Advanced High Porosity Ceramic Honeycomb Wall Flow Filters

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Introduction to GEO₂

Build technology platform and intellectual property

- GEO₂ is a material science licensing company

- Technology focus: High temperature, high porosity, cellular ceramic substrates for filtration, catalytic conversion and fixed-bed reactor applications. Flexible base materials, porosity, pore size

- Well-financed to build, develop and protect technology

- 30 patents and applications. 10 additional applications by end of 2007 covering:
  - Materials and chemistry
  - Process and manufacturing
  - Systems integration
  - Applications

License and transfer technology to partners

- With more than 100 years of experience, team built to transfer:
  - Ceramics
  - Ceramic processing
  - Catalysis
  - Manufacturing
  - Application engineering

- Deliver scaleable processes
  - To manufacturing partners
  - Specific operating procedures
  - Use of industry standard equipment

Share innovation across markets

- Diesel
- 2-Stroke
- Gasoline catalytic converters
- Air-oil separators
- Chemical synthesis
- Other applications

In discussions with leading ceramic and diesel application companies

Supplement intellectual property
Problem Statement: Increasing complexity of emission control
GEO₂ extruded honeycomb ceramics

Mullite

SiC

Cordierite

Others

GEO2 Product and IP Platform
GEO\textsubscript{2} filter has a uniform pore structure through the wall

<table>
<thead>
<tr>
<th>Porosity, pore-size (%)</th>
<th>GEO\textsubscript{2M}</th>
<th>SiC (NGK 300/12)</th>
<th>Cordierite (Corning 200/12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>67%</td>
<td>15µm</td>
<td>43%,</td>
<td>13µm</td>
</tr>
<tr>
<td>MoR (MPa)</td>
<td>8.6</td>
<td>9.4</td>
<td>2.2</td>
</tr>
<tr>
<td>E Modulus (GPa)</td>
<td>7.8</td>
<td>13.3</td>
<td>4.8</td>
</tr>
<tr>
<td>CTE</td>
<td>4.3x10\textsuperscript{-6}</td>
<td>4.0x10\textsuperscript{-6}</td>
<td>0.8-1.7x10\textsuperscript{-6}</td>
</tr>
</tbody>
</table>
Contents

- Back pressure and filtration efficiency – steady state
- Back pressure and filtration efficiency – transient
- Uncontrolled regeneration – thermal shock resistance
- Catalyst efficiency
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☑ Back pressure and filtration efficiency – steady state

☐ Back pressure and filtration efficiency – transient

☐ Uncontrolled regeneration – thermal shock resistance

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Filtration efficiency and backpressure benchmarking against Cordierite and SiC

<table>
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<tr>
<th>Sample</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GEO\textsubscript{2} 200 cpsi DPF ((\varnothing)141mm x 153mm)</td>
</tr>
<tr>
<td>B</td>
<td>Commercial Cordierite 200 cpsi DPF ((\varnothing)144mm x 152mm)</td>
</tr>
<tr>
<td>C</td>
<td>Commercial SiC-based 300 cpsi DPF ((\varnothing)144mm x 153mm)</td>
</tr>
</tbody>
</table>

**Steady state testing:**
- 1.9L TDI common-rail engine
- 1500 rpm, 45 Nm

**Transient testing:**
- 6 NEDC cycles
Particle instrumentation employed

- **SMPS** - A Scanning Mobility Particle Sizing system (consisting of a Differential Mobility Analyzer and a Condensation Particle Counter); electrical mobility method; particles in the range of 10 to 430 nm.

- **ELPI** - An Electric Low Pressure Impactor; aerodynamic method; particles in the range of 30 nm to 8 mm.

- **CPC** - An standalone Condensation Particle Counter.

*Each instrument sampled through a heated two-stage mini-diluter system (190 C), with a dilution ratio of 90*
Pressure drop and filtration efficiency evolution

![Graph showing filtration efficiency and pressure drop for different materials and filters.](image)

- **Cordierite**: FV=1.77 cm/s
- **SiC**: FV=1.26 cm/s
- **GEO2**: FV=1.86 cm/s

Condition: 1500 RPM, 45 Nm
Size distributed Filtration efficiency during soot loading

Time in 135 s steps
GEO$_2$ is a cake/surface filter with high trapping efficiency.
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Filter A: NEDC cycle soot loading, backpressure and filtration efficiency

- CPC
- SMPS-80
- ELPI
- Pressure Drop (mbar)

Challenge mass load (g/m²)

Filtration efficiency (-)

Pressure drop (mbar)
Backpressure and Filtration over NEDC cycles

- Cordierite
- GEO2
- SiC
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Uncontrolled regeneration (Ø141mm x 153mm)

Temperature profiles and thermal shock

Process:

1. Load predefined soot mass load (10g/m² and 15g/m²) without a DOC upstream of filter
2. Place DOC upstream of filter
3. Set engine to the steady state operation point of 1500 rpm and 75 Nm BMEP (corresponding to 340°C filter inlet temperature)
4. Engine exhaust temperature is increased to 650°C with the means of HC port injection upstream of the DOC
5. Drop to idle

The increased exhaust oxygen content, the high filter temperature and the small exhaust mass flow rate lead to a very rapid filter regeneration (worst case regeneration).
Soot loading behavior; pressure drop vs. mass loading

- 1st loading (10g/m²)
- 2nd loading (15g/m²)
Placement of thermocouples for temperature profiling
Uncontrolled Regeneration: temperature profiles at 15g/m²
Uncontrolled regeneration – 10g/m$^2$ and 15 g/m$^2$

No visual defects & no change in permeability
Filters intact and survive the thermal shock
GEO$_2$ filters survive >1400C temperature excursions during uncontrolled regenerations

GEO$_2$ DPF survived >1500C

Thermal Cycling, fatigue testing ongoing

1000 cycles → no visible cracks or defects

MoR, E-modulus → No change
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Backpressure and soot regeneration on catalyzed filters

*filter size: (Ø 25 mm x 50 mm)*

- Commercially catalyzed sample:
  SiC 200 cpsi, 3 g/m² Pt on Al₂O₃ catalyst load

- In-house coated sample:
  GEO₂ 200 cpsi, 3 g/m² Pt on Al₂O₃ catalyst load

- In-house coated sample:
  SiC 200 cpsi, 14 g/m² base metal catalyst load

- In-house coated sample:
  GEO₂ 200 cpsi, 14 g/m² base metal catalyst load
Pressure drop vs. challenge mass load: Pt coated samples

Filtration velocity: 2 cm/s, Exhaust temperature: 250 C

GEO\textsubscript{2} coated sample has significantly lower pressure drop upon loading
NO/NO₂ assisted soot oxidation rate on Pt coated samples

Exhaust composition: 10% O₂ 300 ppm NO

- Uncoated GEO₂
- Coated GEO₂ (O₂)
- Coated GEO₂ (O₂ + NO)
- Commercial (O₂ + NO)

GEO₂ coated sample has higher NO/NO₂ assisted soot oxidation rate
NO Conversion on Pt coated samples

![Graph showing NO Conversion vs Temperature]

- Thermodynamic limit
- GeO2
- Commercial

300 ppm NO, 10% O₂
Pressure drop vs. challenge mass load

*Base metal coated samples*

Filtration velocity: 2 cm/s, Temperature: 250°C

- **Coated SiC**
- **Coated GEO2**
- **Uncoated GEO2**

Base metal catalyst coated GEO₂ filter has lower pressure drop
Direct catalytic soot oxidation

Base metal catalyst coating at 14 g/m²

- Uncoated GeO2
- Coated GeO2

Low temp oxidation. How to sustain?
Conclusions

Advanced high porosity composite filter materials have been developed for wall flow DPF applications:

- Uniform microstructure, interconnected pore-architecture
- Oxide and non-oxide chemistry
- High porosity with strength/robustness
- Low backpressure
- High steady state and transient filtration efficiency
- Filter survives uncontrolled regeneration at >15g/m² soot loading
- Compatibility with catalysts
- Application in multi-functional filters
- Potential for filter size reduction and/or PGM reduction
** Thank you for your time **

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