CLEERS Workshop 2007

Urea SCR- The Volvo Way

Ann W Grant
Volvo Technology AB
Göteborg Sweden
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BUSINESS AREAS at AB Volvo

Mack Trucks

Renault Trucks

Volvo Trucks

Volvo Buses

TRUCKS

Volvo Construction Equipment

Volvo Penta

Volvo Aero

Volvo Financial Services
FACTS ABOUT VTEC

- We are 381 employees
- VTEC turnover is €36M
- Established 1969
- Innovation Areas
  - services
  - production
  - vehicles
  - powertrain
  - electronics
  - processes & methods
- Innovation Services
  - intellectual asset management
  - standardisation intelligence
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Volvo diesel engines with

VOLVO TECHNOLOGY FOR
EURO 4 AND EURO 5
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Global production of Heavy Duty Diesel Engines 2004*

- Volvo Powertrain: 161,000
- DC Powersystems
- Weichai Power
- Caterpillar
- Cummins
- Scania
- MAN
- Yaroslavl

*Engine Production 2004, 9 - 18 litre (excluding licensees / JV’s)
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New Heavy Platform - common technology

- One Cylinder Head
- Overhead Camshaft
- Four Valves per Cylinder
- Central Vertical Injector
- Electronic Unit Injectors
- Electronic Management System
- Rear End Transmission
- Integrated Engine Brake
- Wet Liners
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Legislative Demands
Exhaust Emission Standards

<table>
<thead>
<tr>
<th></th>
<th>PM (Particulate Matter) [g/kWh]</th>
<th>NOx [g/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 3 (2001)</td>
<td>0.14</td>
<td>7</td>
</tr>
<tr>
<td>Euro 2 (1996)</td>
<td>0.12</td>
<td>6</td>
</tr>
<tr>
<td>Euro 4 (2006)</td>
<td>0.10</td>
<td>5</td>
</tr>
<tr>
<td>Euro 5 (2009)</td>
<td>0.08</td>
<td>4</td>
</tr>
<tr>
<td>Euro 6 (2013?)</td>
<td>0.06</td>
<td>3</td>
</tr>
<tr>
<td>2012</td>
<td>0.04</td>
<td>2</td>
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Exhaust Emission Strategy - HD Diesel - Europe

Particulates – g/kWh

NOx – g/kWh

EU3
Cooled EGR
Trade-off
Present HD Diesel

DPF
EU5
EU4

SCR\(_1\) = 65%
SCR\(_2\) = 80%
Engine Optimization and Fuel Consumption

• Variation in injection timing

Fig. 10 NOx Fuel Consumption Trade-off

Higher engine-out NOx gives better fuel consumption (~3%)
## SCR vs. EGR – Euro 3 baseline

<table>
<thead>
<tr>
<th></th>
<th>SCR</th>
<th>EGR</th>
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<tbody>
<tr>
<td>Fuel consumption</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Heat rejection</td>
<td>😞</td>
<td>😞</td>
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<tr>
<td>Power density</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Reliability</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Maintenance</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Euro 5/6 capability</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Total cost</td>
<td>😞</td>
<td>😞</td>
</tr>
</tbody>
</table>
Euro 4 legal requirement

**Certification before Oct 1-05**
- Certify new engines for Euro 4

**Euro 4 step I**
- Mandatory
- Driver warning if:
  - AdBlue tank is empty
  - Dismounted catalyst
  - Lack of AdBlue dosing

**Euro 4 step II**
- Additional requirement
- Driver warning if:
  - > 5 g. NOx/kWh
  - 40% torque reduction if:
  - > 7 g. NOx/kWh

- Oct 1
- 2005
- 2006
- 2007
- 2008
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**SCR - Selective Catalytic Reduction**

**Power plants**
Established technology since 1970.
Possibility to reach 95% NO\textsubscript{x}-conversion with NH\textsubscript{3}.

**Marine applications**
Catalytic converters for marine applications to meet NO\textsubscript{x}-emission levels <2 g/kWh.

**Heavy duty vehicles**
Test around the world, mainly Europe.
Meet legal requirement of NO\textsubscript{x}-emission <3,5 → 2 g/kWh.
The selected solution UREA SCR

- Oxidation catalyst upstream (NO$_2$ production)
- Cleanup catalyst for removal of NH$_3$ slip
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SCR - Selective Catalytic Reduction

- Clean-up catalyst: Removal of NH₃ to avoid smell
- AdBlue tank
- AdBlue level sensor
- AdBlue pump and injection system control unit
- AdBlue injector
- SCR catalyst
- NOₓ sensor
- Additional catalytic converter
- Muffler
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SCR – Muffler and AdBlue injection

- Inlet
- SCR catalyst
- Clean-up catalyst
- Outlet
- Temp sensor
- AdBlue injection nozzle
- NO\textsubscript{x} sensor
- Pre catalyst
- AdBlue injection nozzle
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SCR installation on Volvo B7R/RLE

- AdBlue tank
- AdBlue pump and dosing unit
- Lefthand side variant
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**SCR installation on Volvo B7R/RLE**

SCR system weight between 100 - 125 kg

- Temp. sensor
- SCR muffler
- AdBlue injector
- NO\(_x\) sensor
AdBlue tank and filling neck

The industry has agreed on a automotive AdBlue tank filling neck insert standard to facilitate sealed depot system

Filling neck insert drawing.

B = 43.5 +/- 0.1 mm
C = > 26.8 mm
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AdBlue: Urea \((\text{NH}_2)_2\text{CO}\)

- Meets requirements:
  - non toxic, regarded safe to transport, handle and store
  - Frequently used in other applications
    - Fertilizer, food industry ...
- Water soluble
  - > 50% (108g/ 100 ml H₂O)
  - 32.5 % eutectic point
- Weight 60 g/mol
- Melting point 135 °C
- Meets DIN 70070 standard
- Corrosive to certain metals
  - (zinc, copper, non alloyed steel)
- Produced in large volumes at a stable price

Freezing point °C
-11 °C @ 32.5 % Urea wt%
Urea Infrastructure Development: Some European experiences

Basically three avenues for urea distribution

- fuel stations and/or truck stops
- filling in a fleet depot
- Small canisters available for purchase

Automotive Urea Infrastructure

- Urea tank to be filled each time diesel is filled
- On board diagnostics monitor urea level and notify driver
- The infrastructure will be needed to ensure the compliance to emission legislation
- First step is establishment of a minimum infrastructure to ensure the availability for the first trucks and buses on the market
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Adblue urea filling – Fuel stations

- Open system
- Major oil companies develop infrastructure (Total, Shell, OMV)
- Slim Line spout nozzle (Elaflex)
- Magnetic Ring in the urea tank filler neck inlet prevents spilling
- Public urea filling station (Total Stuttgart)
- New stations being added continuously
- Website Adblue4you.com shows where Adblue can be found in certain European countries
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Urea filling – Depot option

- Sealed / open depot filling system
- Spill-free coupling offers urea filling integrated in a depot system for diesel fuel (Identic)
- Spill free couplings are today used for filling diesel fuel
- Volvo partner YARA (Norsk Hydro) can support customers with infrastructure and AbBlue supplies
Production capacities of urea in 2002

- Norsk Hydro Sluiskil, Netherlands: 750,000 t/yr
- Norsk Hydro Le Havre, France: 333,000 t/yr
- Grande Paroisse Oissel, France: 120,000 t/yr
- Adubos Lavradio, Portugal: 80,000 t/yr
- DSM Agro Geleen, Netherlands: 390,000 t/yr
- Fertiberia Puertollano, Spain: 135,000 t/yr
- Fertiberia Huelva, Spain: 250,000 t/yr
- Norsk Hydro Brunsbüttel, Germany: 530,000 t/yr
- SKW Piesteritz, Germany: 1,041,000 t/yr
- BASF Ludwigshafen, Germany: 545,000 t/yr
- Agrolinz Linz, Austria: 380,000 t/yr

Total amounts in kilotons:
- Austria: 380
- France: 443
- Germany: 2,116
- Italy: 440
- Netherlands: 1,140
- Portugal: 80
- Spain: 385
- Total: 4,984
Automotive urea demand estimation

- Estimations of automotive urea consumption up till 2012 has been reported by ACEA.

- Annual production of urea in 2002 was approximately 5 million tons. Corresponds to approximately 15 million tons of automotive grade urea.

- Automotive grade urea demand in 2012 is estimated to be approximately 3.5 million tons (20% increase in urea-demand).
Some issues in Urea SCR:
Mobile measurements and Ad-blue dosing strategies for low temperature performance

• Dosing strategy test to define the best dosing strategy for ad-blue for vehicles operating at low temperatures
• 23 vehicle multiyear durability study of a combined DPF/SCR system in the US using mobile measurements
Basic Chemistry of the SCR system
(Selective Catalytic Reduction)

Urea \(((NH_2)_2CO)\) decomposes to ammonia \((NH_3)\) and \(CO_2\) in hot exhaust gas \((>130 \, ^{\circ}C)\) through an HNCO intermediate (thermolysis and hydrolysis)

Ammonia reduces \(NO_x\) in the SCR catalyst:
- \(NO_2 + NO + 2NH_3 \rightarrow 2N_2 + 3H_2O\) \textit{fast}
- \(4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O\) \textit{intermediate}
- \(2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O\) \textit{slow}

\(\Rightarrow\) \(NO/NO_2 = 1/1\) is best

Temperature > 200\(^{\circ}\)C needed
Temperature in exhaust system

Before system

After system

SCRT (DPF+SCR)
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Active temperature range for SCR catalysts

- ETC
- US cold
- US warm
- Route 85
- ESC
- Present SCR

Frequency of given temperature vs. Temp °C
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Urea Dosing strategy tests for low temperature operation such as route 85

- Three different engine maps were tested using several different urea injection timing strategies and dosing amounts
- Simulated city bus route cycle for low temperature operation (like route 85)
- Monitoring of both gas phase compounds and particulate matter formation with both FTIR and a state-of-the-art particulate matter measurement
- Balance between NOx conversion and NH₃ slip and production of cyanuric acid at too high dosing rates.
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37% NOx conv.

Nitrous oxide N2O
NOx
Ammonia NH3
HNCO

Concentration (ppm)

NH3 and HNCO concentration (ppm)

Particle diameter (nm)

dN/dlogdp /cc

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77% NOx conv

Concentration (ppm)

Time

NH3 and HNCO concentration (ppm)

Nitrous oxide N2O
NOx
Ammonia NH3
HNCO

Particle diameter (nm)

dN/dlogDp /cc

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test 07-03-13, II serie

- Idling
- Start of urea injection
- Start of Cycle

Graph showing emissions over time with markers for different emissions (e.g., NOx, CO, N2O, NH3, HNCO) and particle diameters. Graphs also show specific events such as start of cycle and start of urea injection.

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Four year durability study of a combined SCR + DPF

Figure 1: Schematic Representation of the Compact SCRT™ Concept
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SCRT System

- Urea tank
- Fuel tank
- Urea dosing system
- Inlet
- Outlet
- Front wheel
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- Multi-year gas phase emission testing of a fleet of 23 vehicles
- Both engine out and tailpipe measurements using mobile FTIR

- Engine Volvo D12C 12 liter 465 hp @1300 rpm
- Total 71.5 liter aftertreatment unit (DPF + SCR)
- 18-mile simulated distribution route:
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*FTIR results from on-road tests on the 18-mile route*

*Truck B228. Tailpipe emissions upstream and downstream of the CEATS system*

[Graphs showing FTIR results for Truck B228 before and after installation of the CEATS system, with data points for CO2, H2O, NOx, N2O, NH3, and CO concentrations over time.]

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Summary of Emission Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Average NOx conversion</th>
<th>NH$_3$ slip</th>
<th>US07 NTE compliance within fleet (cold)</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 2004</td>
<td>75 +/- 6%</td>
<td>20 ppm</td>
<td>91%</td>
</tr>
<tr>
<td>June 2005</td>
<td>73 +/- 8%</td>
<td>28 ppm</td>
<td>91%</td>
</tr>
<tr>
<td>June 2006</td>
<td>61 +/- 12%</td>
<td>30 ppm</td>
<td>70%</td>
</tr>
</tbody>
</table>

Overall durability is very good—
Truck mileage varies +/- 150,000 miles
Some trucks have driven over 350,000 miles
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Summary

• Optimized engine with SCR for Euro VI and EuroV
• Infrastructure availability and refilling of Urea
• Onboard diagnostics
• More work needed for low temperature applications
• Durability, field tests with total 700 000 km driving without major
• NOx reduction >75% possible
Special thanks to:

- Volvo Bus Corporation
- Patrik Klintbom
- Jonas Edvardsson
- Miroslawa Abul-Mihl
- Lennart Andersson
- Lennart Cider
- Heije Westberg