Fundamental investigation of SIDI particulate filtration using an exhaust filtration analysis (EFA) system.

Sandeep Viswanathan and David Rothamer

Motivation
- Engine nano-particles appear in large number concentration and can have high toxicity [Croisan. 1999, Ulrich. 2012]
- Use of gasolone particulate filters (GPFs) to control particulate emissions has been successfully demonstrated [Johnson. 2013]
- Modeling efforts require a fundamental understanding of the filtration process within the filter bed

Goals
- Evaluate the relevance of current filtration theory within the SIDI particulate filtration regime
- Understand the impact of different particle properties, filter properties and loading conditions on the dominant capture mechanisms
- Create high quality database to support modeling efforts for SIDI particulate filtration

Background

Most Penetrating Particle Size (MPPS)
\[ \eta_{\text{Total}} = \eta_d(P_e) + \eta_k(\text{Stk}, a) + \eta_{\text{Int}}(R, a) + \eta_{\text{Int}}(R, P_e, a) \]

(Hinds. 1982)

Stages of Filtration
- Deep-Bed Filtration
  - Particles retained throughout filter medium
  - Length scale for particle capture changes rapidly
- Cake Filtration
  - Particles retained at media surface by filter cake
  - Length scales remain unchanged
  - Filtration Efficiency > 99%

Experimental Setup

Research Engine
- Single cylinder Spark-Ignition Direct-Injection (SIDI)
  - Compression Ratio: 11.97
  - Displacement: 549 cm³
- Tier II EEE fuel (certification gasoline)

Gaseous Emissions
- Raw Emissions: CO₂, CO, O₂, NOₓ, HC
- Diluted Emissions: CO₂

Particle Measurement Instrumentation

Instruments | EEPS | SMPS
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Charging Mechanism (Particle Size) | Unipolar | Bipolar
Measurement duration | 0.1 s | 30 s
Range | 7 to 530 nm | 10 to 1000 nm
Sample flow | 10 lpm | 1 lpm
Particle size resolution | 32 size-bins | 90 size-bins
Noise floor | ✫ | ✫

Exhaust Filtration Analysis System (EFA)

- Steps to minimize particle losses:
  - All temperatures optimized
  - Heated ejector diluter
  - Bypass Valve → Allows for equilibration before data collection
  - High flow rate in inlet line → Reduces diffusional losses

Losses have been characterized for different conditions

Engine Exhaust
Oven (175°C)
Excess Flow
Dilution Air
Ejector Diluter
EEPS / SMPS
CO₂ Analyzer

Layout Optimization
- Engine out PSD fluctuates by as much as 50% during steady state operation
- EEPS & SMPS were compared upstream and downstream of a filter

Exhaust Characterization

Effect of Particle Size Distribution (PSD)

Baseline (EOI 220) Condition
- Simplified unit collector theory [Lee. 1981] was unable to explain the large changes in MPPS despite a negligible change in pressure drop across the filter.

All Conditions
- Decrease in clean filter penetration of diffusion mode particles seen with increasing GMD
- An increase in penetration of nucleation mode particles was observed with time for both the EOI 220 and MBT-15 conditions
- Rich condition might be operating in a regime where filtration length scales are significantly different
  - Currently analyzing data to further understand the effect of accumulation mode particles on diffusion capture

Future Work
- Effect of filter properties on deep-bed filtration performance
- Fundamental filtration experiments using simple pore geometries
- High temperature (600 °C) filtration experiments to understand the effects of filter regeneration

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