OEM – Technology for Particle Elimination

10th ETH-Conference on Combustion Generated Nanoparticles 2006

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Euro IV / V Directive

Emission Limits
- NOx: 5.0, 3.5, 2.0
- PM: 0.10, 0.02, 0.02

OBD
- Engine
- Aftertreatment

Emission-Durability
- Light: 100’000 km, 5 years
- Medium: 200’000 km, 6 years
- Heavy: 500’000 km, 7 years

NOx Control
- Torque-red
- Warning

In-use compliance
- Audit, in-field measurements

Euro III
- 2000 / 2001

Euro IV
- 2005 / 2006

Euro V
- 2008 / 2009

Euro III
- 2000 / 2001

Euro IV
- 2005 / 2006

Euro V
- 2008 / 2009

NOx Control
- Torque-red
- Warning

In-use compliance
- Audit, in-field measurements

Data classification: no
21.8.2006
Euro IV and V

- With the introduction of euro IV and V the HD PM-emissions are reduced by **80% in comparison to Euro III**
- Different technologies have been applied by the European OEM’s:
  - Iveco, DaimlerChrysler, Daf and Volvo: SCR for Euro IV and V
  - MAN: EGR und PM-Kat for Euro IV, SCR for Euro V
  - Scania: EGR and Oxi-cat for Euro IV, SCR for Euro V
- All technologies result in similar emission values in the European Test Cycles

- Emission values are of importance, words can be misleading
Iveco Engine Technology
### Iveco Engine Technology

<table>
<thead>
<tr>
<th></th>
<th>Euro IV</th>
<th>Euro V</th>
<th>EEV-Diesel</th>
<th>EEV-CNG</th>
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</thead>
<tbody>
<tr>
<td>Daily 3,5 t</td>
<td>EGR</td>
<td></td>
<td></td>
<td>MPI-TWC</td>
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<tr>
<td></td>
<td>DPF Option</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Daily &gt;3.5 t Light trucks</td>
<td>EGR + DPF</td>
<td></td>
<td></td>
<td>MPI-TWC</td>
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<tr>
<td>Eurocargo medium</td>
<td>SCR</td>
<td>SCR</td>
<td></td>
<td>MPI-TWC</td>
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<tr>
<td>Trakker Tipper</td>
<td>SCR</td>
<td>SCR</td>
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<tr>
<td>Stralis Heavy</td>
<td>SCR</td>
<td>SCR</td>
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<tr>
<td>Irisbus Citybus</td>
<td>SCR</td>
<td>SCR</td>
<td>SCRT</td>
<td>MPI-TWC</td>
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<td>(closed DPF)</td>
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<tr>
<td>Coach</td>
<td>SCR</td>
<td>SCR</td>
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<td></td>
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<td>(closed DPF)</td>
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</tr>
</tbody>
</table>

**All systems in production and available**

SCR: Selective Catalytic Reduction  
EGR: Exhaust gas recirculation  
DPF: Diesel Particle Filter, closed (>90%)  
MPI-TWC: Multi-point injection, 3-way catalyst  
SCRT: CRT (DPF) + SCR
Injection of AdBlue …
(Urea – Water solution / 32.5 wt.-% Urea) with / w.o. compressed air (dosing system)

Control system connected to engine ECU

\[ \text{NH}_3 = \text{Ammonia} \]
SCRT in city buses

Tector 6 GX127 City Bus application („Close Coupled“ SCRT)

Cursor 8 „Cigar“ application for city buses (Chorus Line, Citelis)
Experiences with chosen technologies

• SCR
  • Significant reduction of fuel consumption
  • Same / extended drain intervals …150’000km
  • Emission reductions effective under all ambient conditions
  • Reduced NO2-emission
• SCRT
  • as SCR (Consumtion, maintenance, emission reduction)
  • PM reduction as expected (gravimetric >90%, number >98%)
  • No increase in NO2-emission in comparison to engines w/o aftertreatment
  • DPF maintenance >300’000km with lowSAP lubricants
• Typically in diesel exhaust (w/o any aftertreatment): 90% NO and about 10% NO₂

• In presence of oxidation catalyst NO₂ portion is significantly increased, oxidation catalysts are needed for PM-Kat and CRT-DPF systems

• Downstream SCR system reduces NO₂ to values similar or lower as w/o any aftertreatment system

• CRT-SCR is the optimal technology combination for
  • Low PM
  • Low NOx and low NO₂
  • Low fuel consumption
Emission Citybus Euro III...V

Filières BUS euro3 Standard

NOx Particules et Gaz à effet de serre (GES)

Estimation

Vmoy + 5 km/h coulor, Feu prioritaire

Euro III

DIESEL

Euro III with DPF

DIESEL et FAP

Quelle : ADEME

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Nano-PM comparison (1)

Nano-PM Emission
Mode B50

PM concentration in exhaust in number/cm³ as function of PM size. Baseline (100%) is the Euro III engine.

Euro-3

PM-Cat

SCR

SCRT

1.3.2006 A. Stark

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PM concentration in exhaust in number/cm³ as function of PM size. Baseline (100%) is the Euro III engine.
Euro VI

- Definition expected in 2007/2008
- Implementation ~2011, early introduction expected as result of fiscal incentives (probably 2009 onwards)
- **Closed DPF will represent the standard solution**
- NOx- limit values still unclear, different scenarios under evaluation (costs, effectiveness, technical solution)

- Integral approach should be chosen, taking into account air quality, fuel (energy) consumption and CO$_2$ as well as costs to the society
## EU limit scenarios

### Emission limit scenarios under investigation

<table>
<thead>
<tr>
<th>Scenario</th>
<th>NOx</th>
<th>PM</th>
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<tbody>
<tr>
<td></td>
<td>g/kWh</td>
<td>g/kWh</td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>0.03</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>0.015</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.015</td>
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<tr>
<td>4</td>
<td>0.4</td>
<td>0.025</td>
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<td>5</td>
<td>0.3</td>
<td>0.02</td>
</tr>
<tr>
<td>6</td>
<td>0.2</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Discussion**

- **Szenario 2**
  - NOx = 1.0 g/kWh
  - PM = 0.015 g/kWh
  - 50% of Euro V

- **Szenario 5**
  - NOx = 0.3 g/kWh
  - PM = 0.02 g/kWh
  - Similar as US 2010
Euro VI – scenario 2 Strategies

BSFC g/kWh

1-stage TC

Fuel cons

Starting point Euro III

Combustion optimisation

PM (g/kWh)

0.1

0.02

0.015

PM-aftertreatment

SCR

SCR: 85..90% efficiency

NOx (g/kWh)

1.0

2.0

3.5

5.0

Euro III

Euro V

Euro IV
Euro VI – scenario 5 Strategies

- BSFC g/kWh
- PM (g/kWh)
- NOx (g/kWh)

1-stage TC
2-stage TC
Fuel cons

Starting point Euro III

Costs for NOx reduction in kt/a 8 times higher
3-5% increased consumption

SCR: 85..90% efficiency

PM-aftertreatment
EGR

+ Combustion optimisation

SCFR: 85..90% efficiency

Euro III

Euro IV

Euro V

Euro VI – scenario 5 Strategies

Data classification: no
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DPF retrofitting

• Germany is most advanced in specifying labels for different emission levels and type approval and classification of retrofit systems
• The labelling will be according to the Euro – classes
• DPF retrofitting will be done by system suppliers in agreement with OEM’s
• Technical Solution:
  • Euro III → Euro IV/V with closed DPF’s, risk: no active regeneration
  • Euro II → Euro III with closed DPF’s or PM-Kat, risk: no active regeneration, plugging (high oil consumption)
  • Euro I and older engines should not be retrofitted with DPF’s.
DPF retrofitting, open points

- Noise emissions with retrofit systems
- Available space for installation
- No active regeneration, operating conditions must be considered first (min temperatures)
- Oil consumption and type of lubricant
  - Lubricant with low ash content is preferred (E7)
  - High oil consumption will plug the DPF in short time
- Fuel quality
  - To use only sulphur-free diesel fuel, as sulphur does reduce the effectiveness of oxidation catalysts and therefore influences the continuous regeneration
Summary

• Euro IV and V HD engines emit 80% less PM than Euro III engines (gravimetric) and significantly less nano-PM

• It is expected, that all Euro VI engines will be equipped with closed DPF’s

• An integrated approach should be envisaged, taking into account CO₂, energy, PM, NOx and NO₂

• As all Euro 5 diesel passenger cars and Euro VI trucks will have DPF’s, the scientific or non-scientific or political or what-so-ever discussion must or will come to an end !!!

• When it comes to DPF applications, only measured values are of importance, words and names can be misleading !!!
however
PM10 A2 with and w/o traffic

A2 Autobahn closed

At A2 Autobahn
Mean hourly PM central Switzerland

At A2 Autobahn

PM10

[Graph showing PM10 levels at different locations in central Switzerland over time]
Daily mean PM Härkingen and Bern

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**A1/A2 Autobahn**

**City road**

**June 2005**

**August 2006**
Hourly mean PM A1/A2 Autobahn Härk.

Data classification: no

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21.8.2006
Hourly mean PM Lugano city-park

01-02 2006

07-08 2006