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Poster Summary

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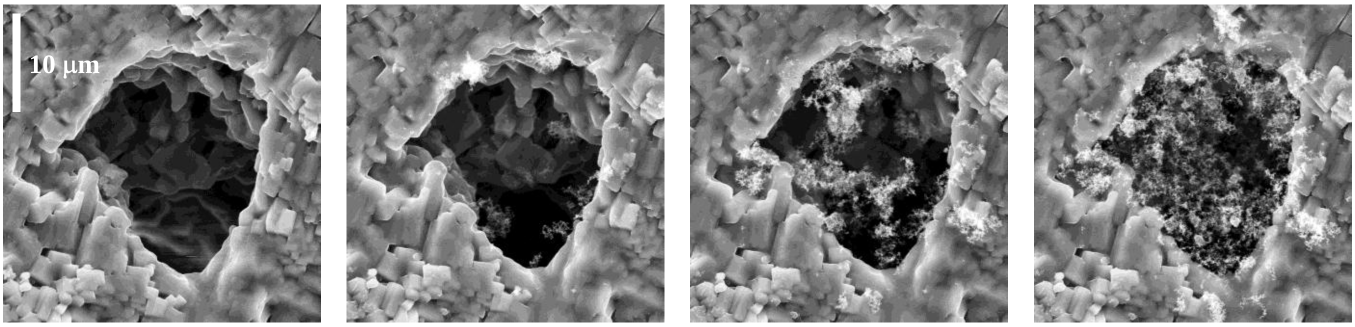
Title: Visualisation and Monitoring of Diesel Particulate Filtration

Summary:

Models describing the performance of the diesel particulate filter (DPF) in the literature typically treat deep-bed filtration and cake filtration as two distinct regimes, with the former incurring considerably greater computational cost. Deposition of particulate matter (PM) in the pores continuously modifies the effective permeability and porosity of the wall and therefore also the filtration efficiency. Moreover, calculation of the instant when a pore is bridged and a cake established is a complex problem which requires a complete understanding of how the growing PM deposit microstructure is determined by particulate characteristics and aerosol flow conditions. Since the deep-bed filtration stage causes the rapid initial increase in exhaust back pressure as a clean DPF is loaded, it is of significant advantage to engine operation to minimise PM deposition within the walls and achieve immediate bridging over the pores. Hence this research focuses on the fundamentals of deep-bed filtration and the mechanisms governing the bridging of filter pores by diesel particulates; understanding of this process is immensely aided by visualisation.

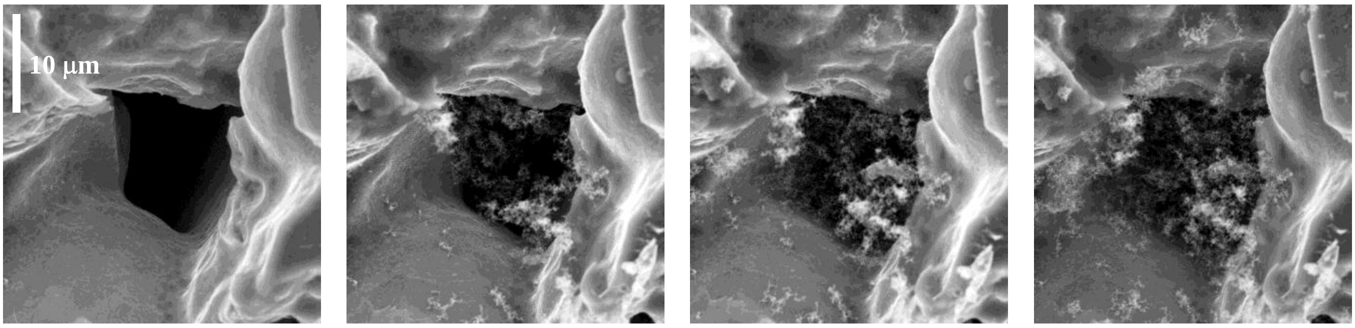
Scanning electron microscopy (SEM) provides sufficiently high resolution to capture images of particulates and the deposit microstructure but not in-situ due to the need to transfer static samples to an evacuated chamber. The original technique that was developed measures pressure drop and filtration efficiency during loading of wall samples at standard conditions for temperature and pressure (STP) with cessation of loading at specified intervals for visualisation with SEM; this entailed a system for relocation of the same pores. The aim was to reveal unprecedented detail of the pore bridging process at successive stages of PM mass loading. The sintered morphology and pore network structure differ significantly between cordierite and silicon carbide, therefore filter walls of both materials (with similar wall geometries) were examined in the visualisation study. The sample aerosol was drawn from the exhaust of the Cambustion Diesel Particulate Generator, of which the mode of the number size distribution is 120 nm. Experiments for the pore filling study were conducted at flow rates producing a mean aerosol velocity of 5 cm/s in the pores at STP, similar to that through DPF walls in real-world operation.

Figures 1 and 2 show successive images of bridging of a cordierite pore and a silicon carbide pore respectively. The incident mass of PM is given as grams per litre (g/l) for the equivalent full-scale DPF.



▲ PM load = **0** g/l ▲ PM load = **0.025** g/l ▲ PM load = **0.05** g/l ▲ PM load = **0.075** g/l

Figure 1: SEM images of the same cordierite pore for successive stages of PM loading.



▲ PM load = **0** g/l ▲ PM load = **0.025** g/l ▲ PM load = **0.05** g/l ▲ PM load = **0.075** g/l

Figure 2: SEM images of the same silicon carbide pore for successive stages of PM loading.

SEM images from repeated loading of the same wall sample indicate that the profile of a DPF pore entrance does not influence the location of initial PM deposition. Growth of dendrites from anchor points on the rim of pores was observed prior to bridging; they typically extended across half the width of 10-20 µm pores and arise from deposition of agglomerates from the tail-end of the PM size distribution. The presence of agglomerates several microns across in an exhaust aerosol can avert the filling of pores in a uniform radial manner ("shrinking pore" behaviour) and therefore reduce the pre-cake pressure drop penalty. Subsequently the PM cake grows out of each pore in a dome-shaped manner until it impinges on cakes rising from adjacent pores to form a complete discrete particulate layer.

Short CV:

Simon Payne has just submitted his PhD thesis (June 2011) at the University of Cambridge following research on the fundamentals of diesel particulate filtration at Johnson Matthey. He previously studied Physics at the University of Bristol, receiving a combined Bachelors and Masters degree.

Visualisation and Monitoring of Diesel Particulate Filtration

Simon Payne[1,2] and Nick Collings[1]

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Introduction

Models describing the performance of the diesel particulate filter (DPF) typically treat deep-bed filtration and cake filtration as two distinct regimes, with the former incurring considerably greater computational cost. Deposition of particulate matter (PM) in the pores continuously modifies the effective permeability and porosity of the wall and therefore also the filtration efficiency. Moreover, calculation of the instant when a pore is bridged and a cake established is a complex problem which requires a complete understanding of how the growing PM deposit microstructure is determined by particulate characteristics and aerosol flow conditions.

Since the deep-bed filtration stage causes the rapid initial increase in exhaust back pressure as a clean DPF is loaded (see Figure 1), it is of significant advantage to engine operation to minimise PM deposition within the walls and achieve immediate bridging over the pores. Hence this research focuses on the fundamentals of deep-bed filtration and the mechanisms governing the bridging of filter pores by diesel particulates; understanding of this process is advanced by visualisation.

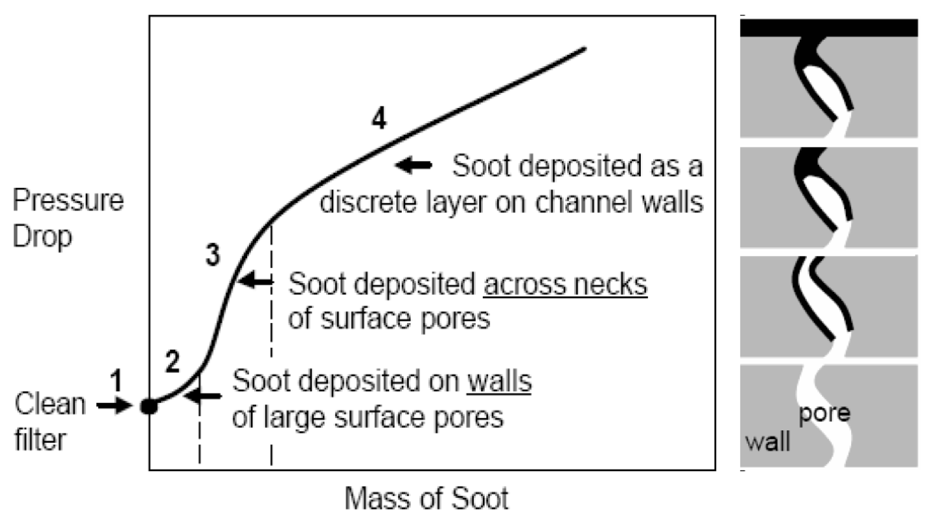

Figure 1: Conceptual illustration of the increase in pressure drop across a DPF as a function of PM loading (Merkel, et al. 2003)

Experimental

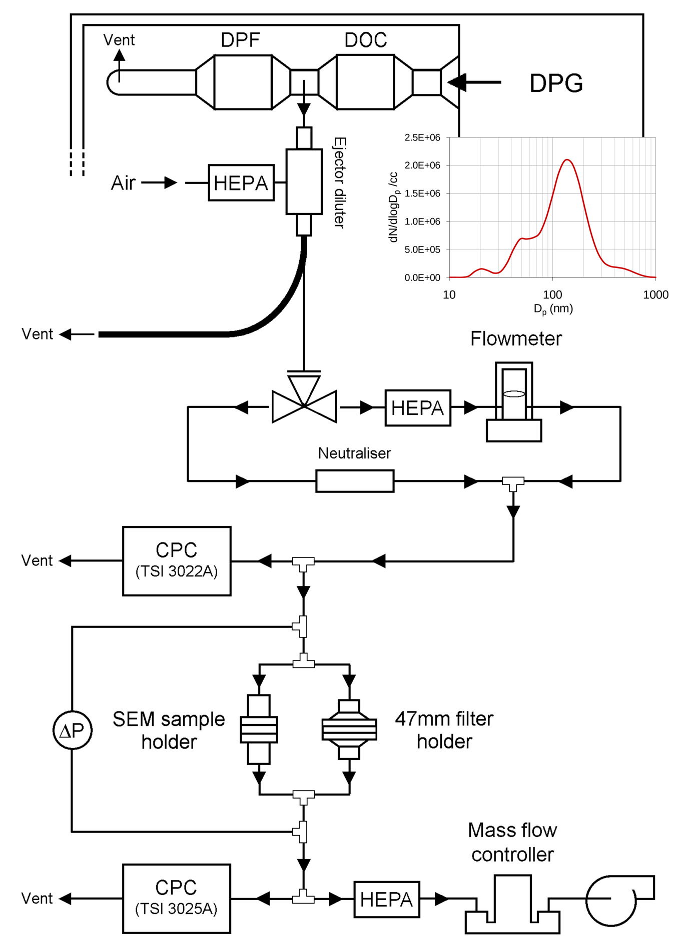

Figure 2: Schematic of apparatus to monitor DPF pore filling (inset graph shows number size distribution of DPG exhaust PM)

Scanning electron microscopy (SEM) provides sufficiently high resolution to capture images of particulates and the deposit microstructure but not in-situ due to the need to transfer static samples to an evacuated chamber. The original technique that was developed (shown in Figure 2) measures pressure drop and filtration efficiency during loading of wall samples at standard conditions for temperature and pressure (STP) with cessation of loading at specified intervals for visualisation with SEM; this entailed a system for relocation of the same pores. The aim was to reveal unprecedented detail of the pore bridging process at successive stages of PM mass loading.

The sintered morphology and pore network structure differ significantly between cordierite and silicon carbide, therefore filter walls of both materials (with similar wall geometries – see Figure 3) were examined in the visualisation study. The sample aerosol was drawn from the exhaust of the Cambustion Diesel Particulate Generator (DPG). Experiments for the pore filling study were conducted at flow rates producing a mean aerosol velocity of 5 cm/s in the pores at STP, similar to that through DPF walls in real-world operation.

	Material	Wall thickness (μm)	Porosity (%)	Mean pore diameter (μm)
Porous wall A	Cordierite	305	48	12
Porous wall B	Silicon carbide	305	42	14

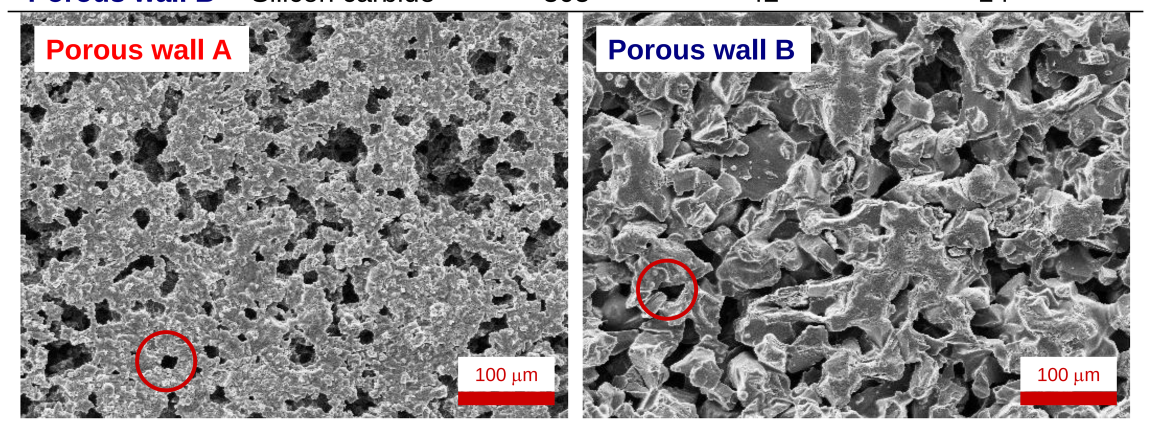

Figure 3: Porous wall parameters and SEM map (PM deposition in circled pore is examined in section below)

Porous wall loading behaviour

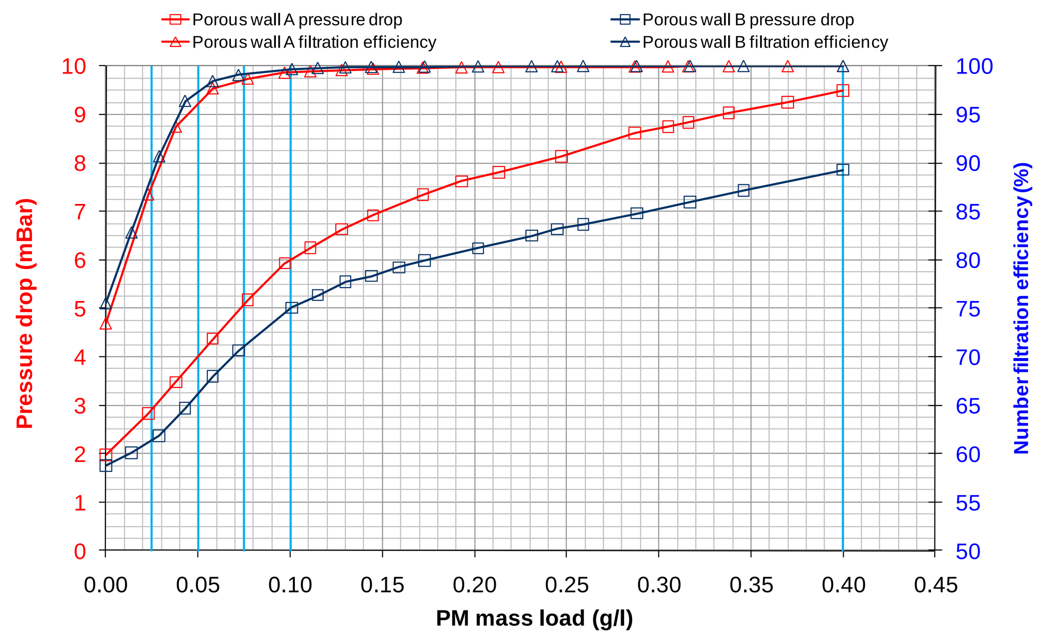

Figure 4: Pressure drop and filtration efficiency data for pore velocity of 5 cm/s at STP

The PM mass load is given as grams per litre for the equivalent full-scale DPF (which in both cases is 300 cells per square inch, 5.66 inches diameter and 6 inches length) and the mass concentration was calculated by correlating readings from a TSI CPC (Condensation Particle Counter) with a R&P TEOM (Tapered Element Oscillating Microbalance). Loading was paused as indicated by the vertical light blue lines in Figure 4 and the wall sample was mounted in the SEM chamber to capture images of pores. Then penetration of soot particulates size-selected by a DMA (Differential Mobility Analyser) through the parallel wall sample in the 47 mm filter holder was measured (see Figure 5) before loading was resumed.

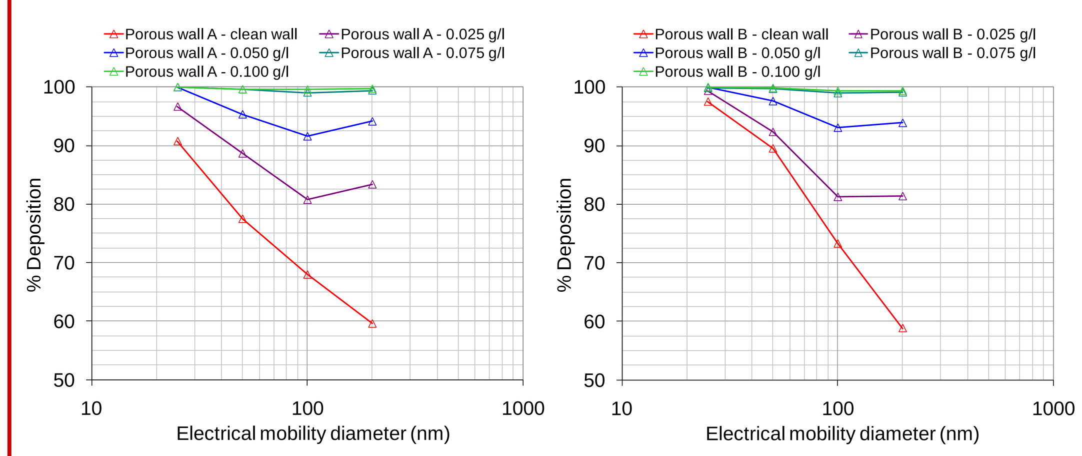

Figure 5: Deposition of mono-mobility aerosol at successive stages of PM loading for porous walls A (left) and B (right)

SEM visualisation of DPF pore bridging

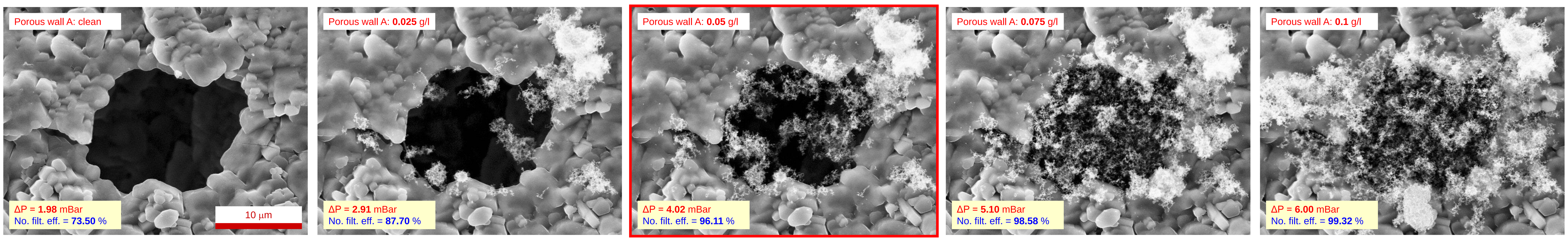

Figure 6: Five SEM images of the same cordierite pore for successive stages of PM loading up to 0.1 g/l

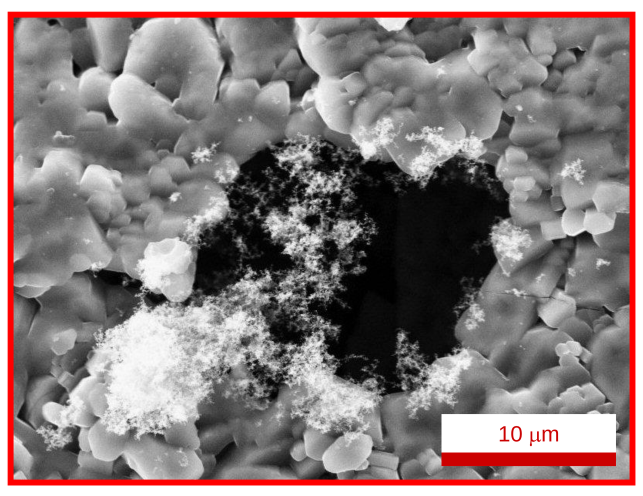

Figure 7: SEM image of cordierite pore at 0.05 g/l during repeated loading (compare to central image in Figure 6 above)

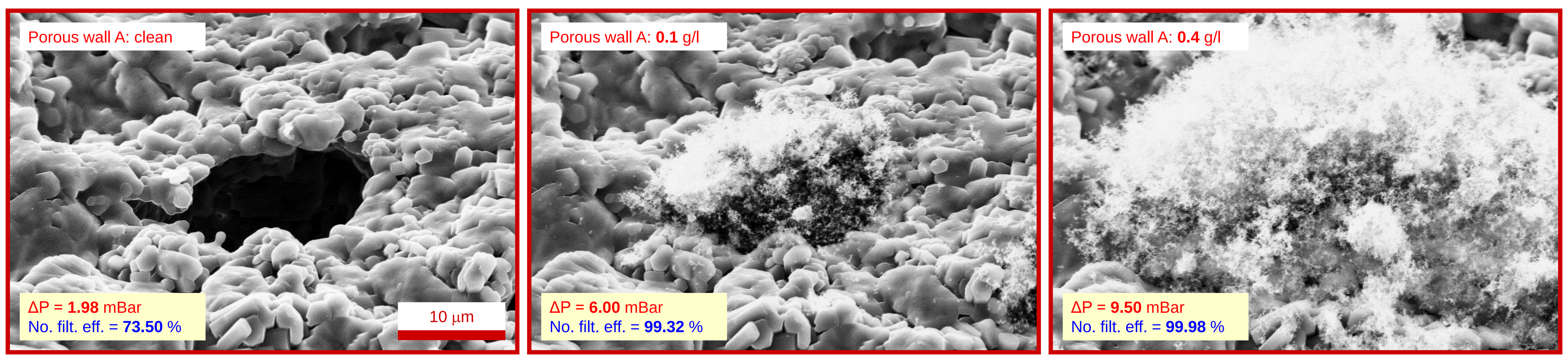

Figure 8: Three SEM images of the same cordierite pore at 45 degrees for successive stages of PM loading up to 0.4 g/l

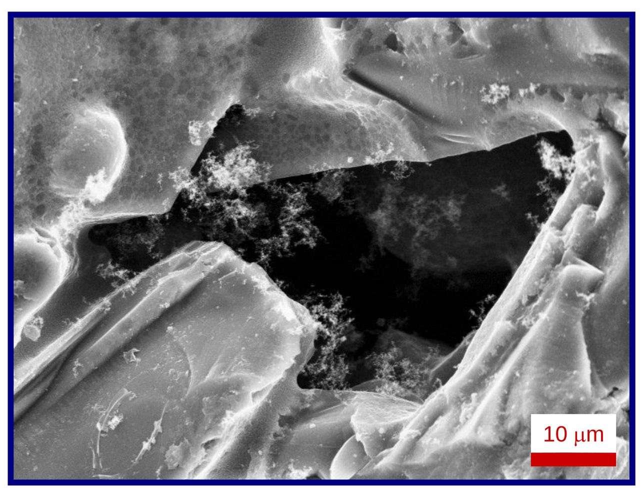

Figure 9: SEM image of silicon carbide pore at 0.05 g/l during repeated loading (compare to central image in Figure 10 below)

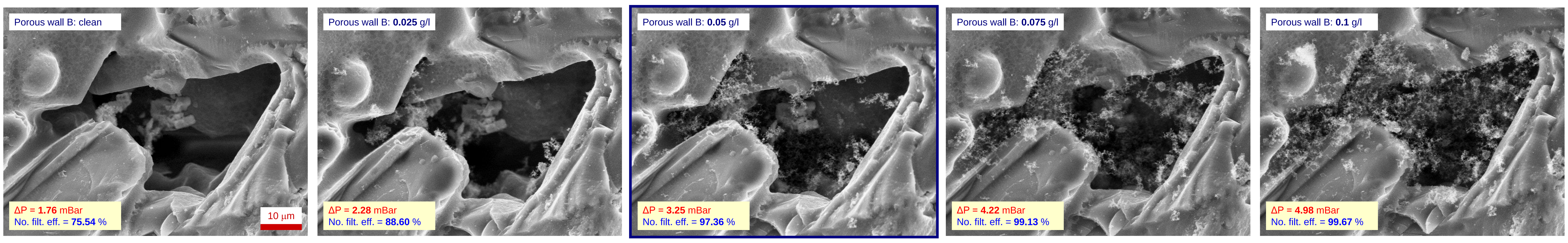

Figure 10: Five SEM images of the same silicon carbide pore for successive stages of PM loading up to 0.1 g/l

Conclusions from SEM images

- Repeated images indicate that the profile of a DPF pore entrance does not influence the location of initial PM deposition.
- Dendrites that extend across half the width of 10-20 μm pores grow from deposition of agglomerates from the tail-end of the PM size distribution. The presence of agglomerates several microns across in an exhaust aerosol can avert the filling of pores in a uniform radial manner (“shrinking pore” behaviour) and therefore reduce the associated pressure drop penalty.
- Subsequently the PM cake grows out of each pore in a dome-shaped manner until it impinges on cakes rising from adjacent pores to form a complete discrete particulate layer.

Reference

- Merkel, G. A., Cutler, W. A., Tao, T., Chiffey, A., Phillips, P., Twigg, M. V., and Walker, A. “New Cordierite Diesel Particulate Filters for Catalyzed and Non-Catalyzed Applications.” Proceedings of the 9th DEER Conference. Newport, Rhode Island, 2003.

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