Micro-scale Investigation of Ash Accumulation Process in a Diesel Particulate Filter

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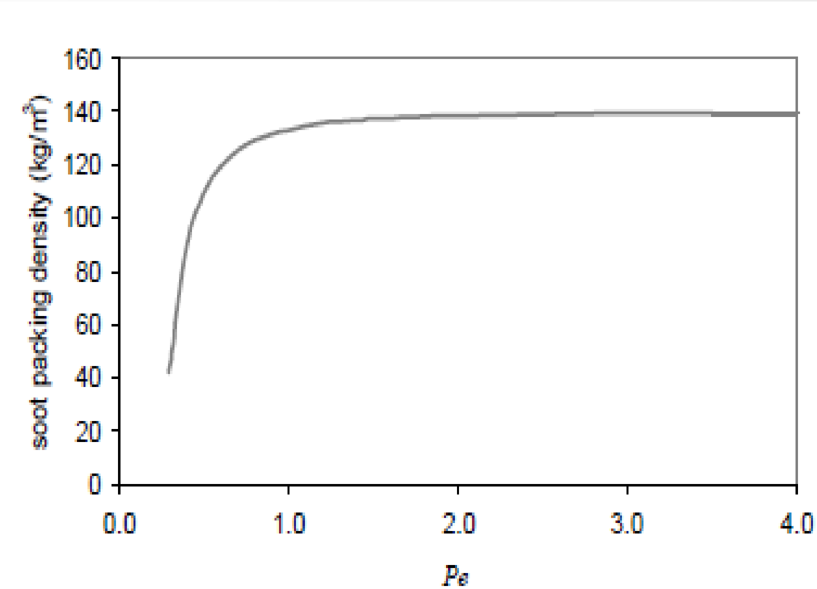
Outline

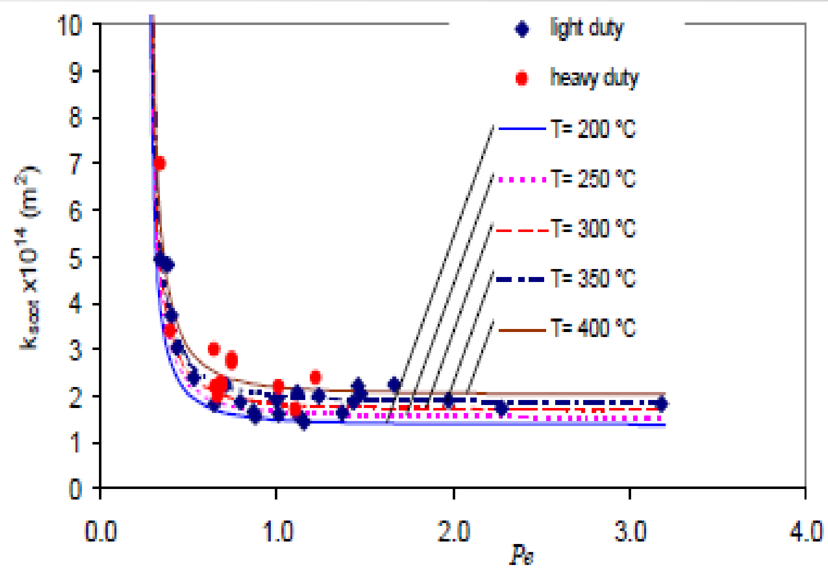
- Background
- Motivation
- Research Objectives
- Experimental Setup
- Previous Work
- Results – Ash Penetration Study
- Results – Substrate Comparison Study
- Conclusions

Background: Impact of Peclet number

[Konstandopoulos, A. G.]

$$Pe \equiv \frac{U_{\infty} L}{D} \quad where \quad \begin{array}{l} U_{\infty} = Freestream\ Velocity \\ L_{char} = Characteristic\ Length \\ D = Mass\ Diffusion\ Coefficient \end{array}$$





The characteristic length scale can vary from the largest pore size to the primary particle size during the wall loading stage making it difficult to use a single Pe number to define the wall loading process.

Motivation

- New PM regulations are calling for better Particle Number (PN) emissions and advanced regeneration strategies. [Johnson, T.]
- DPF regeneration frequency and duration to affects fuel economy as well as DPF life [Rose, D., and Boger, T.]
- This requires an accurate estimate of the soot load and hence, a more fundamental understanding of the PM and ash accumulation process in a DPF [Gaiser, G. and Sappok, A.]

Objectives

- To gain fundamental understanding of the ash deposition process within the walls of a DPF and understand the impact of the PM deposition process on ash accumulation
- To investigate how differences in substrate properties can affect the PM and ash deposition process in a DPF

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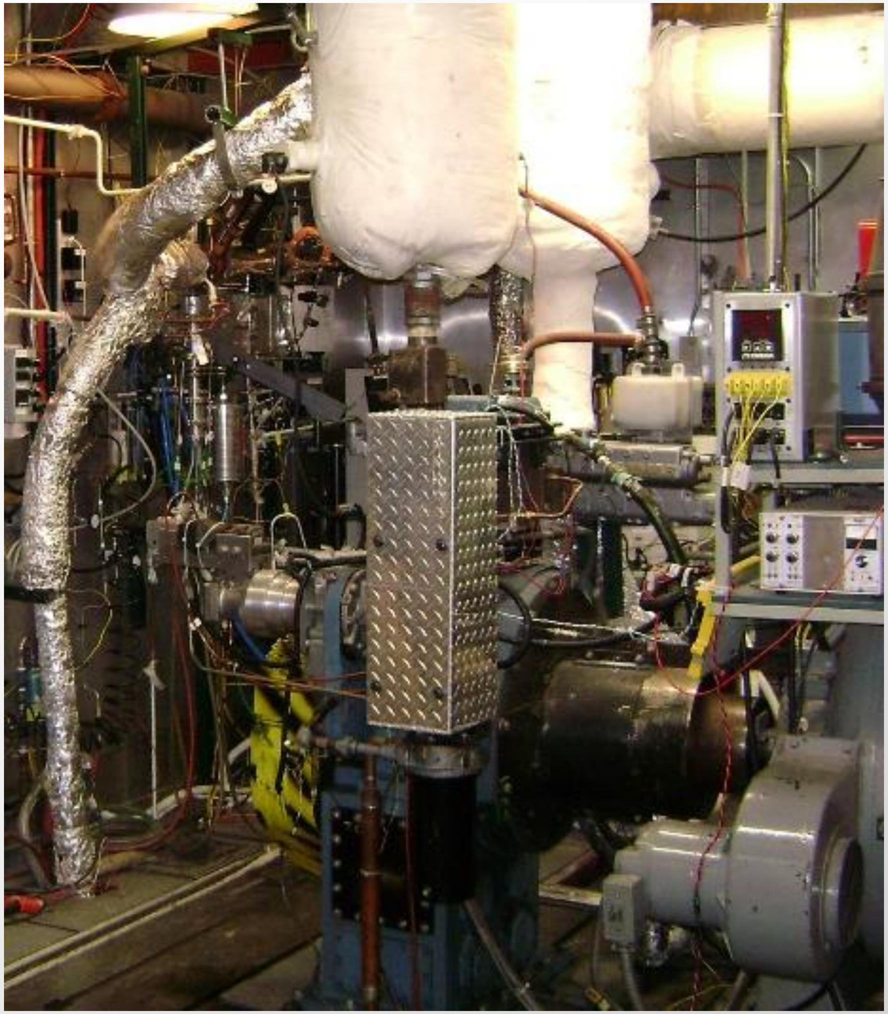
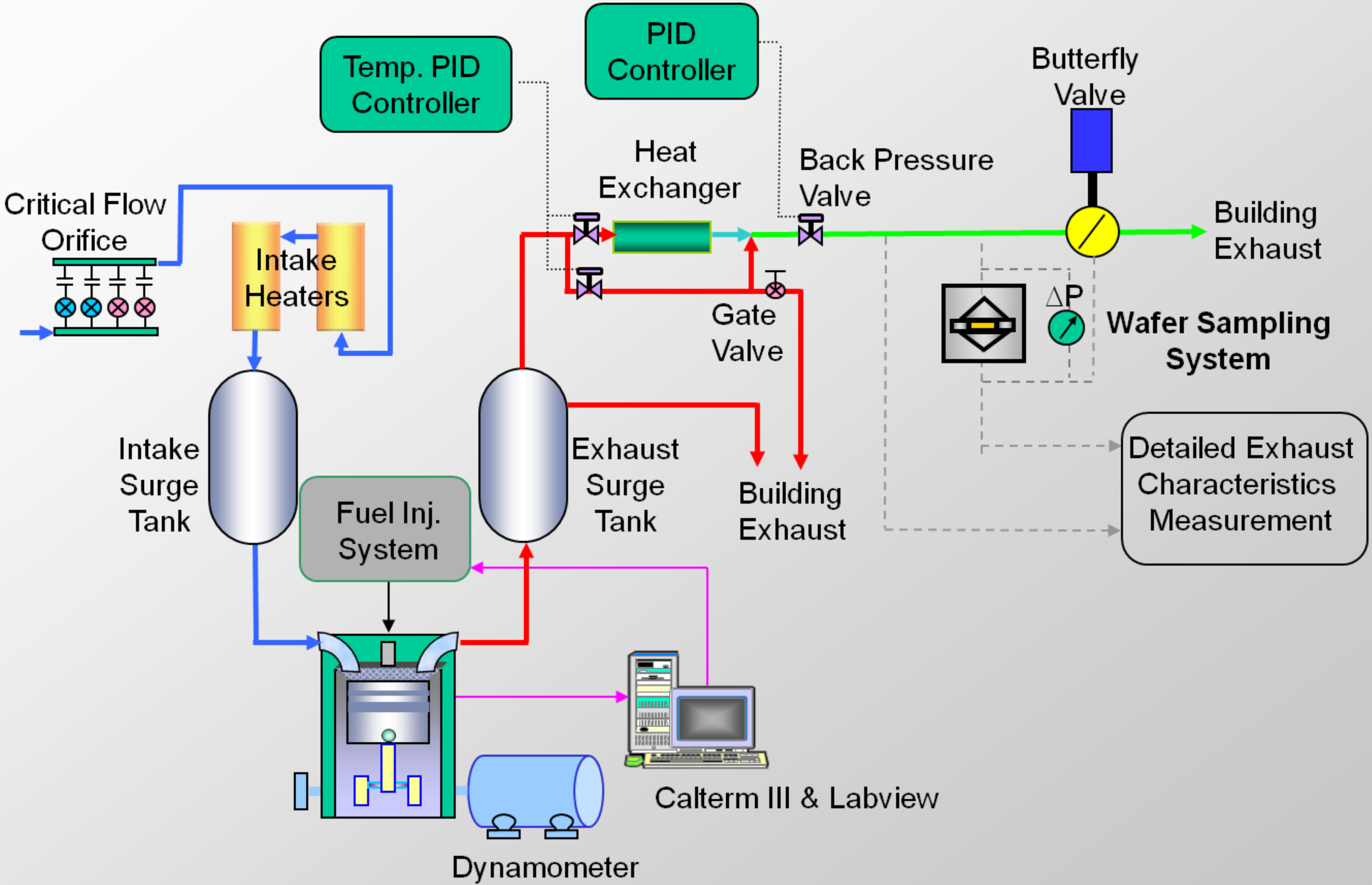
Experimental Engine

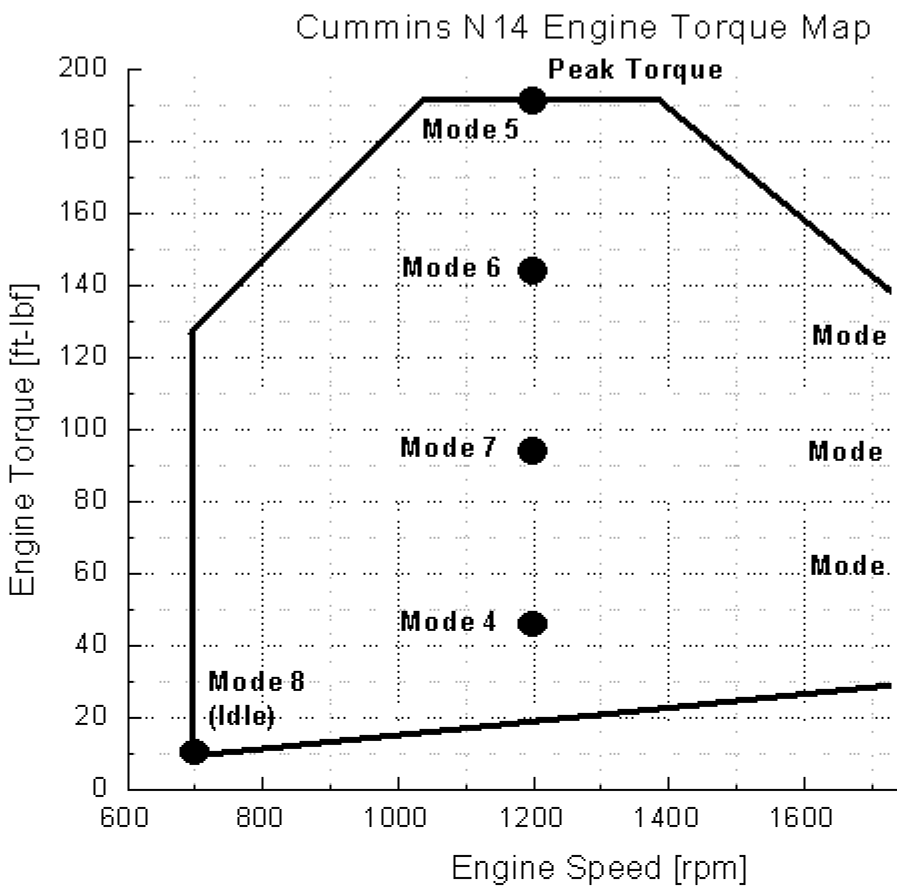


Base Engine	1-cyl. Cummins N14
Displacement	2.3 L
Compression Ratio	14.1:1
Bore x Stroke	139.7 mm x 152.4 mm
Injection System	Common Rail
Fuel	Chevron – Generic No. 2 Diesel
Oil	Low ash, Rotella (0.45 wt% sulfur)

Lab Schematic



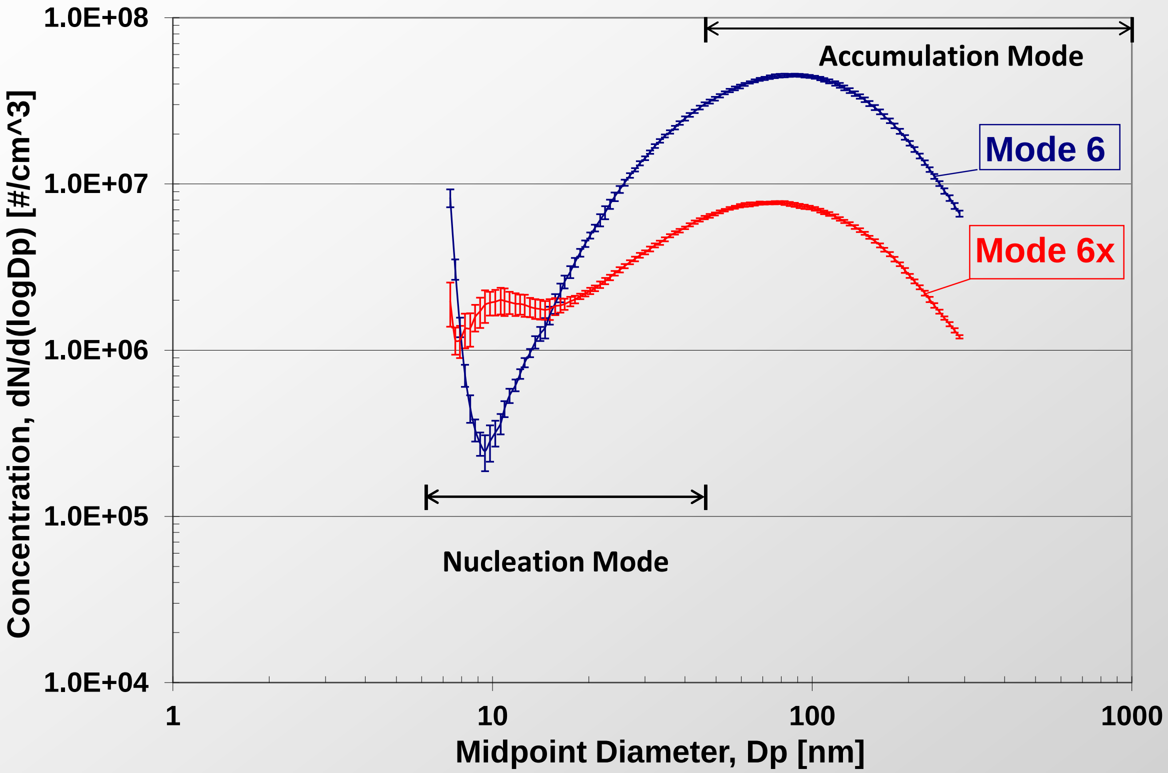
Engine Operating Conditions

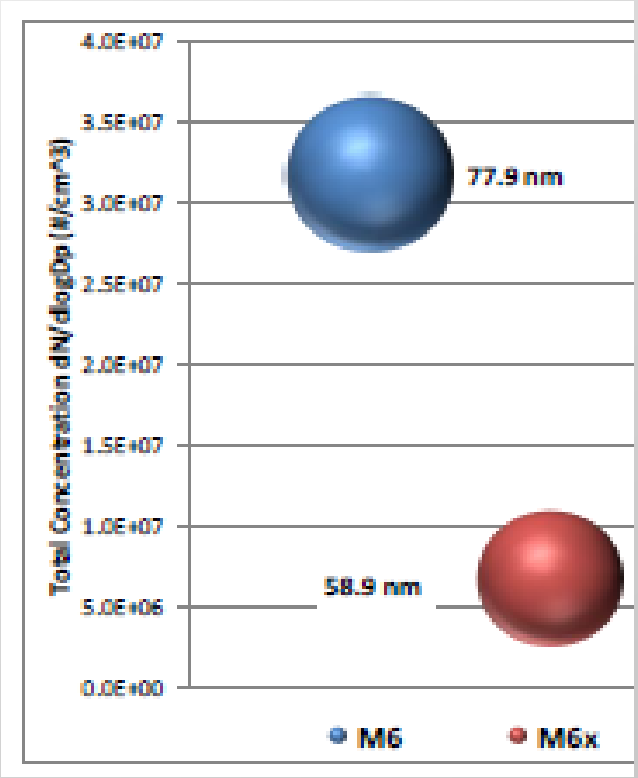


Mode	6	6x
Speed	1200	1200
Torque (N-m)	213.1	225.7
Power (kW)	26.8	28.3
IMEP (bar)	11.45	12.12
Fuel Inj. Press. (bar)	850	1200
# of Injections	1	3
Fuel Flow (kg/min)	0.0880	0.0870
A/F ratio	22.3	27
Abs. Intake Pressure (kPa)	148.5	166.6
Gage Exhaust Pressure (kPa)	65.5	65.5
Exhaust Temperature (°C)	619.9	507.7
DPF Inlet Temperature (°C)	265	265

Two different engine modes used to obtain widely different particle size distributions.

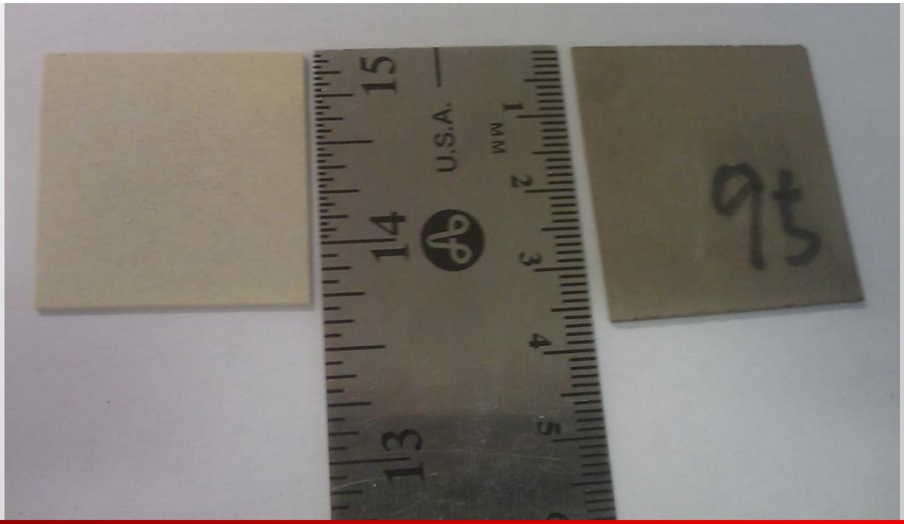
Characterization Results





Wafer Specs

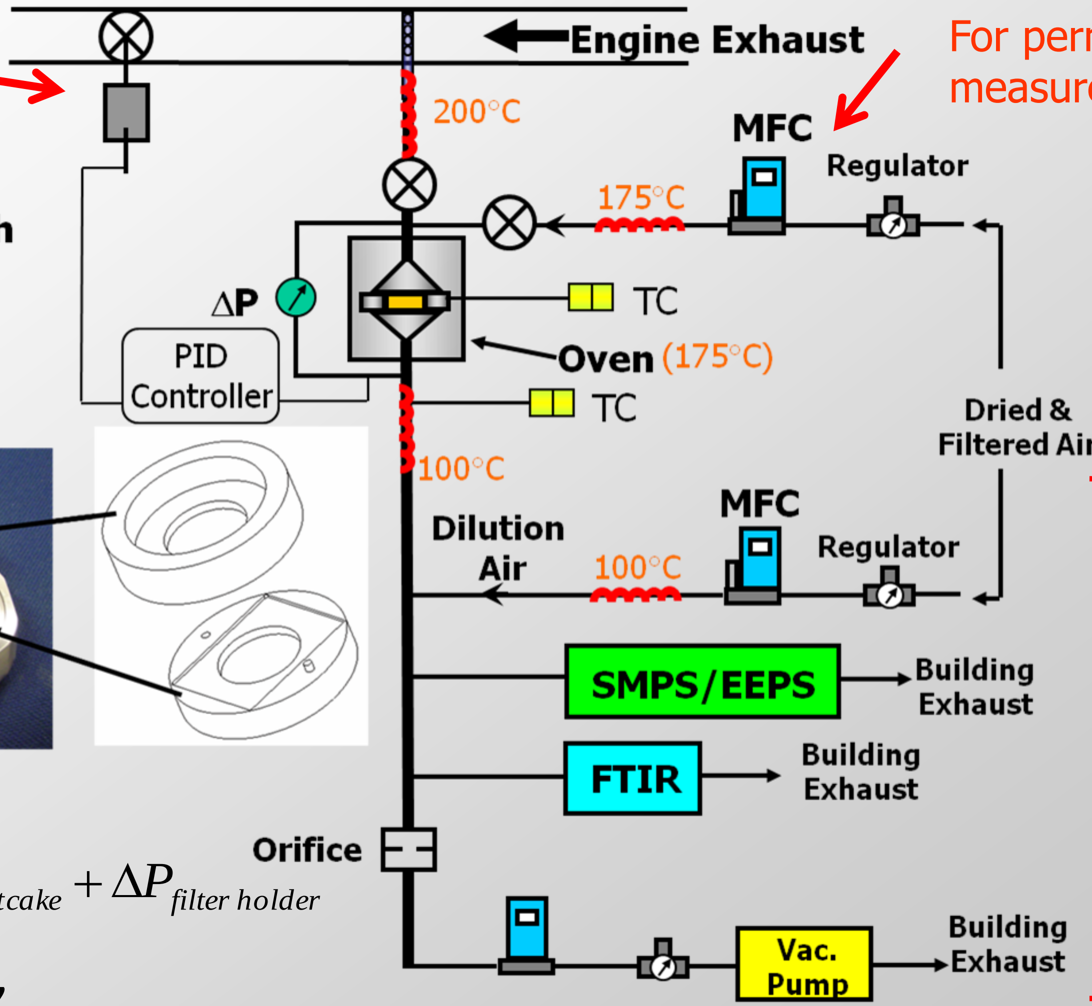
Wafer Designation	A	B
Material	Cordierite	
Manufacturing Batch	3	4
Size (mm x mm)	39 x 31.5	
Thickness (mm)	0.9823	0.9823
Porosity, ε	0.53	
Mean Pore Dia., d_{50} (µm)	12.3	
Washcoat	Yes	
Catalyst Loading	3 g/l Pt	

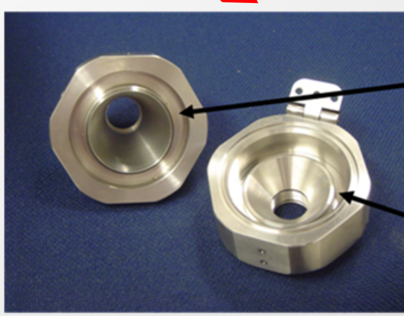


DEFA System/Hot Flow

Valve to maintain down stream pressure close to ambient

Filter holder mounted in oven





For permeability measurement

To precisely control flow through filter.

$$\Delta P_{total} = \Delta P_{loaded\,wall} + \Delta P_{soot\,cake} + \Delta P_{filter\ holder}$$

$$k_w(t) = \frac{\mu \cdot th_w}{\Delta P} \cdot v_{filtration}$$

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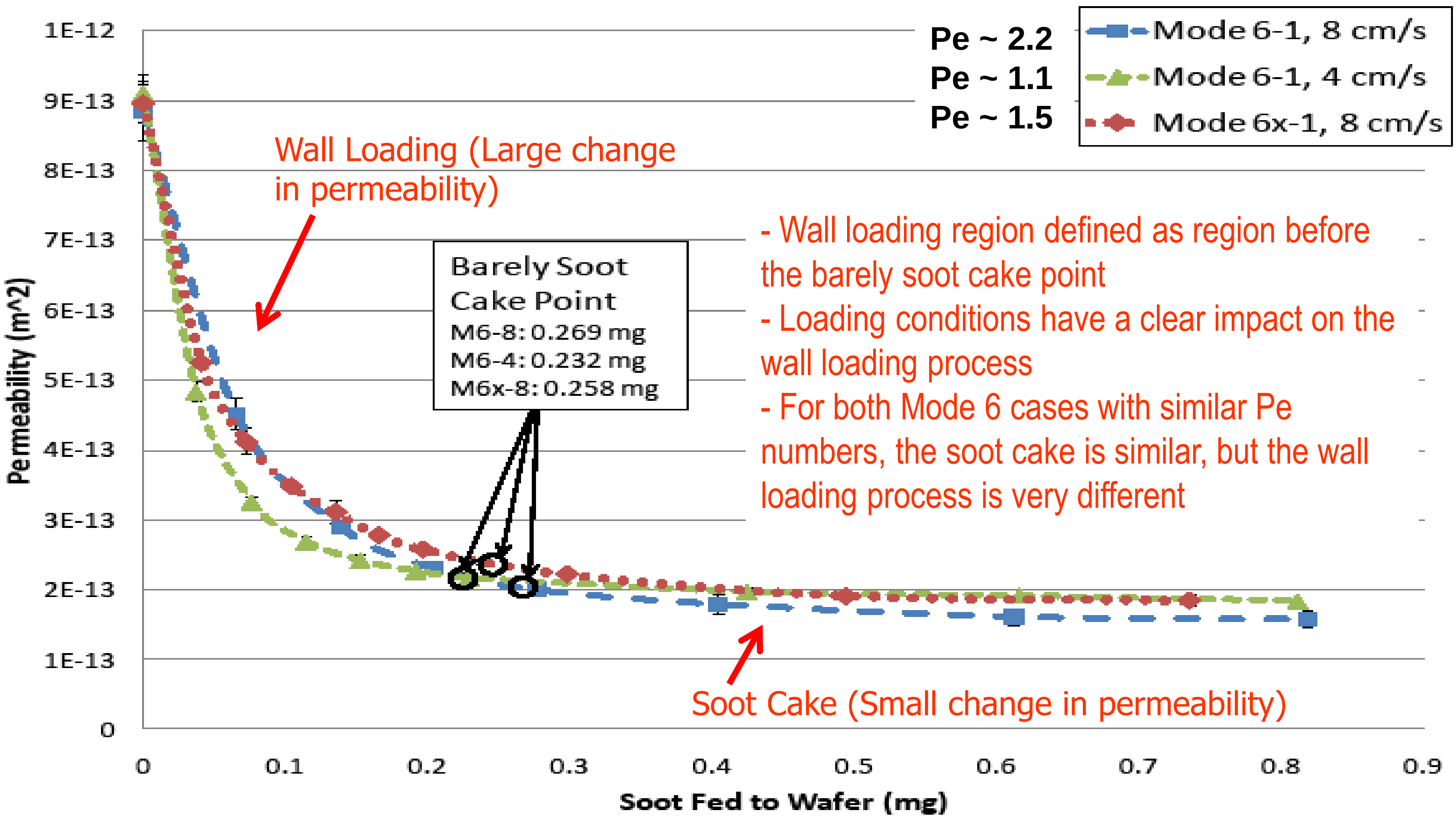
Results - Previous Work

- Three different loading conditions were used namely; Mode 6 at 8 cm/s filtration velocity, Mode 6x at 8 cm/s and Mode 6 at 4 cm/s filtration velocity

- ↓ the filtration velocity (from 8 cm/s to 4 cm/s) ➔ ↓ Pe, accelerated pore bridging, earlier peak filtration efficiency (>100%); due to more diffusional deposition [Rakovec.N]

- ↓ d_{mean} (from ~79nm to ~59nm) ➔ ↓ Pe, ↓ soot packing densities; deeper wall penetration ➔ accelerated pore bridging, (~250%) smaller peak particle breakthrough & (~100%) advanced time to achieve peak filtration efficiency [Rakovec. N, Yapaulo. R]

Results – Previous Work



- Wall loading region defined as region before the barely soot cake point
- Loading conditions have a clear impact on the wall loading process
- For both Mode 6 cases with similar Pe numbers, the soot cake is similar, but the wall loading process is very different

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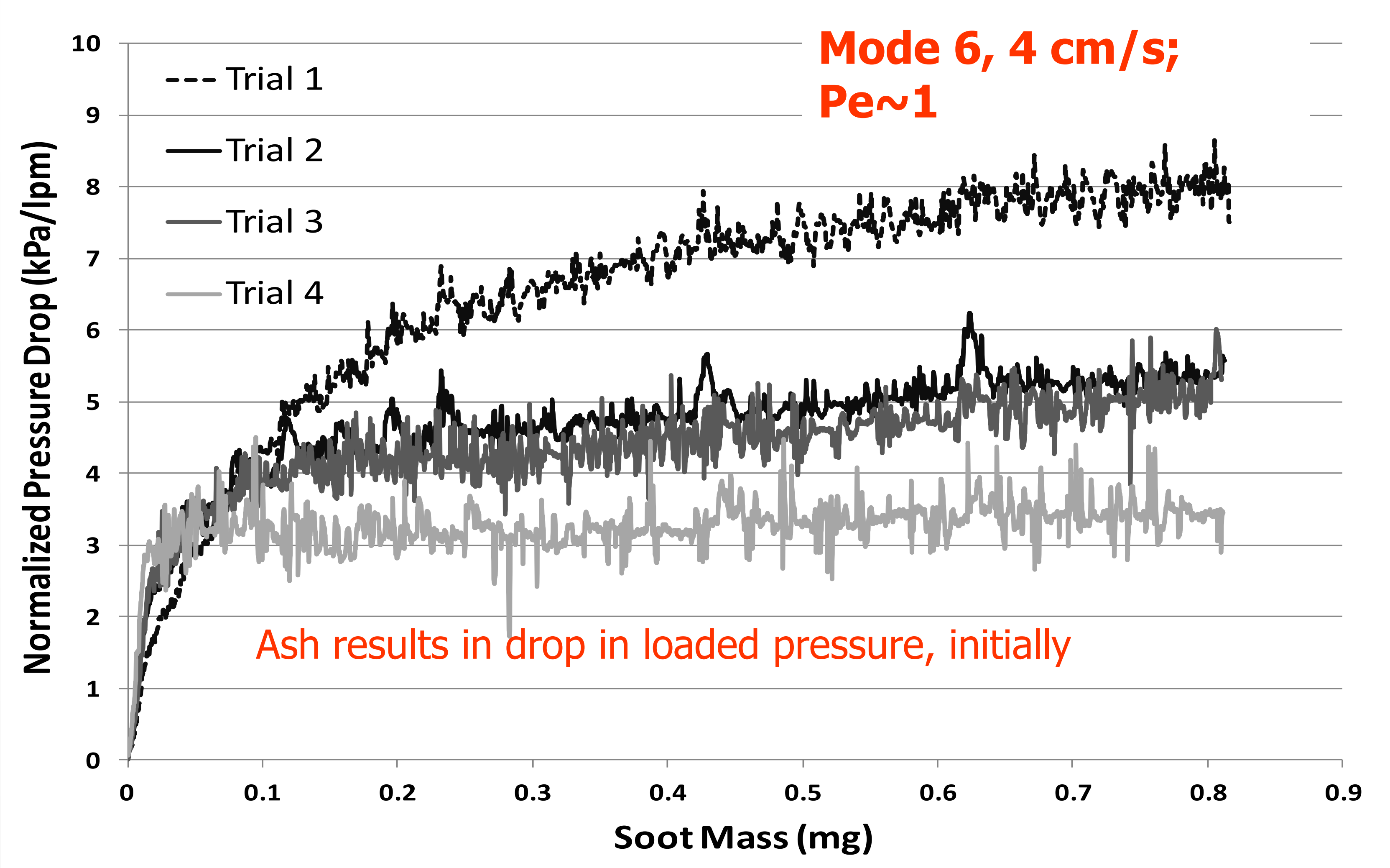
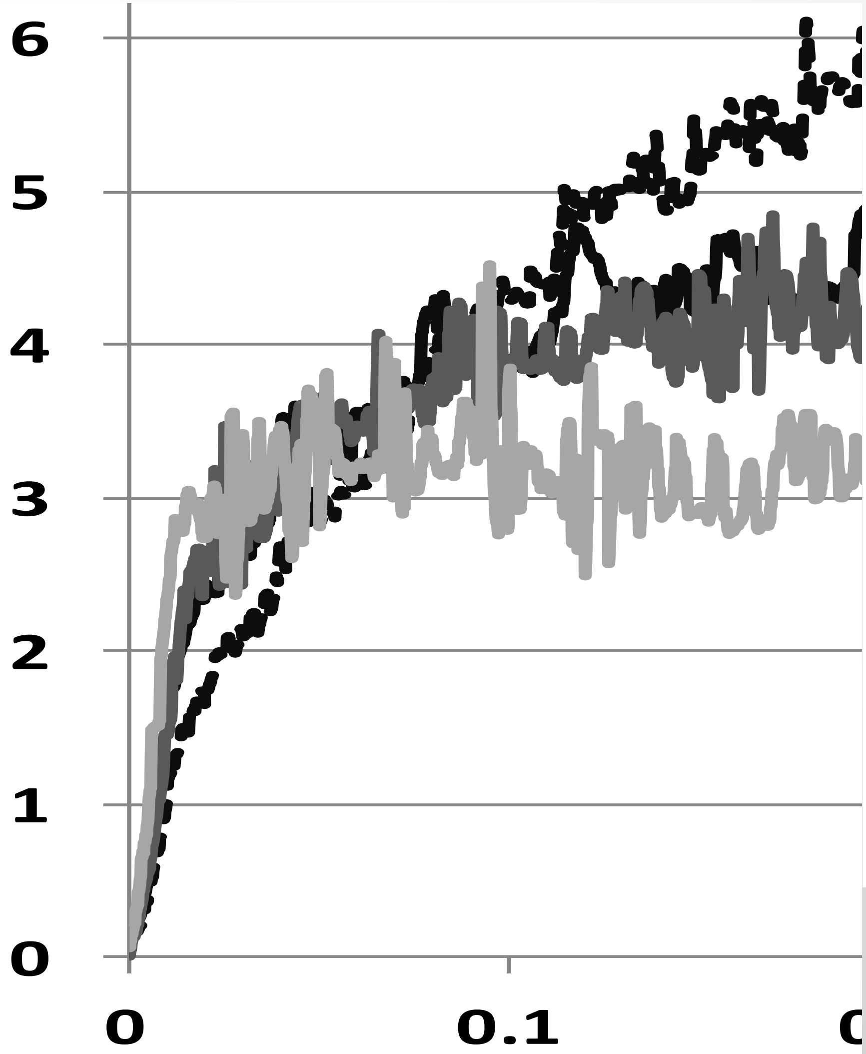
Procedure – Ash penetration study

- 4 wafers were selected for each of the three loading conditions
- Wafers were loaded using the DEFA up to a 1g/l PM loading and regenerated at 650 °C ex-situ
- One wafer was loaded & regenerated once, another one twice, one thrice and the last one four times
- The pressure drop, permeability and PBT history were recorded during each loading 'trial'

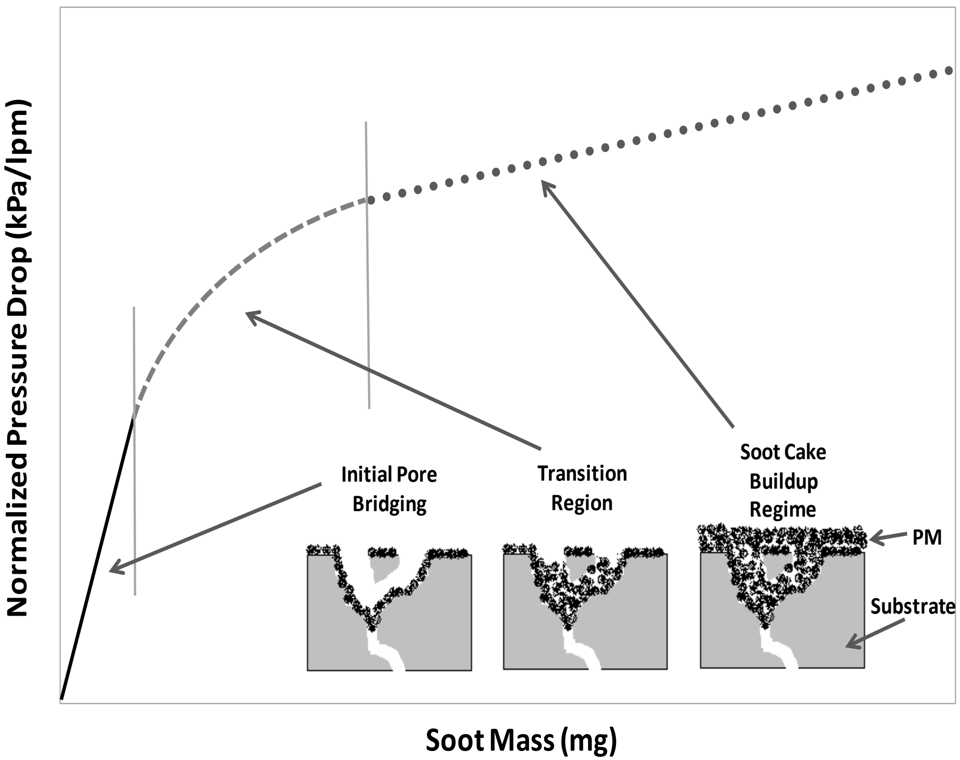
Effect on Pressure Drop



Effect on Pressure Drop

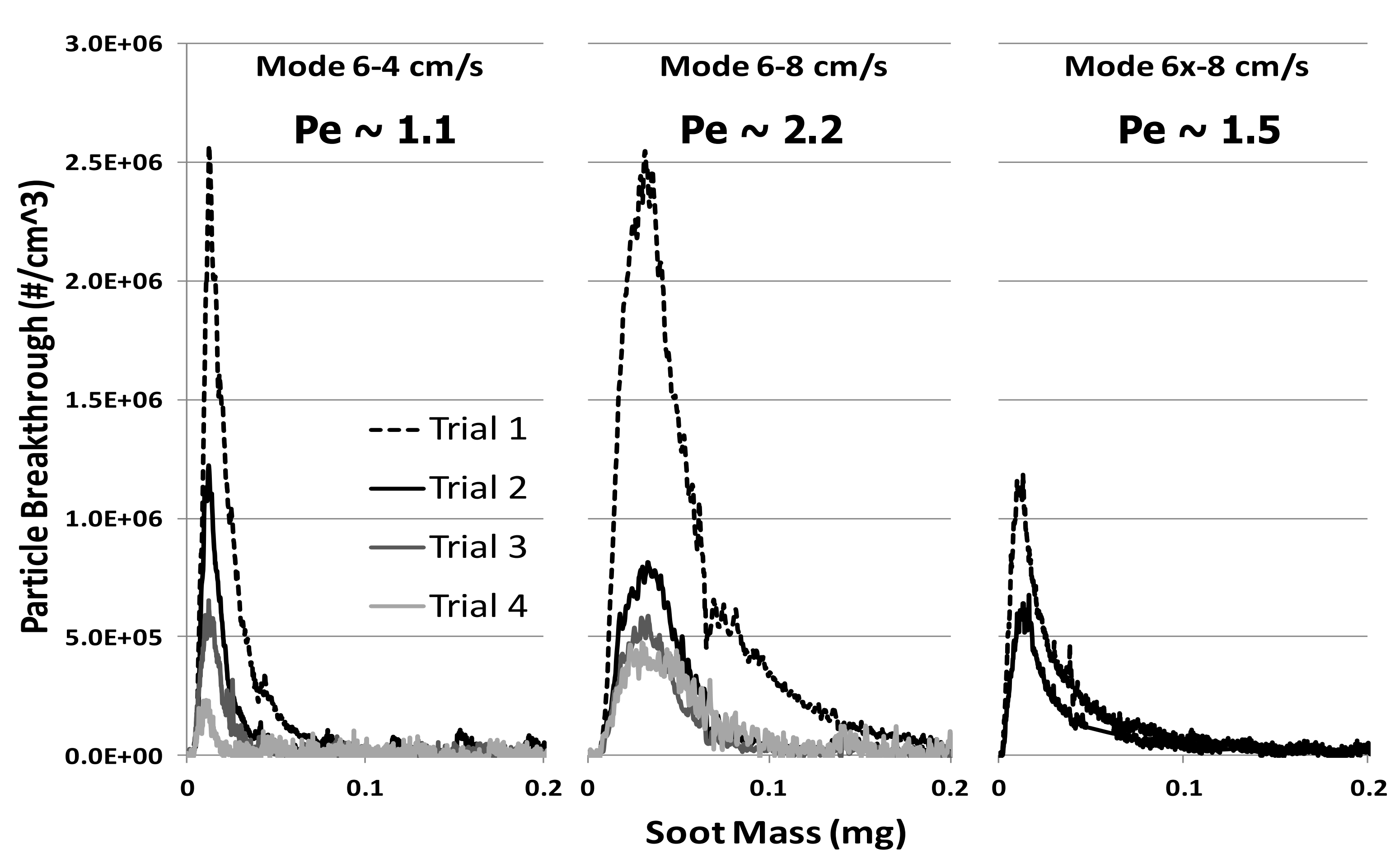


Mode 6, 4 cm/s; Pe~1



Focusing on the wall loading stage, ash effects both the transition as well as pore bridging regions.

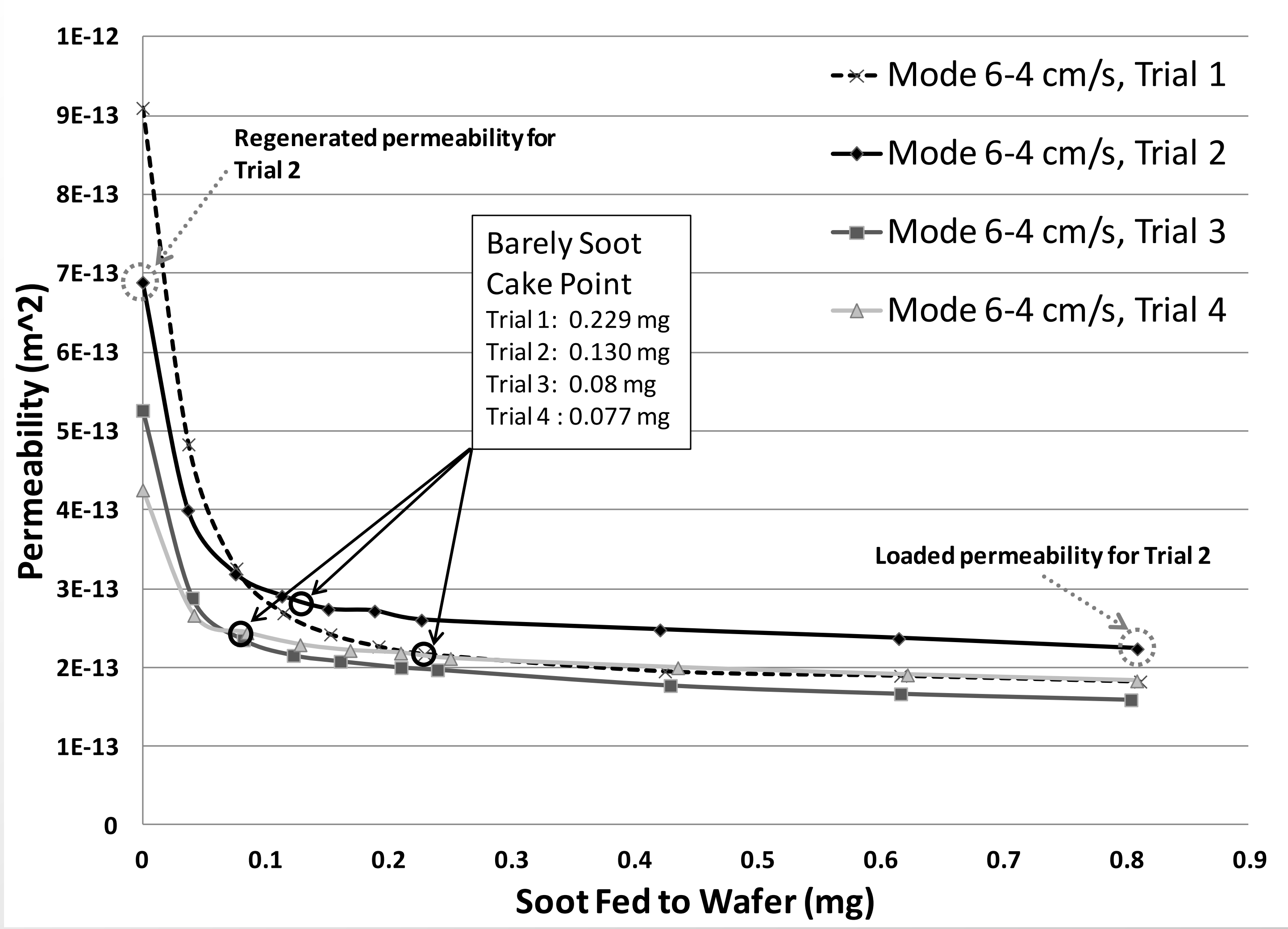
Effect on Particle Breakthrough



Impact of ash is different for different loading conditions :

- M6-4 most influenced overall
- M6-8 most influenced after first trial
- M6x-8 least influenced by ash accumulation

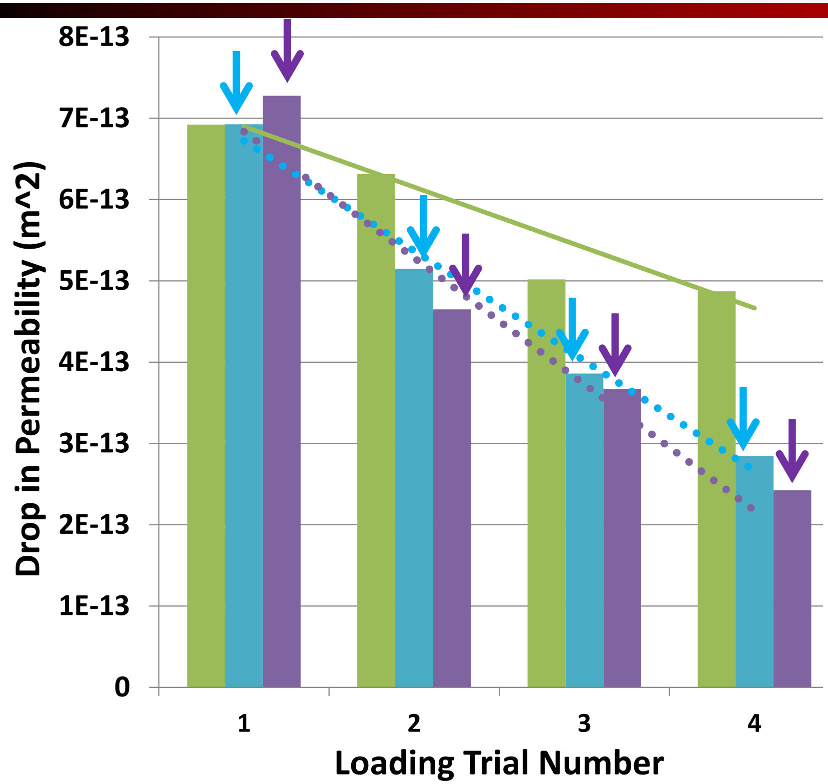
Effect on Permeability Evolution

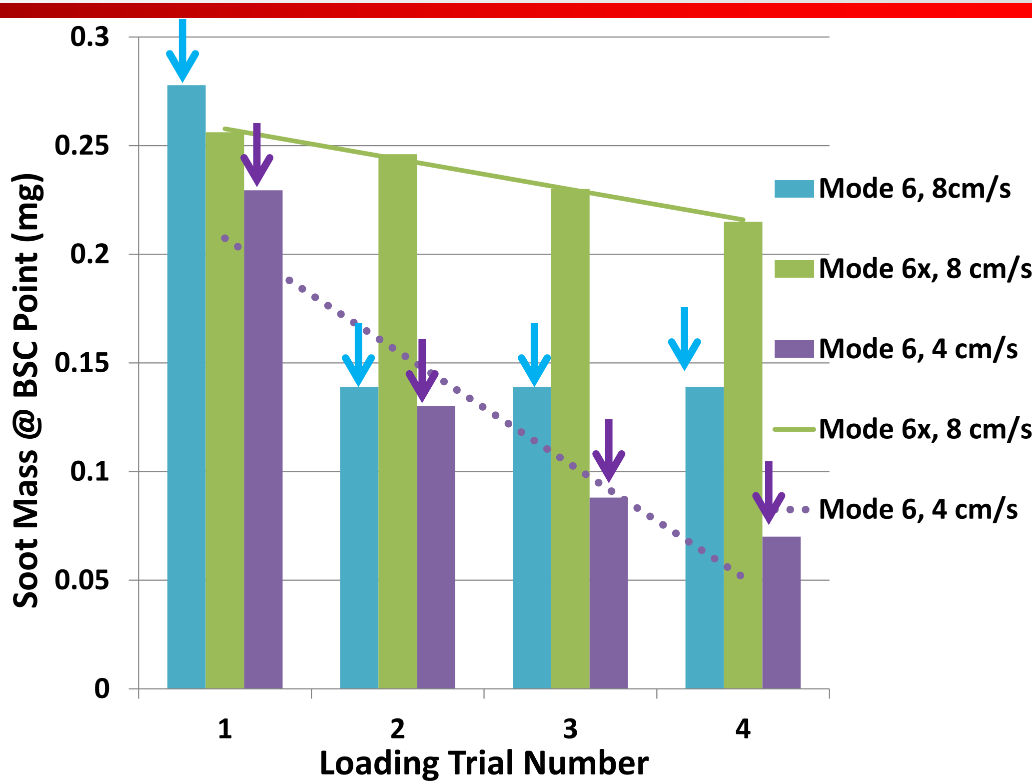


M6-4 loading condition was most influenced by ash accumulation and is shown here

- Drop in clean/regenerated permeability noticed over successive trials due to ash
- Shift in Barely Soot Cake point due to ash was observed.
- Total Permeability Drop (TPD) defined as difference between regenerated and loaded permeability

Ash Accumulation Hypothesis

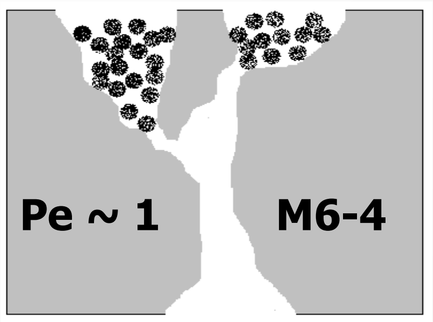


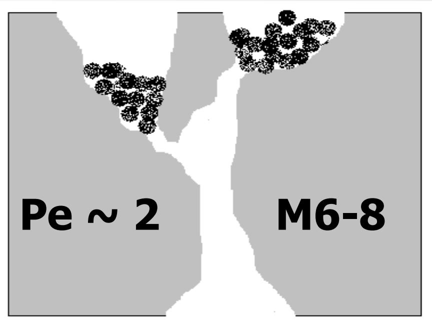


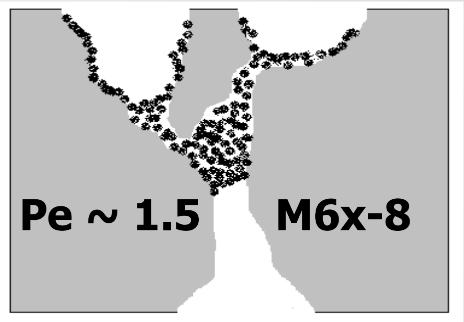
Change in Total Permeability Drop ←→ *Change in DPF substrate structure due to ash*

Change in BSC Point ←→ *Ash displacing PM to soot cake*

Ash Accumulation Hypothesis





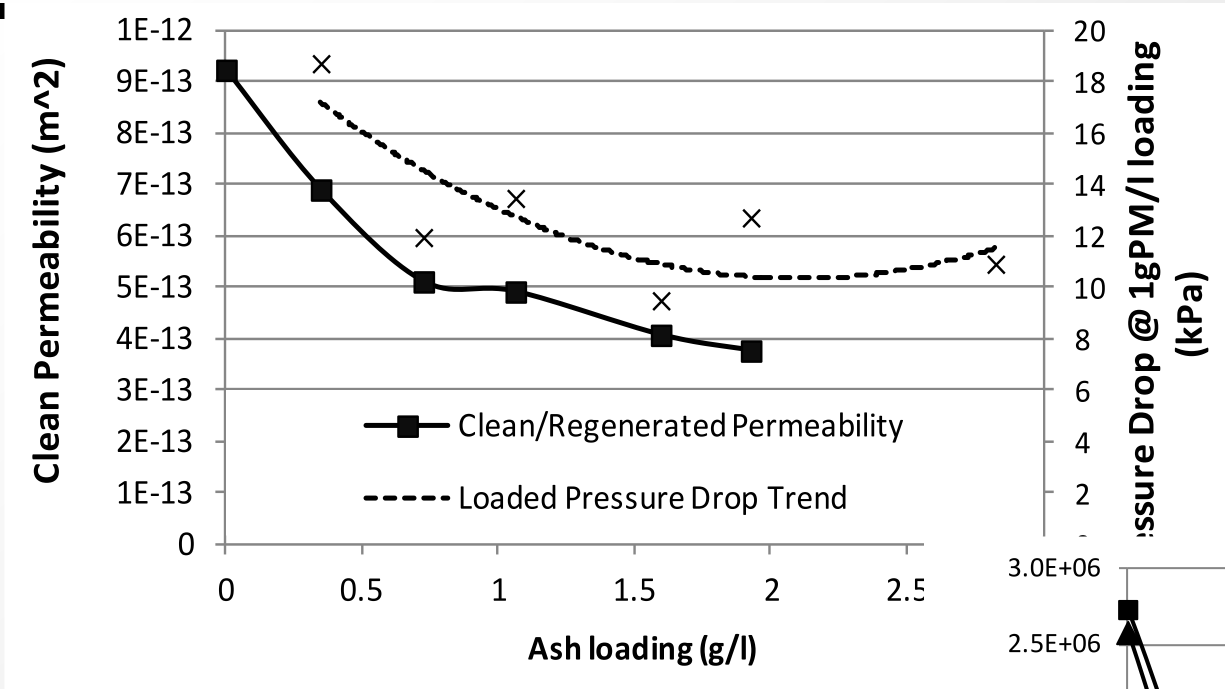


Mode 6-4 cm/s : Exhibits gradual change in both Total Permeability Drop as well as Soot mass at BSC point. This could be the result of Smaller Pe number resulting in more porous PM and hence ash accumulation within the wafer walls.

Mode 6-8 cm/s : Exhibits large changes in both Total Permeability Drop as well as Soot mass at BSC point after the first trial. This could be the result of Larger Pe number resulting in less porous ash accumulation within the wafer walls and hence a quicker transition to ash membrane formation.

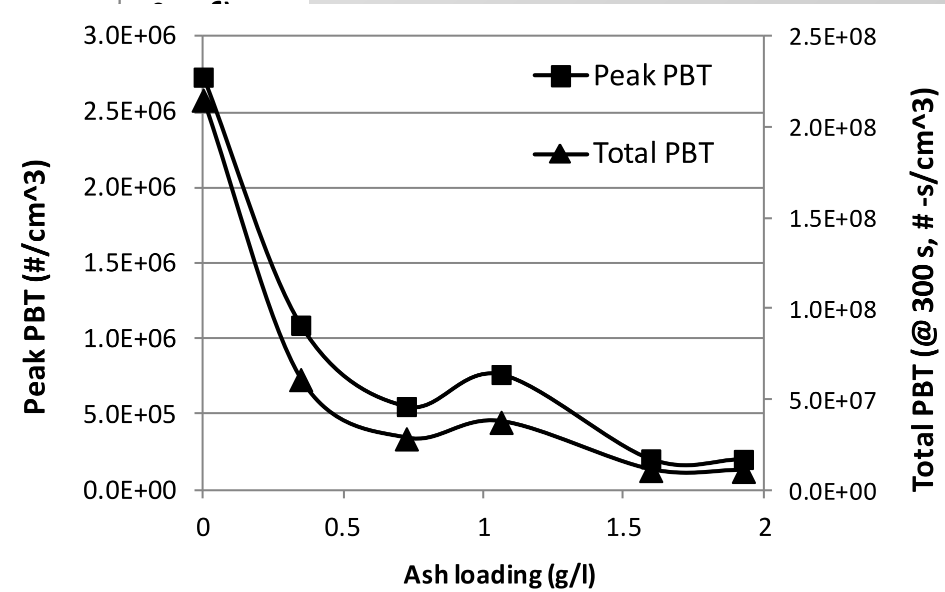
-Mode 6x-8 cm/s : Least affected by ash due to smaller ash agglomerates

High Ash Loads



- Transition to ash membrane formation observed around 2 g/l ash loading, agrees with [Sappok, A.]

- Particle Breakthrough trend agrees well with permeability evolution curve



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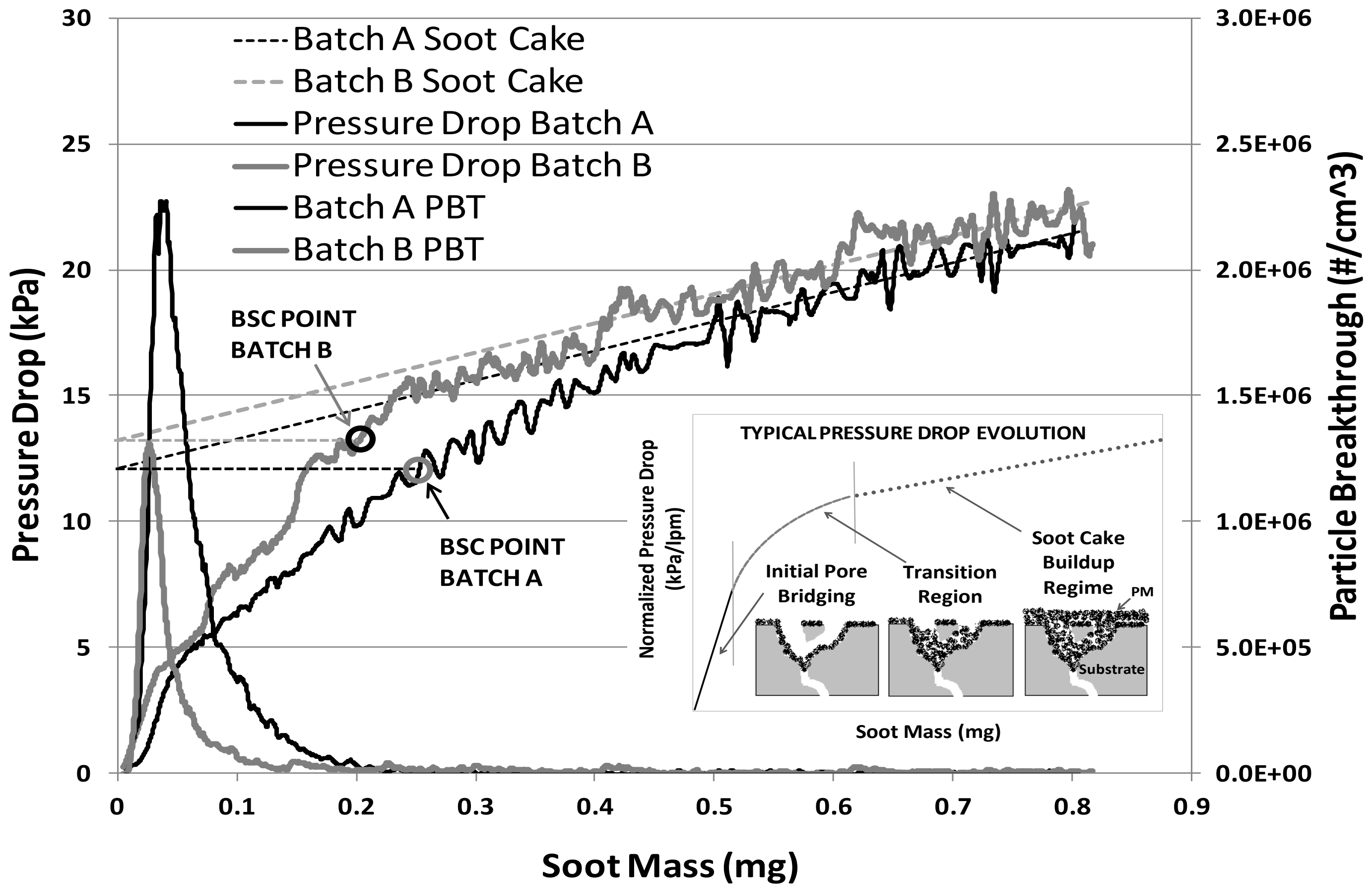
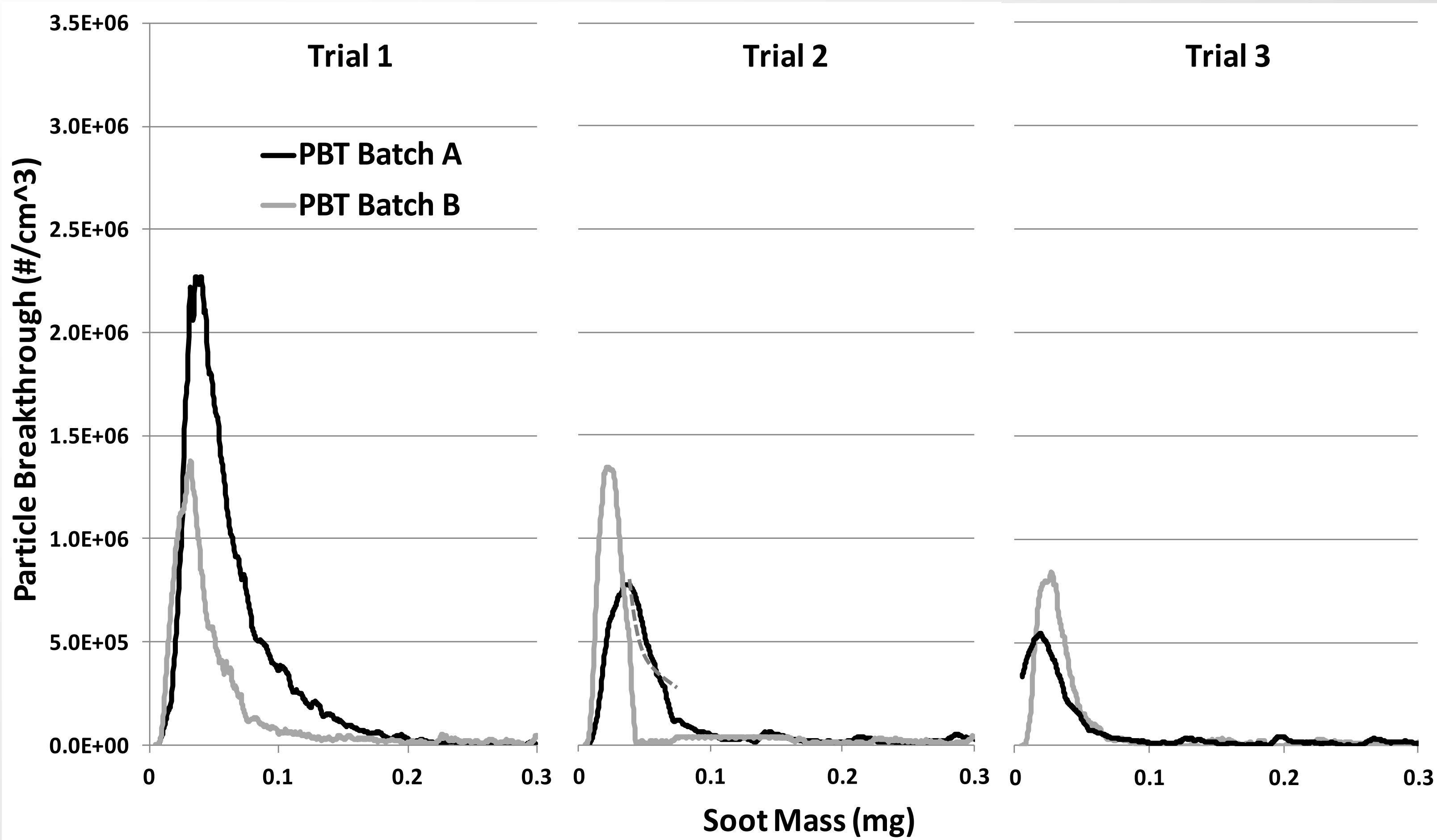
Substrate Comparison-Trial 1



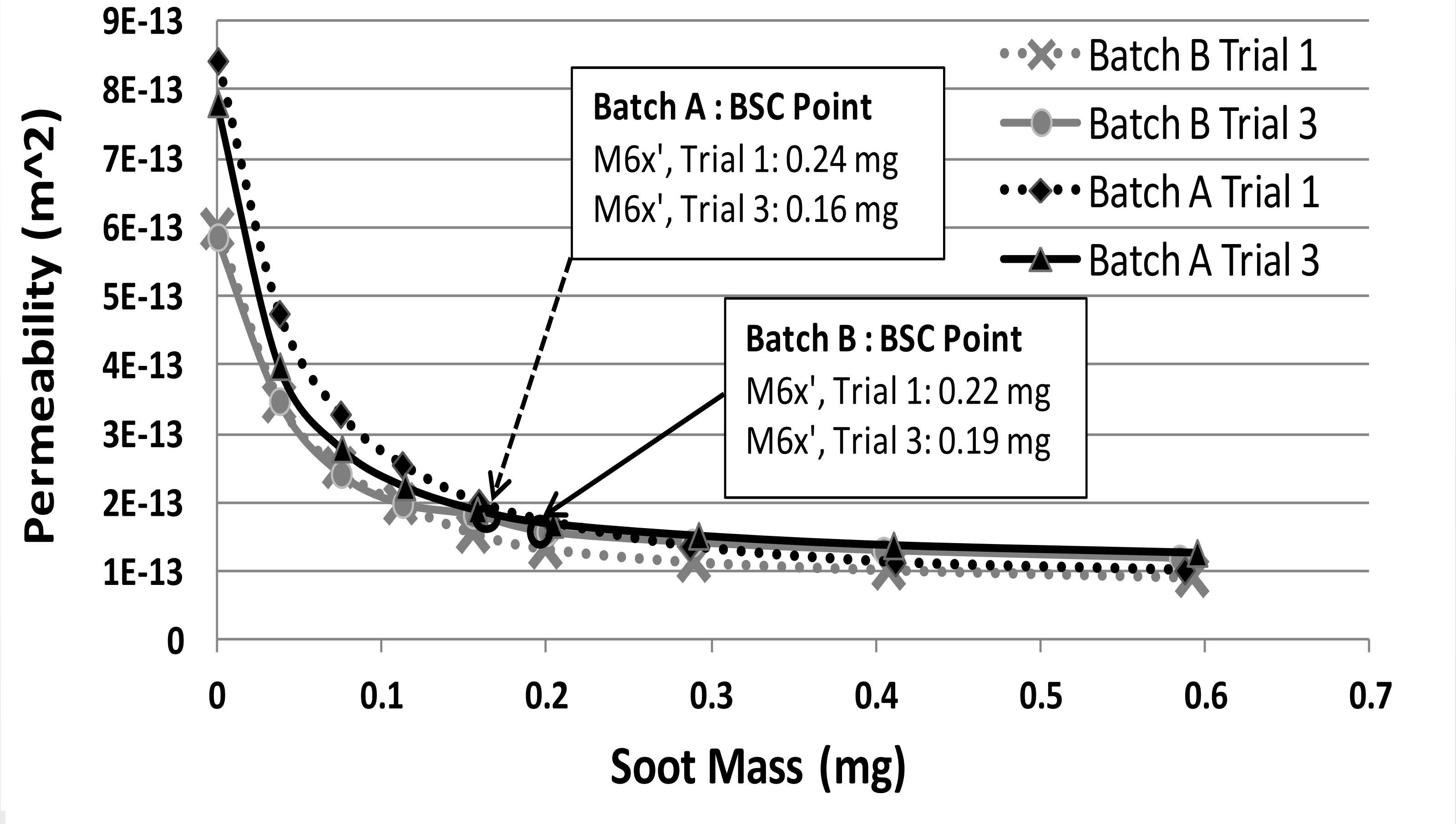
- Batch B had smaller porosity/mean pore diameter, more tortuosity, poor pore connectivity or combination resulting in low permeability.
- Differences in transition and pore bridging region for same PSD & Pe number implies different pore structure
- Pe number cannot be used to accurately define wall loading stage since it does not consider substrate properties
- BSC point earlier for batch B ➔ lesser PM mass in filter pores for batch B compared to batch A

Substrate Comparison- Effects of ash



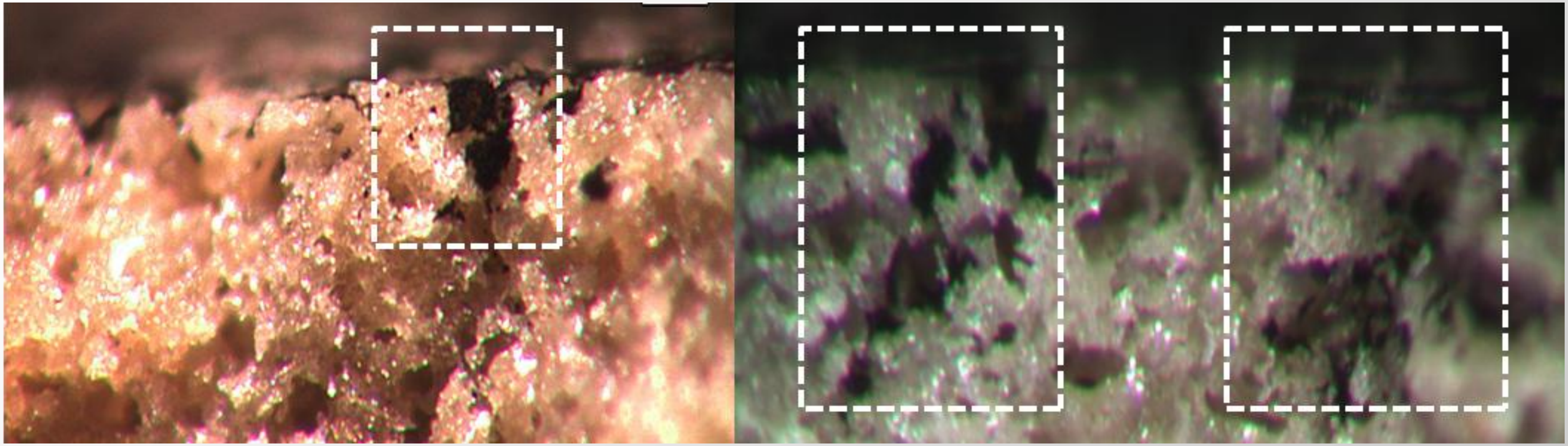
Batch A shows higher improvement in filtration efficiency (~60%) due to more PM and hence ash accumulation within walls.

Substrate Comparison-Effects of ash

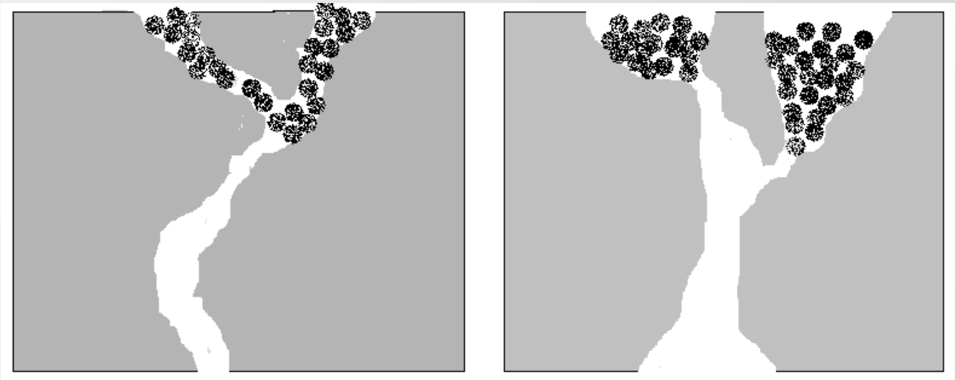


Higher effect due to ash accumulation for batch A for regenerated permeability as well as TPD. Notice very different permeability evolution for batch A after 3 loading trials.

Substrate Comparison



BATCH B



BATCH A

Visual evidence that properties of batch B limits the amount of PM (and hence ash) deposited within the wafer walls compared to wafers from batch A.

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Conclusions

- The ash accumulation process is similar to PM deposition. Wall loaded ash reduces the PBT and pressure drop across the filter. No longer beneficial at high ash loads (> 2 gpl).
- The PM deposition process appears to have a significant impact on the ash accumulation process ~ Ash is an inherent part of diesel PM.
- The sintering process appears to be resulting in larger ash agglomerates which have a significant impact on the subsequent PM loading process
- The impact of ash accumulation was found to be highly dependent on the PM mass trapped within the wafer walls which was in turn affected by substrate properties.

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Thank you!
Questions?

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