Diesel Particulate Filters
Market Introduction in Europe: Review and Status

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Presentation Outline

- The Strategic Situation of Diesel Engines
- The Year 2004 European Situation
- The Challenge of the DPF Regeneration
- The Cost Evaluations of the DPF Technologies
- The Future DPF Evolutions
- Conclusions
The Strategic Situation of Diesel Engines
- Reduction of Green House Effect (25% CO₂ reduction)
- Reduction of Energy Dependence (30% Fuel Economy)

Source: SAE F&L K. Katoh, Renault, June 2004
... and Gasoline Hybrids can only fit niche market

Source: SAE F&L K. Katoh, Renault, June 2004
Constant Increase of Diesel Penetration in Europe

- **Fuel Economy**
- **Direct Injection Turbo Diesel**
- **“Fun-To-Drive”**
- **Cost of ownership**

- **1990**
- **1995**
- **2000**
- **2005**
- **2010**

- **2002**: 40.3%
- **2003**: 44.3%
- **2004**: 47.5%?
- **2010**: > 50%?

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September 2, 2004
The Year 2004 European Situation
IAA Frankfurt Automotive Motor Show 2003
## Announcements of DPF Implementation in Europe

<table>
<thead>
<tr>
<th></th>
<th>Fuel-Borne Catalyst DPF</th>
<th>Pt-Coated DPF</th>
<th>Pt-Impregnated Catalyzed DPF</th>
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<tbody>
<tr>
<td>DPF</td>
<td>Ibiden, NGK Europe</td>
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<tr>
<td>Catalyst</td>
<td>Octel, Rhodia</td>
<td>Engelhard, Umicore</td>
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<tr>
<td>Car manufacturers</td>
<td>Fiat / Lancia Ford Motor Co., PSA Peugeot Citroën, VW AG</td>
<td>Mercedes</td>
<td>Audi AG, BMW, GM / Opel, Renault, VW AG</td>
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<tr>
<td>Start of production</td>
<td>since 2000</td>
<td>end of 2003</td>
<td>scheduled in 2004</td>
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The two main DPF technologies (w/ FBC and w/ Pt) can coexist within the same Car Manufacturer.
- on the market since May 2000
- as a standard equipment
- about 850,000 vehicles sold
- a proven technology with 4-years+ experience
- with flexibility (under-floor or close-coupled)

- constant Improvements since market introduction:
  “zero” DPF maintenance is available in 2004, thanks to global improvements:
    - SiC-DPF design (ash storage),
    - FBC Catalytic enhancement
    - Engine Strategy

- with better Vehicle Integration and Global Cost Reduction
DaimlerChrysler (Platinum-Coated DPF)

Close-Coupled Position DPF System:
- Diesel Oxidation Catalyst: 2.5 liters
- DOC Platinum loading: >120g/ft³
- One-Can Box w/flange (filter maintenance)
- SiC-DPF (Ibiden): 2.5 liters - round shape
  DPF Pt loading: 30 to 40g/ft³

- available since October 2003 (4 cyl.; E & C Class)
- DPF is offered as an option: 580€
- 80% of the sales are with DPF (EURO 4 tax incentives)
- about 50,000 vehicles have been sold since Oct. 2003
- DPF maintenance @ 100,000 km (standard replacement)
BMW AG (Catalyzed DPF)

- available since February 2004
- 6 cyl.; 525d and 530d models
- standard equipment
- w/EURO 4 compliance

- SiC-DPF in under-floor position:
  - racetrack _ 4.7 liters
  - 530 w/200cpsi - 525 w/300cpsi
  - Ibiden and NGK Europe
  - DPF Platinum loading <90g/ft3

Diesel Oxidation Catalyst in Close-Coupled Position

Exhaust line thermal insulation

- announced “without DPF maintenance”
EURO 4 Vehicle NOx and PM Emissions

- Combustion chamber
- Fuel injection system
- EGR control

Passenger cars

DPF equipped Vehicles
Germany's car makers have agreed to equip diesel cars sold in Germany with filters:

- with a plan to provide tax incentives of € 600 from 2005
- the proportion of DPF should reach 75% by the end of 2007
- and 100% by 2009

Additional “Bonus/Malus” rules, based on CO$_2$ (g/km) emissions may be also available in 2005 (French initiative)
…with only 2 or 3 DPF manufacturers as real players
The Challenge of the DPF Regeneration
Sequential DPF Regeneration Cycle

w/ ΔP sensors to follow the DPF Regeneration
Catalyst does not help the Catalyzed-DPF regeneration: 
no big difference between coated and uncoated filters;
Nonhomogeneous DPF regeneration with Platinum-based Technologies

Source: J. Michelin – VDI Wolfsburg 12/2003
Incomplete and partial DPF regeneration causes dramatic soot modifications in:

- physico-chemistry and composition
- structure, porosity and morphology

Source: T. Johnson – Corning
DEER 2003
April 3, 2004

Mazda Motor Corporation said it will recall a total of 2,656 diesel vehicles in four models in the Japanese market to fix a defect in the diesel particulate filter (DPF) system. Subject to the recall are the Bongo truck, the Bongo Brawny van, the Delica van and the Vanette van manufactured between last December and February. Mazda said that the level of PM emissions from the vehicles may exceed mandated standards due to the DPF system problem.

The vehicles are powered by a 2.0 liter common-rail diesel engine utilizing catalyzed wall-flow particulate filter and exhaust gas recirculation for NOx control. The filter is regenerated through the combined effect of the catalyst and increased combustion temperature, controlled by common-rail injection system. The problem was caused by computer software which did not properly control filter regeneration. All affected engines will be fitted with new Engine Control Units featuring updated software. The regeneration problems may have caused overheating and failure of the filter element and/or the temperature sensor positioned downstream of the filter. If damaged, these component will be also replaced at no charge.

The new Mazda Bongo was the first light commercial vehicle in Japan fitted with a diesel particulate filter.

Source: www.Dieselnet.com
The Cost Evaluations of the DPF Technologies
- Diesel Oxidation Catalyst Platinum loading
  - targeting the EURO4 - 100,000km durability requirement
  - Pt from 90 to 140 g/ft³ (CO/HCs, post-injection management)

- Can and sensors (w/o flange for one or two boxes)

- SiC-based DPF: no difference in design and in scale effect

- Fuel-Borne Catalyst (tank, dosing system, interface, wires, connections, additive fluid)

- Platinum DPF wash-coating
  - Platinum loading (30 to 90 g/ft³)
  - specific wash-coat (Catalyzed-DFP with SiC)
Platinum Price Evolution (London Fixing PMG)

Platinum Price Evolution
in $/once

over the 1996-2004 period
max. 936 $/once – 04/19/2004
min. 333 $/once – 10/30/1998

max. 936 $/once – 04/19/2004
min. 767 $/once – 05/10/2004
### Chart based on the Market Data

#### Market data

<table>
<thead>
<tr>
<th>SIC DPF (high volume price)</th>
<th>€/litre</th>
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<tbody>
<tr>
<td>200cpsi SQ</td>
<td>€/litre</td>
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<tr>
<td>300cpsi SQ 8&quot;</td>
<td>€/litre</td>
</tr>
<tr>
<td>200cpsi OS2 10&quot;</td>
<td>€/litre</td>
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</table>

**Specific SIC wash-Coat**: €/litre

<table>
<thead>
<tr>
<th>Platinum price</th>
<th>636,61 €/oz</th>
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<tbody>
<tr>
<td>29-mars-04</td>
<td>22,46 €/g</td>
</tr>
<tr>
<td>767 $/oz</td>
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**Volume**
- 1 ft³: 28,3 litres
- 1 m³: 28,3 litres

**Specific MAT for C-DPF not included**
- Round / Oval shape difference not taken into account
- Oxicat wash-coating not taken into account
- Flange for two CAN not taken into account (approx. 10€)
- Specific exhaust part insulation not taken into account

**Charts details**

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<tbody>
<tr>
<td></td>
<td>53%</td>
<td>73%</td>
<td></td>
<td>67%</td>
<td>60%</td>
<td></td>
<td>34%</td>
<td></td>
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**Maintenance**

<table>
<thead>
<tr>
<th>Fuel penalty</th>
<th>4 to 6%</th>
<th>0.6%</th>
<th>5.50%</th>
<th>0.06</th>
<th>4 to 6%</th>
<th>0.06</th>
<th>4 to 6%</th>
<th>0.06</th>
<th>4 to 6%</th>
<th>0.06</th>
<th>2.60</th>
<th>% average</th>
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<tbody>
<tr>
<td>Extra fuel cost</td>
<td>900</td>
<td>average</td>
<td>900</td>
<td>average</td>
<td>900</td>
<td>average</td>
<td>900</td>
<td>average</td>
<td>900</td>
<td>average</td>
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</tr>
</tbody>
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(based on 250000 km, fuel consumption of 15-18 km/l, 0.800/€ Diesel fuel)
Cost Evaluation of DPF Technologies

Additive-based DPF

Pt-based DPF (Underbody)

Pt-based DPF (Close-Coupled)

Year

Cost (in €)

2000 2001 2002 2003 2004 2005 2006 2007

1000 980 710

590 540 480

450 430
Situation of Platinum-Based DPF Technologies

at similar scale production (vs. additive-based reference):
- underbody Pt-based DPF is never competitive
- close-coupled Pt-based DPF may be competitive, but a DPF maintenance is required

still some points to be addressed:
- fuel penalty for DPF regeneration (time, temperature)
- lubricant dilution and engine parts damages
- DPF maintenance operation and Pt recycling
- partial and incomplete regeneration (maintenance, recall)

Platinum cost part represent (in 2006):
- 45-70% of Pt-based Close-Coupled Position
- 40-60% of Pt-based Underbody Position
- 35-40% of Additive-based DPF

Large market introduction of Pt-based DPF need dramatic changes and evolutions of the present Pt-based technologies
The Future DPF Evolutions
Future Evolutions to Fit the Market Requirements

**Pt-based DPF**
Reduction of Pt loading
20 to 5g/ft³

**FBC-based DPF**
Reduction of FBC dosing rate

- additional exhaust heat injection
  - to reach Carbon Pyrolysis (>850°C)
  - to save engine parts (lubricant)
- new DPF design
  - for unburned soot management
- combination Pt-based w/ FBC
  - integration of DOC
  - volume saving (close-coupled)
- constant system improvement

**to prepare the next EURO5/Tier2-Bin5 (NOx+PM)**
(volume saving, thermal management, cost reduction, flexibility)
with **New Injection Technology Systems**
The Future Challenge for NOx, PM, and CO2

Fuel Consumption

Passenger cars < 3,5 tons

EURO 3

PM (g/km)

0,050

0,040

0,030

0,020

0,010

0,000

0,000

0,100

0,200

EURO 4

EURO 5

Fuel Economy

• Combustion chamber
• Fuel injection system
• EGR control

DPF equipped

+ NOx-Cat

...and 120 to 160,000km (74 to 94,000 miles) durability

Passenger cars < 3,5 tons

Fuel Economy

...and 120 to 160,000km (74 to 94,000 miles) durability
Conclusions

- In 2004, the DPF is well accepted by the European car makers;
- At present, the additive-based DPF is the only proven technology;
- Some platinum-based DPF technologies have been proposed since Oct. ‘03, with important points to address, as the maintenance issue, the lubricant dilution, partial and uncontrolled DPF regenerations…;
- In addition, the platinum price evolution does not favour the market introduction of these technologies;
- The platinum-based DPF technologies need dramatic improvements and new approaches for significant market introduction;
- If the present EURO 4 was based on an emotional choice and marketing strategy, the next EURO 5 stage should be different, with integration of NOx and PM aftertreatments while targeting the CO2 and cost challenges.