Value Analysis of Alternative Diesel Particulate Filter (DPF) Substrates for Future Diesel Aftertreatment Systems

DEER Conference
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Global Marketing Director - Powertrain and Emissions
Outline

• Regulations Driving New and Optimized Systems Architectures
• Aerify™ Acicular Mullite Diesel Particulate Filter
• Case 1 – Heavy-Duty Engine
• Case 2 – Light-Duty Engine
Tightening Emissions Regulations Drive Engine Management and Aftertreatment

Engine Controls Move the Trade-Off Curve

But Lower Standards Push Strategies From PM or NOx

PM and NOx

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Aerify™ Diesel Particulate Filter (DPF)

- Wall Flow Ceramic Filter - High porosity substrate with excellent strength
- Mass production begins 2011
- Additional chemical process performed in manufacturing to create the acicular mullite unique microstructure
- Product families include monolith and segmented parts, depending on customer requirement
- Enables flexible value proposition
  - High Filtration Efficiency – Both mass and particle number
  - Reduced fuel consumption
  - Reduced package size
  - Reduction of total systems cost
  - Improved systems integration
    - i.e. SCR on filter
• “Soot-in-the-wall” is the cause for pressure drop hysteresis
• The high porosity and permeability protects AERIFY DPF from being vulnerable in regards to “soot-in-the-wall”
• Soot lay down on unique needle structure provides high contact area between soot and needle structure
Case 1 – Heavy – Duty Diesel
# Heavy Duty Needs

<table>
<thead>
<tr>
<th>HD Market Attribute</th>
<th>Engine Design Goals</th>
<th>Ways to Improve</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fuel is a large variable cost for the end user</td>
<td>• Reduced fuel consumption</td>
<td>• Reduce post injection occurrences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More passive regeneration</td>
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<td></td>
<td></td>
<td>• Reduced DPF backpressure for lower pumping losses</td>
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<tr>
<td>• Aftertreatment is a large system expense</td>
<td>• Reduced system cost</td>
<td>• Downsize the aftertreatment system</td>
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<tr>
<td></td>
<td></td>
<td>• Reduce PGM usage</td>
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<tr>
<td></td>
<td></td>
<td>• Integrated solutions</td>
</tr>
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<td>• Long life – minimize downtime due to reliability</td>
<td>• Reduce in-field warranty</td>
<td>• Reduce post injection occurrences – less chance of uncontrolled regeneration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Improve control system and soot mass measurement</td>
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<tr>
<td></td>
<td></td>
<td>• Improve DPF material robustness</td>
</tr>
</tbody>
</table>
HD Diesel Aftertreatment
- System Architecture Trends

New systems to take advantage of engine out NOx to increase passive regeneration

Post 2013 US / EU Trend

US 2007 On-road trucks

Euro IV / V HD On-road trucks
AERIFY DPF Can Be Downsized!

- High porosity and permeability of AERIFY DPF makes the wall contribution small compared to the channel contribution.

\[ \Delta P_{total} = \Delta P_{wall} + \Delta P_{soot} + \Delta P_{channel \ flow} + \Delta P_{entrance \ / \ exit} \]

- Optimal filter length is shorter for AERIFY DPF than for other commercially available DPF.
Back Pressure Advantage - CDPF
- Significant Length Downsizing (>25%)

- Low back pressure compared to competitive materials
  - Segmented Acicular Mullite filter versus Monolith cordierite
- Linear backpressure profile for improved soot load predictions and OBD control

- Results in improved fuel economy on the engine dyno
Improved Strength Of High-Porosity Mullite DPF

High-porosity Mullite exhibits higher flexural and isostatic strength compared to Cordierite.

- Acicular Mullite
- Cordierite

Graph showing the relationship between porosity (%) and strength (MPa) for Acicular Mullite and Cordierite.

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Excellent Soot Mass Limit
DTI Tests For Coated 12x8.5 Mullite DPF

Temperature Isotherms - 100 °C/min ramp, drop-to-idle

- High robustness by segmentation and downsizing

120 grams
~ 5.5 g/L 12x12”
~7.5 g/L 12x 8.5”

120 grams
Value Analysis – HD (Downsized DPF)

AERIFY Value Creation
Lower Total Systems Costs
Downsized package size
Less Sensitivity to PGM price variations
Backpressure (fuel efficiency) advantages
Weight savings

Process Step

<table>
<thead>
<tr>
<th>Engine</th>
<th>DOC</th>
<th>DPF</th>
<th>SCR</th>
<th>Engine</th>
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</table>

Cost to OE ($)

- DPF (Cd)
- PGM
- Coating
- Canning
- Dow DPF
- PGM
- Coating
- Canning

- Cd 12 in x 12 in (22.2L)
- Dow ACM 12 in x 8.5 in (15.7L)

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Heavy-Duty System

• Conclusions
  – Heavy duty trucks have some unmet needs
    • Reduced fuel consumption
    • Reduced the system cost
    • Improved the system reliability
  – System architectures are evolving to help meet those needs
    • Aftertreatment design
    • More passive regeneration
    • Improved controls
  – New DPF products like Acicular Mullite offer multiple improvements
    • Have a higher SML and strength than cordierite – improved robustness
    • Enable system downsizing
      – Lower system cost
      – Less exposure to PGM pricing
      – Smaller package
    • Reduced system backpressure for reduced fuel consumption
Case 2 – Light-Duty Vehicle
# Light Duty Needs

<table>
<thead>
<tr>
<th>LD Market Attribute</th>
<th>Engine Design Goals</th>
<th>Ways to Improve</th>
</tr>
</thead>
</table>
| • Aftertreatment is a large system expense for diesel – competing against gasoline engines | • Reduced system cost | • Reduce PGM usage  
• Downsize the aftertreatment system  
• Integration of aftertreatment |
| • Emission regulation | • Improved efficiency  
• Reduce light-off time | • Improved catalyst technology  
• Lower thermal mass substrates |
| • CO2 regulation | • Reduced fuel consumption | • Reduce post injection occurrences – more passive regeneration  
• Reduced DPF backpressure for lower pumping losses |
| • Customer satisfaction | • Maintain / reduce warranty while implementing new substrate materials | • Find appropriate high porosity substrate materials |
LD Diesel Aftertreatment
- System Architecture Trends

Integration critical to reduce aftertreatment costs to maintain diesel engine competitiveness

Integration critical to reduce aftertreatment costs to maintain diesel engine competitiveness

**Euro IV / V LD**
- Engine
- DOC
- DPF
- SCR / LNT

**Euro 6 / US Tier 2 Bin 5**
- Engine
- DOC
- DPF
- SCR / LNT

**Integrated Solutions**
- Engine
- DOC
- DPF/SCR
- DOC / LNT
- DPF
- DPF / DOC
- SCR / LNT

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Superior Coatability and Strength at High Porosity-Enables Multi-function Substrates without FE penalty

Coatability

- Standard AERIFY: Low backpressure at low & moderate coating concentrations
- Adv AERIFY: Add’l backpressure advantages at high coating concentrations

Curves are a combination of modeling and test data
### Value Analysis – LD (Integrated DPF/SCR)

#### Process Step

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<td>Coating (2)</td>
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<td>Integrated DPF/SCR</td>
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<td>PGM</td>
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<td>Coating (1)</td>
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<td>Canning (1)</td>
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<tr>
<td>System Cost</td>
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<td>Savings</td>
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#### Cost to OE ($)

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- **Value Creation**
  - Downsized package size
  - Lower Total Systems Cost
  - Less Sensitivity to PGM variations
  - Backpressure (fuel efficiency) advantages
  - Weight savings
  - Lower thermal mass (faster light-off)
Light-Duty System

• Conclusions
  – Light-duty vehicles have some unmet needs
    • Reducing the system cost
    • Reducing CO2 / fuel consumption due to regulation
    • Maintain durability performance
  – System architectures are evolving to help meet those needs
    • Integrated solutions are the trend
    • Improved controls enable high porosity solutions
  – New DPF products like Acicular Mullite meet multiple needs
    • Enable high washcoat loadings while minimizing backpressure on DPF
    • Eliminate separate substrates and cans to enable system cost savings
    • Provide higher soot mass limits and durability than other materials at the same porosity
Thank You