Exhaust Aftertreatment of Gasoline Engines with Coated Particulate Filters

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Agenda

• Umicore – Who we are
• Global Automotive World
• Market and System Trends
• Umicore c-GPF Portfolio - Technical Requirements
• Performance Data
• Durability Run Data
• Summary
Who we are

A global materials technology and recycling group

One of three global leaders in emission control catalysts for light-duty and heavy-duty vehicles and for all fuel types

A leading supplier of key materials for rechargeable batteries used in portable electronics and hybrid & electric cars

The world’s leading recycler of complex waste streams containing precious and other valuable metals
From substrate to end consumer

Development phase

Catalyst & emission system
Architecture contract negotiation

Production phase

Substrate manufacturer
Canner
Car/engine manufacturer
End consumer

End-of-life phase

Recovery of precious metals from automotive catalysts
(in Business Unit UPMR)
Global Automotive World

LDV Production by Region

Sustainable Solutions

Air Pollution

Upcoming legislation...

1000 sec; 23.3 km; Max Accel.: 1.60 m/s²
Upcoming legislation…

**CO₂ target**
- 2012: 130 g/km 100% fleet
- 2013: 95 g/km 100% fleet

**Emission standards**
- Euro 5
- Euro 6b
- Euro 6c

**NEDC/WLTC**
- NEDC-based testing
- WLTC-based testing

**Real Driving Emissions**
- Development and measurement phase
- NTE-Limit – Conformity Factor (CF)
  - CF stage 1
  - CF stage 2

**On Board Diagnostics**
- Euro 5b
- Euro 6-
  - 6-1
  - 6-2

All dates: New type approval PC not confirmed by final regulation.

**WLTC**
- Time [s]: 0 25 50 75 100 125 150 1750
- Speed [km/h]: 0 25 50 75 125 150
- 1800 sec; 23.3 km; Max Accel.: 1.60 m/s²
Sustainable solutions

Advanced ICE configurations

- Down-sized turbo-charged gasoline
- Gasoline direct injection
- Lean burning gasoline engines
- Diesel
- (Flex fuel)

Requires more complex emission control catalyst solutions

Electrification of the vehicle

- Start-stop mechanism
- HEV: Mild HEV → Full HEV
- PHEV: Parallel → Range extender
- EV: BEV → FCEV

Requires larger battery and still automotive catalyst (except EV)
Strengthening EURO 6 PN limits require GPF

EURO 6 legislations addresses the number of particulates, with a transition period of 3 years for gasoline engines.

- Diesel: $6 \times 10^{11}$/km
- Gasoline Direct Injection (DI): $6 \times 10^{12}$/km

Gasoline Direct Injection (DI) engines have higher Particulate Number (PN) emissions compared to diesel engines with Diesel Particulate Filter.

With RDE introduction most of the gasoline vehicles will need a GPF.
Market Trend

System Trends – Regions with PN Limits

Usual Layouts

- TWC
- TWC
- TWCTWC

Layouts from 2017

- TWC
- GPF/cGPF
- TWC
- GPF/cGPF
- TWC
- GPF/cGPF

Trends:
- more Volume
- more PGM
- GPF Introduction for almost all DI
Catalyzed Gasoline Particulate Filter

The catalyzed Gasoline Particulate Filter c-GPF

Addressing:

Hydrocarbons HC
Carbon Monoxide CO
Nitrous Oxides NOx
Particulate Mass PM
Particulate Number PN

All the traditionally limited HC, CO, NOx and PM as well as the new challenge PN are substantially being reduced in parallel.
Advantages of Different GPF Positions

- Diagnosis unchanged over CC1 TWC
- Good filtration efficiency
- Additional conversion of traditional emissions, especially regarding RDE

- Diagnosis unchanged over CC1 TWC
- Good conversion of traditional emissions
- Good soot regeneration

- Packaging and system costs benefit
- Good soot regeneration
Umicore c-GPF Portfolio

Technical Requirements

e.g.: high performance cars, application with very low raw emissions

Pressure Drop

Filtration Efficiency

e.g.: to stay safe in RDE, applications with high PN emissions

e.g.: in CC1 position

TWC Activity

e.g.: in CC1 position

Different technical requirements call for dedicated technologies

- Special technologies for lowest pressure drop
- Portfolio of high three-way active GPF designs
- Designs for increased fresh filtration efficiency
Significant Improvements of TWC activity
Stress Field: Activity vs. Back Pressure continues
Pressure Drop and Maximum Power

@ Rated Engine Speed

<table>
<thead>
<tr>
<th>Pressure drop [mbar]</th>
<th>TWC+TWC</th>
<th>TWC+GPF</th>
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<td>400</td>
<td>500</td>
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<th>Maximum power at rated speed (%)</th>
<th>TWC+TWC</th>
<th>TWC+GPF</th>
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Real World Fuel Consumption
Central European Driving, German Motorway included
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Central European Driving, German Motorway included

Fuel Consumption (l/100km)
Number of Refill

Production System
TWC1 + TWC2

Prototype System
TWC1 + GPF
Real World Road Durability Validation

TWC + Add On c-GPF downstream, PN over Durability Distance

Particulates NEDC [#/km]

- Engine out: 2.20E+12
- fresh: 3.40E+11
- 500 km: 2.30E+11
- 50 Kkm: 4.60E+10
- 100 Kkm: 5.20E+10
- 160 Kkm: 8.60E+10
- Engine out @ 160 Kkm: 5.00E+12

PN EU 6c
Summary

Strengthening EURO 6 PN limits require GPF for Gasoline (DI) Engines

Variable coatings in the c-GPF family are available:
- Pressure drop optimized technologies
- Portfolio of high three-way active GPF designs
- Designs for increased fresh filtration efficiency

Attention has to be turned to the conversion of gaseous emissions due to:
- High aging requirements in a CC1 position
- Lower washcoat amounts on a filter compared to a flow through substrate → assure sufficient conversion of harmful emissions over lifetime

Filtration efficiency is increasing over lifetime due to ash accumulation
Thank you for your attention

Questions ?