New Cordierite Diesel Particulate Filters for Catalyzed and Non-Catalyzed Applications

G.A. Merkel, T. Tao, W.A. Cutler
Corning

A. Chiffey, P. Phillips, A. Walker
Johnson Matthey
Outline

- General overview of pressure drop behavior
- Relationship of pressure drop to pore microstructure for bare cordierite filters
- Effects of catalyst on pressure drop
- Optimization of pore microstructure for pressure drop, filtration efficiency, strength, and thermal mass
Pressure Drop versus Soot Loading

1. **Clean filter**

2. Soot deposited on walls of large surface pores

3. Soot deposited across necks of surface pores

4. Soot deposited as a discrete layer on channel walls

Optimize pore microstructure to minimize effect of soot in wall
Experimental Study

- Objective: Quantify relationship between pressure drop and pore microstructure and utilize to design optimized filter
  - Fabricated 2” x 6” cordierite filters (200 cpsi) with over 100 different pore microstructures
  - Characterized %porosity, median pore size, and width of pore size distribution by mercury porosimetry
  - Measured clean and artificial soot-loaded pressure drop vs flow rate at room temperature
  - Derived a model for pressure drop in terms of pore parameters
  - Catalyzed selected candidates to determine optimum pore microstructure for catalyzed filter
Porosity and Median Pore Size

35-65% porosity
4-40 μm pore size
Pore Size Distribution

Measures of the width of the pore size distribution curve:

- Full width: \( \frac{(d_{90} - d_{10})}{d_{50}} \)
- Coarse fraction: \( \frac{(d_{90} - d_{50})}{d_{50}} \)
- Fine fraction: \( \frac{(d_{50} - d_{10})}{d_{50}} \)
Pore Size Distribution

(d_{50} - d_{10})/d_{50}

Median Pore Diameter (microns)
Key Learnings from Data Analysis

• **Clean pressure drop** decreases for larger values of $(\%\text{porosity})(\text{median pore size})^2$
  - Consistent with models of flow through cylindrical capillary pores
  - Median pore size is dominant

• **Soot-loaded pressure** drop decreases for larger values of $\%\text{porosity}$ and smaller values of $(d_{50}-d_{10})/d_{50}$, narrower pore size distribution
  - Better pore connectivity
  - Lower gas velocity through pore necks
  - Less dense packing of soot in near-surface pores
Curves Computed from Regression Equations: Effect of Pore Size Distribution

50% Porosity
\(d_{50} = 12 \, \mu m\)

Narrower pore size distribution reduces effect of soot in surface pores

Pressure Drop (kPa)

Soot Loading (grams/liter)

2” x 6”
200/12
144,000 hr\(^{-1}\)
Curves Computed from Regression Equations: Effect of Porosity

\[
\frac{(d_{50}-d_{10})}{d_{50}} = 0.60 \\
d_{50} = 12 \, \mu m
\]

Higher porosity also reduces effect of soot in surface pores

2” x 6”
200/12
144,000 hr⁻¹
Catalysis Coating Study

- Six cordierite materials with range in pore microstructures
- 2” x 6” filters, 200 cpsi, 12 mil walls
- Artificial soot loaded and pressure drop tested
- Soot burned out at 650°C
- Catalyzed and soot-loaded pressure drop re-measured
- Two catalyst systems examined
  - Detailed results for System “A”
  - Summary of System “B” versus “A”
Porosity and Median Pore Size

% Porosity

Median Pore Diameter (microns)

50-9N  60-13N  60-14B  60-29B
50-11B  50-29B
Examples of Pore Microstructures

60-13 N
60-14 B
60-29 B
50-9 N
50-11 B
50-29 B

100 µm
Soot-Loaded Pressure Drop of Catalyzed Filters
Bare & Catalyzed Pressure Drop: 50% Porosity

2” x 6”
200/12
144,000 hr⁻¹

Pressure Drop (kPa)

Soot Loading (grams/liter)

- Large increase in soot-loaded pressure drop
- Small increase in clean pressure drop

Catalyst A
Bare

50-11B
Bare & Catalyzed Pressure Drop: 50% Porosity

2” x 6”
200/12
144,000 hr⁻¹

Soot Loading (grams/liter)
Pressure Drop (kPa)

Catalyst A
Bare

Large increase in soot-loaded pressure drop
Modification of pore microstructure by catalyst results in denser packing of soot in pores

Small increase in clean pressure drop

“Cat A”
Bare & Catalyzed Pressure Drop: 50% Porosity

Modification of catalyst formulation enables low pressure drop for coated 50-11B

- Catalyst A
- Catalyst B
- Bare
Bare & Catalyzed Pressure Drop: 50% Porosity

2” x 6”
200/12
144,000 hr⁻¹

Narrower pore size distribution more important than median pore size
Bare & Catalyzed Pressure Drop: 60% Porosity

2” x 6”
200/12
144,000 hr⁻¹
Pressure Drop Summary (5 grams/liter soot loading)

2” x 6”
200/12
144,000 hr⁻¹

Catalyst A

- Pore microstructures that yield low $\Delta P$ for bare filters also provide low $\Delta P$ on catalyzed filters
- Percent increase is larger for filters with higher pressure drop

Graph showing:
- Bare Pressure Drop (kPa) vs. Catalyzed Pressure Drop (kPa)
- Points indicating +100%, +50%, +40%, +30%, +15% increase

Additional notes:
- 2" x 6" 200/12 144,000 hr⁻¹
- Pressure Drop Summary (5 grams/liter soot loading)
Pressure Drop Summary (5 grams/liter soot loading)

2” x 6”
200/12
144,000 hr⁻¹

Catalyst A shows similar trend, lower pressure drops

Modification of catalyst formulation enables any filter to be catalyzed with only small increase in pressure drop
Thermal Durability during Regeneration
Regeneration and Volumetric Heat Capacity

- Temperatures reached during uncontrolled regenerations must be minimized for survivability of both filter and catalyst.
- Peak temperature is reduced for filters with high “thermal mass” (heat capacity per unit volume).
Pressure Drop vs Volumetric Heat Capacity of Bare Filters

- **DuraTrap CO 200/12**: Increased thermal mass
- **DuraTrap RC 200/19**: Reduced pressure drop
- **DuraTrap EC 200/12**: Reduced pressure drop

Pressure Drop:
- 5 grams/liter
- 144,000 hr\(^{-1}\) (kPa)
Pressure Drop vs Volumetric Heat Capacity of Bare Filters

- **Pressure Drop**
  - 5 grams/liter
  - 144,000 hr\(^{-1}\) (kPa)

- **Volumetric Heat Capacity of Filter** (Joules/liter K)

- **DuraTrap CO**
  - 200/12

- **DuraTrap RC**
  - 200/19

- **Developmental HTM filters**
  - 42% Porosity 200/16 SiC
  - 60% Porosity 300/12 SiC

- **Developmental ULPD filters**

![Graph showing pressure drop vs volumetric heat capacity for different filters](image-url)
Summary

- By tailoring the ceramic pore microstructure or catalyst formulation, very low pressure drops have been achieved for catalyzed cordierite DPFs.
- Soot-loaded $\Delta P$ for bare or catalyzed filters is minimized for high pore connectivity (high porosity or narrow psd).
- Bare or catalyzed filters with moderate %porosity and fine, narrow pore size distribution yield soot-loaded $\Delta P$ equivalent to high-porosity filters with coarse, broad pore size distribution.
Conclusion

- Research on effects of pore microstructure, cell geometry, and catalyst formulation have yielded new catalyzed cordierite DPFs with unique combinations of low $\Delta P$, high %FE, and higher thermal mass, without sacrificing strength.