SLOAN AUTOMOTIVE LABORATORY

A Consortium to Optimize Lubricant and Diesel Engines for Robust Emission Aftertreatment Systems

A Revealing Look Inside Passive and Active DPF Regeneration: *In-Situ Optical Analysis of Ash Formation and Transport*

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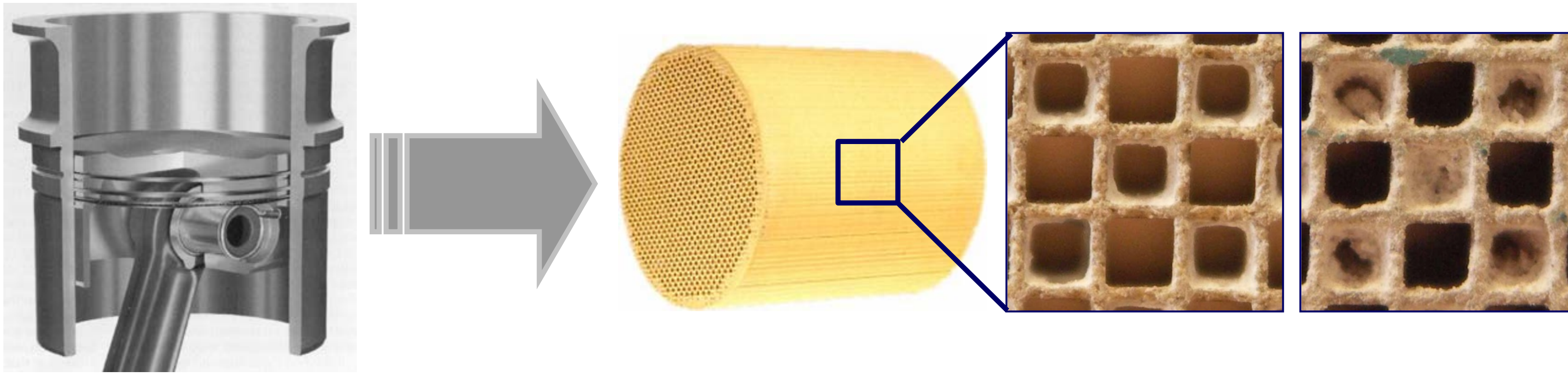
U.S. DEPARTMENT OF ENERGY

DEER 2012 DEARBORN

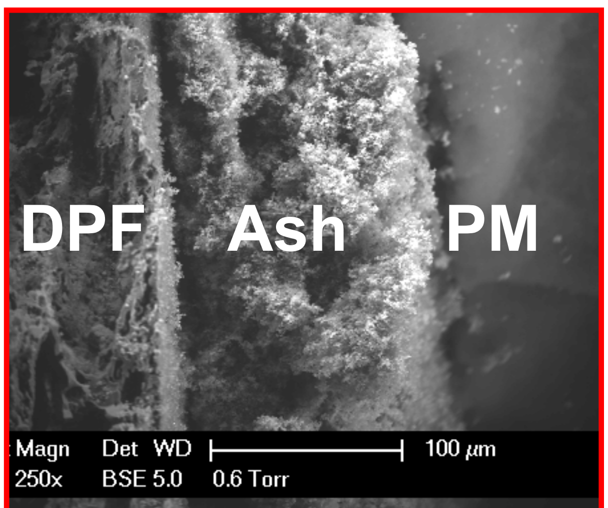
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE

Ash Impacts on Particulate Filter Performance

Particle filters (DPF, GPF) trap incombustible “ASH” emissions.



Ash alters DPF performance over filter’s useful life.



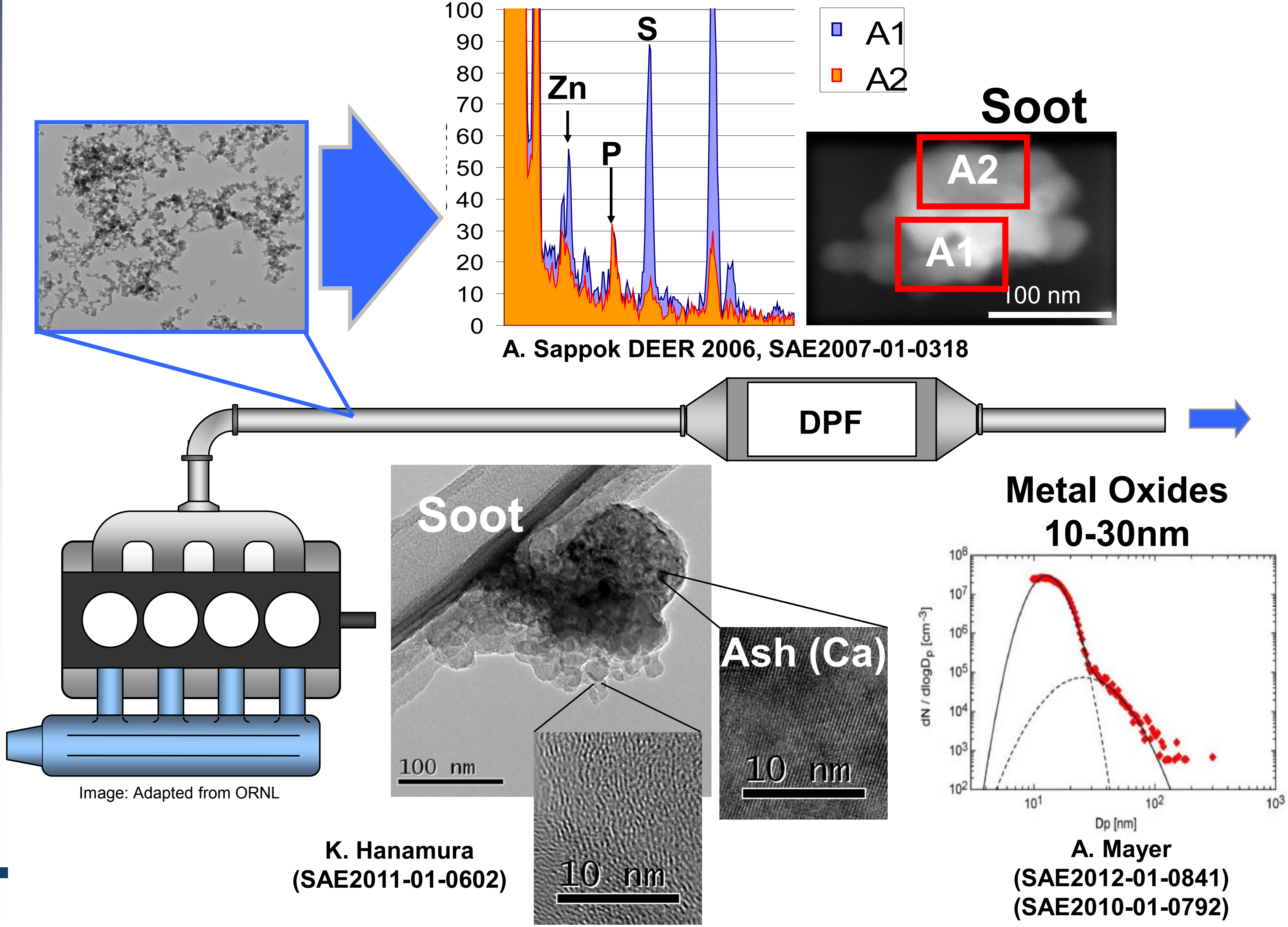
- Total pressure drop
- Pressure drop response
- Catalyst performance
- Soot storage capacity
- Soot distribution

Fuel Economy (ΔP & Regen)

Filter Life (Plugging)

Understanding fundamental ash properties is critical !

Engine-Out Ash Precursors Small (< 100nm)



Ash Agglomerates Grow Larger in DPF (1-10 µm)

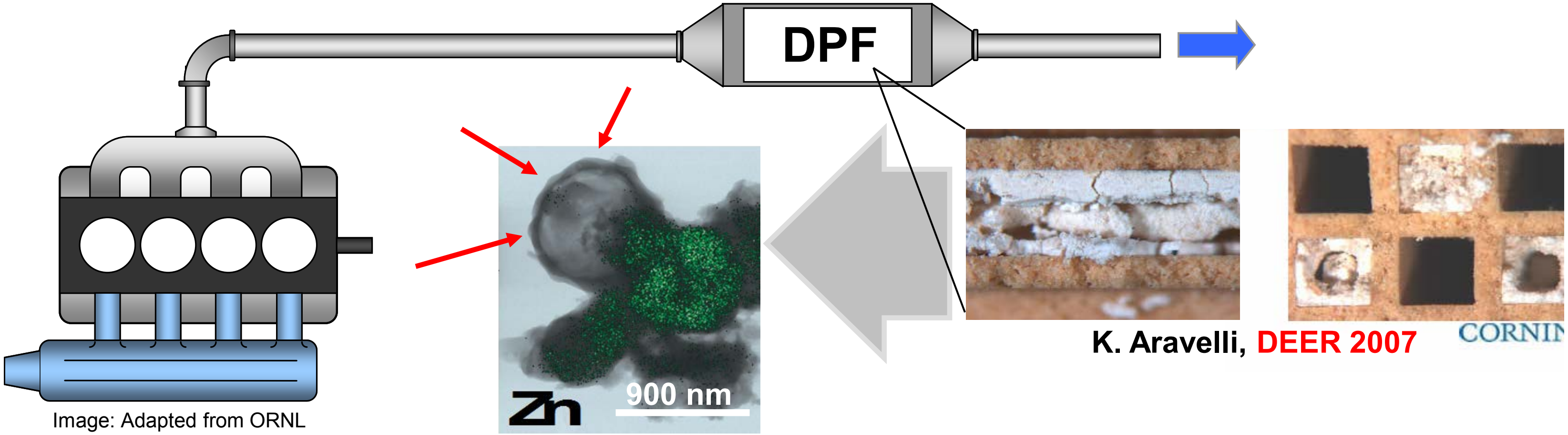
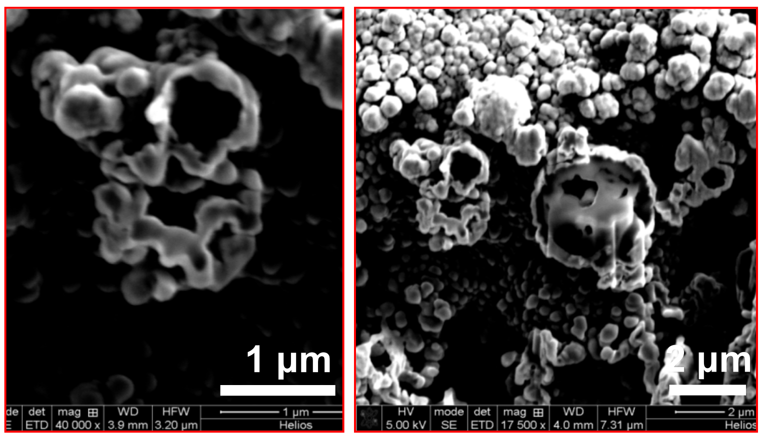


Image: Adapted from ORNL

K. Aravelli, DEER 2007

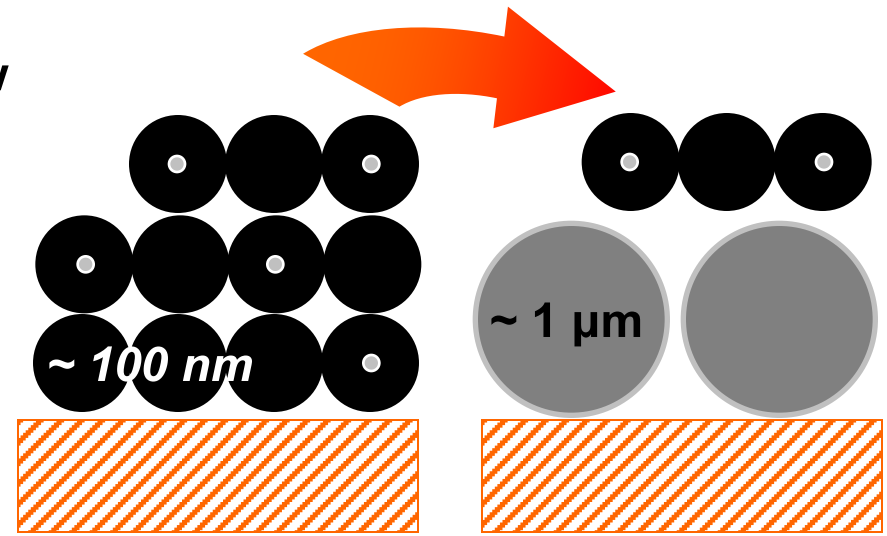
A. Sappok, DEER 2006, SAE2007-01-0318

Ash Agglomerates Porous/Hollow



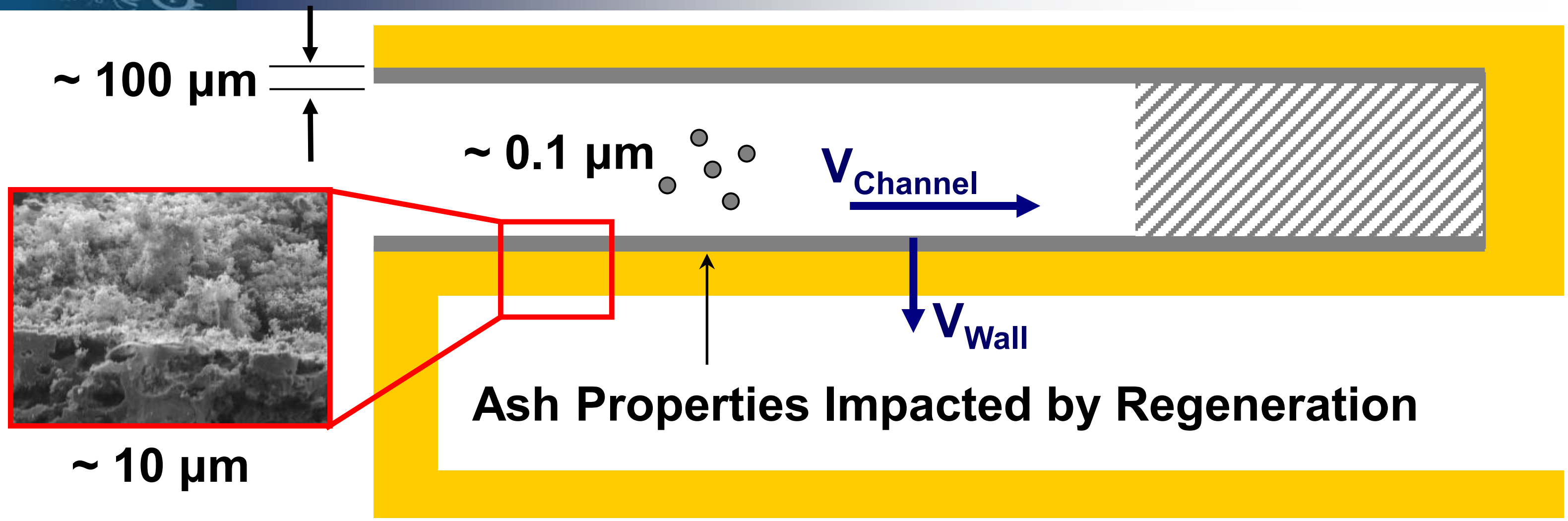
C. Kamp, DEER 2011, SAE2012-01-0836

Ash Particle Growth in DPF

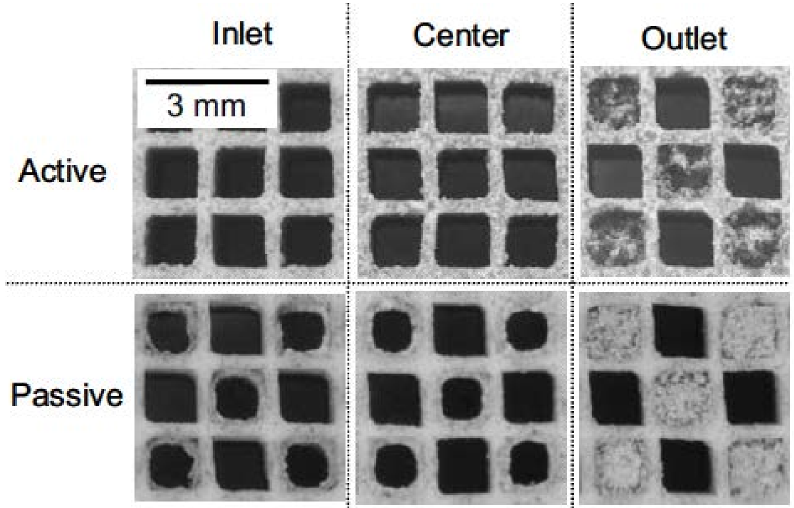


Impacts Efficiency and Performance

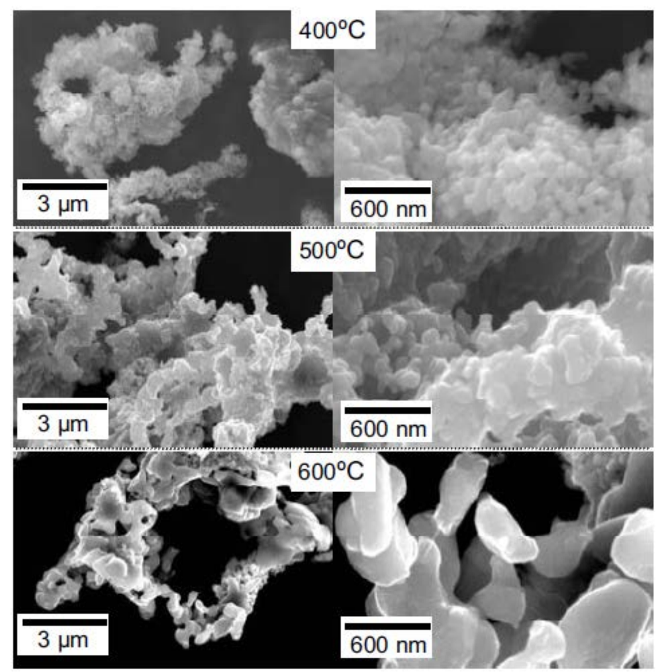
Ash Build-Up in the DPF is a Dynamic Process



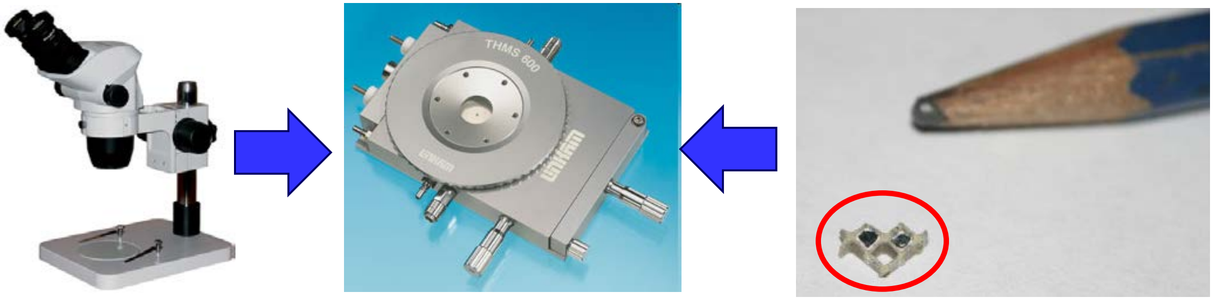
Regeneration may exert large impact on ash morphology and distribution



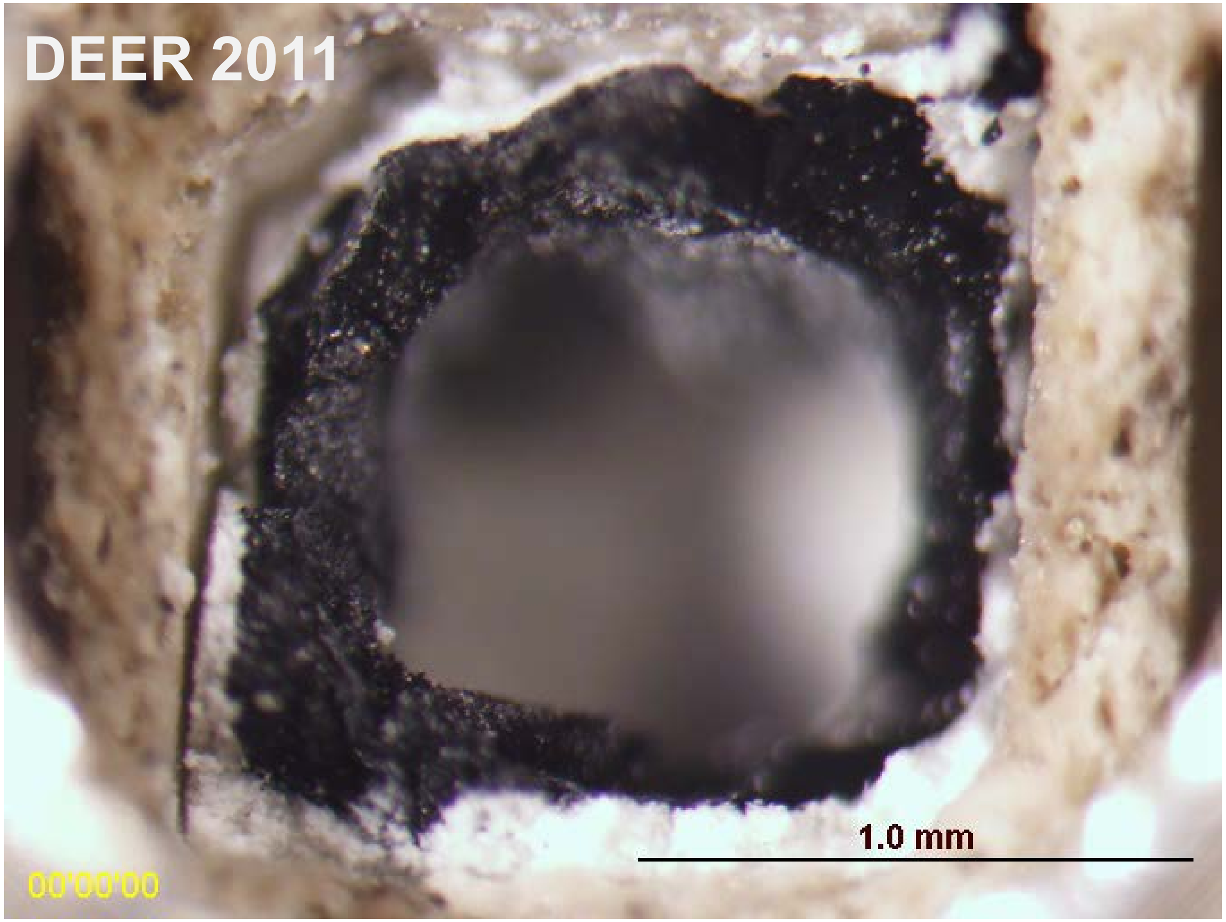
SAE 2009-01-2882



Initial Results Show Soot-Ash Interactions During Regen



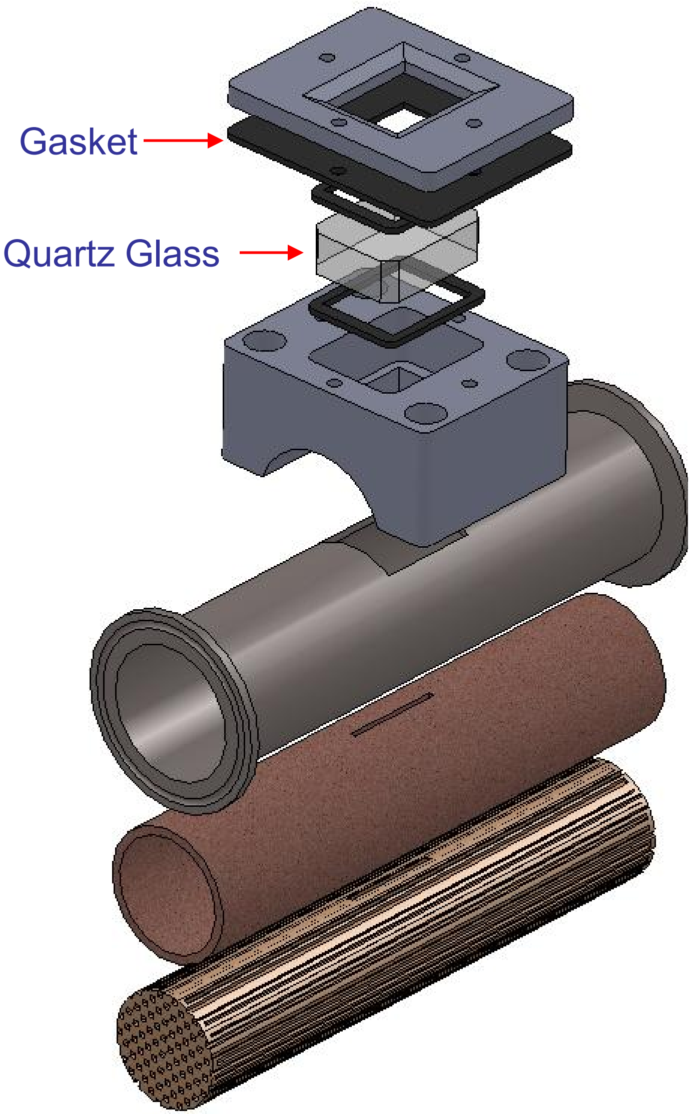
Initial Optical Studies

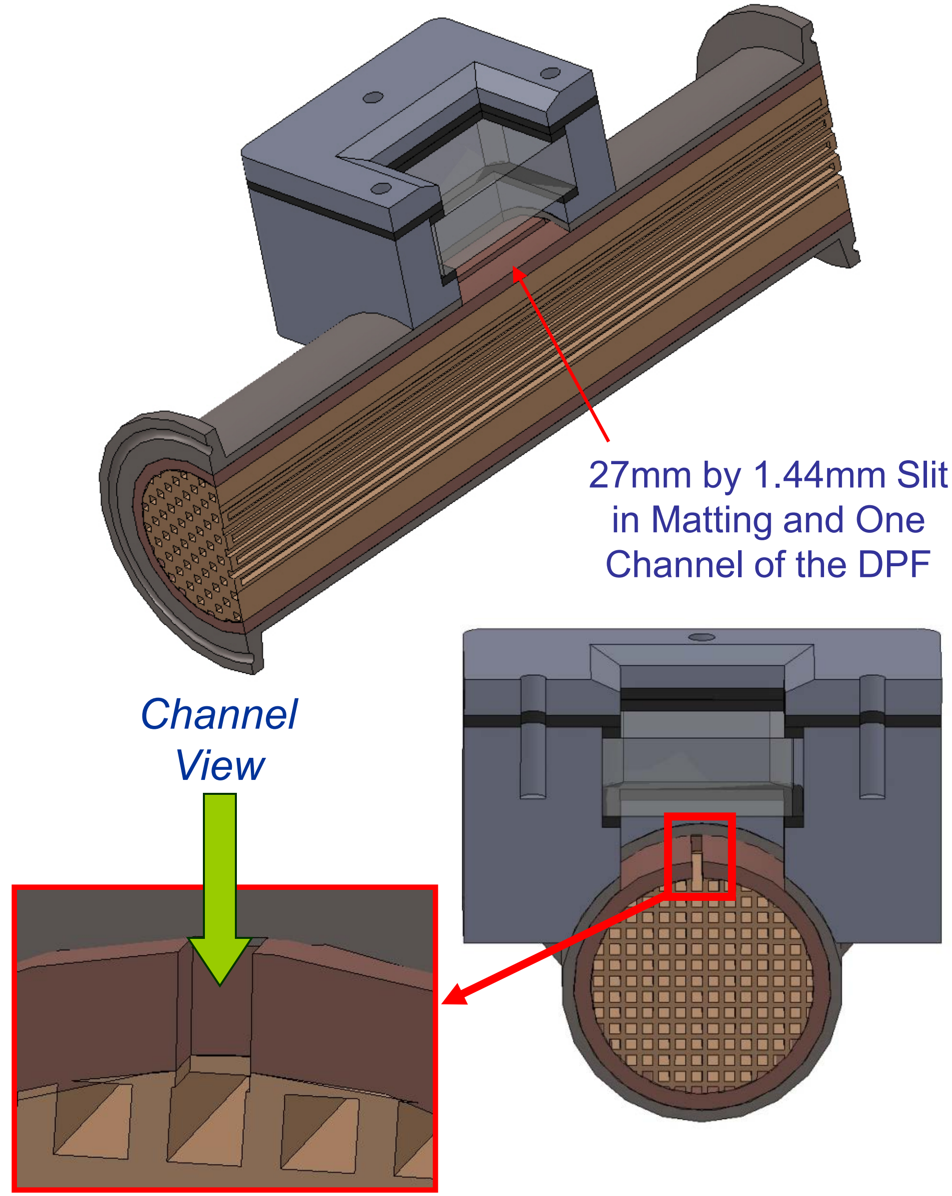


Conditions

- Stereo Microscope
- Soot Oxidation
- Existing Ash Layer
- Air
- No Flow
- 600 °C

Optical Setup for Regeneration Visualization Studies





Bare and Ash-Loaded Filter Evaluation Sequence

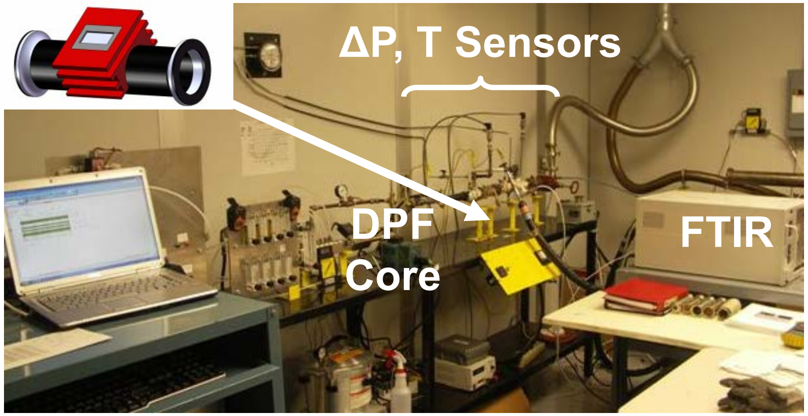
1. Ash Loading

- Accelerated ash loading system
- Simulate over 180K miles
- Utilize full-size DPFs
- Significant validation and comparison with field DPFs

2. Core Sample Preparation

3. PM Loading (*Cummins, Yanmar*)

4. Optical Bench Regeneration



Large Test Matrix to Investigate PM Oxidation/Ash Formation

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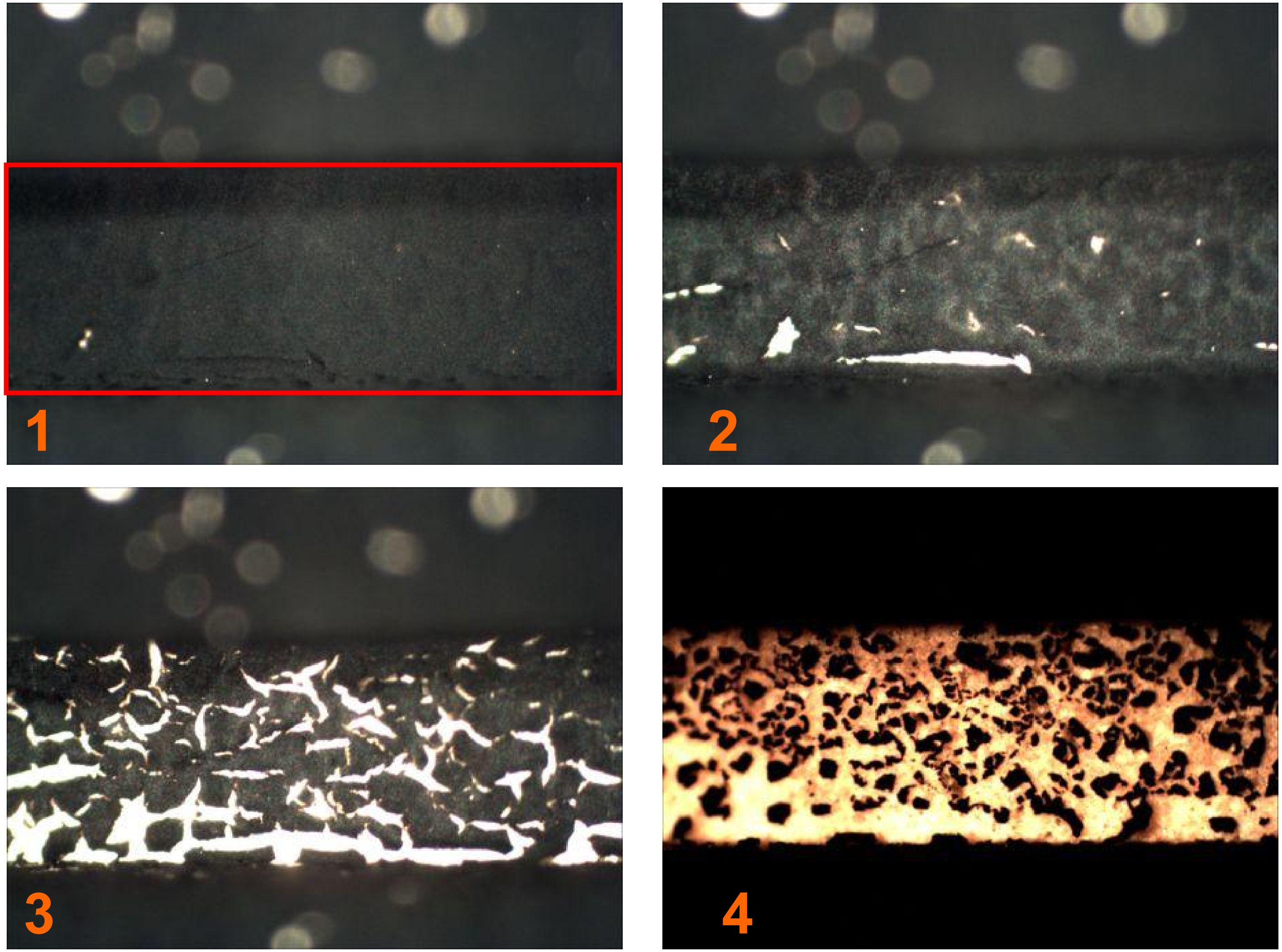
PM Level	Configuration	Flow	Ash Level	Temperature
1. Impact of PM Level at Start of Oxidation on PM Mobility and Ash Interactions				
Low	CDPF	Moderate	0 g/L	Moderate
Moderate				
Low			30+ g/L	
Moderate				
High				
2. Effect of NO2 Source (DOC vs. CDPF) on PM/Ash Mobility				
Moderate	DOC+CDPF	Moderate	0 g/L 30+ g/L	Moderate
3. Impact of Exhaust Flow Rate During Regeneration on Ash/PM Mobility				
Moderate	DOC+CDPF	Low High	30+ g/L	Moderate
4. Impact of Exhaust Temperature During Regeneration on Ash/PM Mobility				
Moderate	DOC+CDPF	Moderate	30+ g/L	High
5. Impact of Oxidation Mechanism via O2 vs. NO2 on Ash Formation				
Moderate	CDPF	Moderate	0 g/L 30+ g/L	High
	UCDPF	Moderate	0 g/L	

Local Regeneration on C-DPF Concentrates Remaining PM

Regeneration on bench reactor shows localized PM mobility



Video: PM Oxidation on Clean CDPF (Moderate PM)

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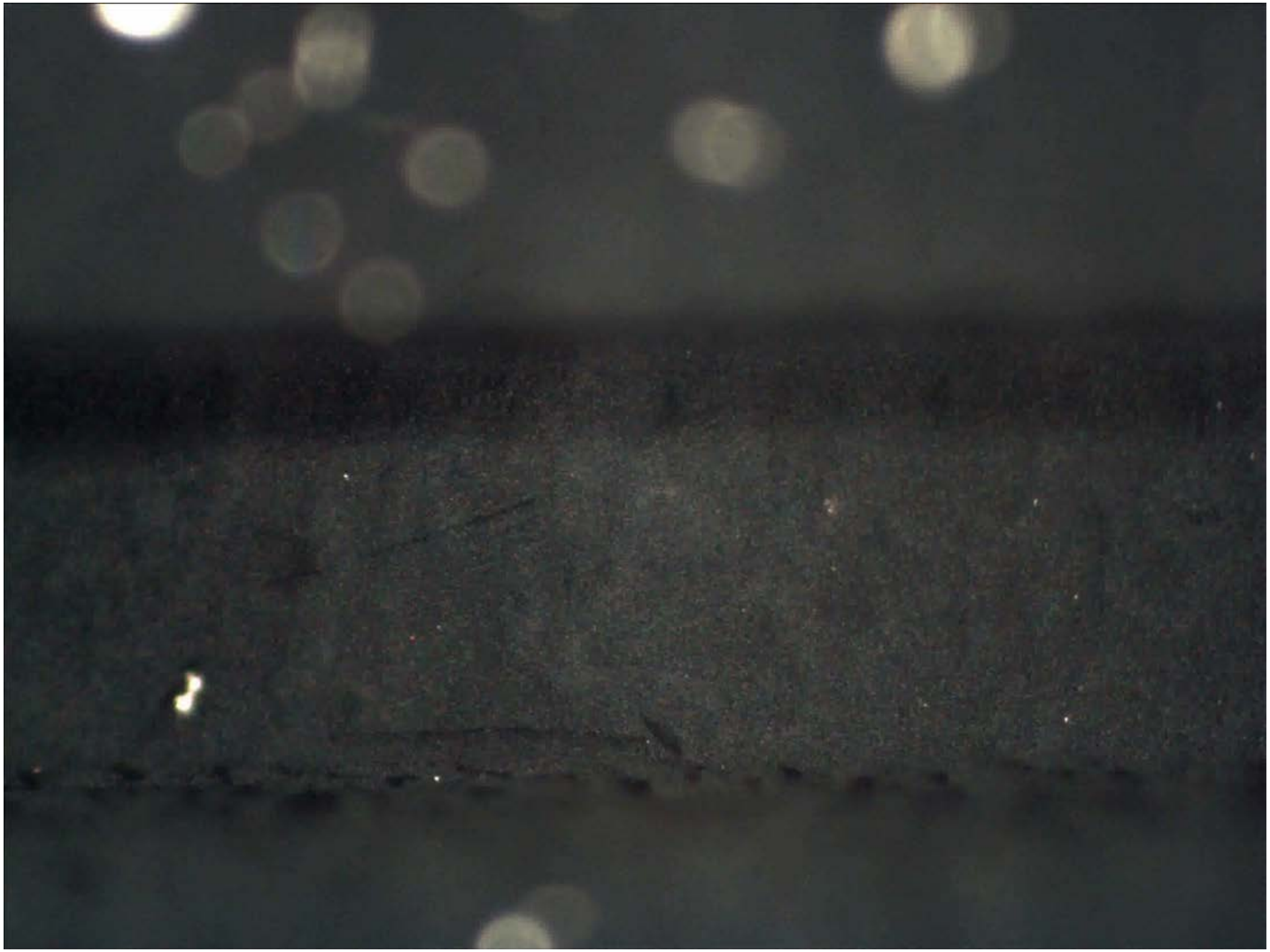
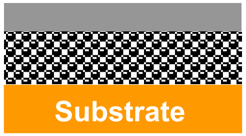
Regeneration Conditions: 450 °C, 500 ppm NO, 40,000 GHSV



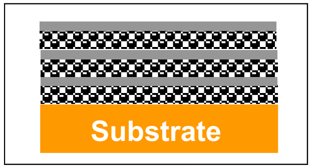
Video: Ash Formation and Agglomeration



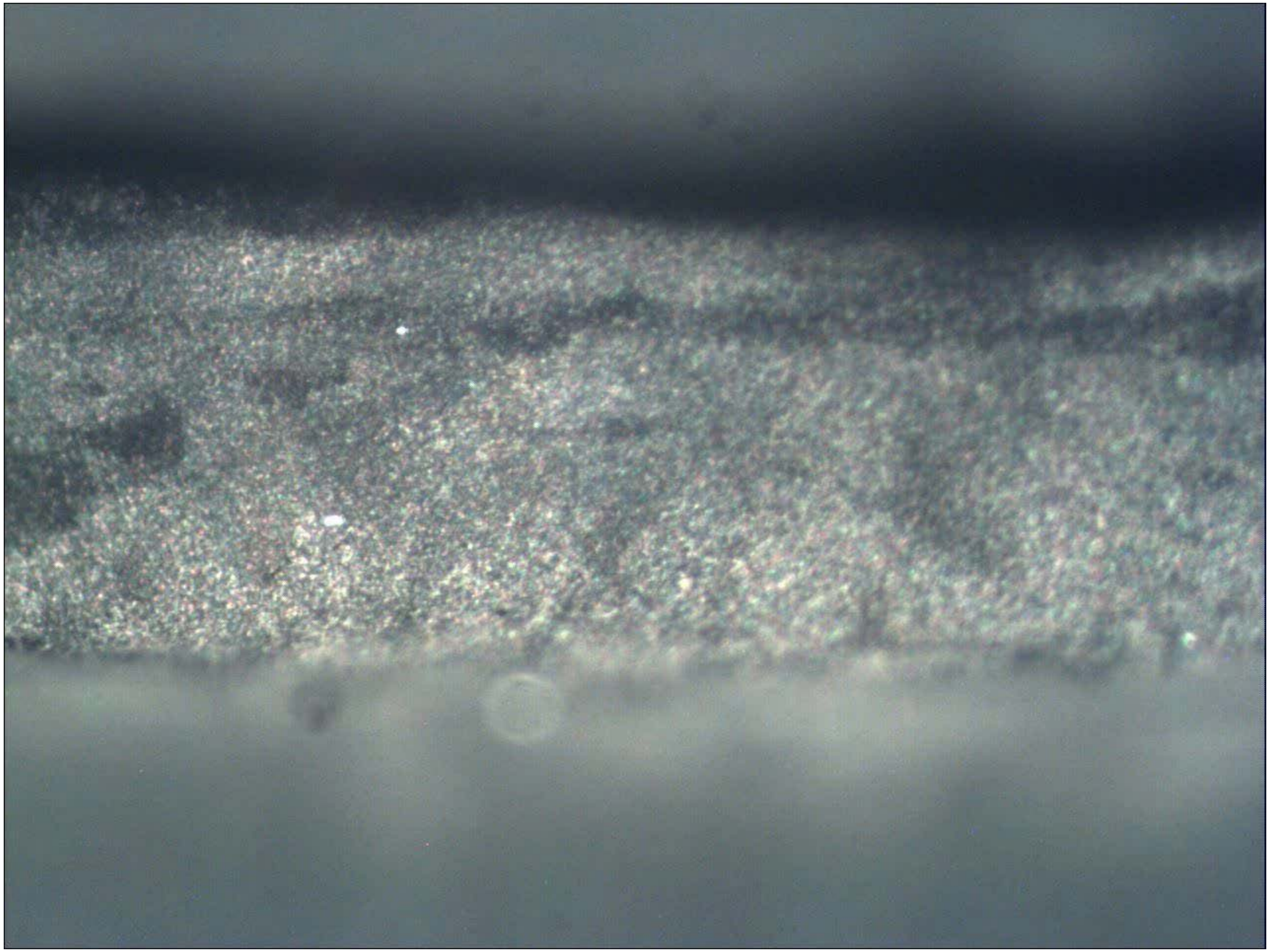
Regeneration Conditions: 450 °C, 500 ppm NO, 40,000 GHSV

Light "dusting" of CJ-4 ash applied on top of PM layer using burner system to visualize ash agglomeration process.

Video: Ash Formation and Particle Transport



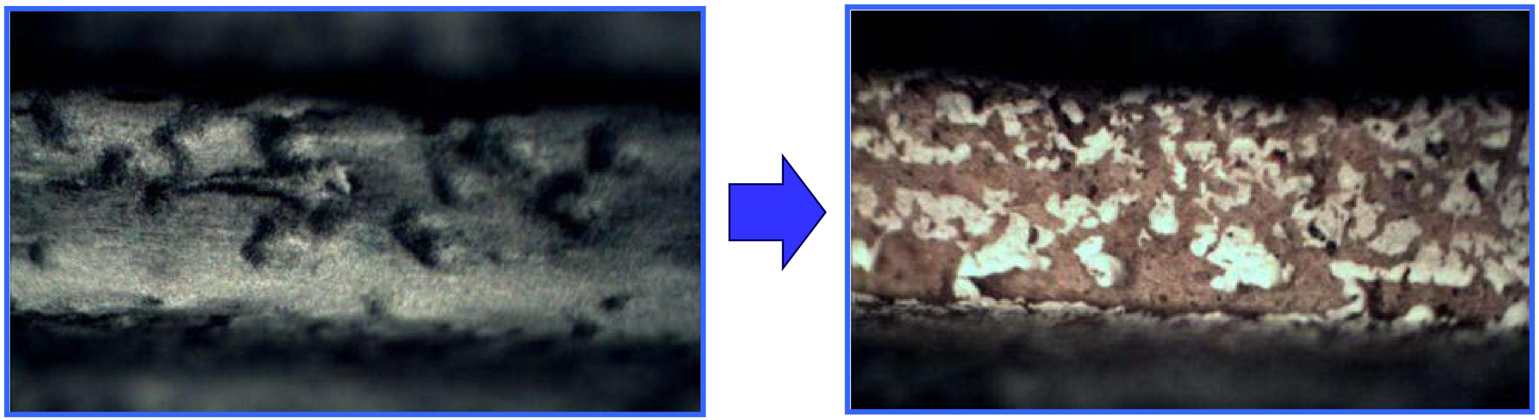
Regeneration Conditions: 400 °C, 500 ppm NO, 20,000 GHSV



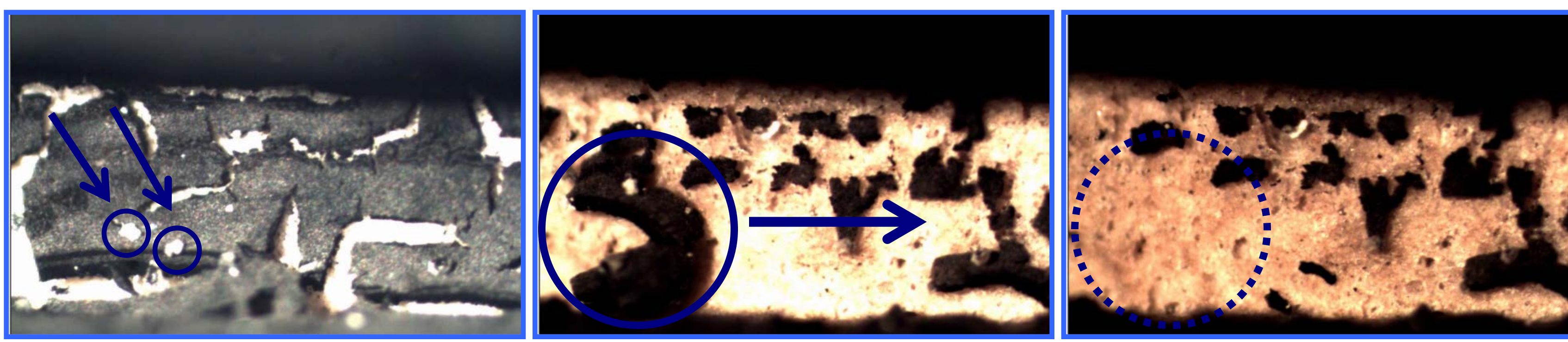
PM with elevated CJ-4 ash concentration generated using burner system in combination with engine to visualize ash formation.

General Observations of Ash Formation and Transport

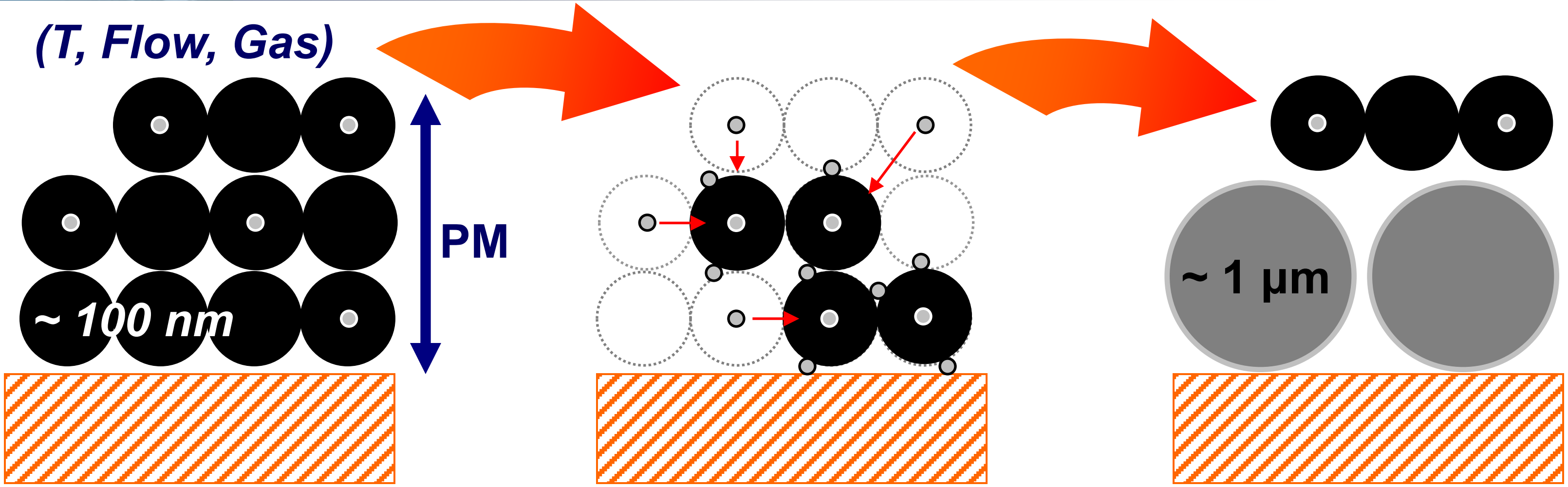
Regeneration with elevated ash concentration in PM shows local soot and ash mobility and significant agglomeration.



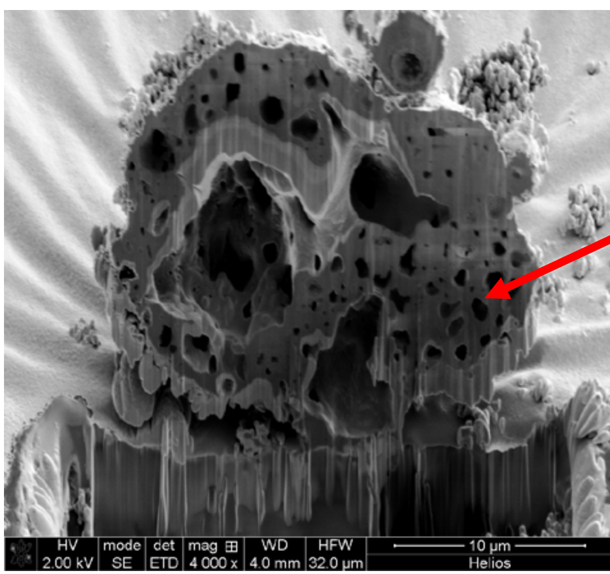
Bulk soot and ash transport along DPF channels observed during regeneration for larger particles loosely bound to surface.

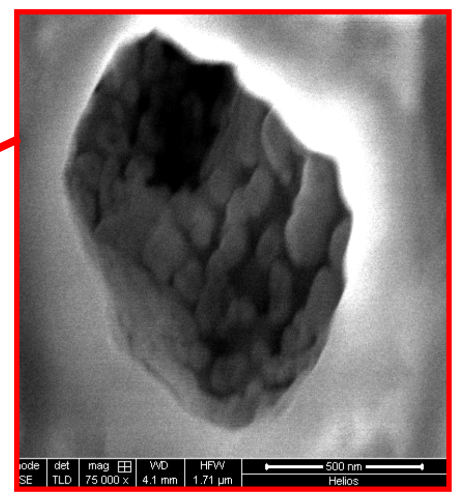


Summary of Ash Agglomeration During PM Oxidation



Ash residence time in DPF is long ~ 100,000 + Miles





Internal void shows walls composed of ~nm scale particles

Summary and Conclusions

Processes occurring during regeneration (active or passive) play an important role in influencing ash particle formation and transport.

- PM oxidation proceeds locally and exhibits some surface mobility for the cases investigated (C-DPF)
- Mobility of soot cake on DPF surface during regeneration most pronounced at elevated PM levels
- Regeneration with soot cake appears to concentrate ash precursors during PM oxidation process
- Concentration of ash deposits may promote ash particle agglomeration and growth
- Transport of bulk **ash and soot** observed during regeneration for agglomerates that become loosely bound to surface
- *Current investigations ongoing to understand underlying mechanisms outlined in full test matrix*

Acknowledgements

SLOAN AUTOMOTIVE LABORATORY

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- Detroit Diesel	- Infineum	- *Komatsu*
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