Particle Sizing Experience with Composite and Extruded Diesel Particulate Filters

Z. Gerald Liu, Joseph Lincoln, Randy G. Zoran and Robert K. Miller
Fleetguard/Nelson, A Cummins Company

In order to reduce diesel particulate emissions, extruded cordierite and silicon carbide diesel particulate filters are currently used in some aftertreatment system applications. The micro-structures of cordierite and silicon carbide diesel particulate filters tend to accelerate soot-cake formation. After the soot-cake is formed, particles are primarily collected through surface filtration. A composite diesel particulate filter made of fibrous materials is being developed (Miller, et al., 2002). The microstructure of the fibrous filter is supposed to be effective for nano-particle collection. Also, the fibrous filter performs depth filtration, therefore, it is anticipated that this type of filter has high soot holding capacity. The three types of filters were characterized for validating assumptions and for comparing performance.

This paper reports our preliminary experience of particle sizing with the three types of diesel particulate filters described above. The paper describes the particle size distributions downstream of the three filters, explain new findings and observations, validate assumptions, and compare filter performance.

The composite filter has triangular cell geometry with overall dimensions of 26.7cm (10.5 in.) in diameter and 22.9 cm (9 in.) long. To make this filter, a layer of pleated composite media is laminated to a flat layer of medium with an edge of the structure being sealed as the two layers are brought together. The resulting laminate is then wound upon itself while the alternate and opposite edges are also sealed to form a wall-flow diesel particulate filter (Miller et al., 2002). The cordierite and SiC DPFs are extruded monolithic with square cell geometry. The cordierite DPF has a cell density of 100 cell per square inch (cpsi) while the SiC DPF has a cell density of 200 cpsi. Both of these DPFs have overall dimensions of 26.7 cm (10.5 in.) in diameter and 30.5 cm (12 in.) in length. They are all canned using a perforated star-plug to uniformly direct the exhaust to the DPF inlet. The flow distribution across the DPF inlet surface was simulated and tested to be close to uniform.

In this study, particle number and volumetric distributions of engine out emission without a DPF clearly demonstrate a mono-modal distribution for the majority of the ISO-modes, although two modes have a bimodal size distribution. The lack of nuclei-mode should be attributed to the ultra-low sulfur content of the diesel fuel.

The fractional efficiency results show that all three filters yield efficiencies greater than 99% for most ISO-modes, with the lowest efficiencies occurring at ISO-modes of high engine load, such as 6 and 8. For the cordierite DPF, the lowest efficiency occurs during ISO-mode 6, with a minimum efficiency at a particle size of approximately 100 nm. SiC also experiences its lowest efficiency during ISO-mode 6, but with a minimum efficiency at a particle size of approximately 250 nm.

This study also shows that the total efficiency values measured by the FTP procedure are always 10 – 50% lower than the efficiencies calculated with the SMPS data. In addition, the FTP efficiency values are fluctuating without a pattern throughout the testing.

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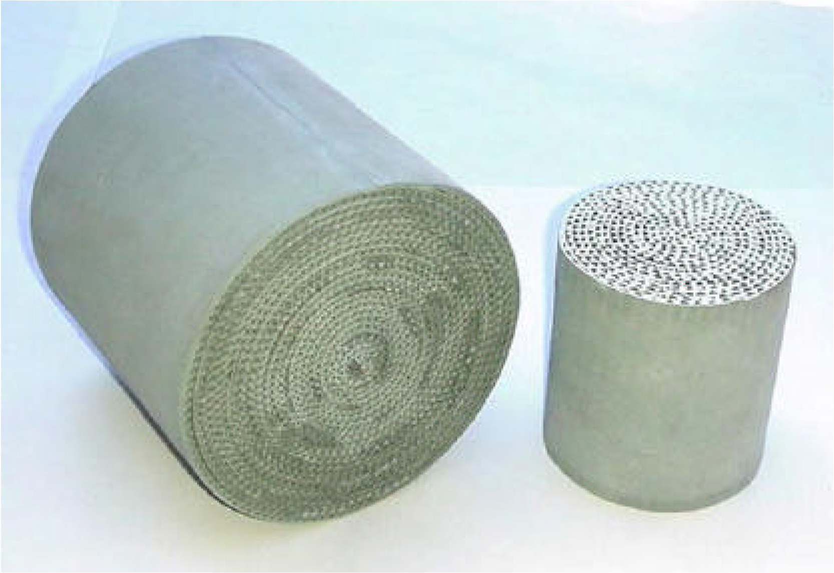
Introduction

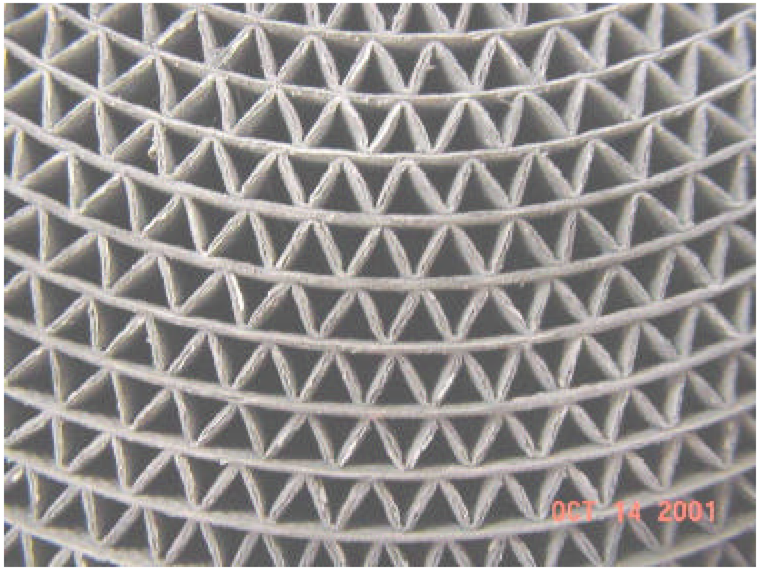
- DPFs are used to meet increasingly stringent emission standards in diesel engine applications.

- DPFs include extruded monolithic, spiral wrapped, and other structures.

- DPFs are made of silicon carbide, cordierite, ceramic fibers, and other porous materials.

Introduction





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Introduction

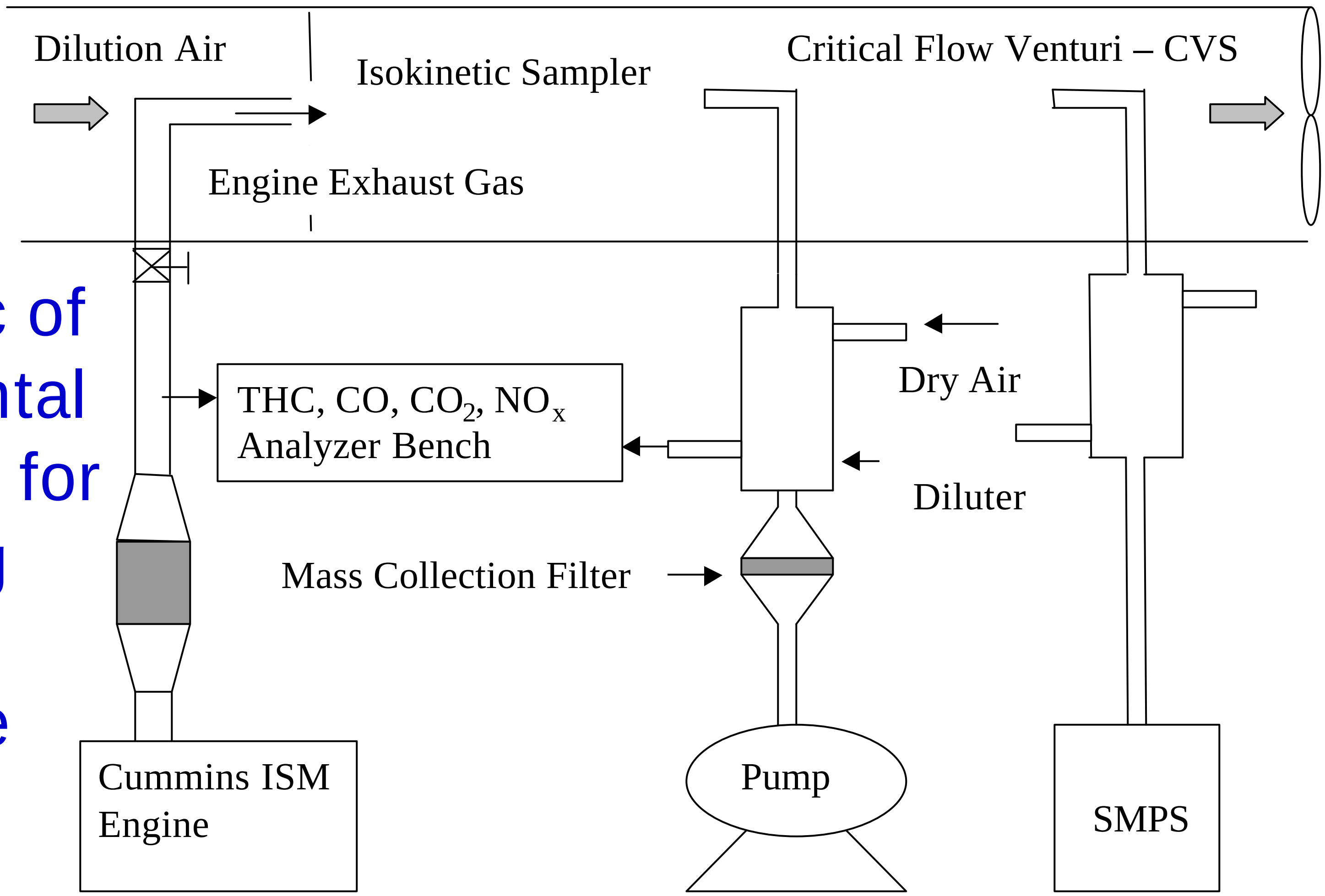
- Current regulations have focused on reducing the mass of PM emissions.
- The size distributions of PM influences their environmental behavior, as well as their impact on the engine, itself.
- Epidemiological studies have shown the health impact of diesel exhaust to be a function of particle size.

Introduction

- Fractional efficiency is an important measure of DPF performance.
- DPF performances are currently measured using various laboratory procedures.
- This paper reports on studies for measuring the fractional efficiency and particle size distributions of DPFs with various porous materials - a part of FGN/3M effort for testing methods evaluation.

Experimental Methods

- Schematic of experimental apparatus for Evaluating Diesel Particulate Filters



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Experimental Methods

- DPF data: 10.5” D by 9” L fibrous composite, 10.5” D by 12” L cordierite and silicon carbide.

Property	Composite Media	100 cpsi Cordierite	200 cpsi Silicon Carbide
Filter Bulk Density (g/cc)	0.26	0.46	0.73
Porosity (%)	85	49 [11]	42 [12]
Median Pore Size (μm) (via Mercury Intrusion)	-	13 [11]	8.7 [12]
Open Pore Size (μm) (via Capillary Flow)	11	6	-
Permeability (1/m)	8.0e-12	6.1e-13 [11]	1.2e-12 [12]
Inertia Parameter (m^2)	7.4e+5	5.4e+7 [13]	-
BET Surface (m^2/gm)	1.0	0.17	-

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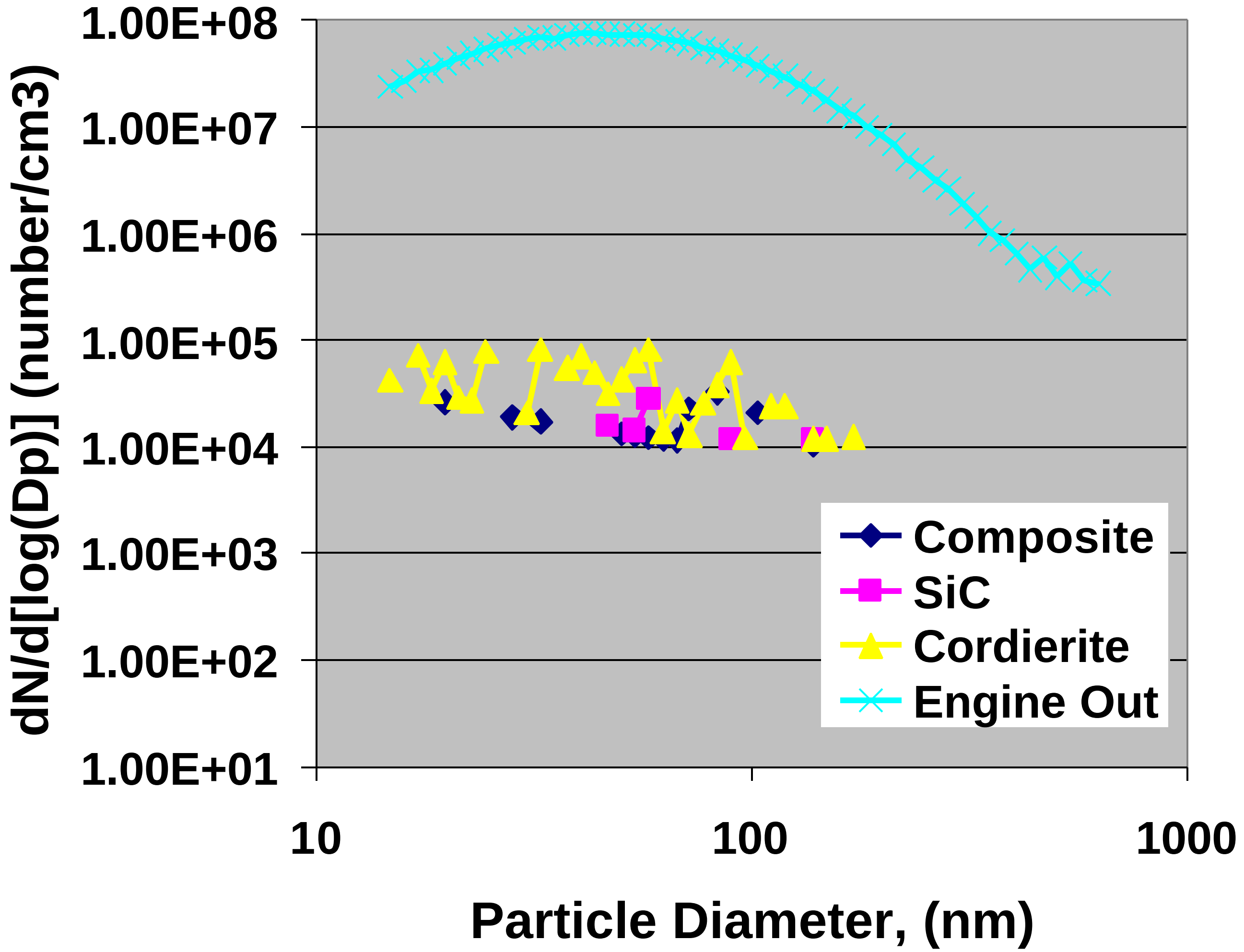
Particulate Size Distributions

- Number distribution for ISO Mode 3



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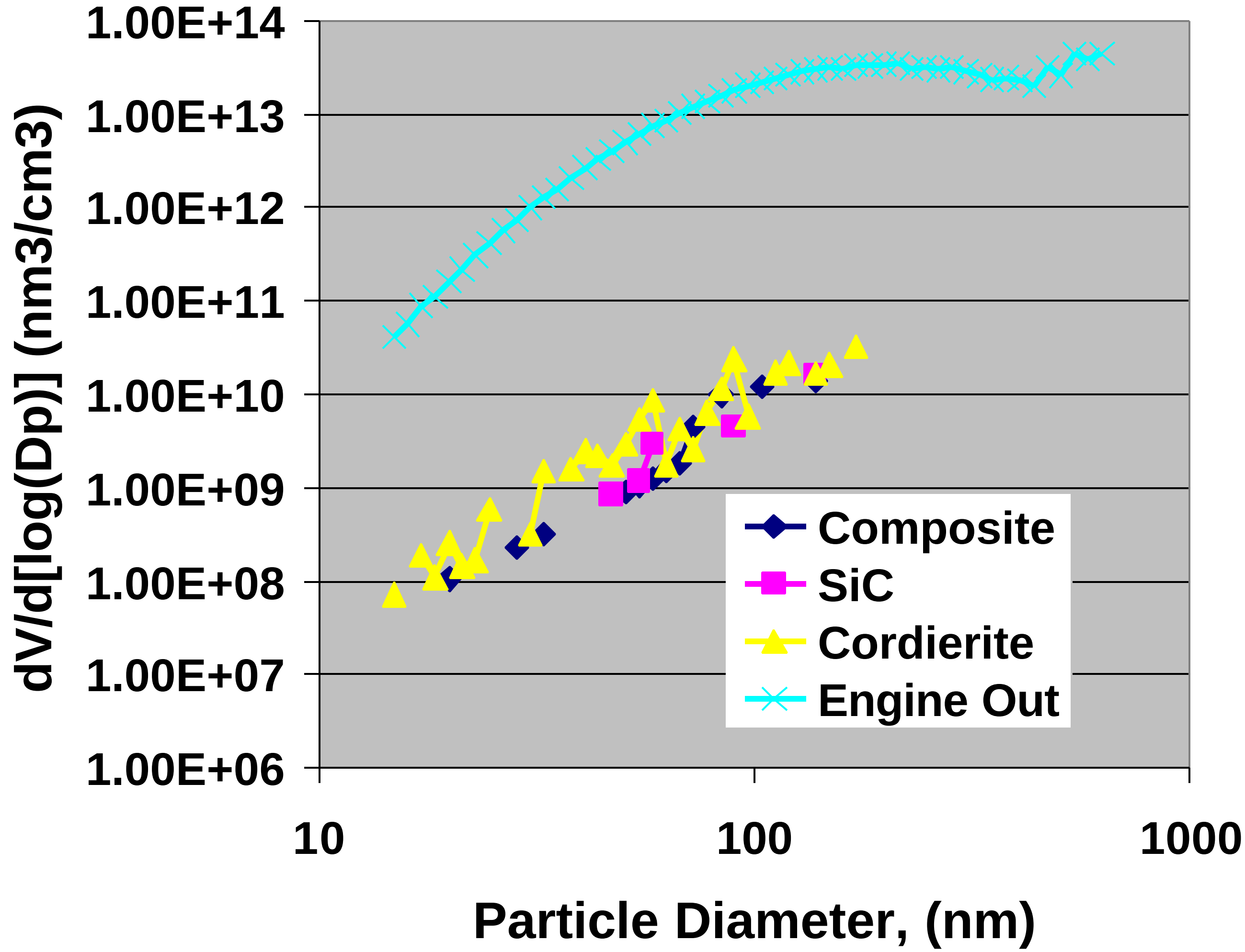
Particulate Size Distributions

- Volumetric distribution for ISO Mode 3



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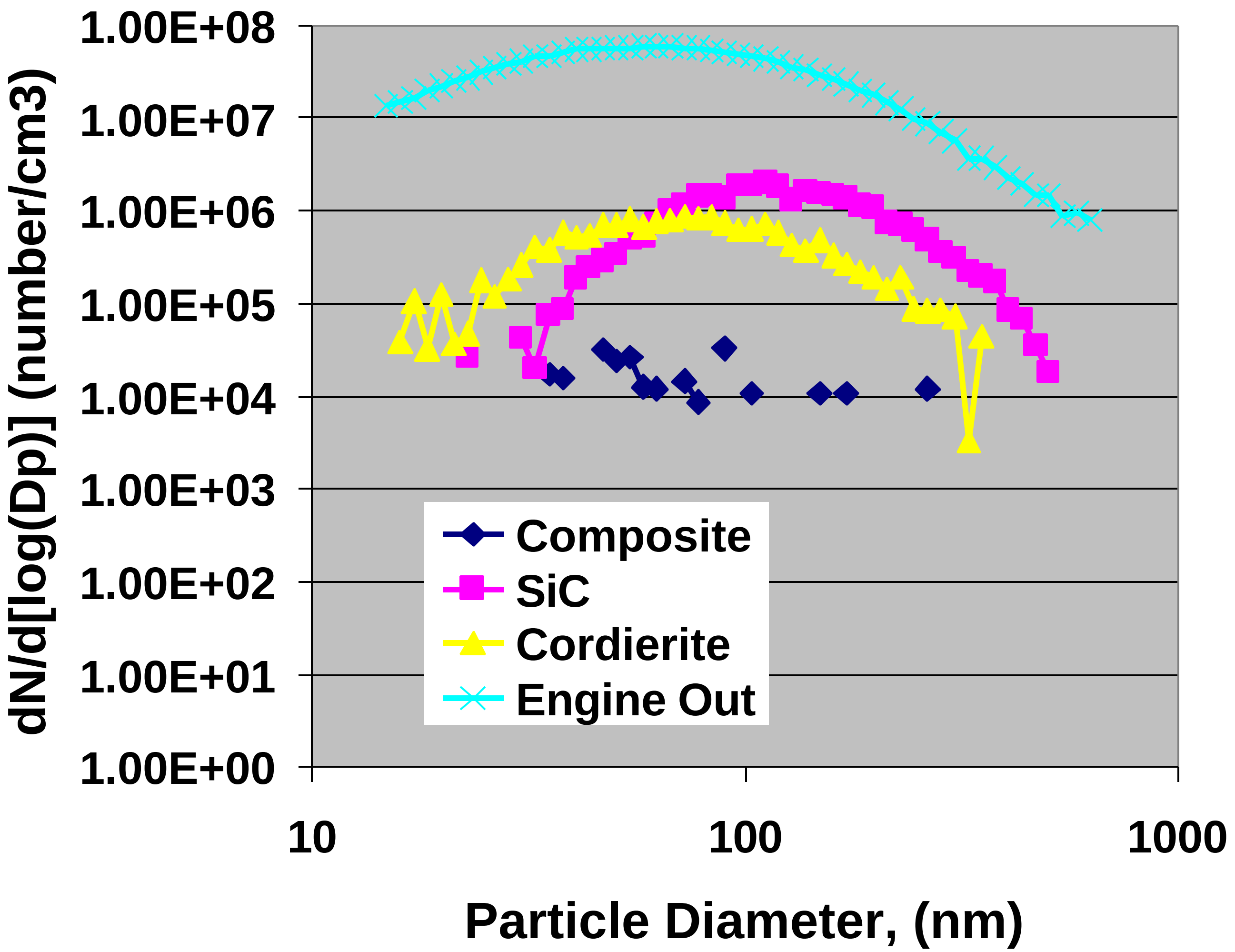
Particulate Size Distributions

- Number distribution for ISO Mode 6



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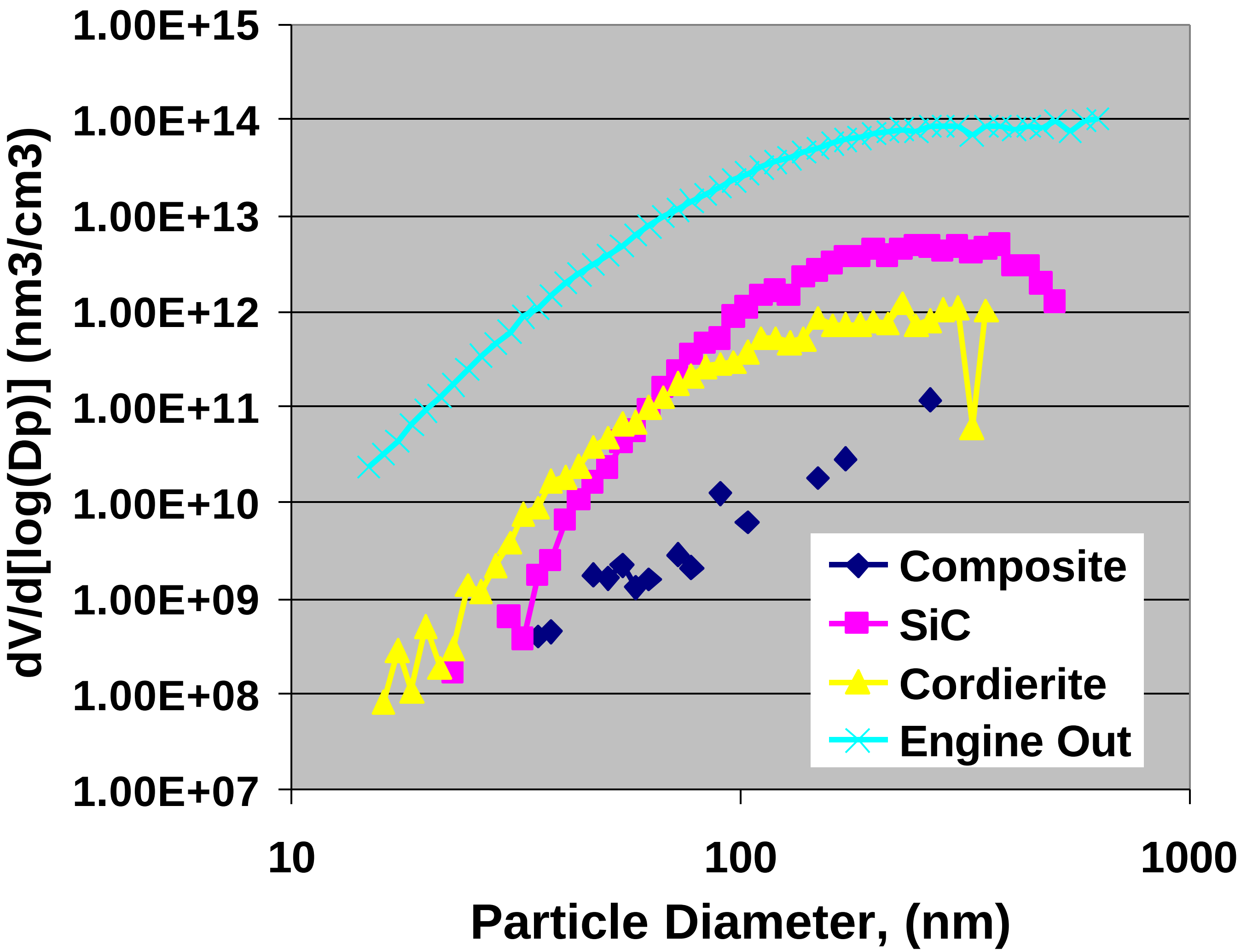
Particulate Size Distributions

- Volumetric distribution for ISO Mode 6



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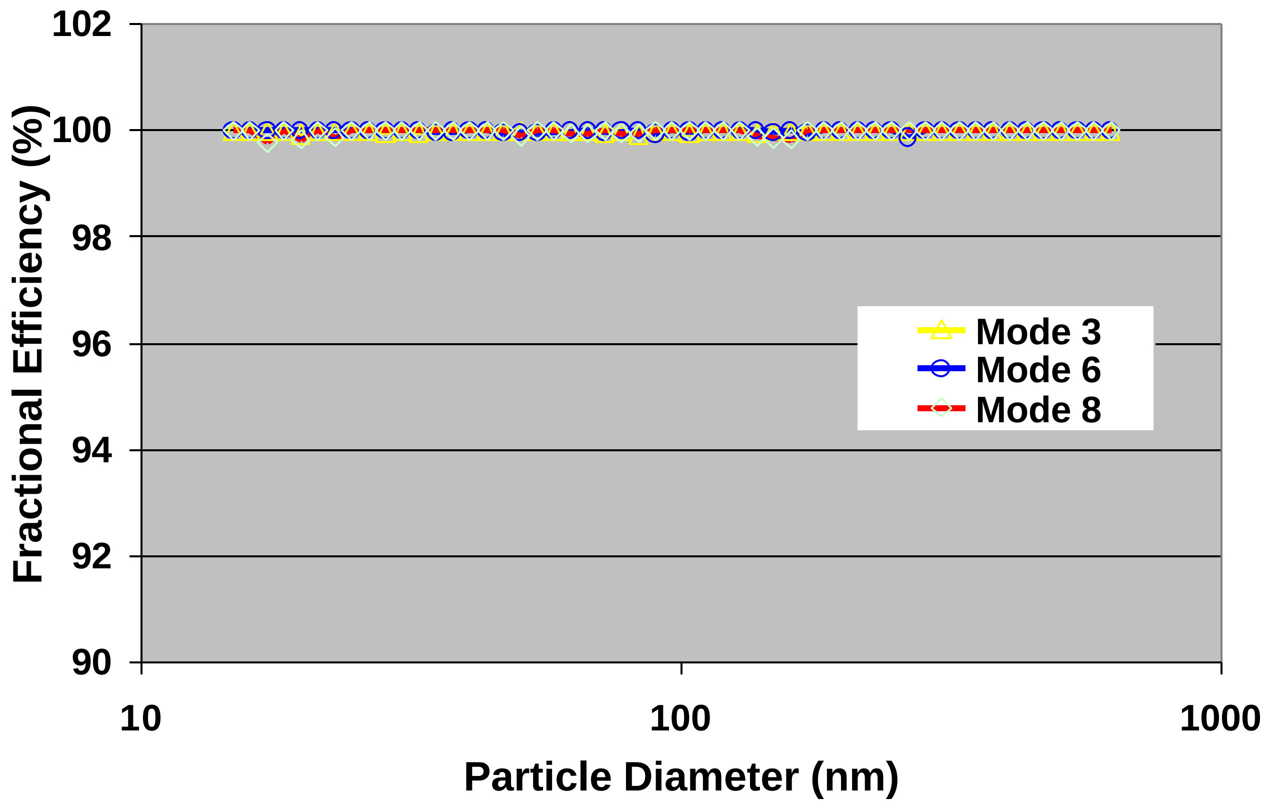
Fractional Efficiency Results

- Fractional Efficiency Results for a Composite DPF



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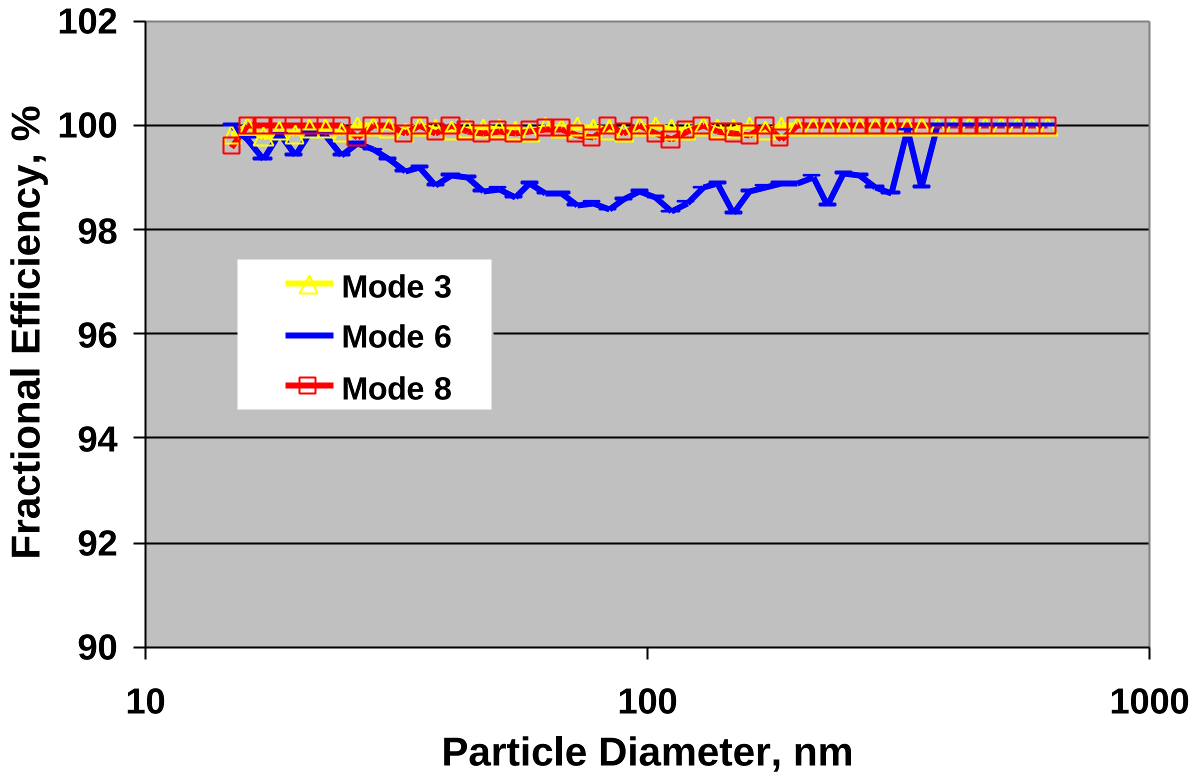
Fractional Efficiency Results

- Fractional Efficiency Results for a Cordierite DPF



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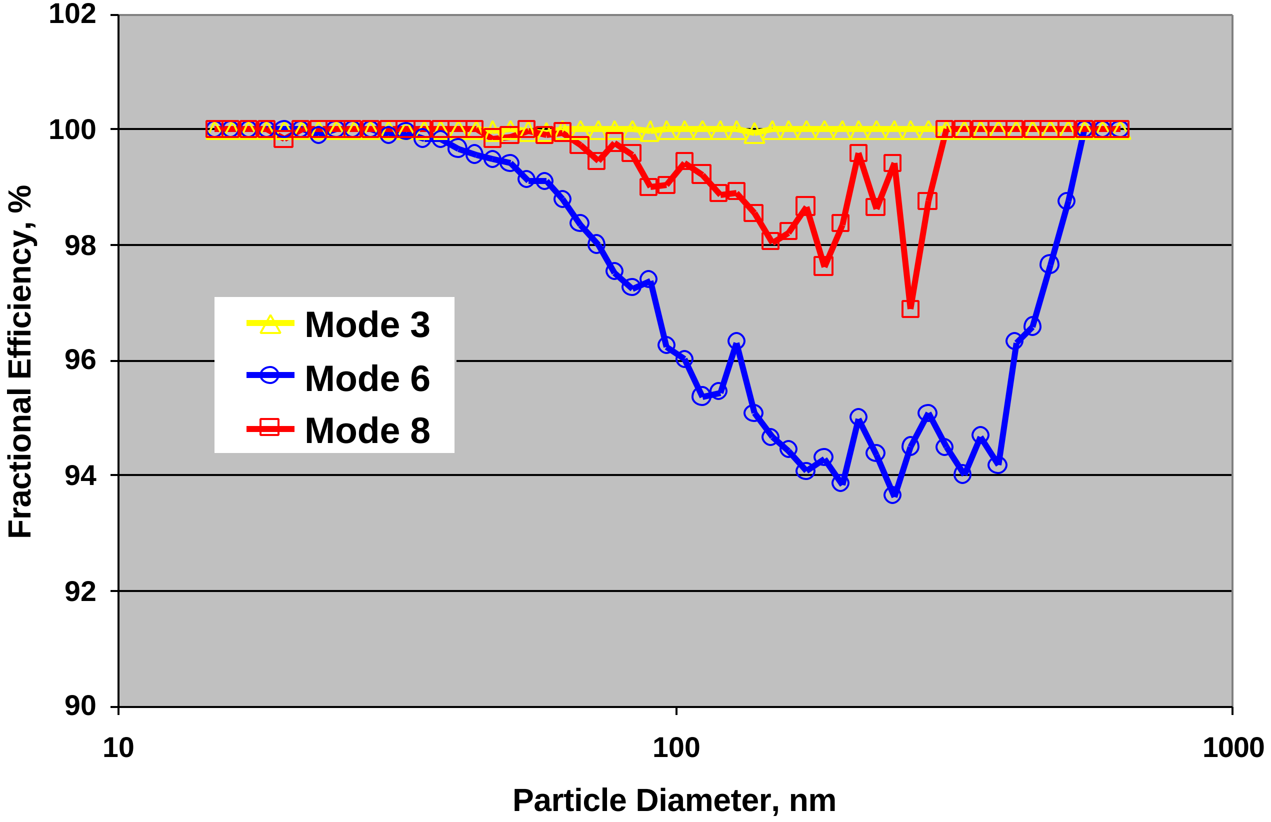
Fractional Efficiency Results

- Fractional Efficiency Results for a SiC DPF



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Conclusions

- On-engine fractional efficiency testing of DPFs that simulates atmospheric dilution is feasible, but test conditions, sampling and dilution procedures must be representative and well-defined.

- Sulfur contamination seems to have the greatest impact on the measurement of fractional efficiency.

Conclusions

- The efficiency based on the gravimetric method is always lower than the fractional efficiency. EC/OC/SOL analysis agrees better with the SMPS measurements.
- The fractional efficiency of the DPF behaves as predicted by filtration theory. At ISO Mode 6, more particles penetrate some extruded DPFs. These particles need to be determined if they are the most penetrating particles or contamination.