The microstructure of soot fractal aggregate deposits

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Abstract

In the literature it has been common practice to assume that the soot layer grown on DPF walls can be described by a uniform density (equivalently porosity), surface area and permeability, which are parameters that have to be tuned according to experiments, leading to widely varying values among different publications. We have shown that during DPF loading the microstructure of the soot cake is determined by the convective-diffusive transport of the soot aggregates towards the deposit and it was also demonstrated that soot cake packing density and permeability are related to the local value of the dimensionless mass transfer Peclet number. In addition these parameters can be related to the porosity and primary particle properties of the soot aggregates. Further insight into soot cake properties has been obtained by model experiments with soot aggregates generated by a Combustion Aerosol Standard (CAST) burner (Matter Engineering, Switzerland). The CAST is a quenched diffusion flame gas (propane) burner that allows the stable and controlled generation of soot aggregates over a much larger size range than that found in diesel exhaust. The model experiments performed with the CAST burner involved the loading of flat disk shaped glass-fiber filters at a wide range of Peclet numbers (0.05-30)-which was achieved by changing the sampling flow for each case- and for soot aggregate sizes between 95 and 200 nm (as measured with the Scanning Mobility Particle Sizer). The results presented show that the porosity of soot deposits depends strongly on the Peclet number, as well as on the aggregate mobility diameter. When soot loaded filters are exposed to a critical pressure drop, soot layer compaction occurs. The microstructure of the resulting deposits, is shown to be well represented in terms of universal power-law functions with respect to the Peclet number and the deposit yield pressure drop.

The Microstructure of Soot Fractal Aggregate Deposits

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Motivation

Structure of soot aggregate deposits is important for a number of applications:

- **Pressure drop of diesel particulate filters**
- **Health effects of soot particles/deposits (contact/interaction with tissues)**

Methodology

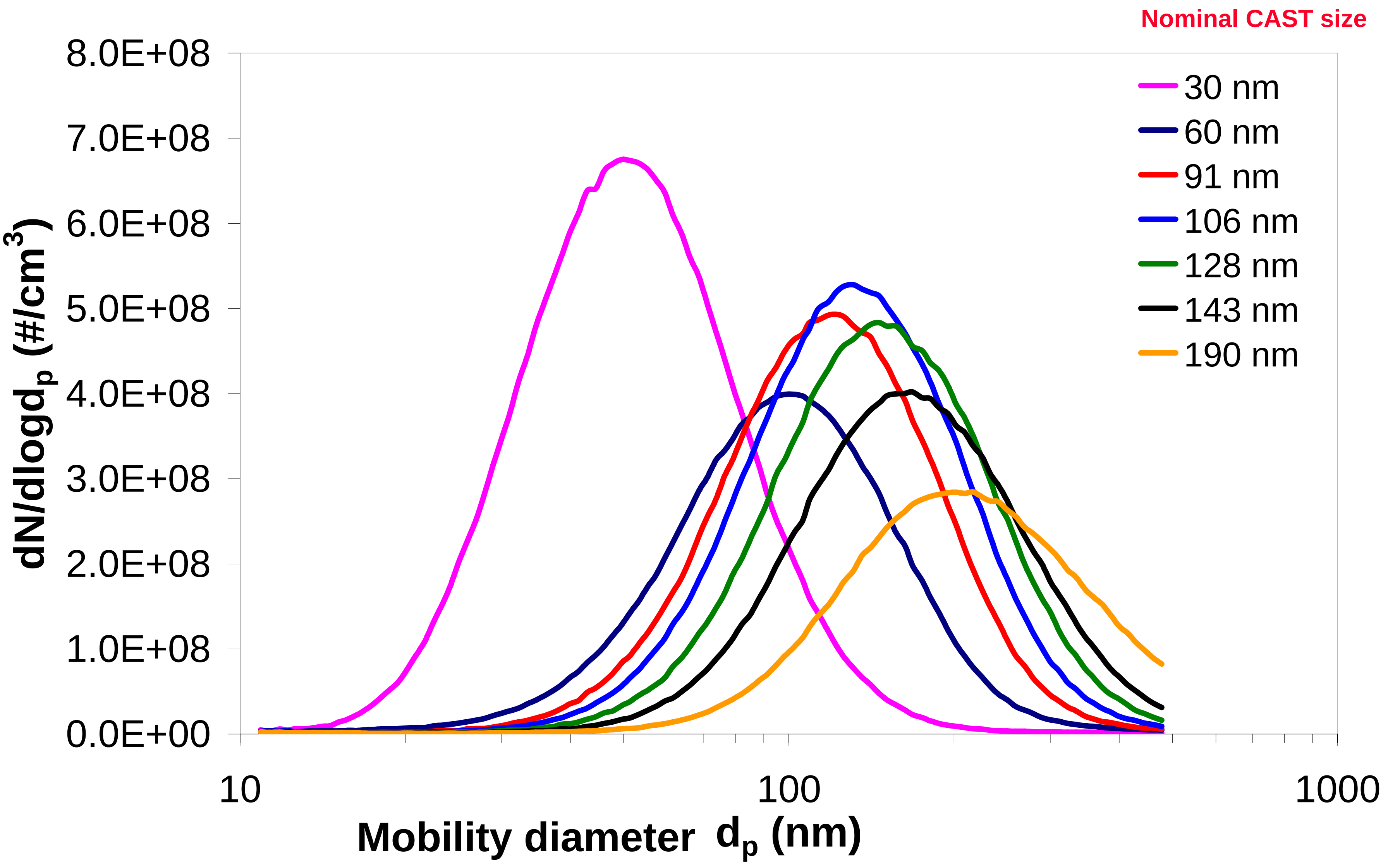
Study the microstructure of soot aggregate deposits using:

- Reference soot size distributions collected on glass fiber absolute filters
- Measurements of filter pressure drop at different Peclet numbers by varying the filtration velocity
- Analysis of results to extract the flow resistance 1/(packing density x permeability) of the collected deposits
- Appropriate dimensionless numbers and correlations to describe the results

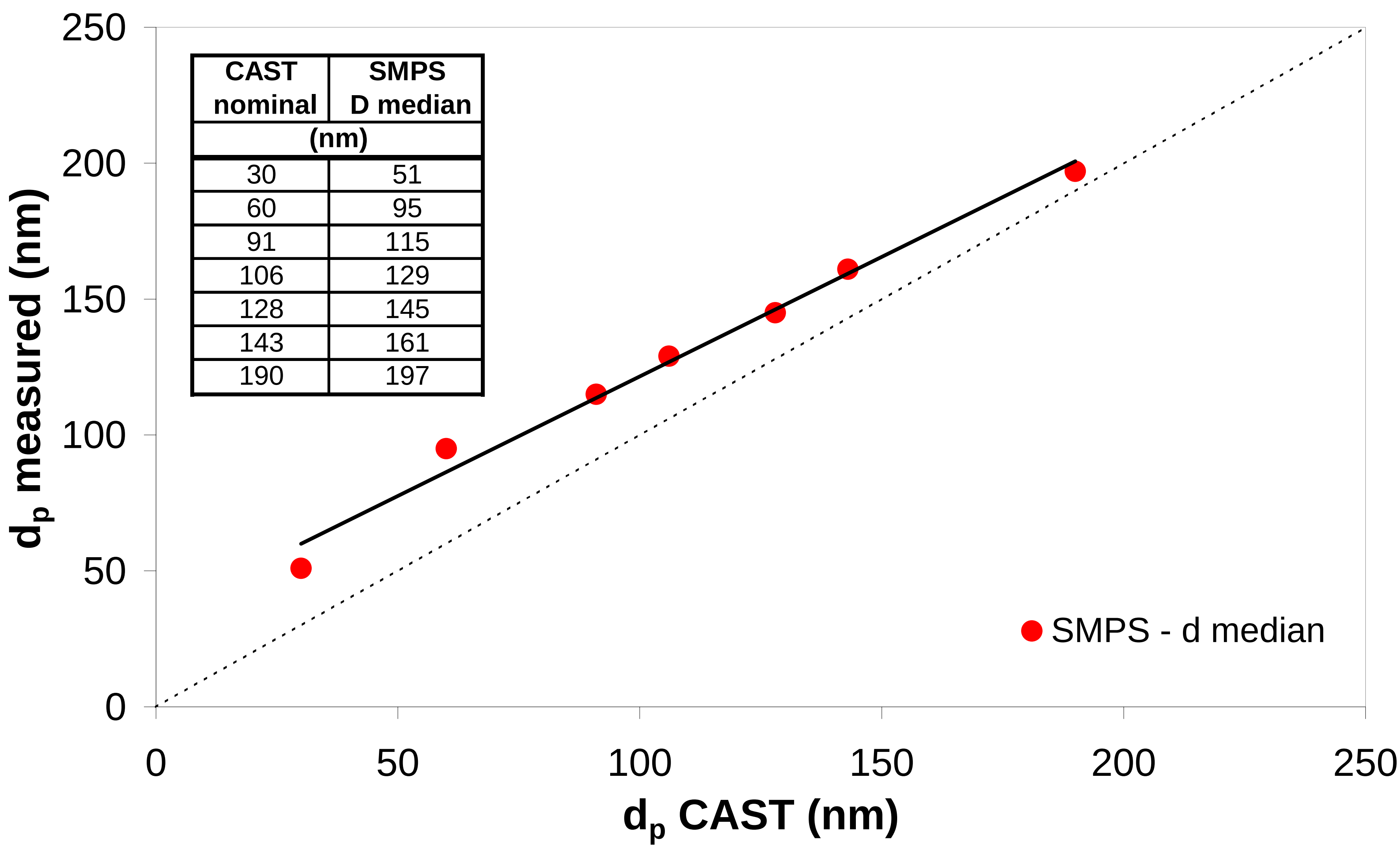
Combustion Aerosol STandard (CAST, Matter Engineering)

Quenched Flame Burner provides reference soot size distributions

CAST soot size distributions

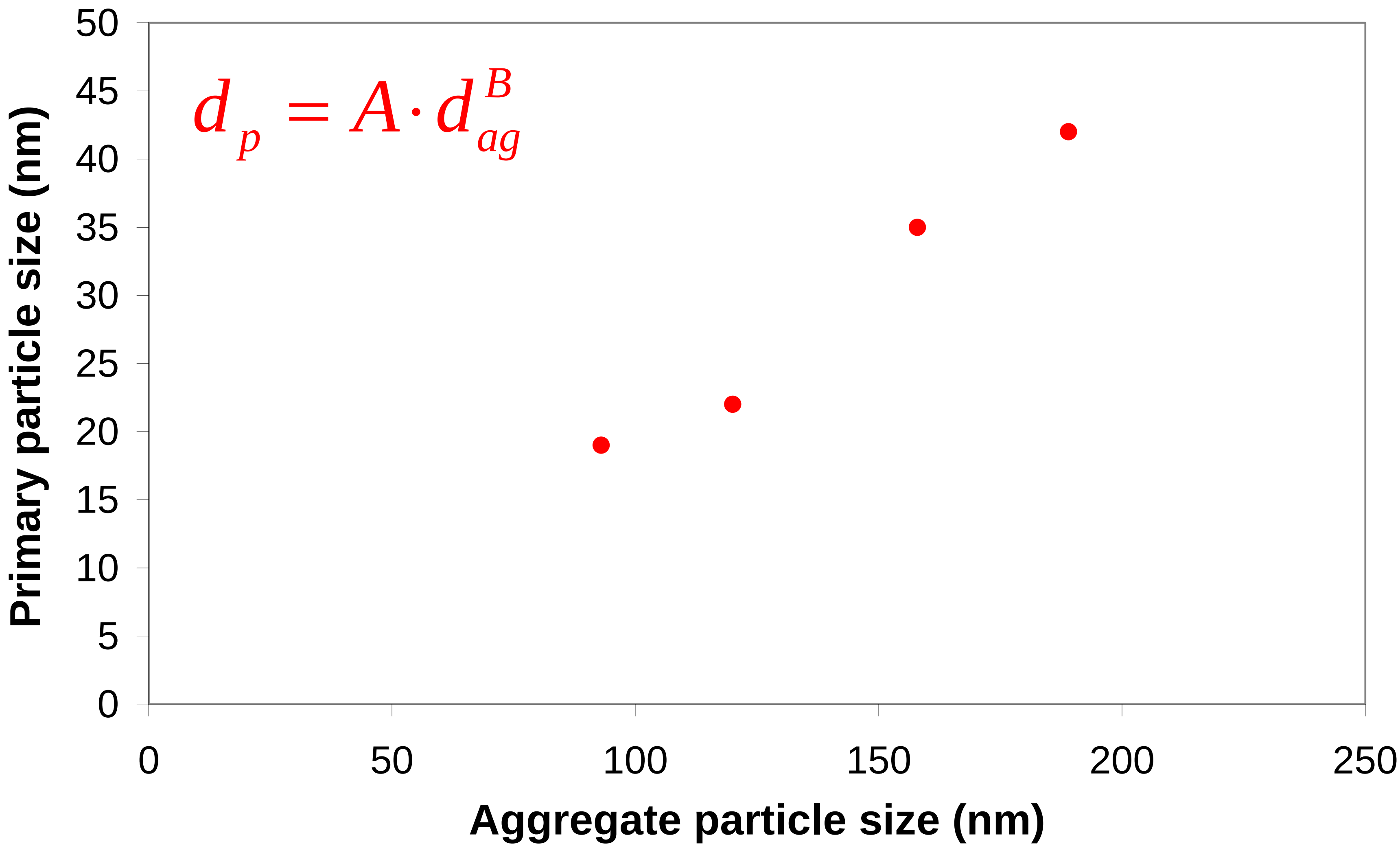


Nominal (CAST) vs. measured (SMPS) diameter

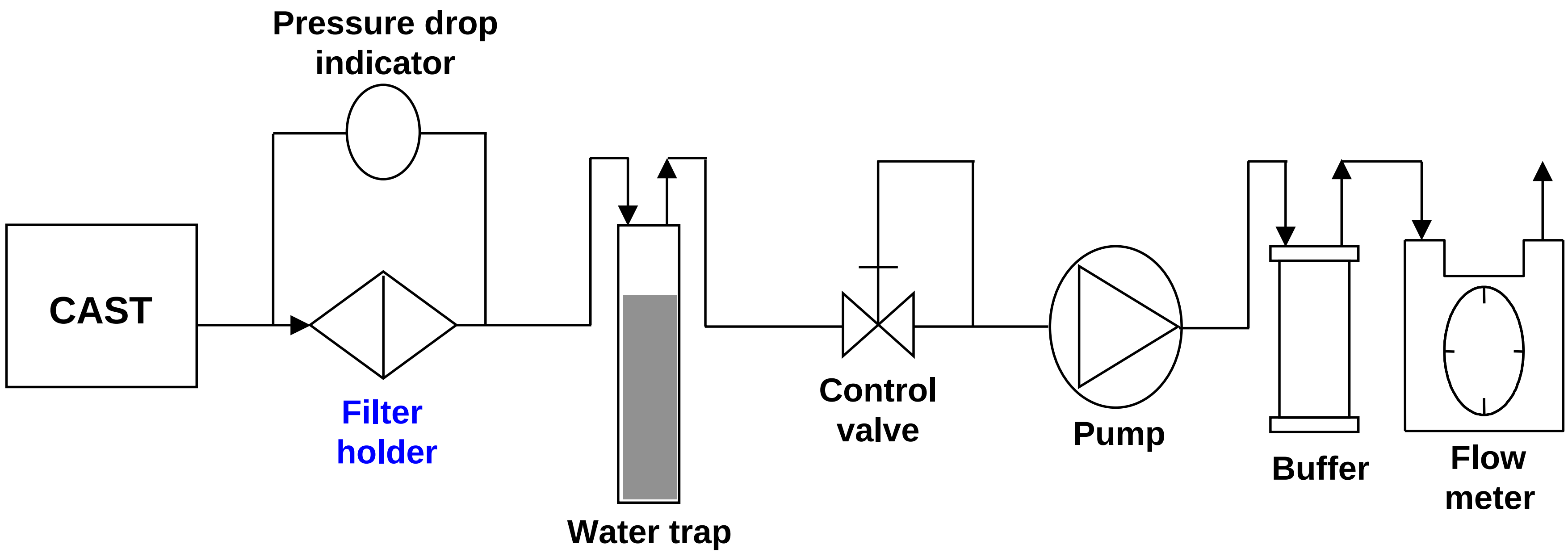


CAST nominal	SMPS D median
(nm)	
30	51
60	95
91	115
106	129
128	145
143	161
190	197

CAST Primary vs. Aggregate particle size



Experimental setup

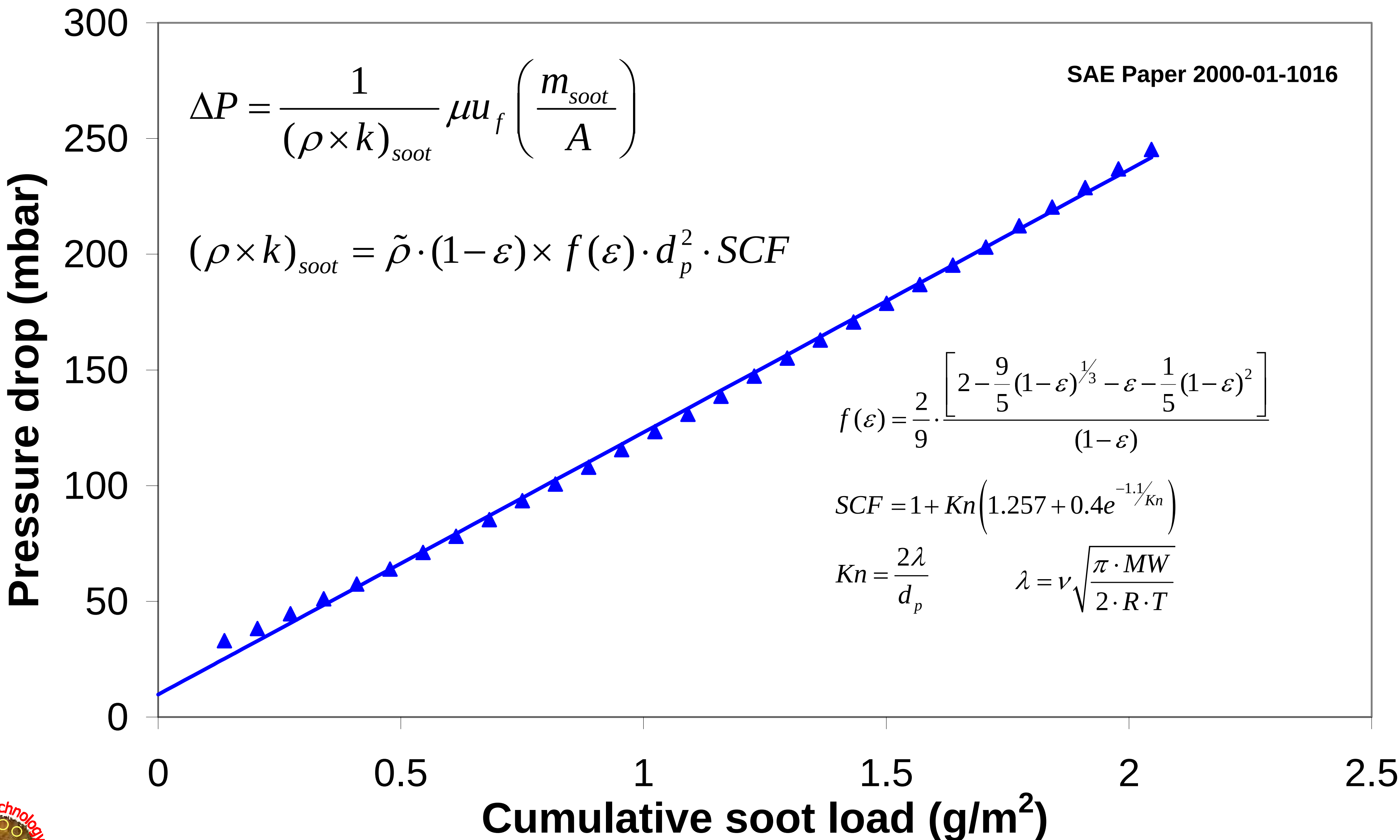


Experiments were performed using the CAST to load small glass fiber absolute filters with raw exhaust using 6 different size distributions and varying the filtration velocity

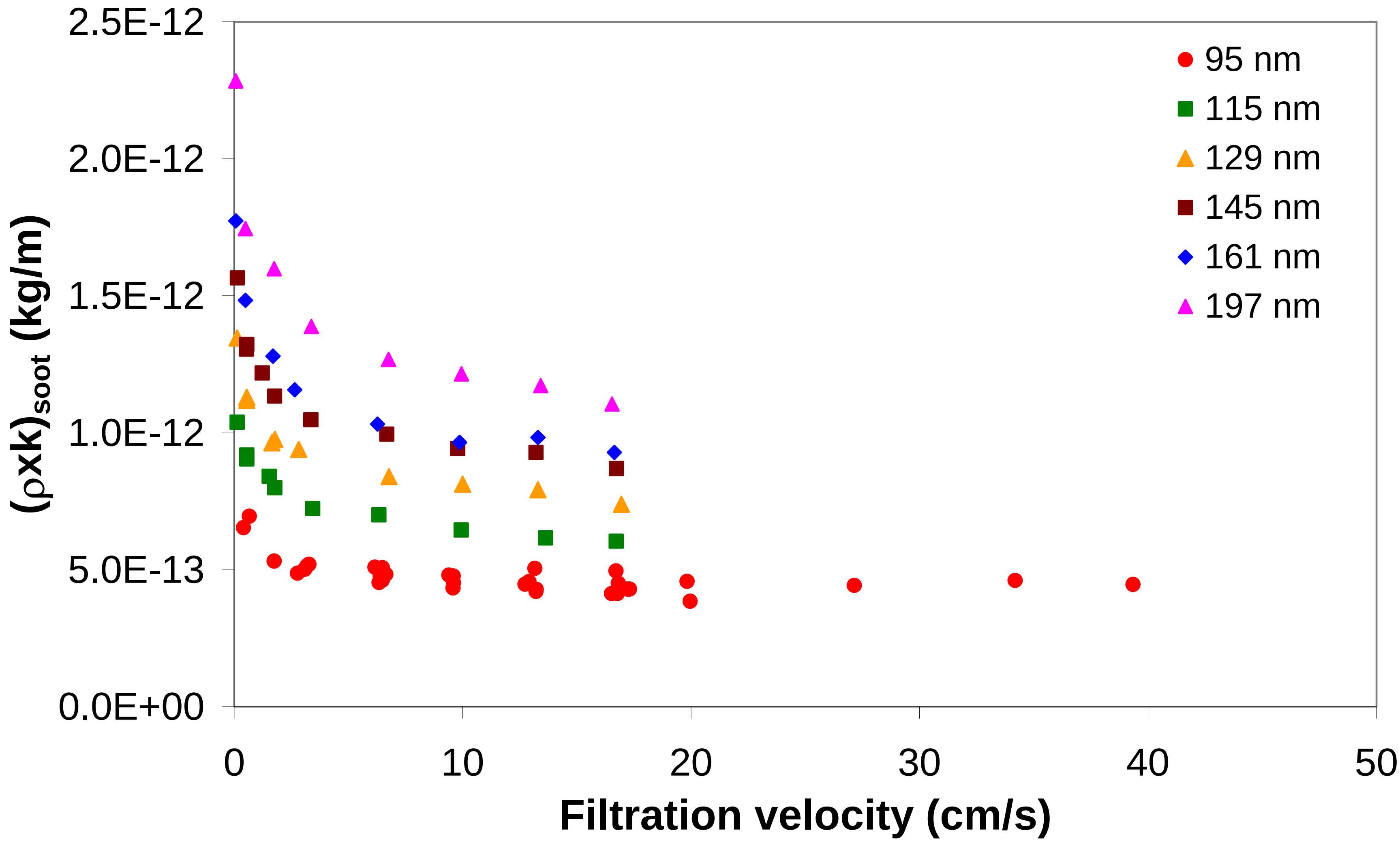
Experimental test matrix

Filtration velocity (cm/s)	Particle mobility diameter d_p (nm)						
	60	91	106	128	143	190	Nominal (CAST setting)
	95	115	129	145	161	197	Measured (SMPS)
40	■						
33	■						
26	■						
25							
20	■						
17	■	■	■	■	■	■	
13	■	■	■	■	■	■	
10	■	■	■	■	■	■	
7	■	■	■	■	■	■	
3	■	■	■	■	■	■	
1.7	■	■	■	■	■	■	
1.2				■			
0.7	■						
0.5		■	■	■	■	■	
0.4	■						
0.2			■				
0.1		■	■	■			
0.07					■	■	

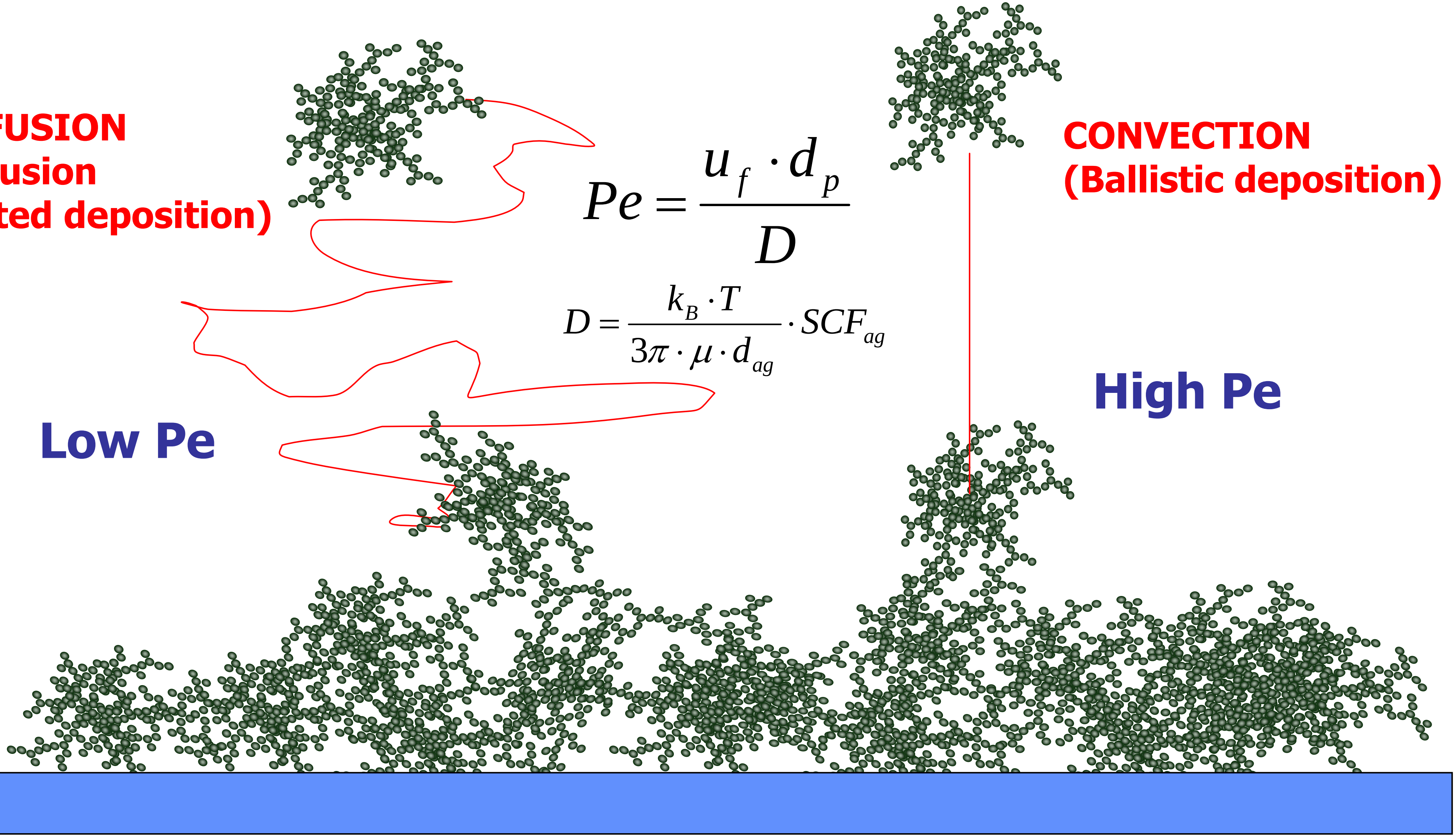
Soot cake flow resistance



Flow resistance vs. filtration velocity



Peclet number effect on soot cake microstructure

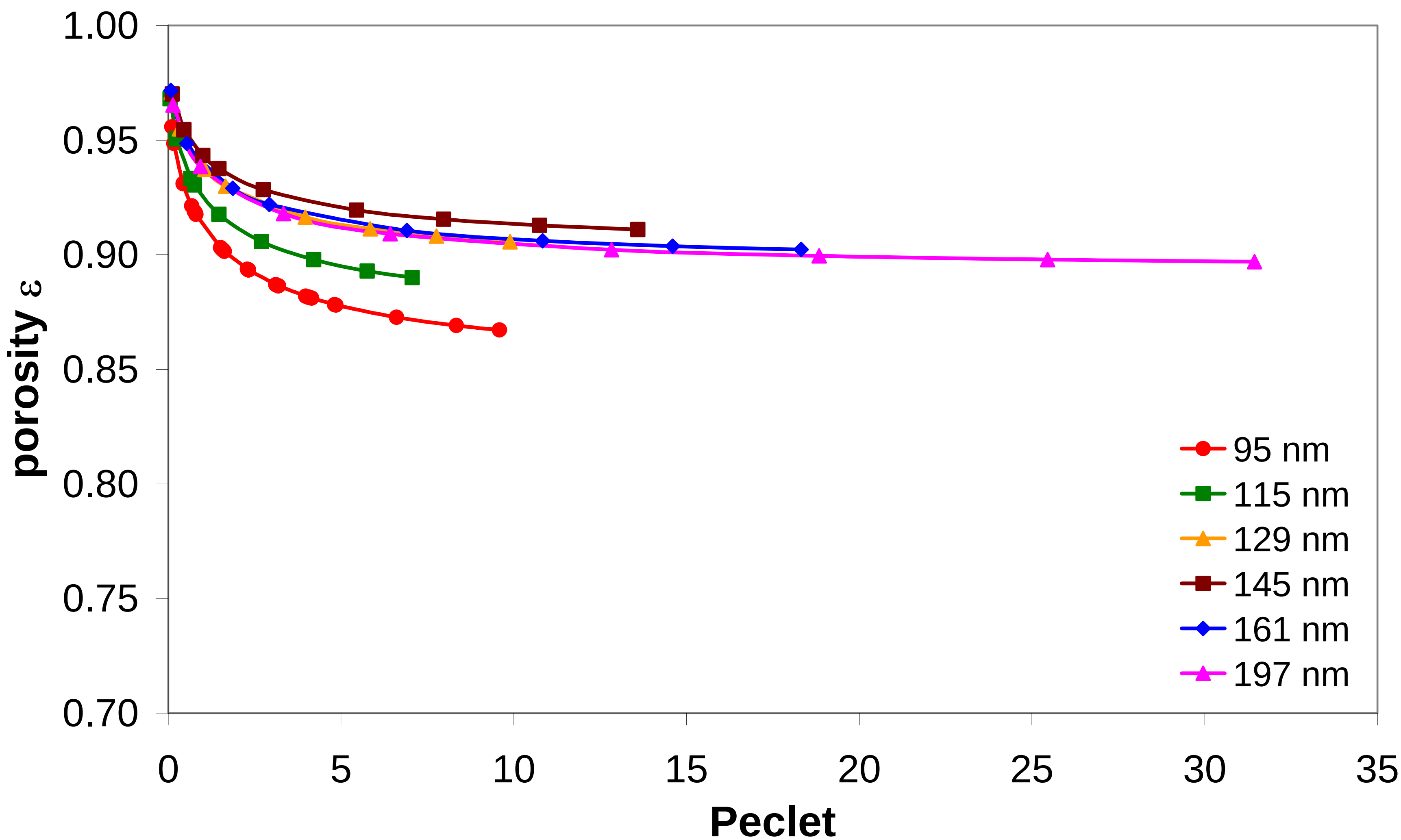


$$Pe = \frac{u_f \cdot d_p}{D}$$

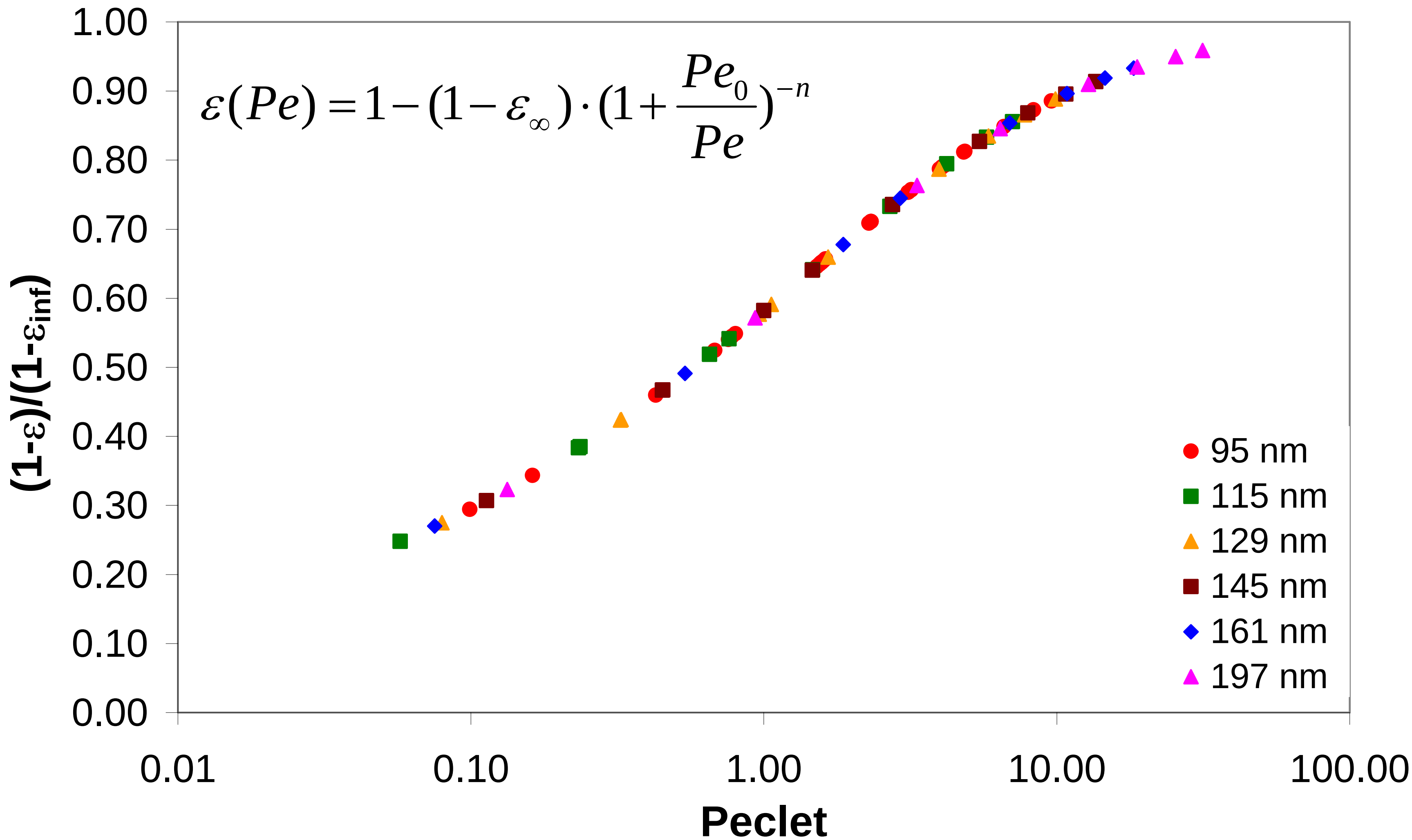
$$D = \frac{k_B \cdot T}{3\pi \cdot \mu \cdot d_{ag}} \cdot SCF_{ag}$$

Konstandopoulos A. G., Skaperdas E., Masoudi M., (2002) "Microstructural Properties of Soot Deposits in Diesel Particulate Traps", SAE Tech. Paper No. 2002-01-1015 (SP-1673)

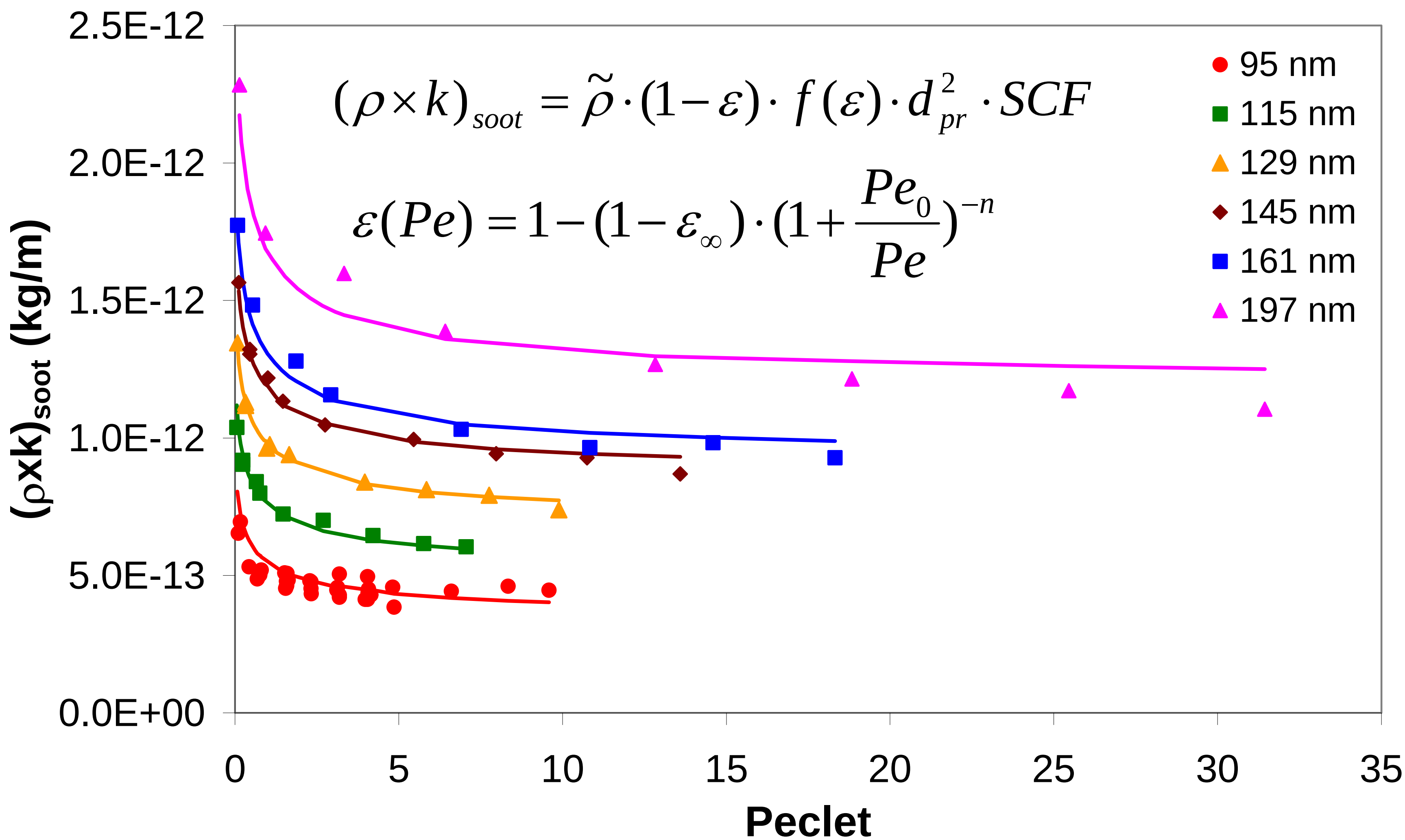
Porosity ε vs. Peclet number



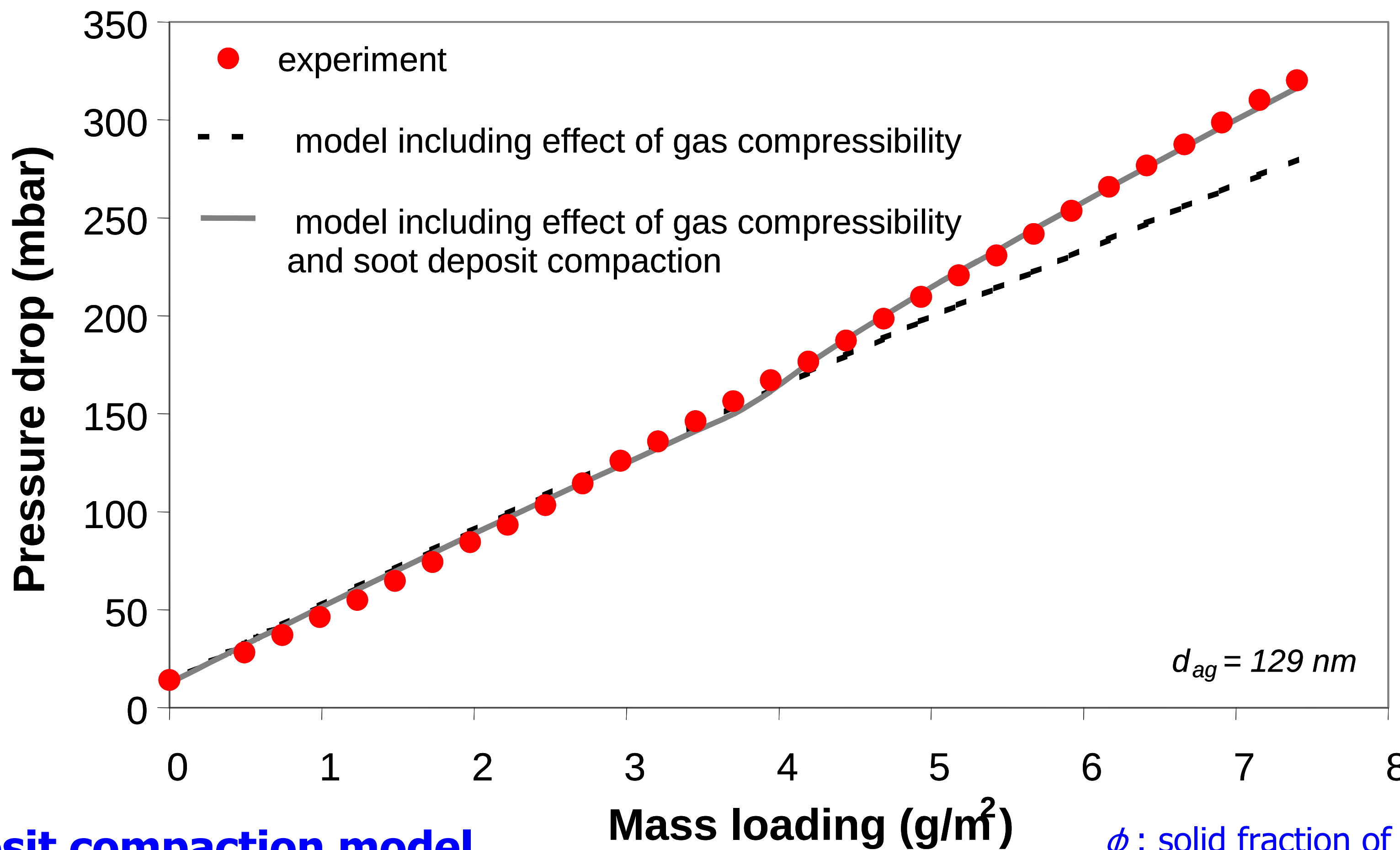
Porosity ε vs. Peclet number correlation



Flow resistance vs. Peclet number



Soot deposit compaction



Deposit compaction model

$$\frac{\phi}{\phi_0} = \left(\frac{\Delta P - \Delta P_{cr}}{\Delta P^*}\right)^{\delta}$$

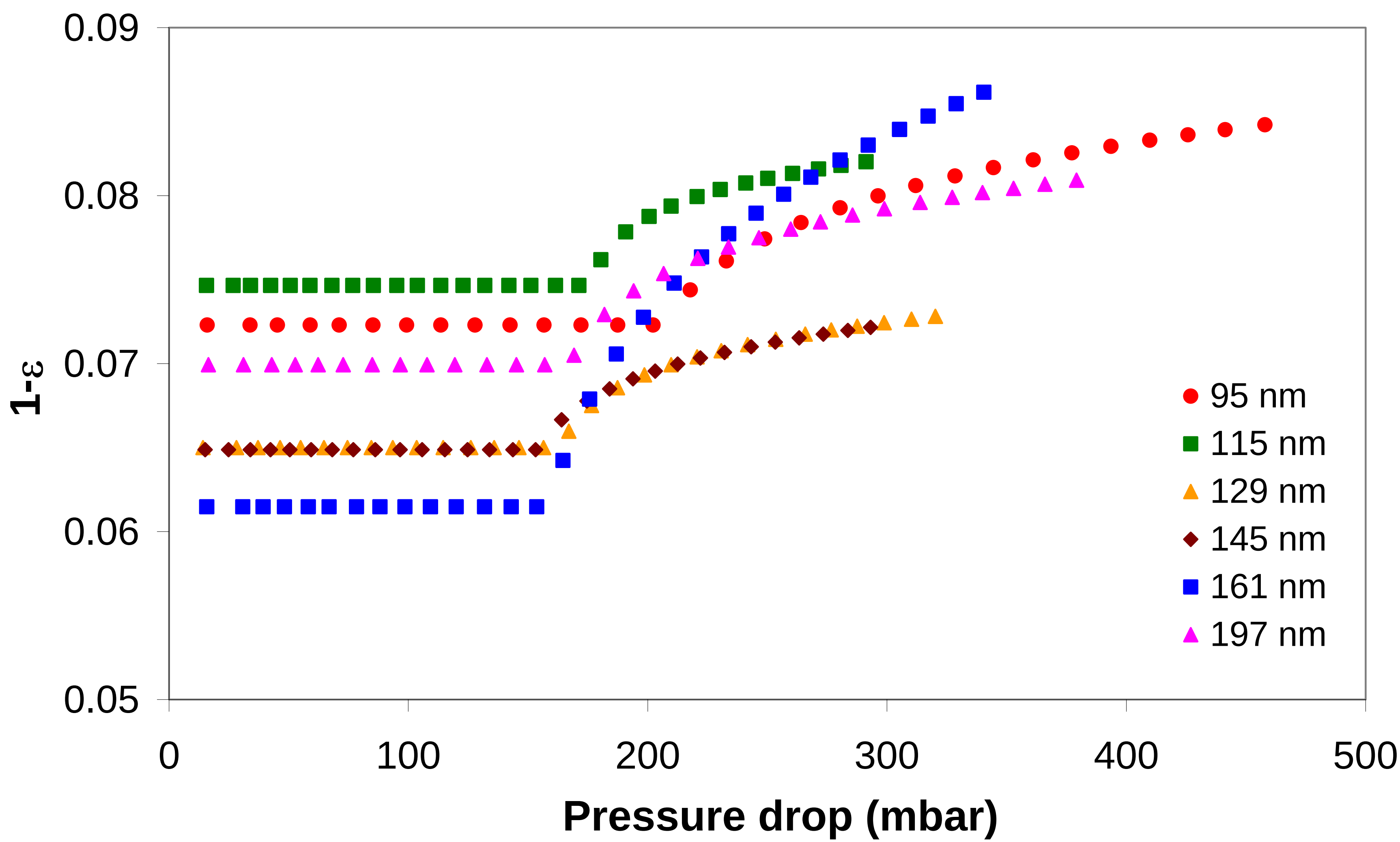
ϕ : solid fraction of deposit (1-ε)

ϕ_0 : ϕ in the uncompacted stage

ΔP_{cr} : deposit compaction sets in

ΔP^* : scaling constant

Effect of ΔP on soot deposit compaction



Conclusions

- ✓ **The microstructure of soot aggregate deposits was studied using reference soot from CAST on glass fiber absolute filters**
- ✓ **The CAST primary particle size was found to scale with the aggregate size with a power law:** $d_p = A \cdot d_{ag}^{B}$
- ✓ **The flow resistance of soot deposits was calculated varying the Peclet number for 6 different size distributions**
- ✓ **The porosity of soot deposits was linked to the Peclet number through a power law correlation:** $\varepsilon(Pe) = 1 - (1-\varepsilon_{\infty}) \cdot (1 + \frac{Pe_0}{Pe})^{-n}$
- ✓ **Soot deposit compaction occurs after a critical pressure drop is reached and the solid fraction of the compacted deposit can be described by a Bingham-like behavior:** $\phi / \phi_0 = [(\Delta P - \Delta P_{cr}) / \Delta P^*]^{\delta}$

Acknowledgements

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