performance – Phase II

ICAT, LASD, Hyundai FEL
NOx Reduction vs. Dosing Temperature

NOx Reduction depends on amount of time system is dosing
Caterpillar Unit
- Backpressure stable
- 32 hours of operation
- CRT filter was operating properly
Hyundai Unit

- October 2009 – LASD Arranged Service for non-SCRT related issue
- After service, SCRT system stopped operating
- JM discovered issue during January 2010 inspection
- Investigation revealed the system was re-wired to 24V system
- Caused over-voltage to critical components of SCRT system. System malfunctioned and stopped operating.
Caterpillar Unit

• No SAE J1939 Datalink found on machine during system installation

• Contacted CAT Distribution network

• After investigating, CAT distributors were not able to identify a solution for communication
Operator Worksite Visibility

- Not identified as a requirement at beginning of project
- Became apparent during discussions with Distributors knowledgeable with off-road markets
- Will need to understand requirements prior to integrating technology on future projects
- Cal/OSHA looking to revise Title 8 language for safety/visibility
- May limit available space for mounting components on machine chassis
Summary

- CRT and CCRT Diesel Particulate Filter systems operated well on the chosen off-road applications.
- The SCRT system demonstrated > 70% NOx Reduction on the Hyundai machine.
- Effective design of SCRT system enabled retrofit installation within a tight packaging envelope.
- The SCRT system on the Caterpillar machine was not operational due to the lack of the J1939 datalink.
- SAE J1939 datalinks may not always be available on off-road machinery.
- Emissions control equipment should be designed to accommodate a wide range of operating voltages found on off-road equipment.
- An on-board compressed air option should be made available for off-road equipment.
• Questions??