Ceramic Wall Flow Filter for Particulate Emission Reduction of Petrol Engines

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NGK EUROPE GmbH

Cambridge Particle Meeting
Content

- **Introduction**
  - Background
  - Legislation

- **GPF* Concepts**
  - System Layout
  - Non-catalysed Applications
  - Catalysed Applications

- **Conclusion**

* GPF: Gasoline Particulate Filter
Some European areas show high Particulate Matter concentrations.
## Trend of Particulate Matter Regulation (PC/LDV)

<table>
<thead>
<tr>
<th>Year</th>
<th>Euro5 NEDC</th>
<th>Euro6b NEDC</th>
<th>Euro6c WLTC + RDE</th>
<th>Euro7? WLTC + RDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>Diesel: PM 5.0 mg/km</td>
<td>Diesel: PM 4.5 mg/km PN $6 \times 10^{11}$#/km</td>
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### Post New Long Term
- JC08(hot) + JC08(cold)
  - Diesel: PM 5.0 mg/km
  - Gasoline (GDI): PM 5.0 mg/km

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- JC08(hot) + JC08(cold)
  - Diesel: PM 5.0 mg/km
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New European Driving Cycle: NEDC
Worldwide harmonised Light vehicles Test Cycle: WLTC
Real Driving Emission: RDE

Particle and $CO_2$ emission limits become stricter. Gasoline and Diesel limits will merge.
EU Commission demands RDE/PEMS

“Any engine measure must be applicable to all engine working conditions to ensure that, in the absence of aftertreatment devices, emission levels in real life driving conditions are not worsened.”

Source: European Commission Regulation No. 459/2012 of 29 May 2012 §(7)

A real-driving test performed by the JRC using PEMS © EU, 2013

Source: http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt_code=NWS&obj_id=16180&ori=RSS

“…it was decided in December last year to primarily develop on-road testing with PEMS as the main real-driving test procedure. ... The real-driving test procedure …will only become fully effective from 2017 onwards.”

Source: http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&dt_code=NWS&obj_id=16180&ori=RSS

RDE = Real Driving Emissions
PEMS = Portable Emission Measurement System
**CO₂ Comparison between Gasoline MPI and DI**

(source: KBA Mar.2012 data, Passenger car. class M1, certified 2008-2012)

Note: There is no indication of DI or MPI in KBA data sheet in 2012. MPI or DI is estimated from PM data existence (with PM data → DI, no PM data → MPI)

Direct Injection (DI) shows lower CO₂ than MPI. Approximately 10% CO₂ reduction by DI can be seen at 150 kW condition.

### EU5-Gasoline

<table>
<thead>
<tr>
<th>Number of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>With PM data → DI?</td>
</tr>
<tr>
<td>No PM data → MPI?</td>
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</table>

Direct Injection EU5

**CO₂ Emission [g/km]**

- CO₂ Emission [g/km]
- Max. Power [kW]
Combustion engines will remain dominant propulsion method in the future. GDI technology will increase in future with downsizing and turbo charging for reduced fuel consumption and CO₂ emission.
Technical Solution for PN and CO$_2$

**Particle Number (PN)**
6x10$^{11}$#/km (Sep/2017~)

PN reduction in all operation points by emission control system

**Low fuel consumption**
Low CO$_2$ emission

Minimize pressure drop of emission control system

**Low pressure drop Cordierite Gasoline Particulate Filter (GPF)**
Content

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  - Legislation

- GPF* Concepts
  - System Layout
  - Non-catalysed Applications
  - Catalysed Applications

- Conclusion

* GPF: Gasoline Particulate Filter
## Selection of Suitable GPF Material for any Application

<table>
<thead>
<tr>
<th>Material</th>
<th>Cordierite Gasoline Particulate Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Porosity</strong></td>
<td></td>
</tr>
<tr>
<td>40-50 %</td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>System Layout</strong></td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td></td>
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<tr>
<td><strong>Micro Structure [SEM]</strong></td>
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<tr>
<td>**Wall Thickness / Cell Density *</td>
<td></td>
</tr>
<tr>
<td>5 mil / 220 cpsi</td>
<td>10 mil / 300 cpsi</td>
</tr>
<tr>
<td>6 mil / 220 cpsi</td>
<td>12 mil / 200 cpsi</td>
</tr>
<tr>
<td>5 mil / 360 cpsi</td>
<td>12 mil / 300 cpsi</td>
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<tr>
<td><strong>Application</strong></td>
<td></td>
</tr>
<tr>
<td>Add-on type GPF (None/Low Catalyst amount)</td>
<td>Replace type GPF (High Catalyst amount)</td>
</tr>
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* mil = 1/1000 inch  
  cpsi = cells per square inch
Particle Number Reduction by GPF

- **Vehicles:** 1.4L and 1.8L GTDI \( \lambda = 1 \)
- **GPF:** \(~48\%\) porosity, uncoated
- **Position:** Underfloor

**GPF reduces PN significantly in transient test cycles and different ambient temperatures.**
Vehicle: 1.4L Gasoline DI $\lambda=1$
GPF: 48% porosity, $\phi118.4 \times 127L$, 6mil/220cpsi without catalyst
Position: Underfloor

NEDC and WLTC test show no big impact by GPF on CO$_2$ emission.
2nd Generation Material Concept - Higher OFA Structure -

Thin Wall Concept with 42% Porosity

1. Increase material strength by dense material while keeping permeability.
2. Apply higher OFA structure like thinner wall to reduce pressure drop.

To increase strength apply new material which is
- Dense material (42% porosity)
- Sharper pore size distribution

High OFA
Thinner wall

6mil/220cpsi with 42%

5mil/220cpsi with 42%

6mil/220cpsi with 48%
Performance of 2nd Generation GPF Material

**Test mode:** Cold flow bench
- **GPF:** $\phi 118.4 \times 127L$
- **Temperature:** 25deg.C

*New 5mil/220cpsi shows 11-24% lower backpressure.*

**Test mode:** Wide open throttle step up
- **Engine:** 1.4L GDI $\lambda=1$
- **GPF:** $\phi 118.4D \times 127L$

**Pressure drop (kPa)**

- **48% Porosity 6mil/220cpsi**
- **42% Porosity 5mil/220cpsi**

**Flow rate (Nm³/min)**

- 0 2 4 6 8 10

**Engine speed (rpm)**

- 0 1000 2000 3000 4000 5000 6000

- 12 24 36 48 60 72 84

- -11% -24%
### Suitable GPF Material for un/catalysed Applications

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Performance of Three-Way-Filter (TWF™)

Comparison of Performance between

System A: TWF™ emission optimised washcoat
System B: TWF™ backpressure optimised washcoat

DEMOnstratIOn of EU6 comPlIant TWF™ system

- Coated NGK 4.66 x 5.5” (1.54L) C650 cordierite filter samples
  - PGM 40/0:12:1
  - Emissions optimised washcoat vs. backpressure optimised washcoat
- Oven ageing at 1100 °C, equivalent thermal load to JM Lean Spike engine ageing cycle
- Evaluation on a 2.0 litre DI EU5 vehicle

Both systems can meet the Euro 6c limits for gaseous emissions during NEDC.

Source: Dr. David Greenwell, 2nd IQPC Conference - Advanced Emission Control Concepts for Gasoline Engines, 13-14.05.2013, Bonn
Performance of Three-Way-Filter (TWF™)

Comparision of Performance between
System A: TWF™ emission optimised washcoat
System B: TWF™ backpressure optimised washcoat

Both systems can meet the Euro 6c PN limit (6e11/km) during NEDC.

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Summary and Conclusion

• There are difficulties to meet PN limits in all test cycles by GDI engine measures. GPF is an effective technology to reduce particulate emission with high filtration performance under all engine operation points and ambient temperature variation.

• NGK developed new robust GPF material with high permeability to enable further reduction of pressure drop using 2nd generation GPF (5mil/220cpsi).

• The pressure drop performance of 2nd generation GPF was confirmed under different engine operation points (11-24% lower Δp).

• High porosity material for catalyst integration is available. Cell structure optimisation and catalyst loading amount are key for low pressure drop.

Low pressure drop Cordierite Gasoline Particulate Filter (GPF)
Thank you for your Attention

2013 Cambridge Particle Meeting