Single Channel DPF Experiments to Investigate Soot Cake Structures

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Presenter Tom Gallant, PNNL

Collaborators

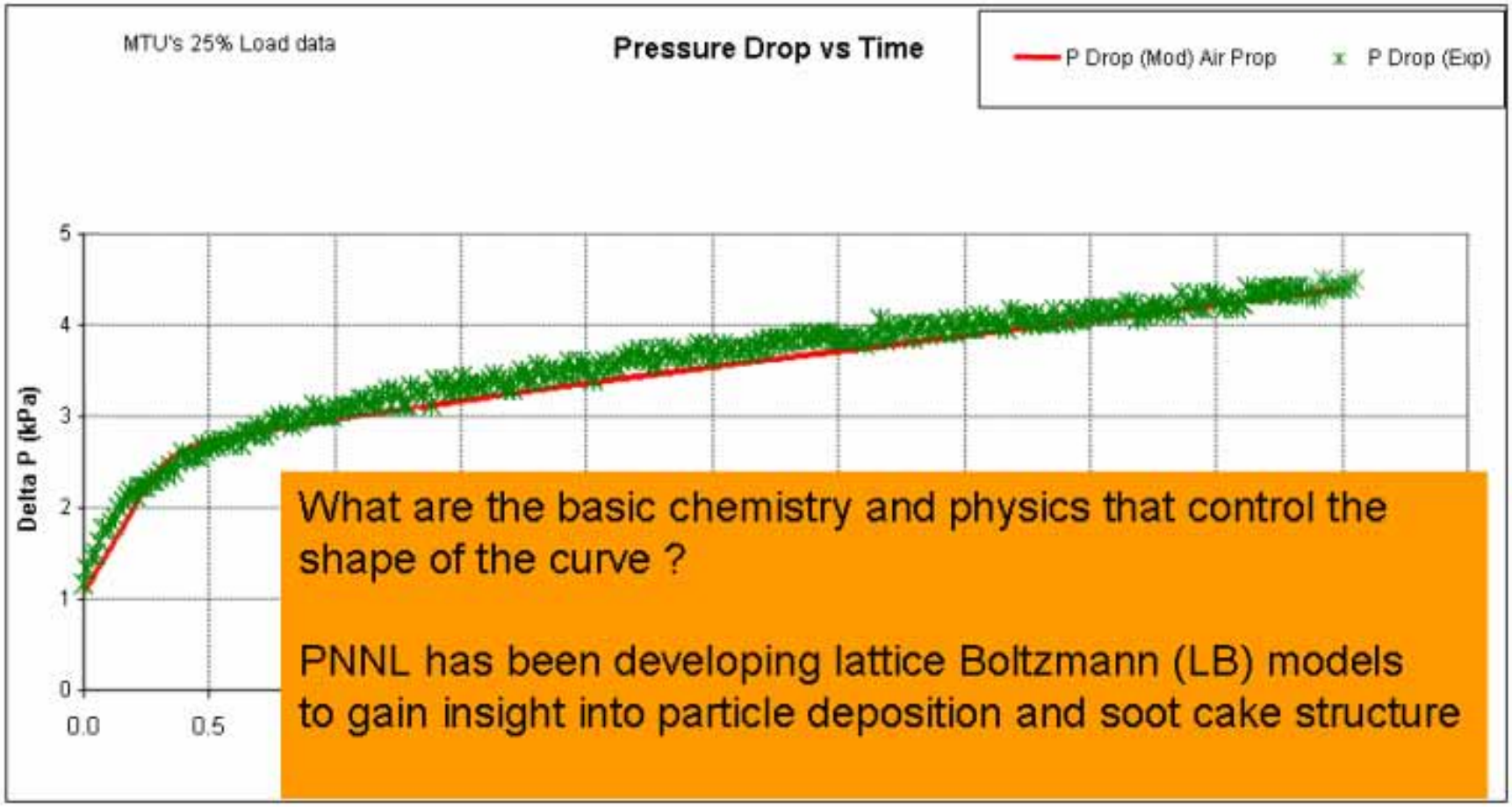
PNNL
Gary Maupin, Mark Steward, and Heather Dillon

ORNL
Thomas Watkins, Jiaming Bai, Laura Riester, Mattison Ferber, Doug Blom, Michael Lance

ANL
Pete Jemian

OFCVT
Sid Diamond

Transition from Deep Bed to Cake Filtration



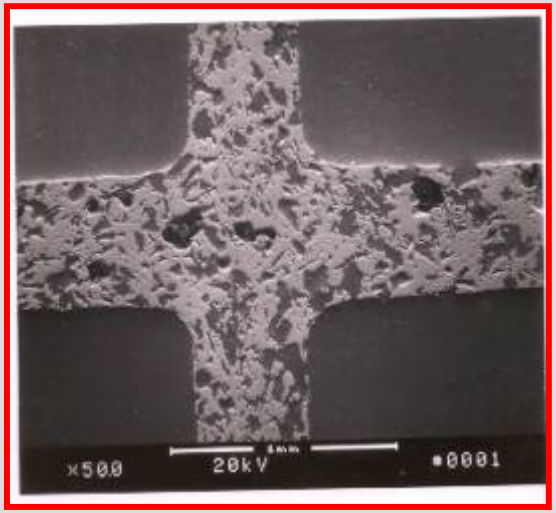
What are the basic chemistry and physics that control the shape of the curve ?

PNNL has been developing lattice Boltzmann (LB) models to gain insight into particle deposition and soot cake structure

Source: pressure vs time UW-Madison

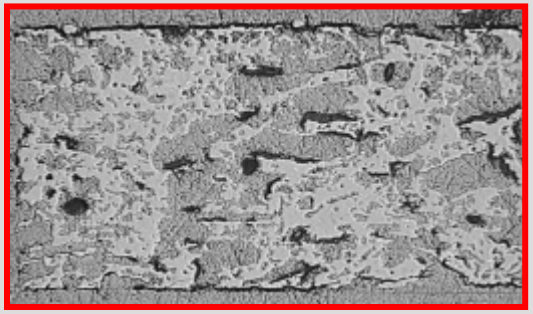
Digital Mapping of Substrate Microstructure

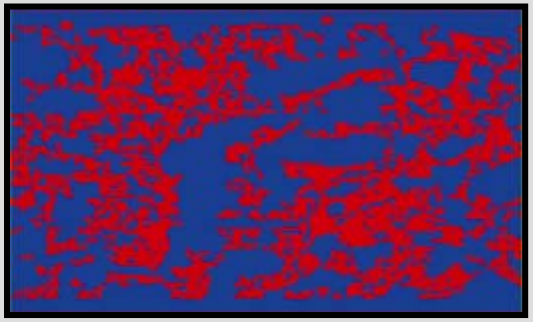
Physical



Corning EX-80, 100 cpi

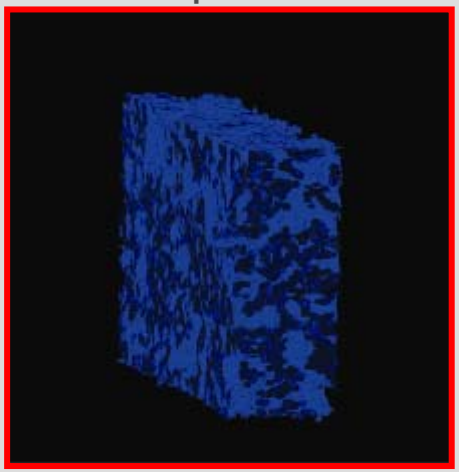
Source: Mark Steward CLEERS





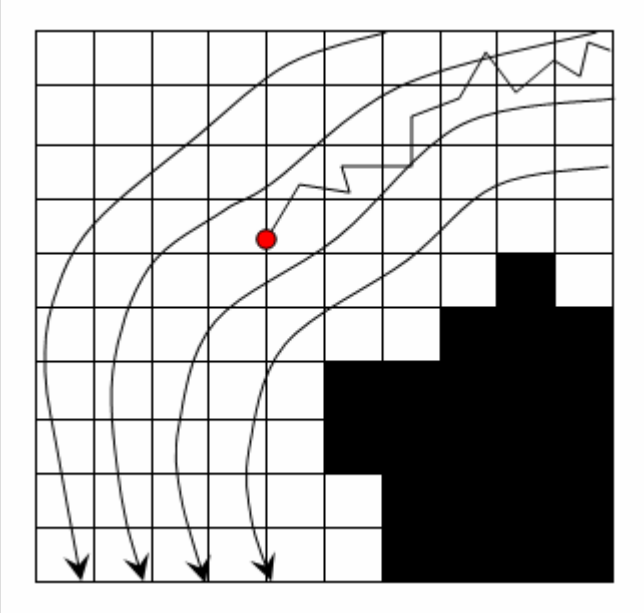
- SAE 2003-01-0835

Computational



Simulation of Particle Motion

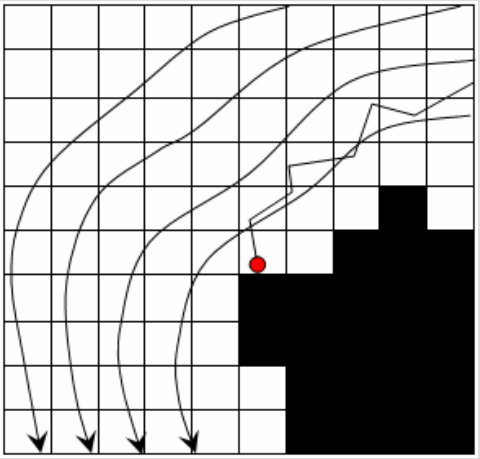
- Parameters:
  - Aerodynamic diameter 100 nm
  - Contact diameter 1μm
  - Particle time step 3×10^{-7} s
- Motion derived from flow field
- Brownian motion superimposed
- Deposition upon impact
- Deposits exert Darcy resistance
- No regeneration, restructuring



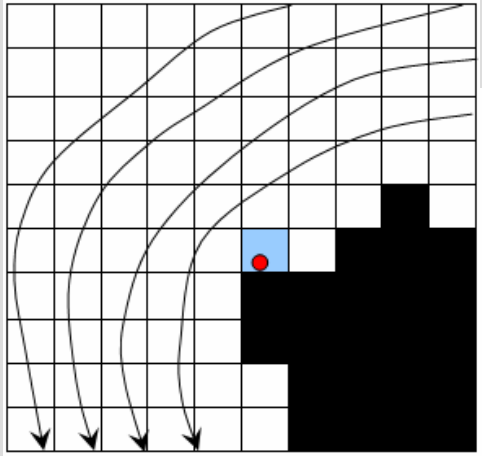
Source: Mark Steward CLEERS

Resistance of Deposits to Flow

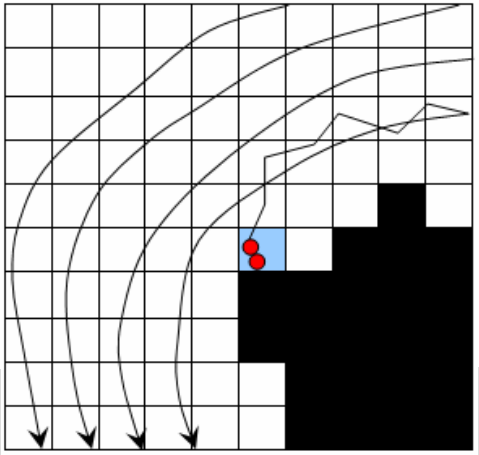
- Deposition of single particle



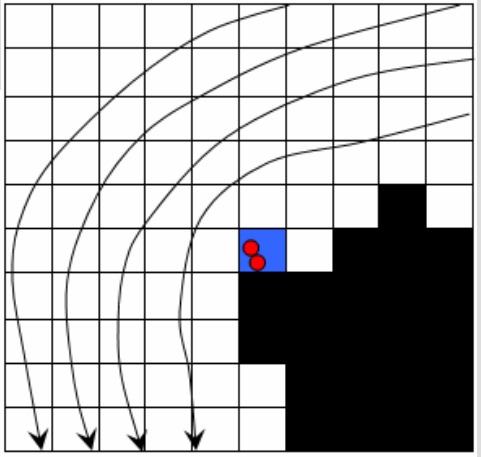
- Increased resistance
- Distortion of Flow Field



- Deposition of second particle

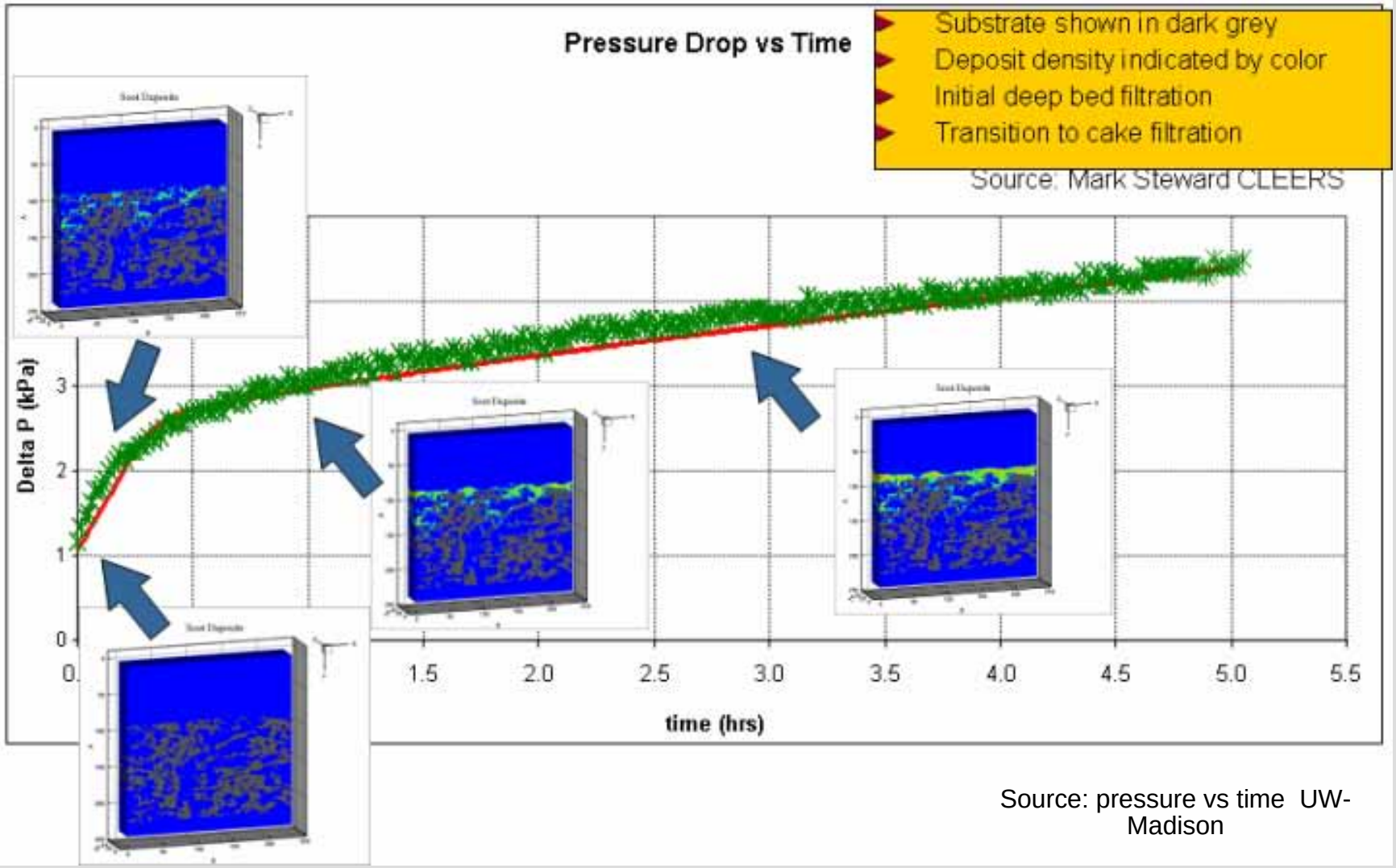


- Increased resistance
- Distortion of Flow Field



Source: Mark Steward CLEERS

Transition from Deep Bed to Cake Filtration - Lattice Boltzmann Model



Source: pressure vs time UW-Madison

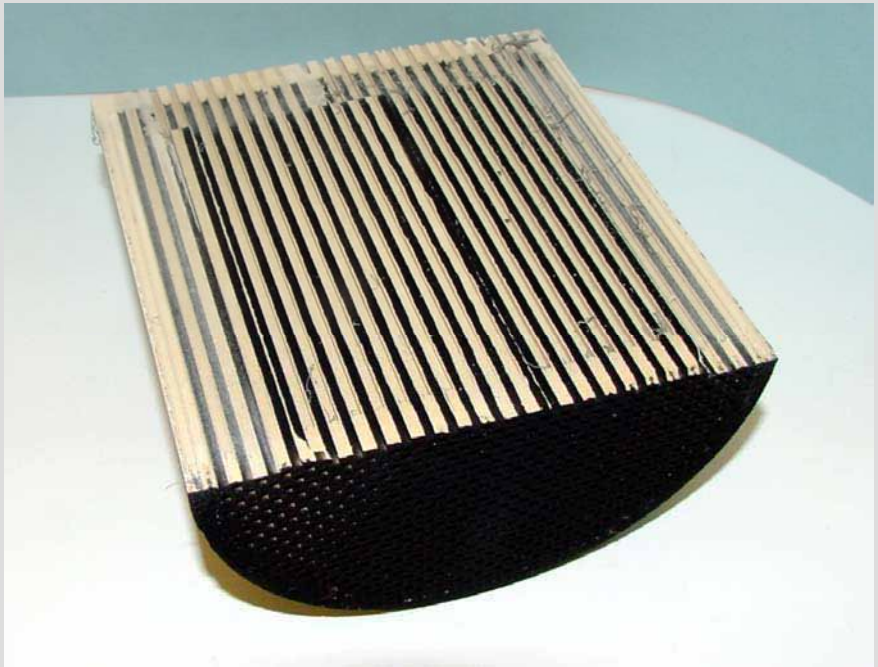
Validation of LB Models at the Microscopic Scale

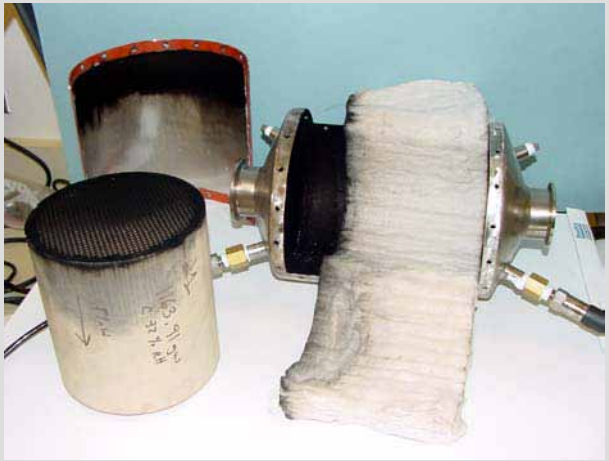
- Visual Comparison at Soot Cake / Substrate interface
- Comparison of Soot Deposition and Cake characteristics as predicted by the LB Model

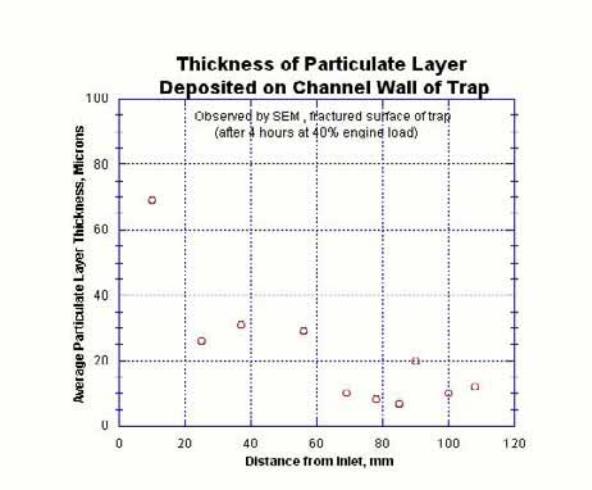
However, the challenge is to

1) Prepare DPF samples under precise conditions of flow, temperature and particulate/cake characterization consistent with LB model.
2) Utilize techniques that are consistent with the microscopic scale

Full Scale DPF Testing







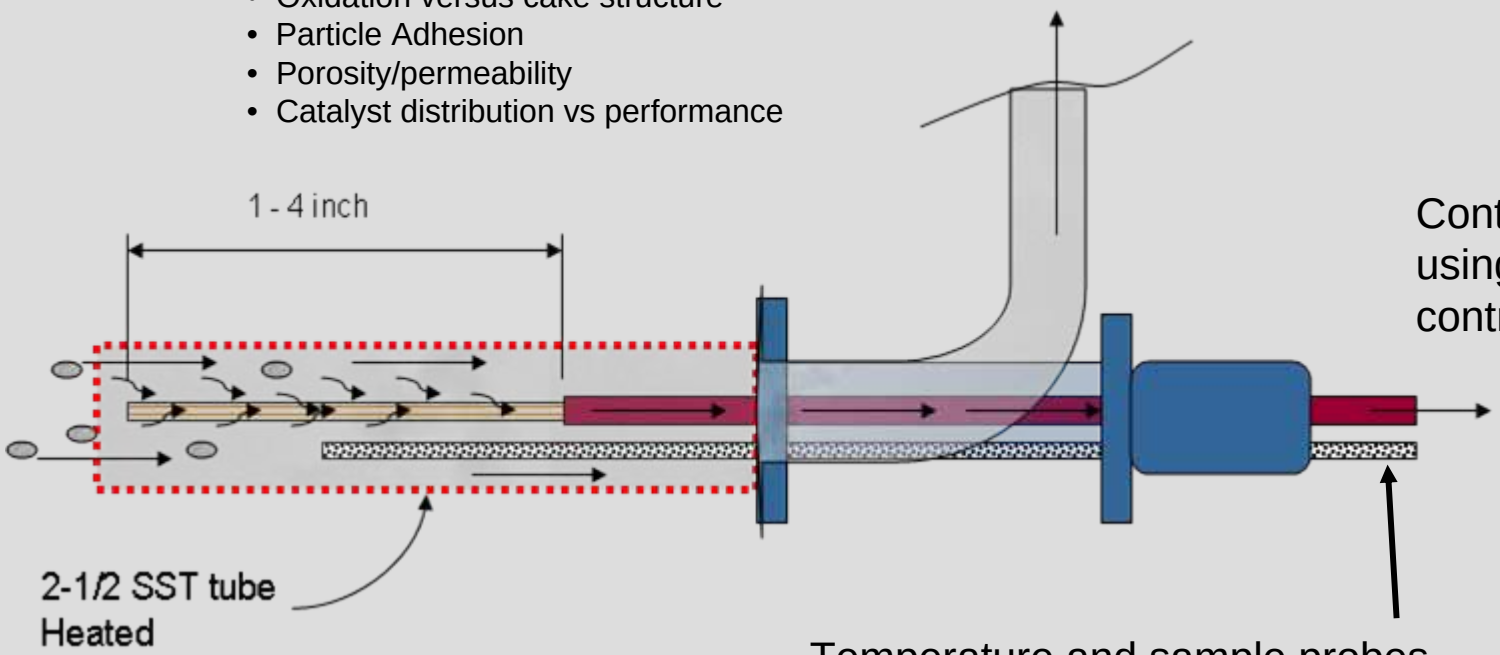
Limitations for Microscopic Studies

- Axial and radial flow distribution
- Temperature distribution
- Sample preparation

Single Channel Filter Assembly

Single channel objectives

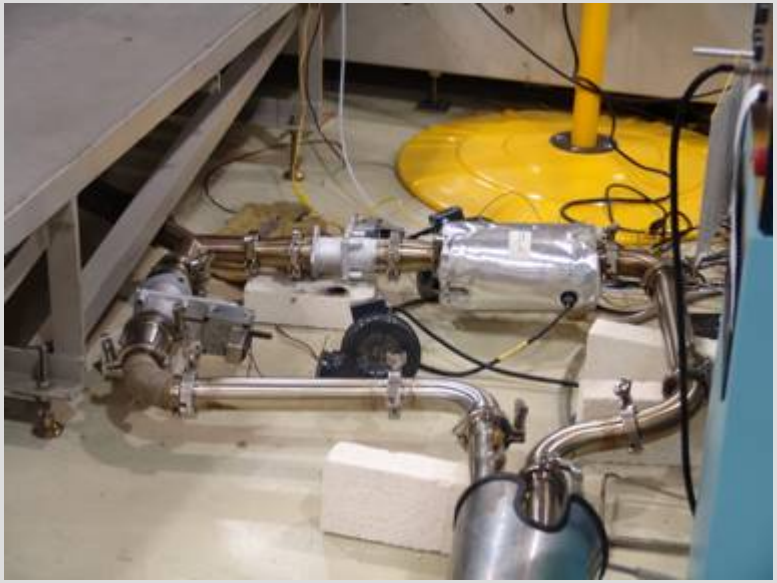
- Validations of LB models
- Soot cake structure
- Oxidation versus cake structure
- Particle Adhesion
- Porosity/permeability
- Catalyst distribution vs performance

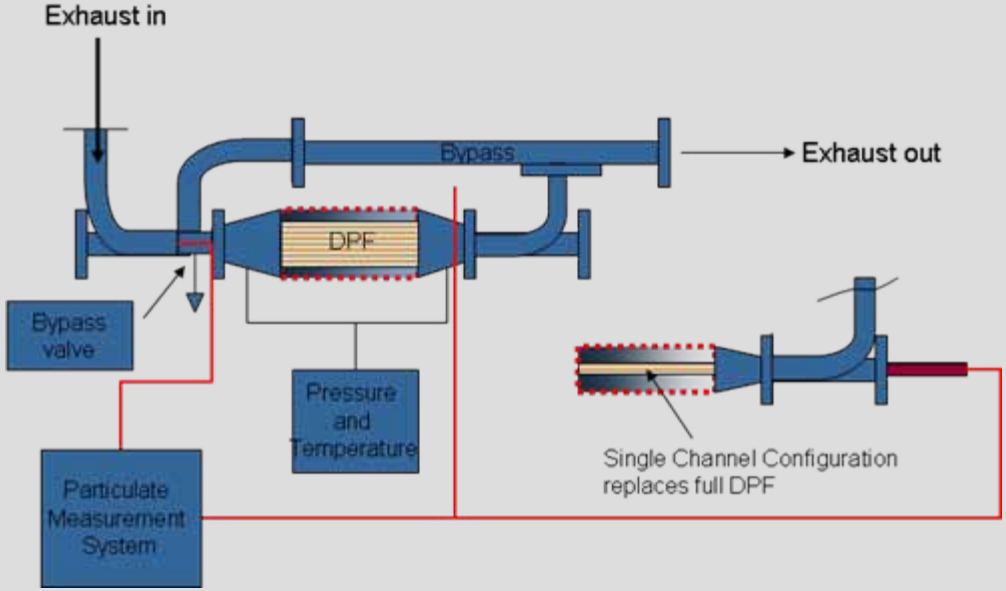


Controlled flow rate using mass flow controller

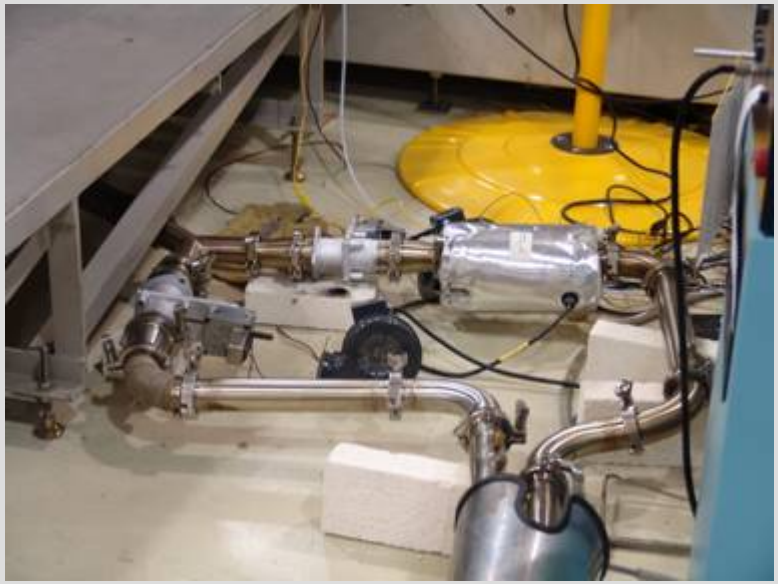
Temperature and sample probes

Single Channel Filter Vehicle Exhaust Assembly





Single Channel DPF Exhaust Assembly

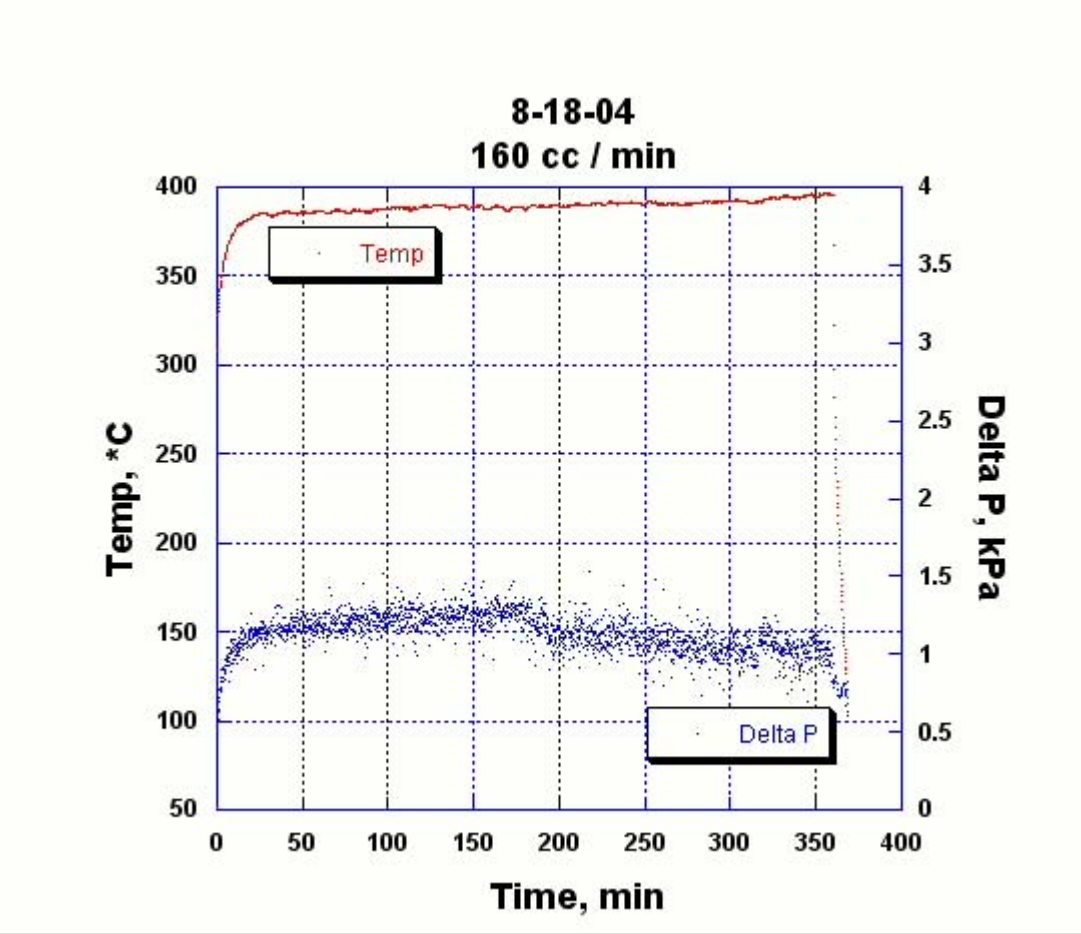


Single Channel Experiments

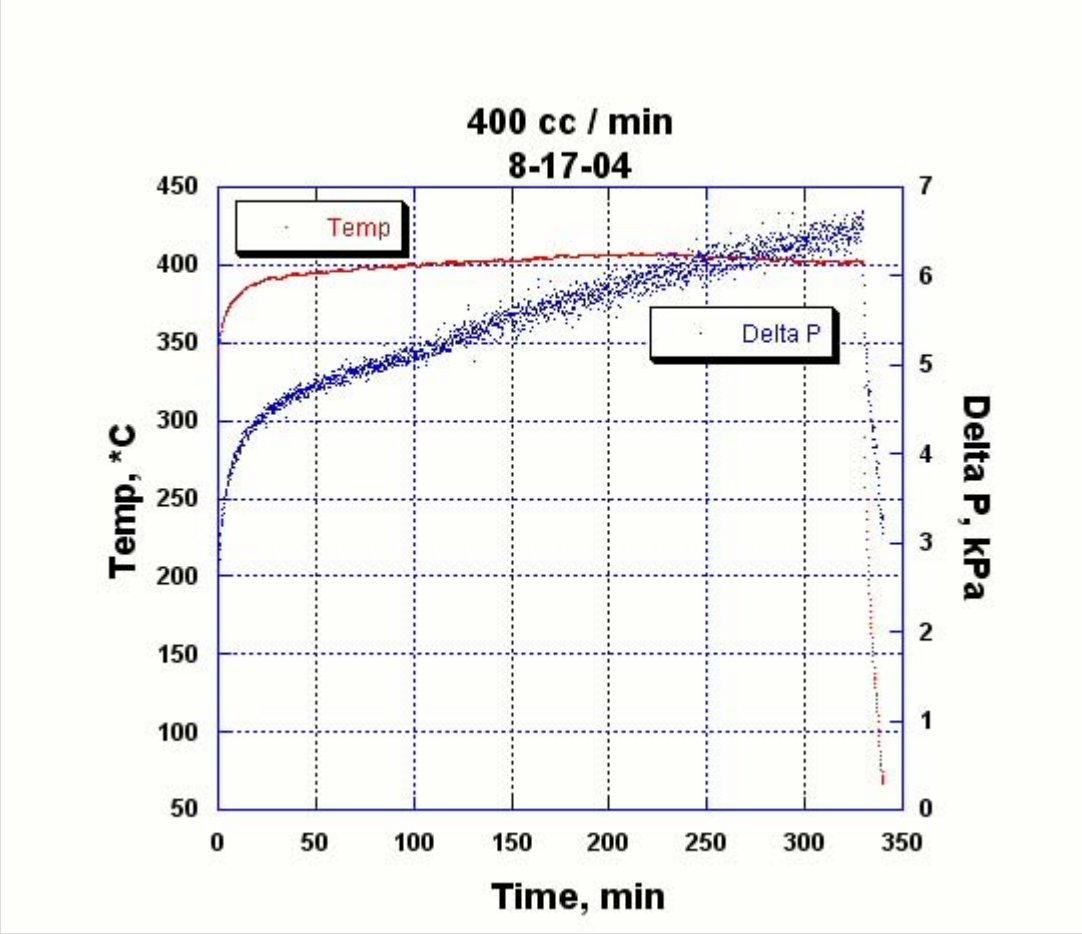
- Single channel cut from filter
- Outside surfaces loaded by drawing exhaust through the single channel

Soot Cake Properties

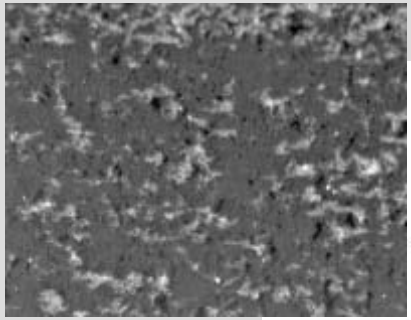
Soot Loading Curve
Pe# ~ 0.3

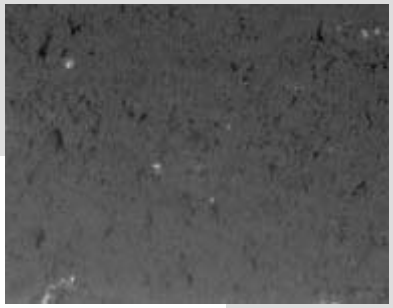


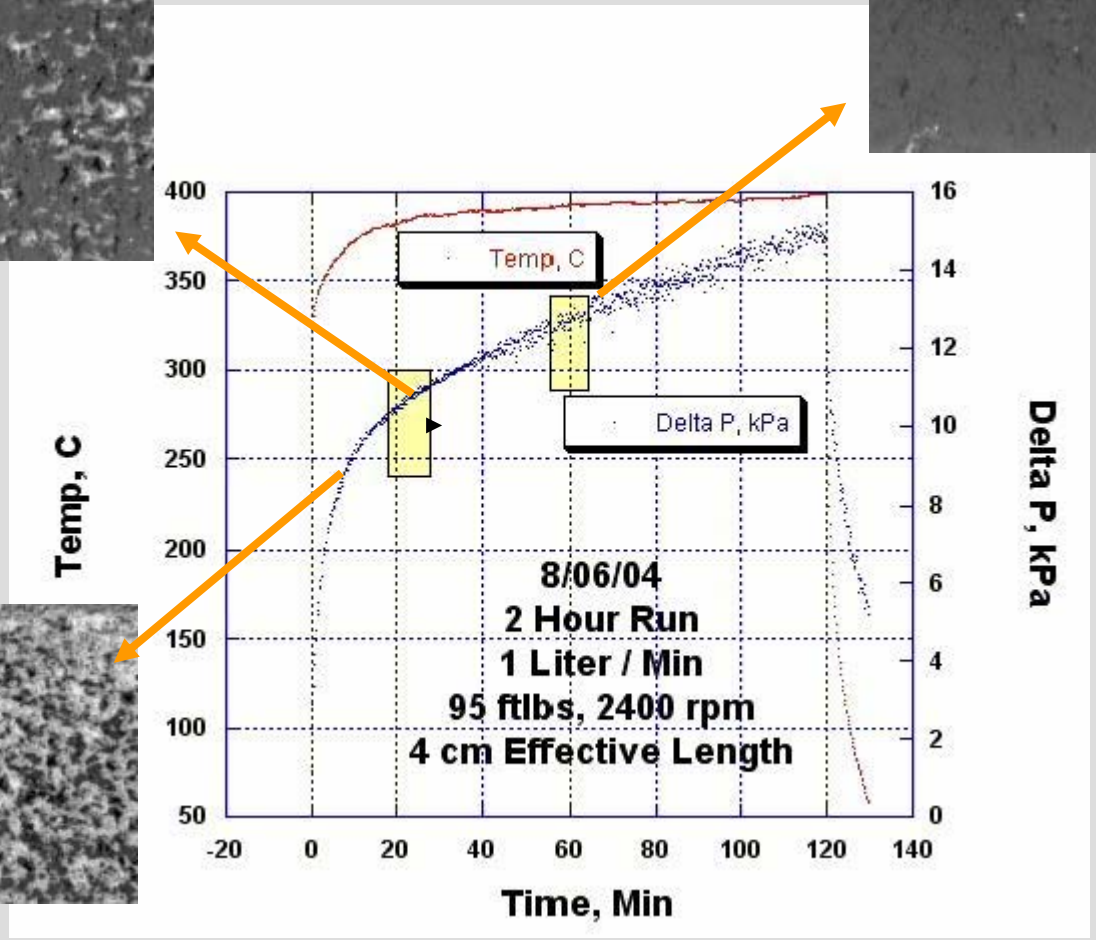
Soot Loading Curve
Pe # ~ 0.75

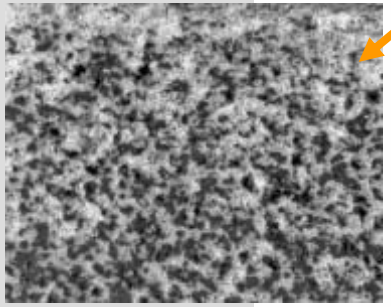


Soot Loading Curve
Pe# ~ 4

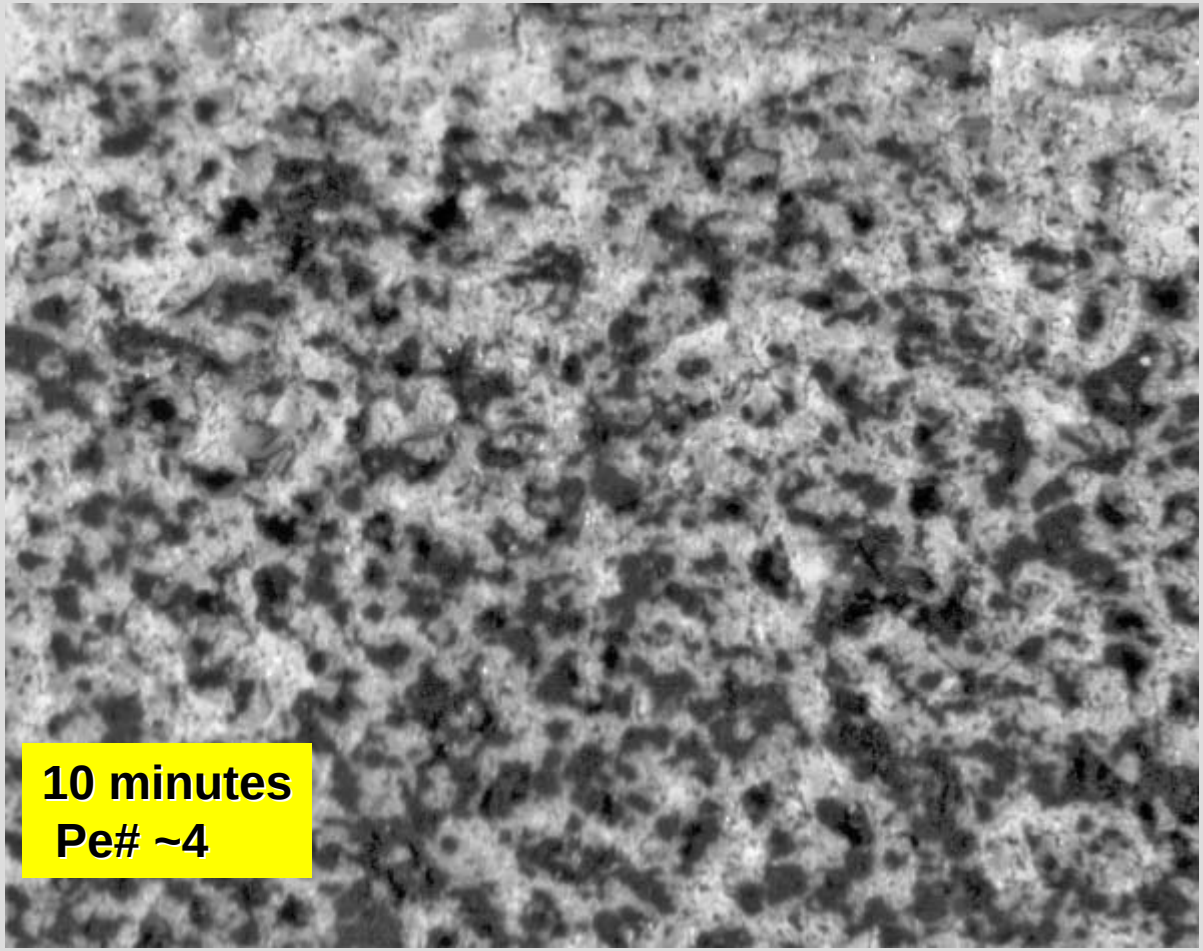






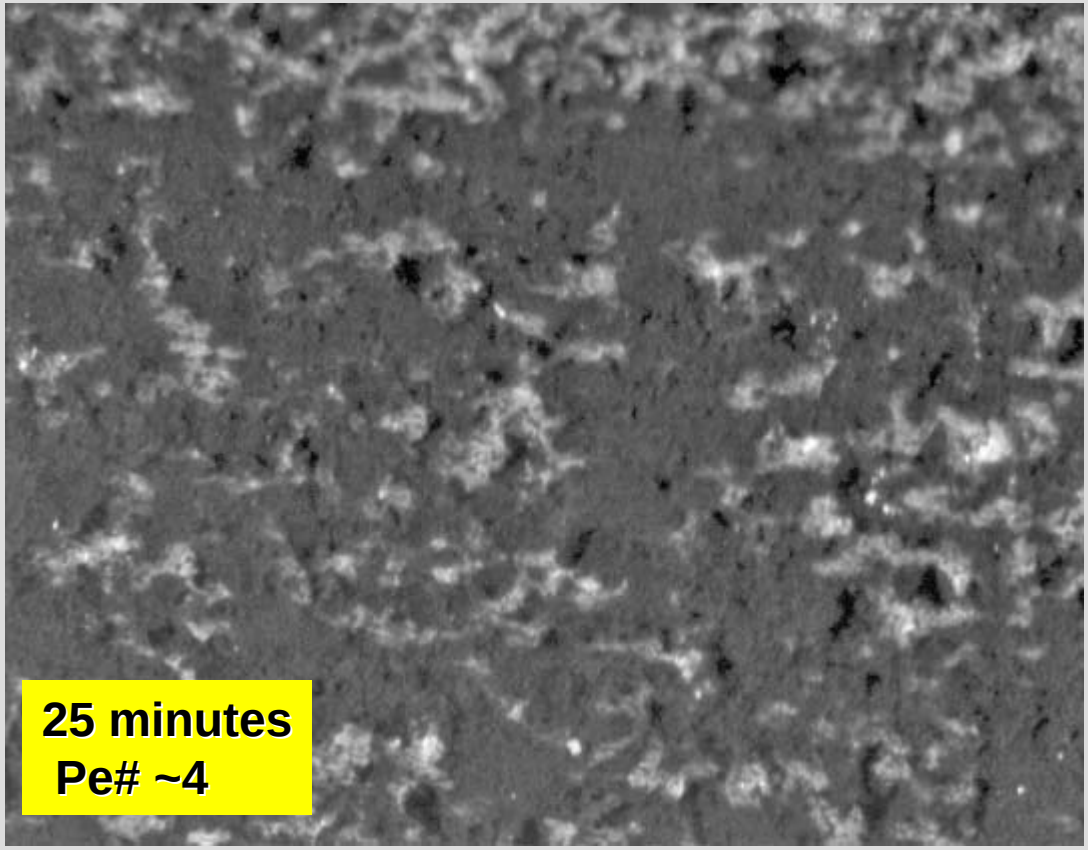


Deep Bed Filtration



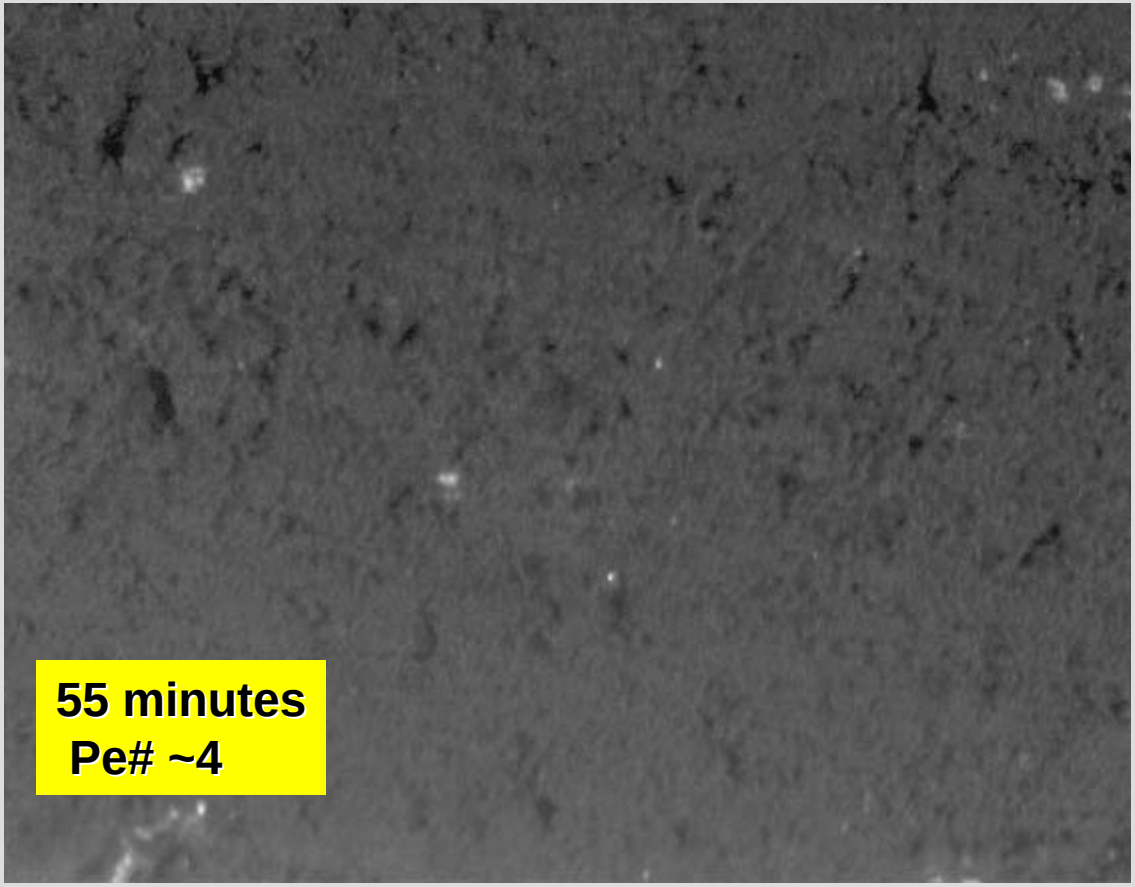
Transition from Deep Bed to Soot Cake Filtration

Pores remaining open

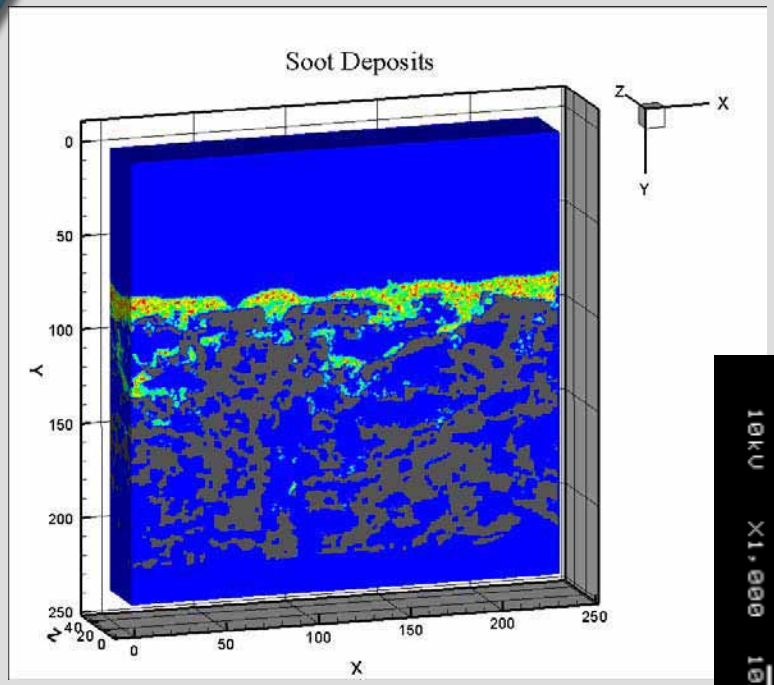


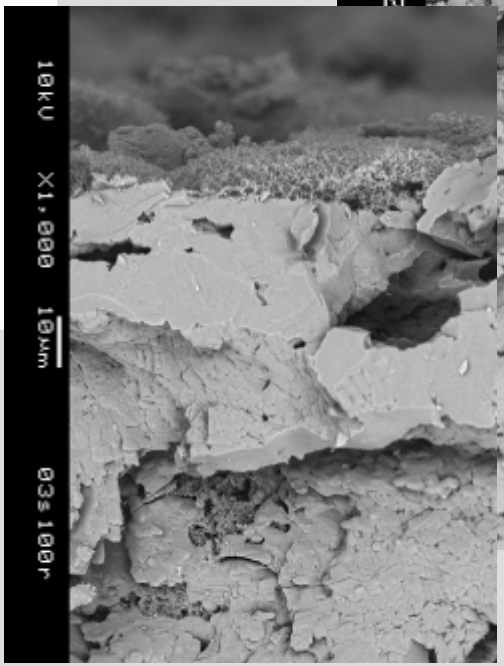
Fully Developed Soot Cake Filtration

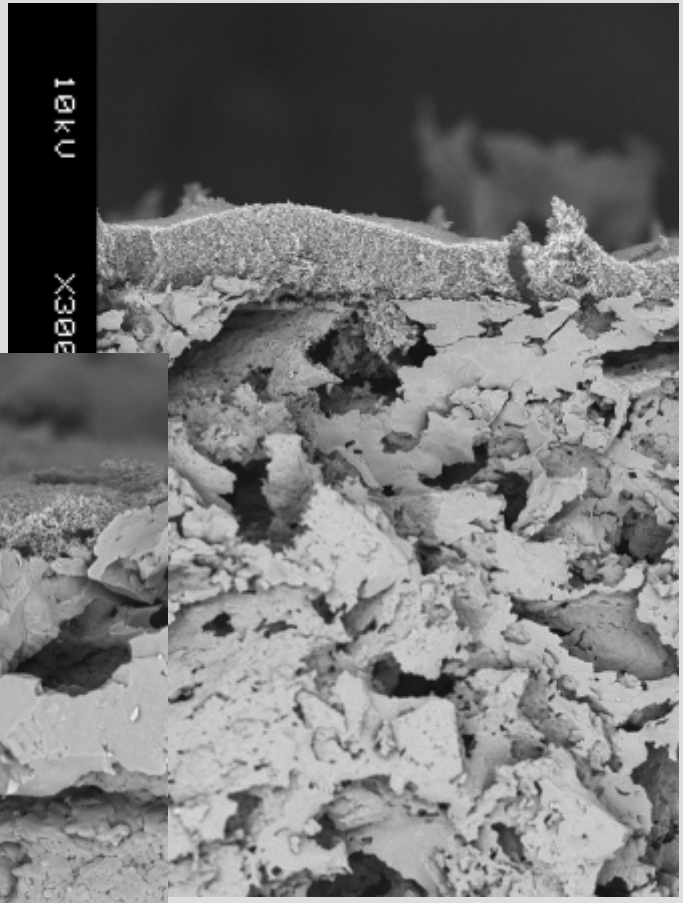
Pores remaining open



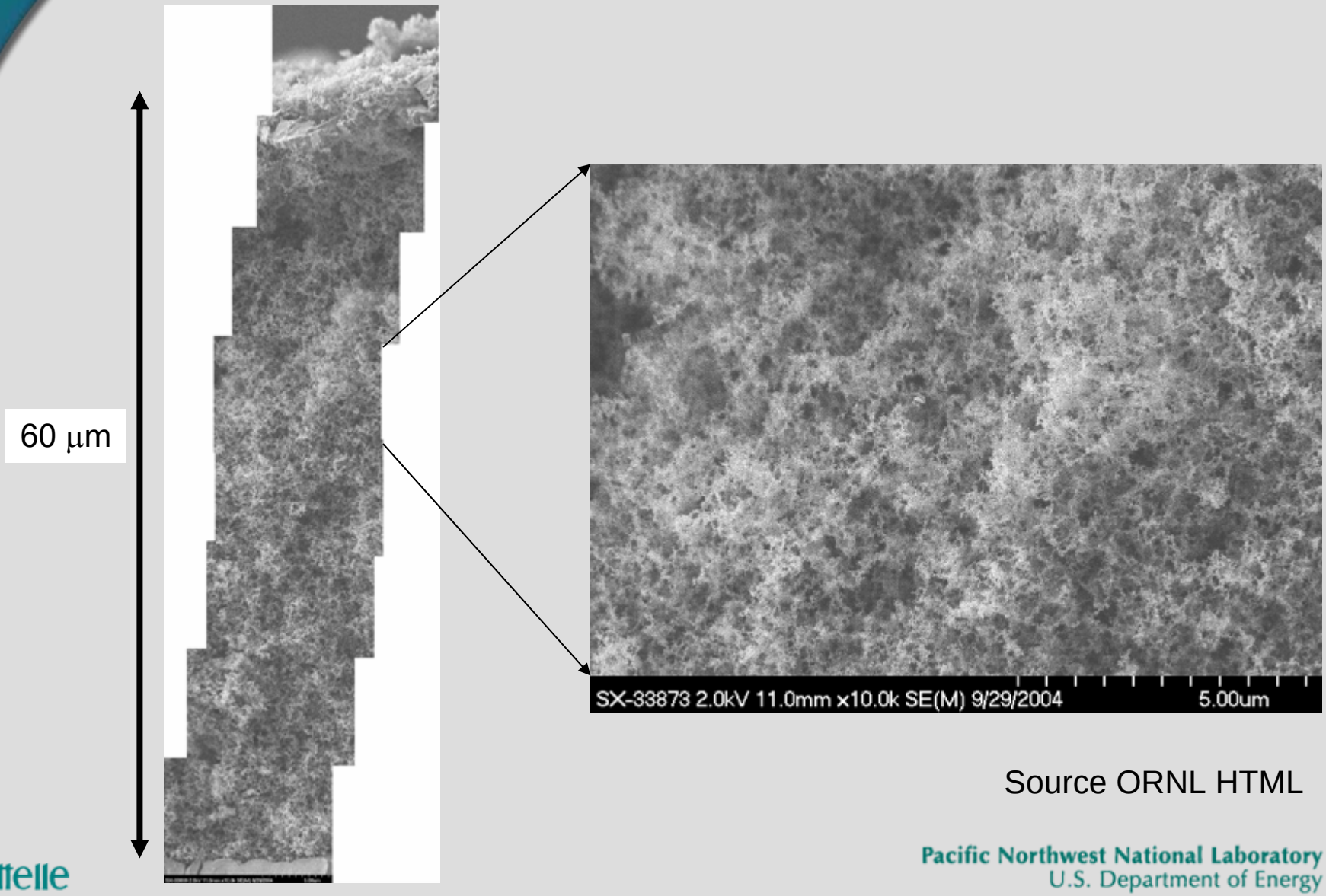
Microscopic Comparison to Real Soot Deposits





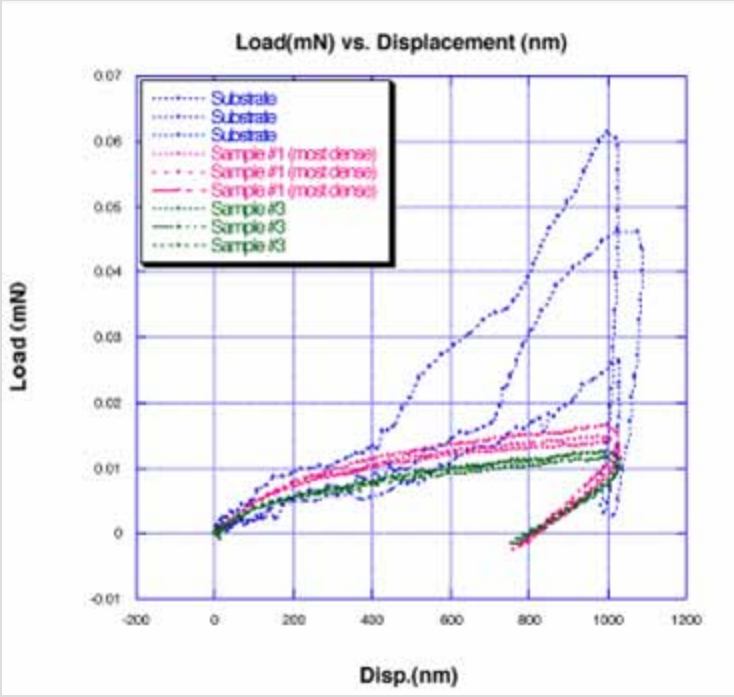


Low voltage SEM Soot image



Source ORNL HTML

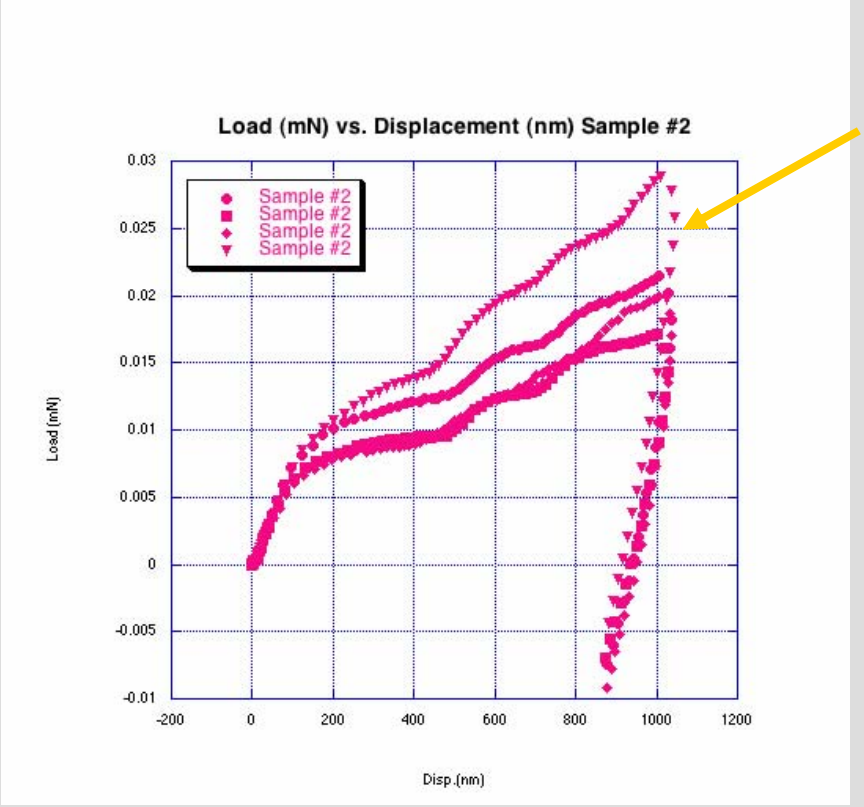
Nano-indentation
Young's Modulus and Hardness



Sample	Comment	E (Mpa)	H (Mpa)
0	Cordierite Sub.	141	2.43
0	Cordierite Sub.	74.7	1.65
0	Cordierite Sub.	92.8	0.95
1	Most dense	11.8	0.95
1	Most dense	11.0	0.84
1	Most dense	10.5	0.79
3	Least dense	8.05	0.68
3	Least dense	8.31	0.77
3	Least dense	8.21	0.76

Source ORNL HTML

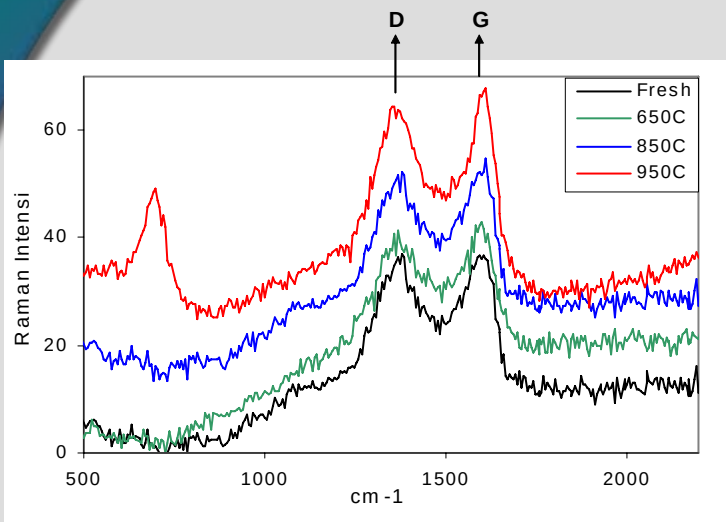
Nano-indentation
Multi Runs



The bulge in displacement curve during unloading is an Indication of an adhesive force (stickiness)

Source ORNL HTML

Raman spectroscopy long-range order (graphitization) in soot



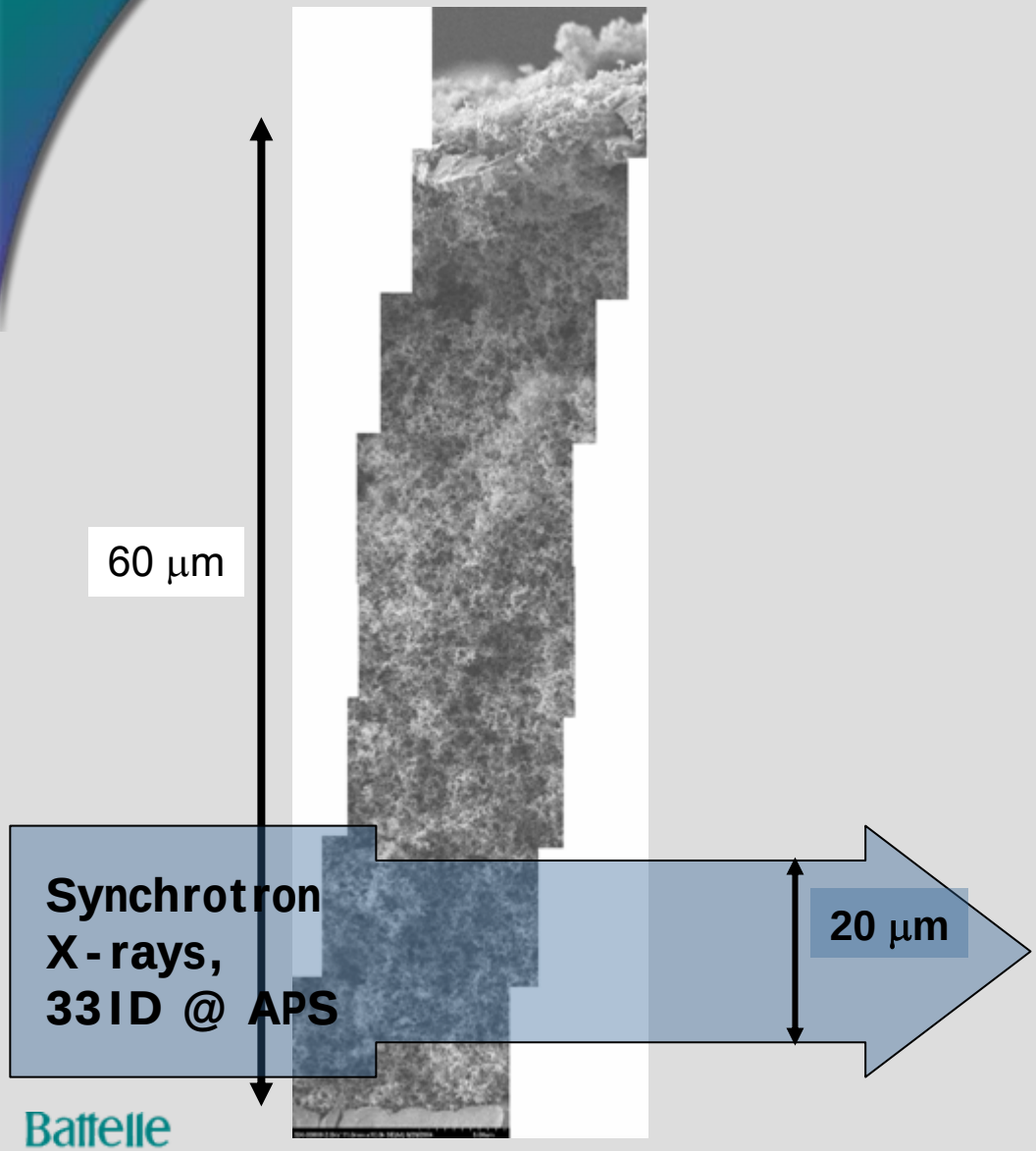
Sample	Comment	G/D
1	Most dense	1.06
1.1	Most dense	1.08
2	Middle dense	1.31
3	Least dense	1.14

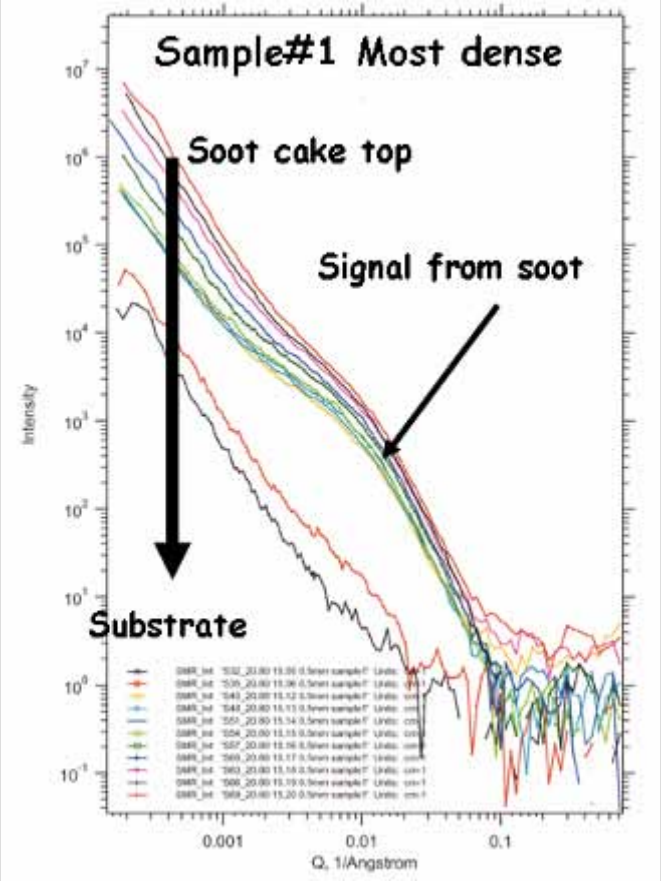
An increase in the ratio of the “G” (graphite) band to the “D” (disorder) band indicates more long range order

Sample 2 experienced temperatures ~ 20 C higher than samples 1 and 3 for a period of an hour which may explain the higher G/D ratio.

Source ORNL HTML

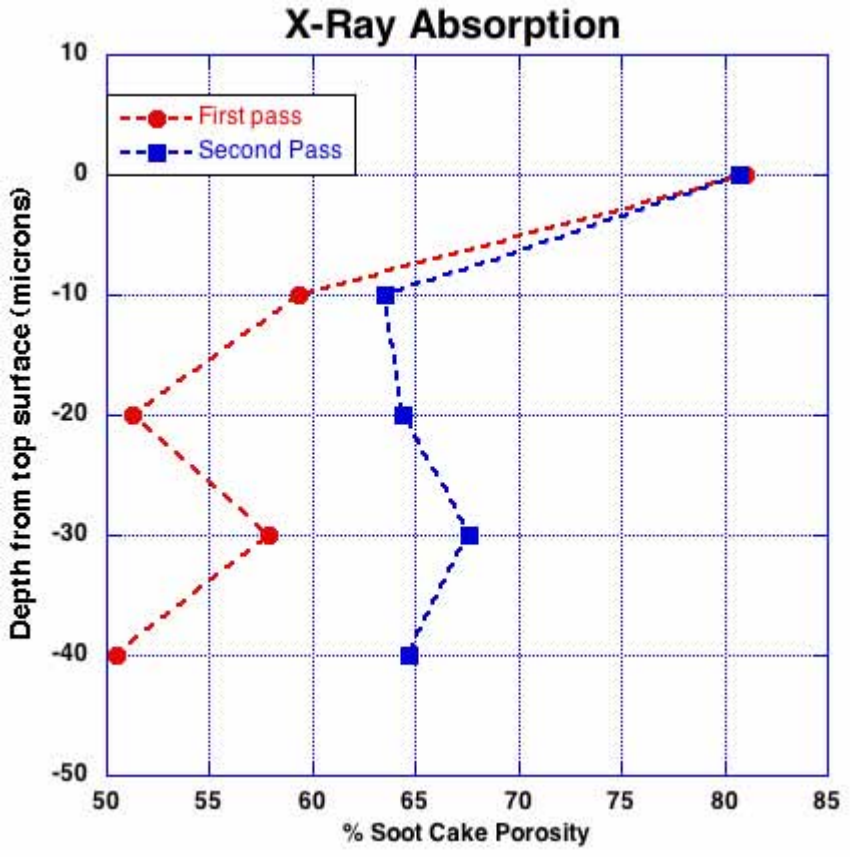
USAXS Results

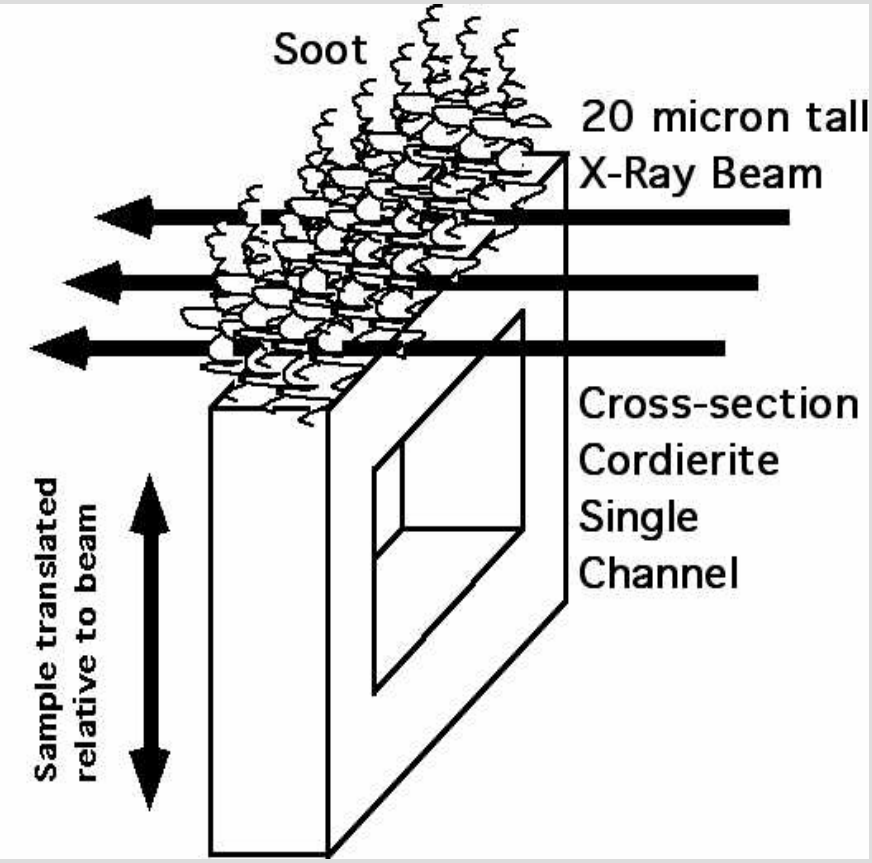




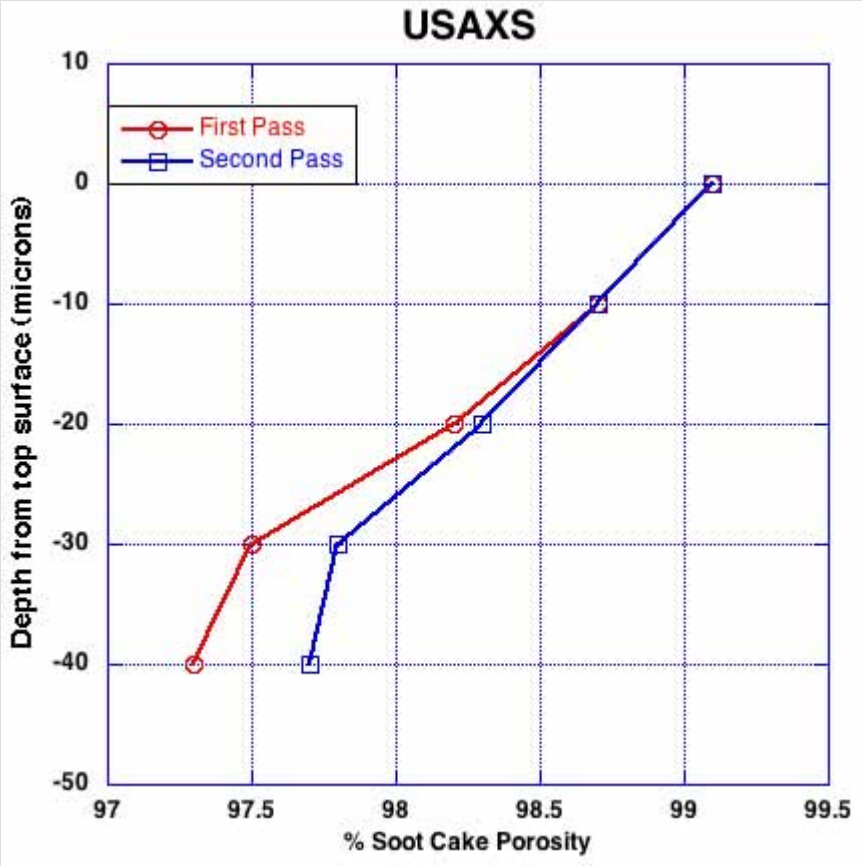
Source ORNL HTML

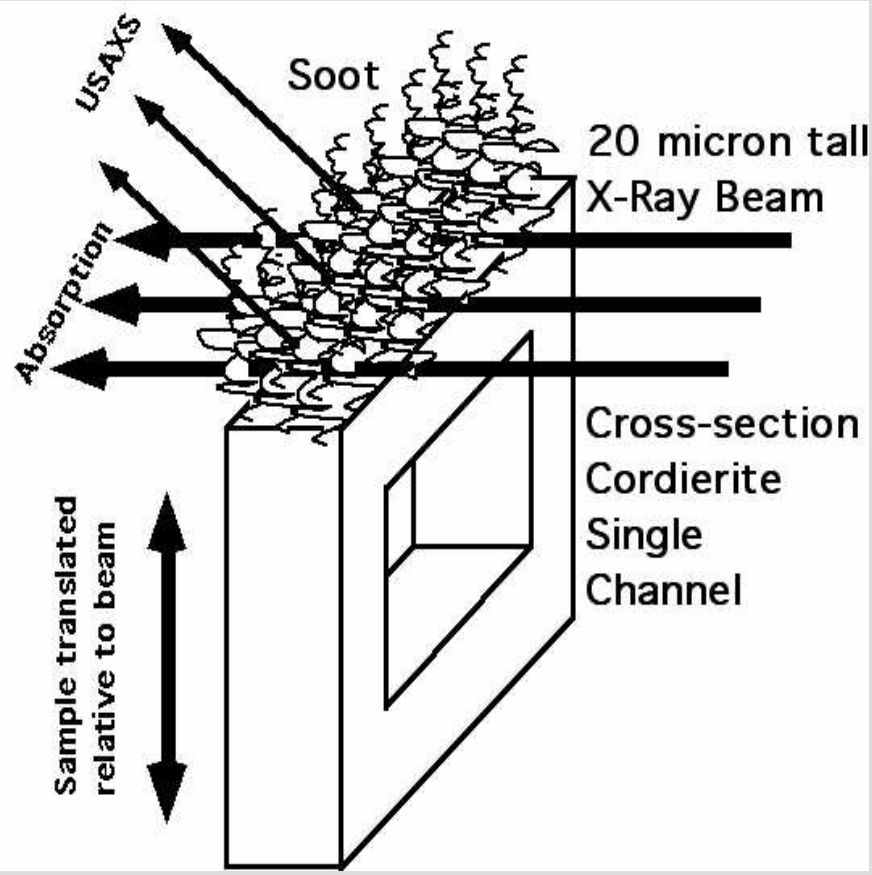
USAXS Absorption Results



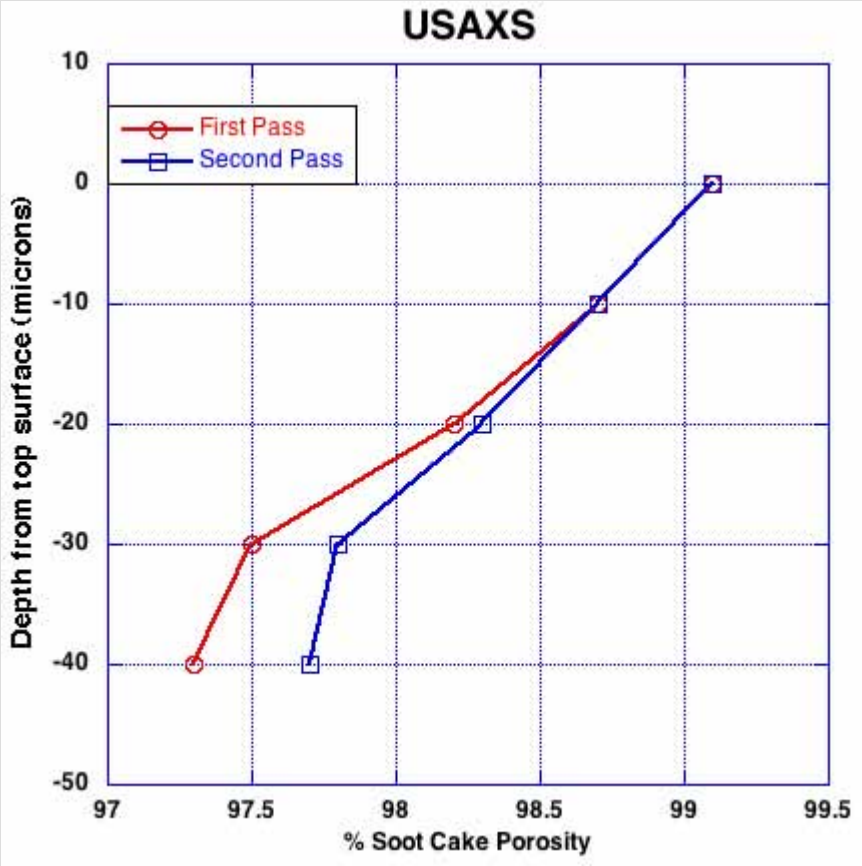


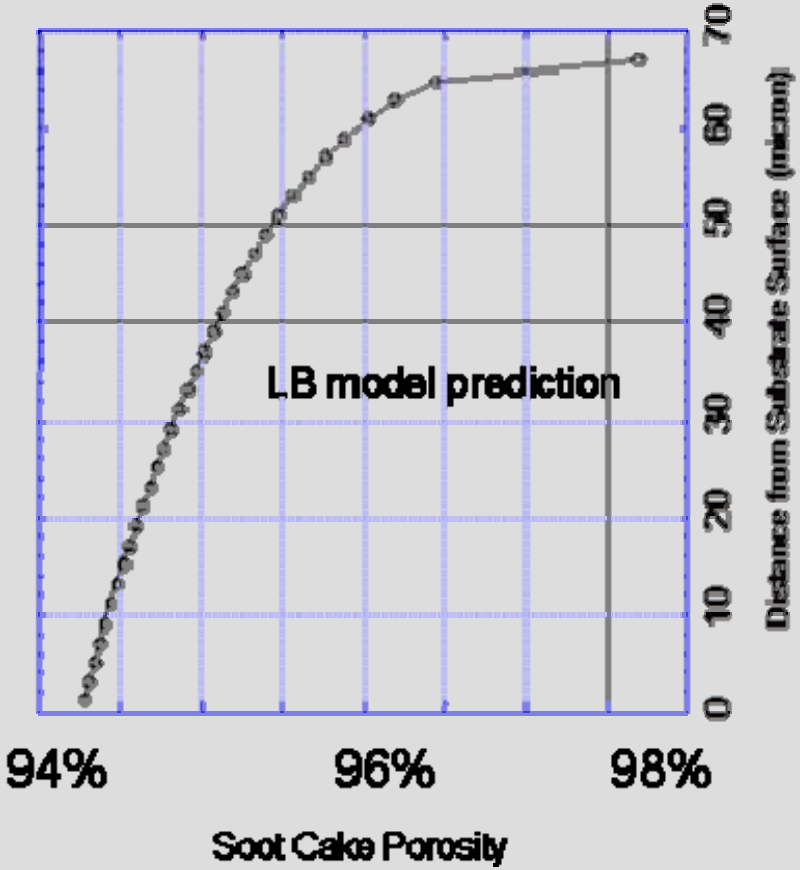
USAXS Results

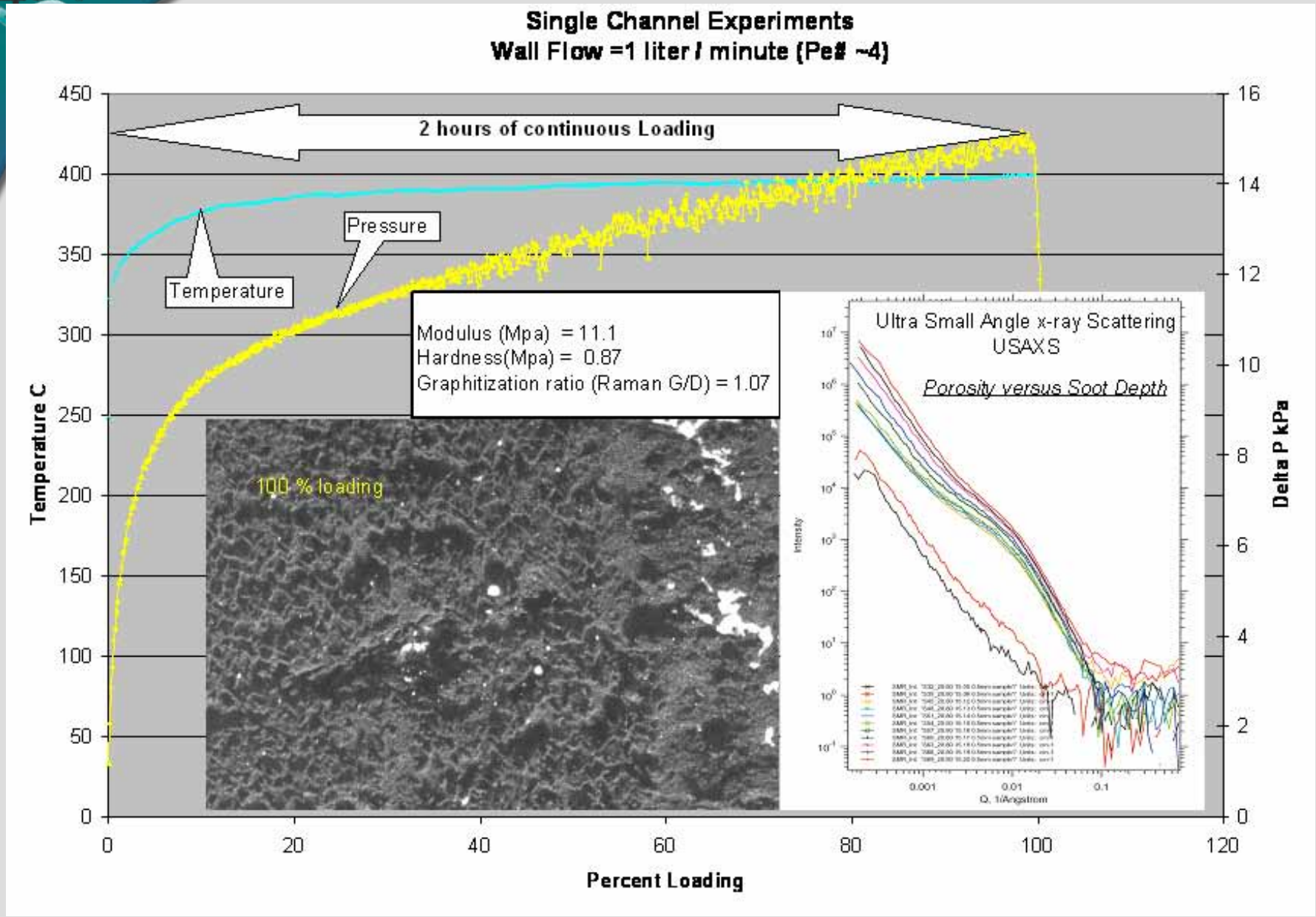




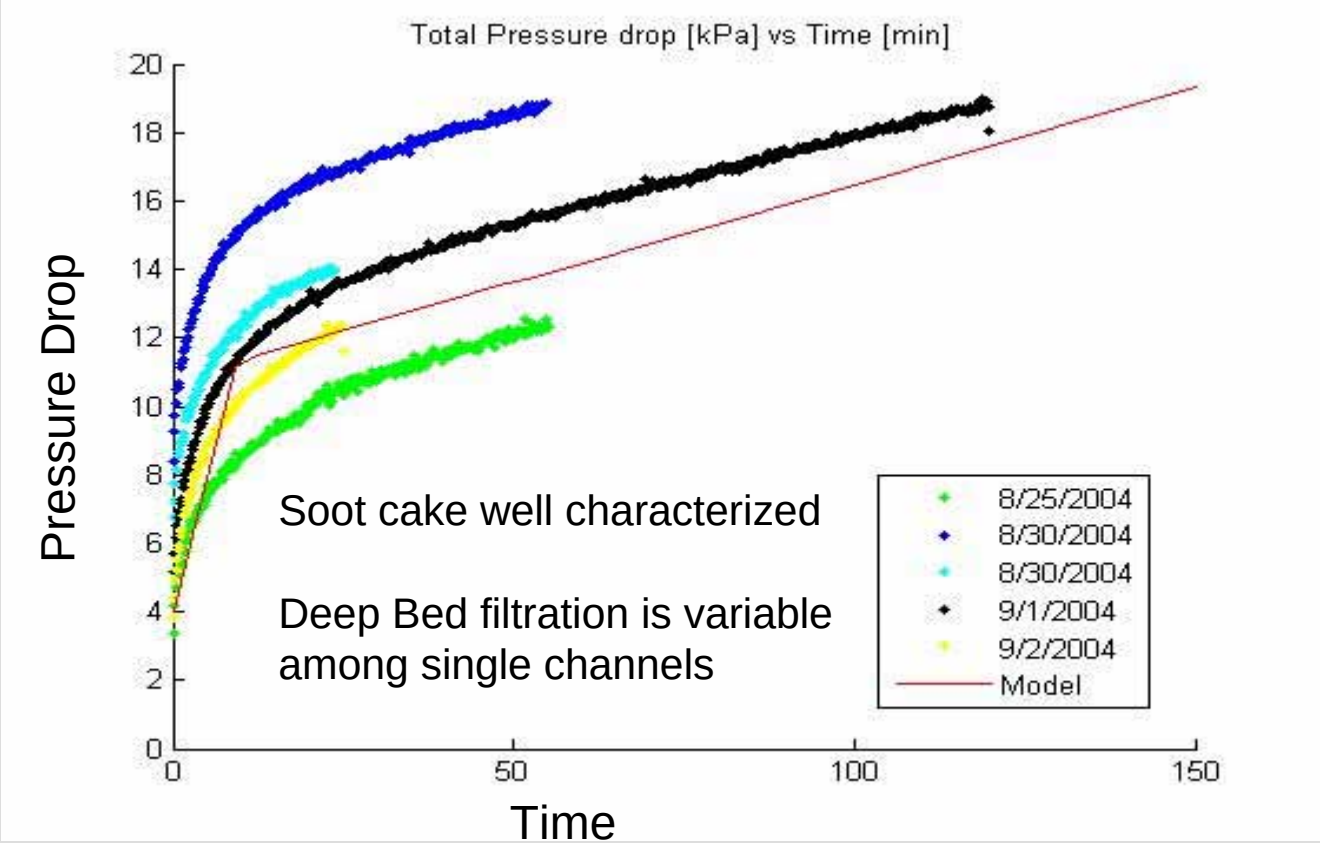
USAXS Results versus LB model Prediction






Single Channel Experiments
Wall Flow =1 liter / minute (Pe# ~4)
2 hours of continuous Loading
Pressure
Temperature
Modulus (Mpa) = 11.1
Hardness(Mpa) = 0.87
Graphitization ratio (Raman G/D) = 1.07
100 % loading
Ultra Small Angle x-ray Scattering
USAXS
Porosity versus Soot Depth
Intensity
Q, 1/Angstrom
Temperature C
Delta P kPa
Percent Loading
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
0
20
40
60
80
100
120

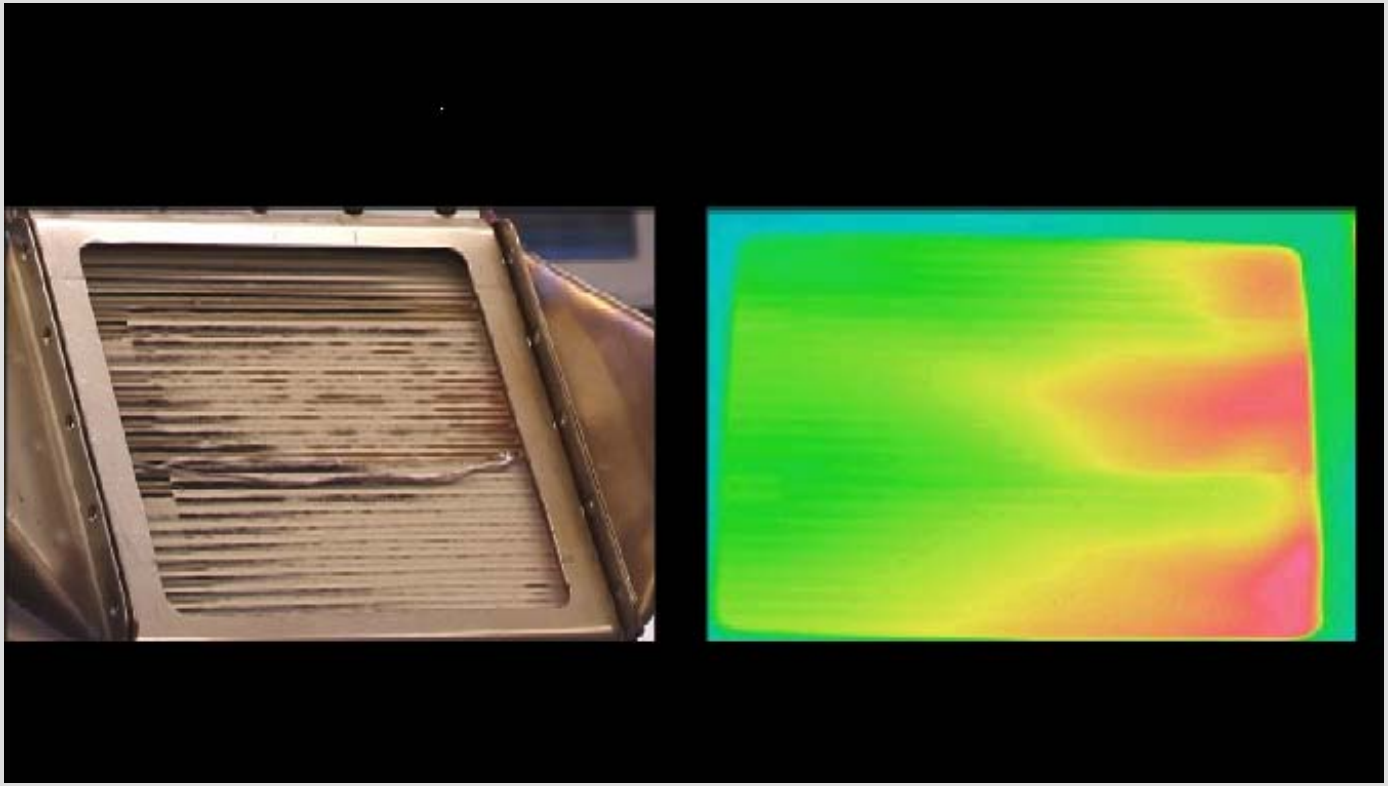
LB Model versus Experimental Results



Oxidation Kinetics

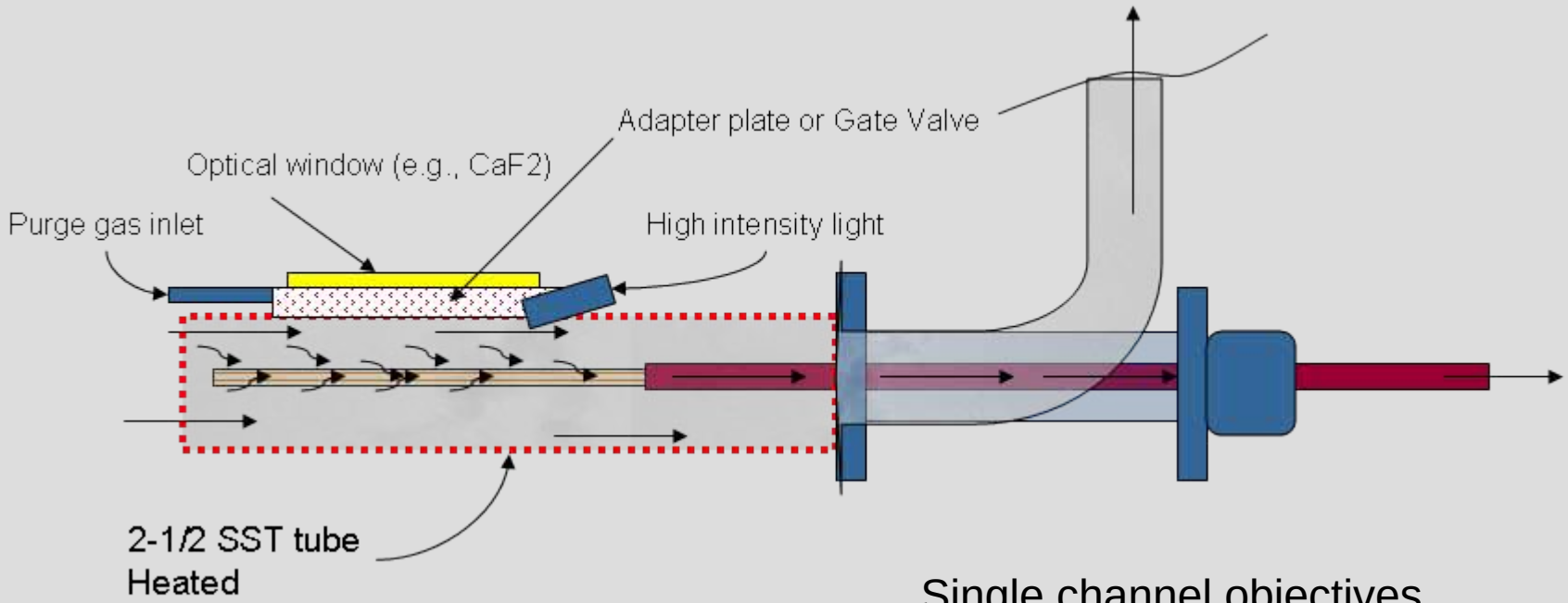
Infrared Camera Analysis

Infra Analysis of Soot Oxidation of Full Brick



Variations in radial and axial soot deposition makes it difficult to support LB modeling of oxidation reactions

Infrared Camera Analysis
Single Channel Filter Assembly



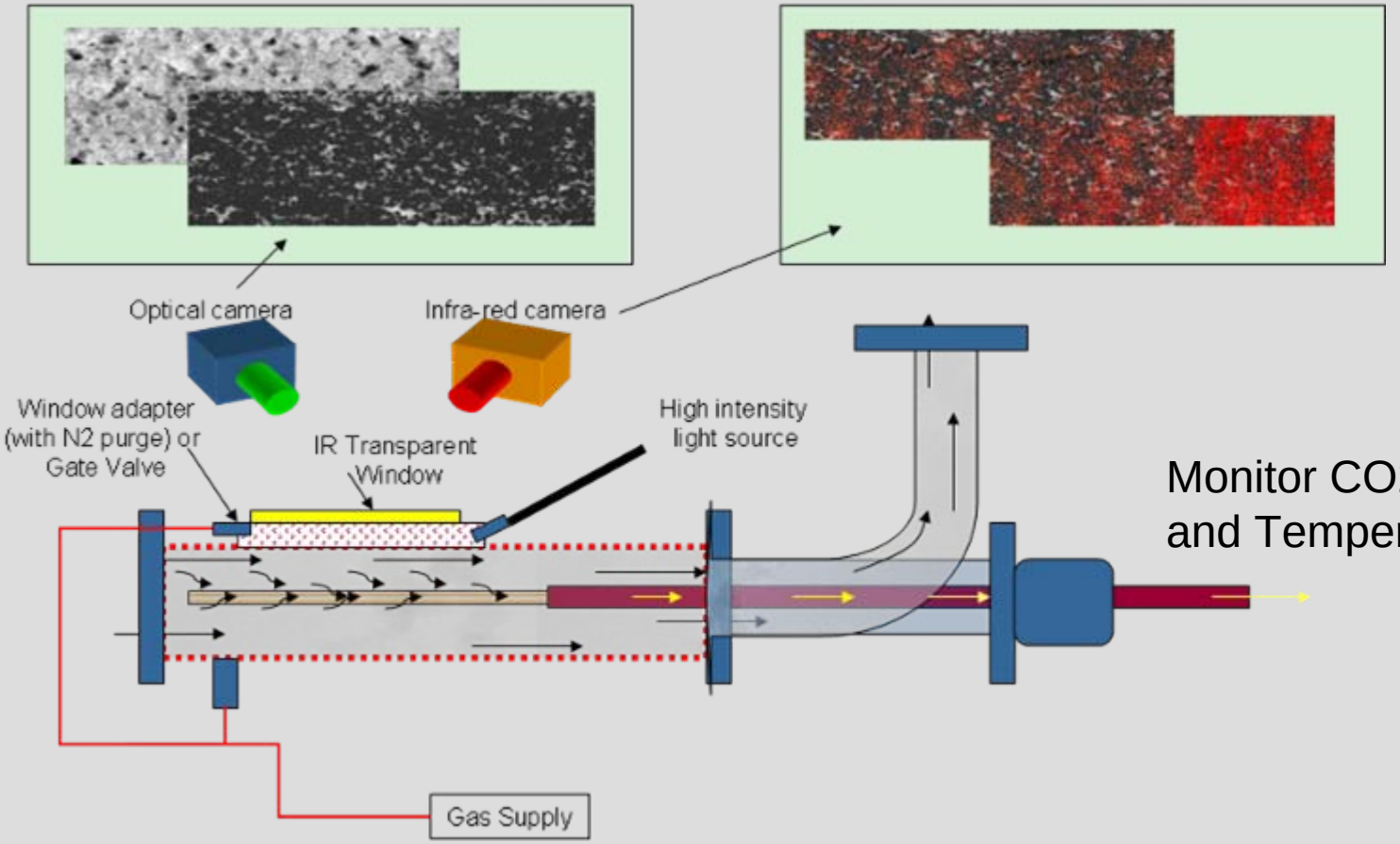
Single channel objectives

- Oxidation versus cake structure
- Particle Adhesion
- Porosity/permeability
- Catalyst distribution vs performance

Optical Access and Soot Coated Channel

Infrared and Video Camera Setup

Single Channel Oxidation Kinetics



Monitor CO2, NOx and Temperature

Conclusions

- Single channel filter technique has the ability to validate the LB model.
- Deep bed filtration of single channels may not be uniform.
- USAXS, Raman, and Nano indentation techniques provide insight into the changes in soot cake characteristics.
- Optical techniques in conjunction with USAXS, Raman and Nano-indentation can be used to understand the effect different regeneration strategies soot regeneration.