Effect of Catalyst Coating on Filtration Performance of Diesel Particulate Filters

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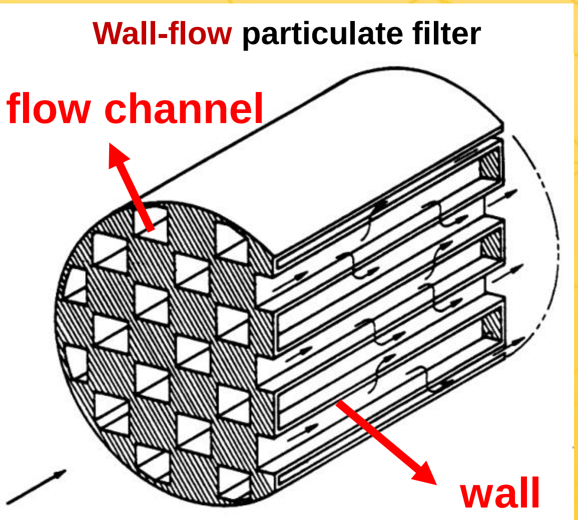
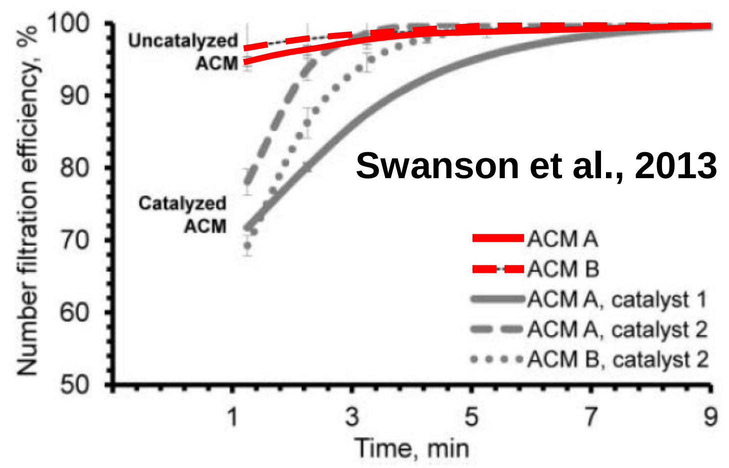
Introduction

- Diesel particulate filters are widely used on diesel engines after-treatment system to mitigate **the particulate matter emission**.
- Usually, catalyst is applied onto the monolithic wall-flow particulate filter substrate, when both gaseous and particulate emissions need to be controlled. However, previous study (Swanson et al., 2013) showed that the soot removal efficiency decreases with catalyst coatings, which **the reason is not yet clear**.





ACM: advanced ceramic material

Objectives

- To evaluate pressure drop and initial soot removal efficiency of ceramic wall flow substrates with different catalyst coating levels.
- To confirm the hypothesis that decreasing initial efficiency after wash-coating is due to media pore size distribution shift.
- To reconstruct 3-D micro-porous structure and study the effect of wash-coating via simulation method.

Test method and results

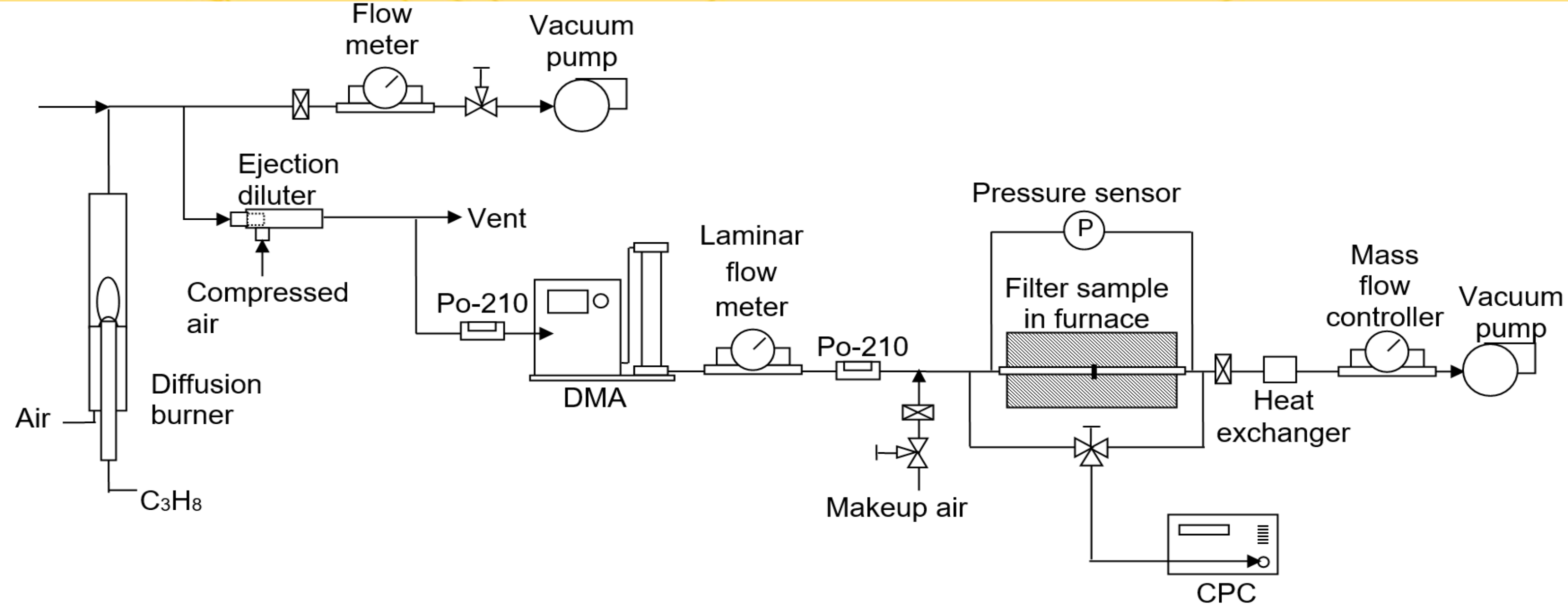
- Flow resistance

- Initial soot removal efficiency

- Pore size distribution

Test method

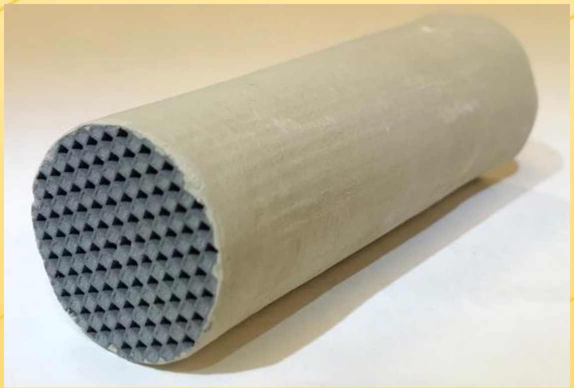
- Pressure drop and efficiency of different SiC wall-flow core samples are measured using monodisperse soot particles from a home-made propane diffusion flame burner, at
  - Volumetric flow rate: 12.9 or 32.3 L/min at standard condition.
  - Temperature: 25^{o}C or 300^{o}C.



Materials

- Substrate: SiC; Outer diameter: 1”; Length: 3”;
- Cell density: 300 cpsi; Wall thickness: 12 mil.

Sample #		Catalyst Coating Amount
Blank	Blank-1	0.0%
	Blank-2	0.0%
	Blank-3	0.0%
	Blank-4	0.0%
A	A-1	24.3%
	A-2	23.5%
B	B-1	49.3%
	B-2	48.9%
C	C-1	97.2%
	C-2	100.0%



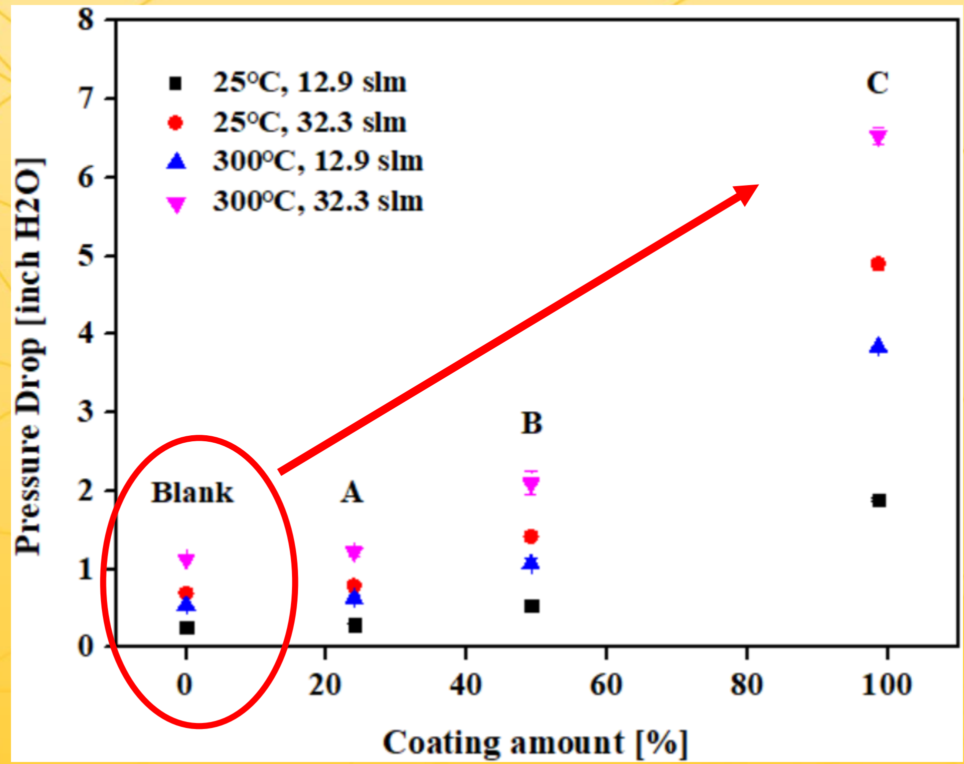
* 100% coating amount: the coating amount needed for desired catalytic conversion.

* cpsi: cells per square inch.

* mil: 1/1000 inch.

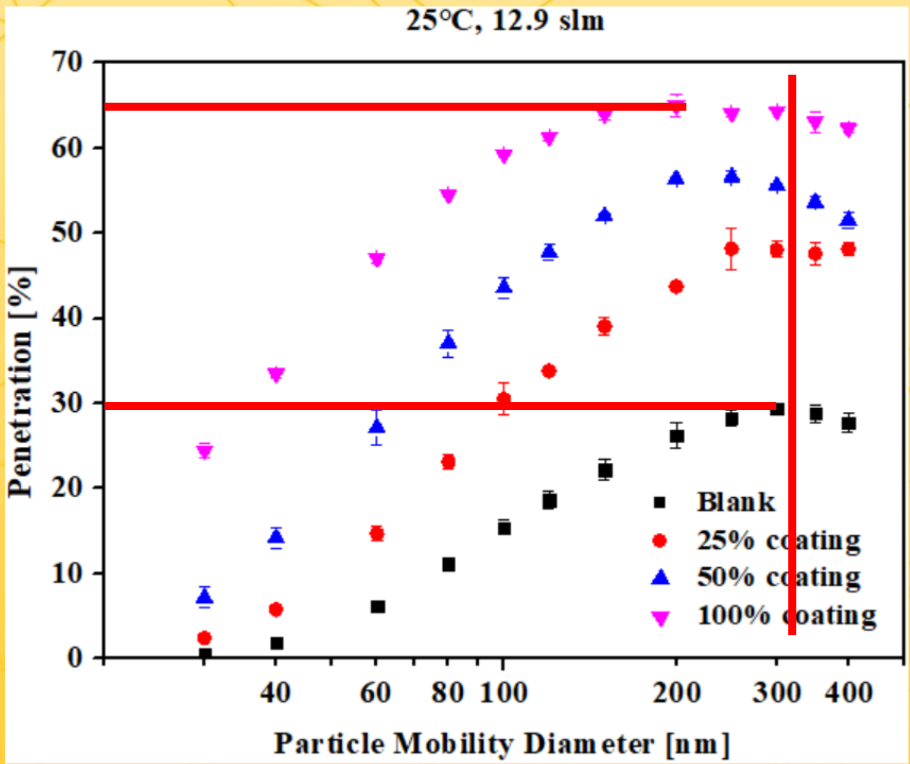
Flow resistance

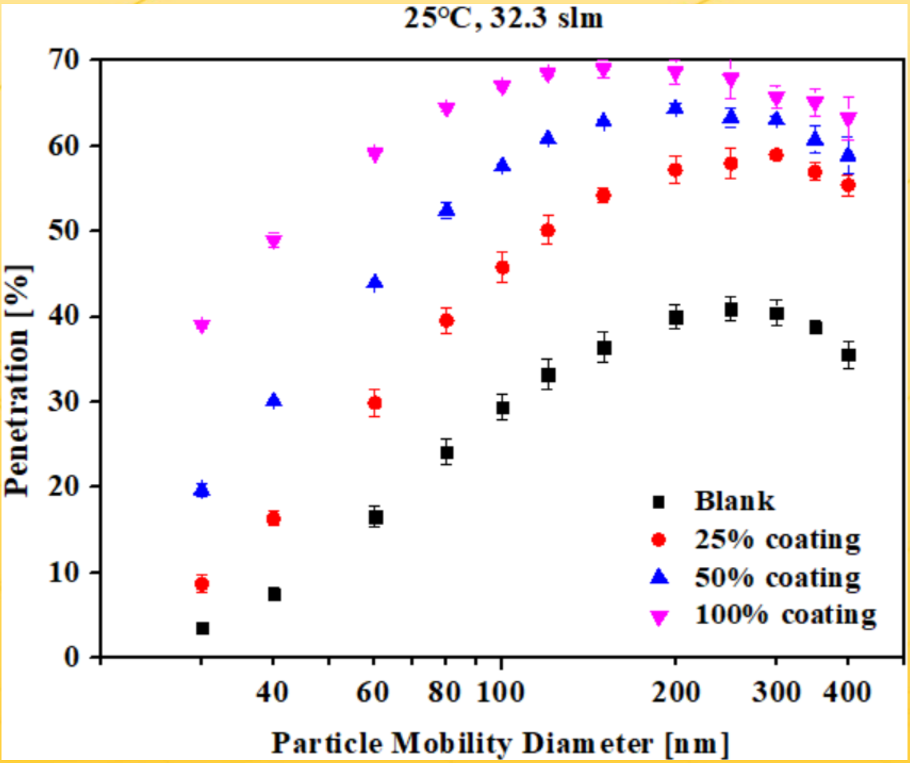
- With an increase in the coating amount, there are more catalyst in the samples, leading to lower porosity, so the pressure drop increases under the same test condition.



Initial efficiency – 25°C

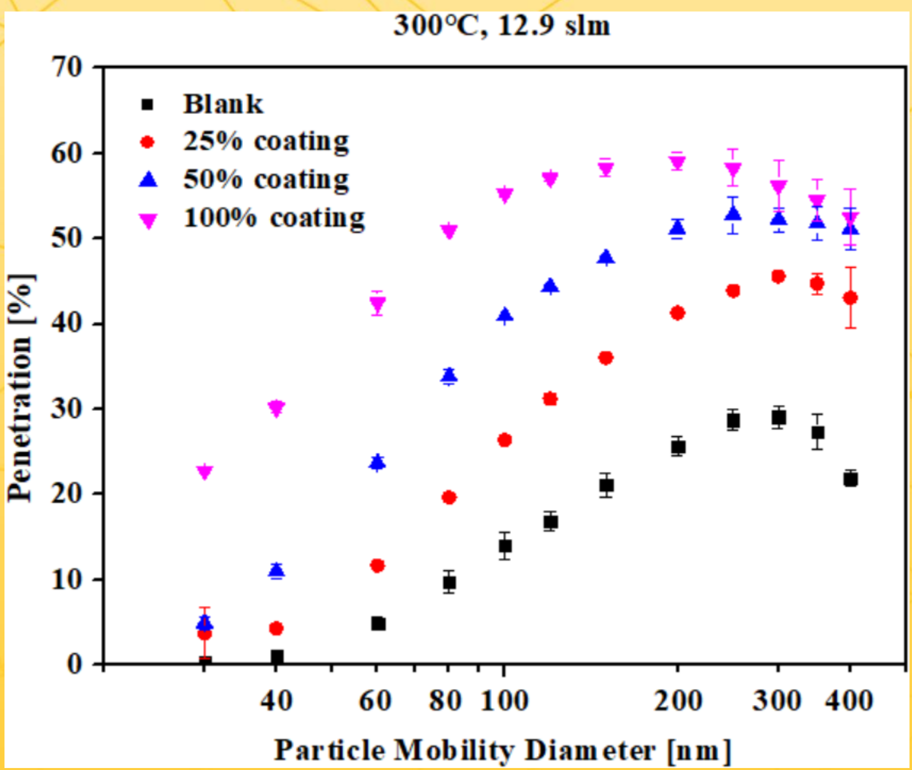
- Higher penetration was found at all test conditions as the coating amount increases. The MPPS (most penetrating particle size) of each test condition reduces after coating.

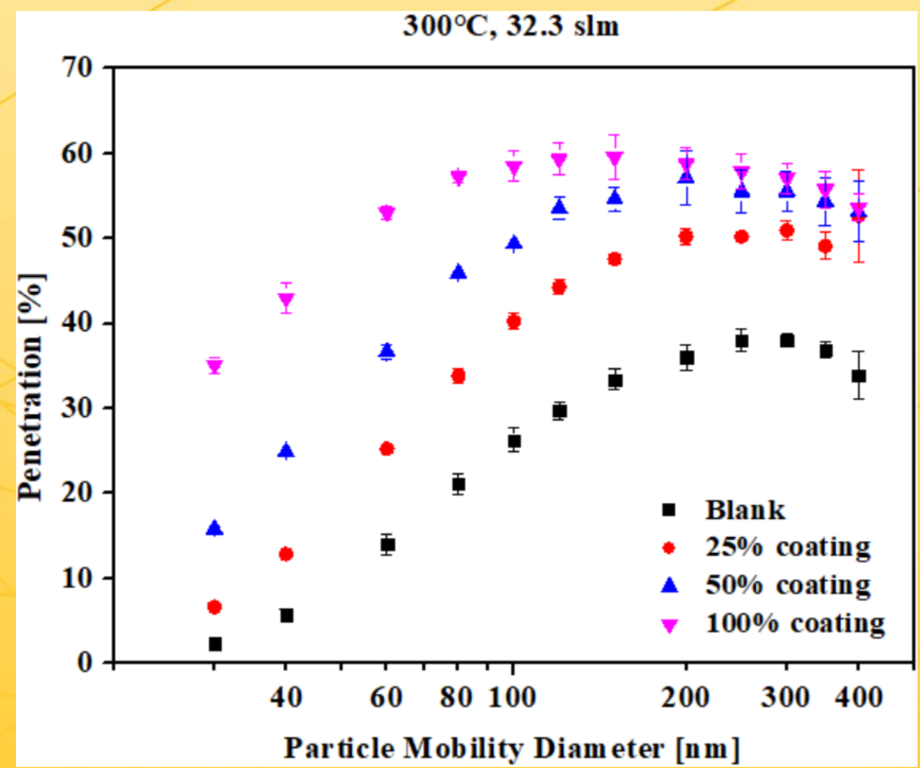




Initial efficiency – 300ºC

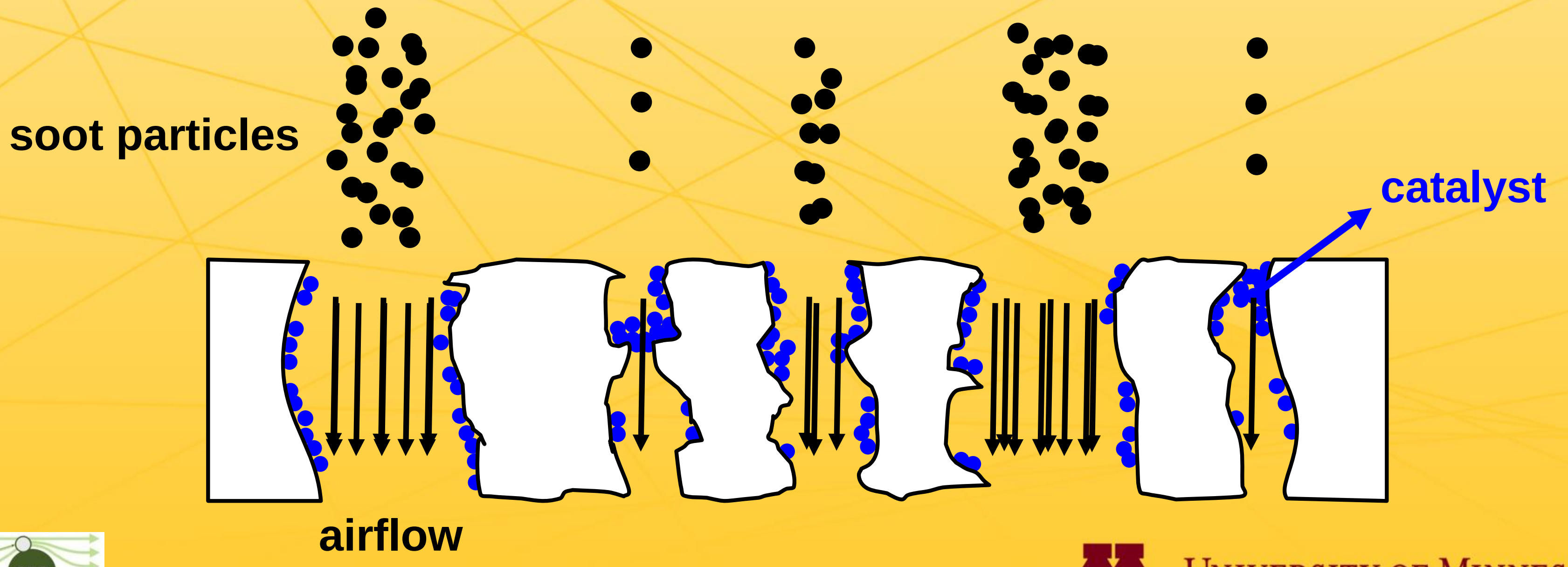
- Higher penetration was found at all test conditions as the coating amount increases. The MPPS (most penetrating particle size) of each test condition reduces after coating.





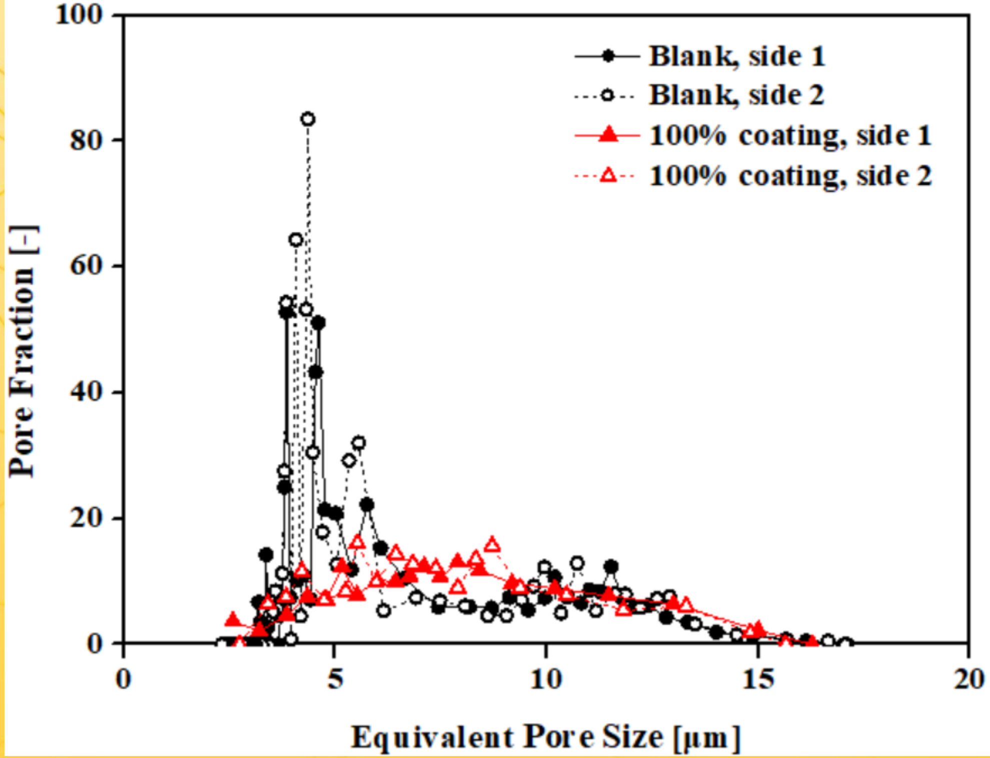
Hypothesis on reduced eff. – pore size shift

- One possible explanation of reduced efficiency after coating is that media **pore size distribution shifts**.
  - ➢ The capillary-driven wash coating process may preferentially block smaller pores, while leaving larger pores open.
  - ➢ The reduced pore (flow channel) numbers and the shift on pore size distribution induces more air flow towards larger pores, where more penetration occurs.



Pore size distribution measurement – capillary flow porometry

- The pore size distribution shifts towards larger size after coating.



* The results were measured by PMI capillary flow porometer.

Pore size distribution measurement – capillary flow porometry

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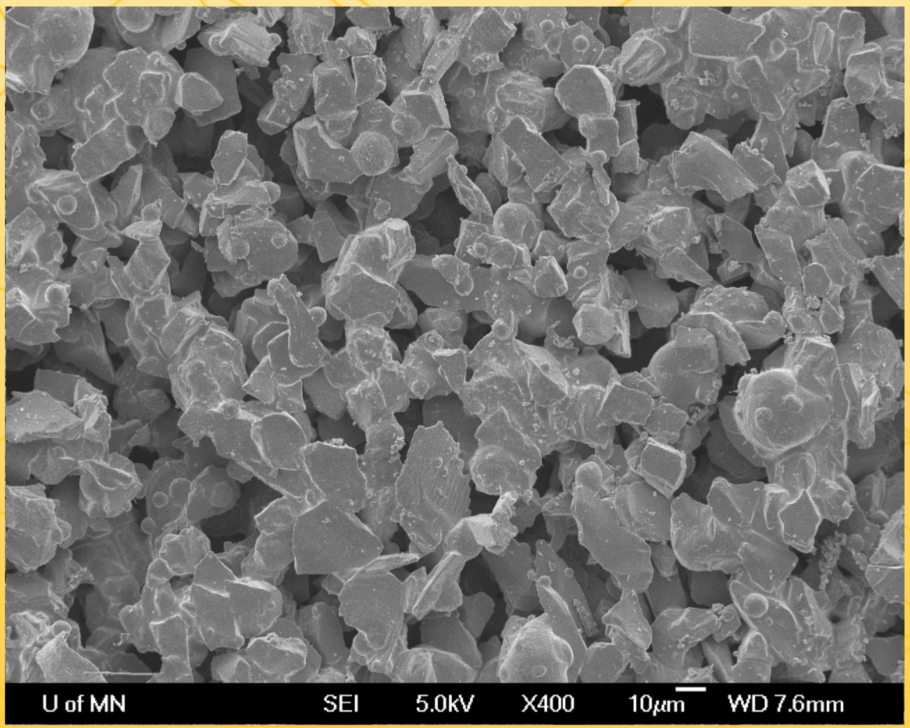
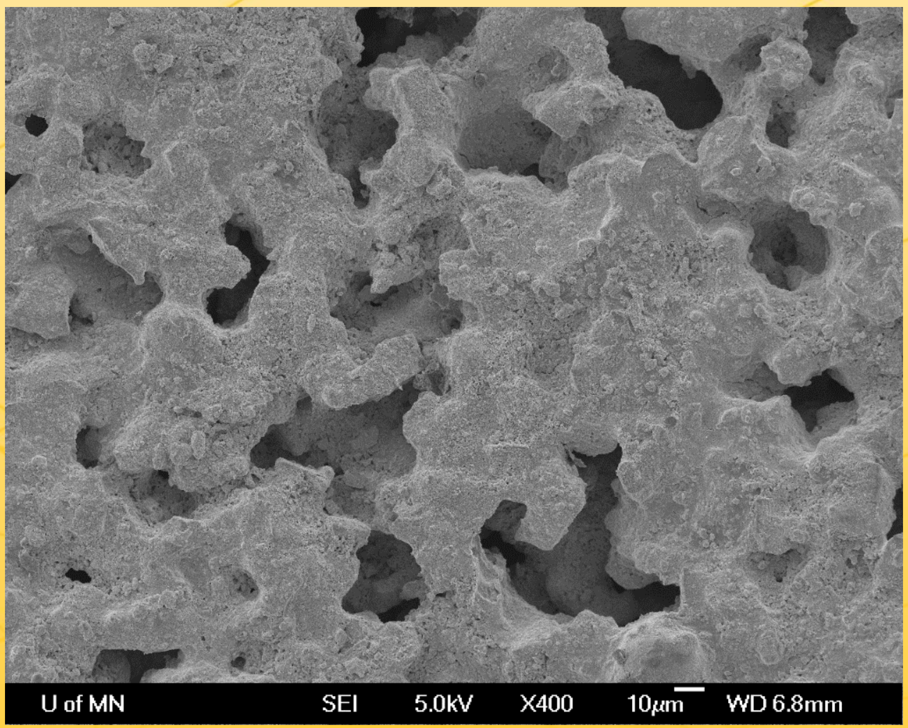


Blank



100% coating

Simulation method and results

- Micro X-ray computed tomography

- GeoDict simulation software

- Filtration performance of blank and coated samples

Simulation method – μ-CT

- Micro X-ray computed tomography (CT) can provide a 3-D reconstruction of the micro-porous structure.
- About 2000 slices of the samples along Y direction were obtained.

Resolution: 1.8 μm

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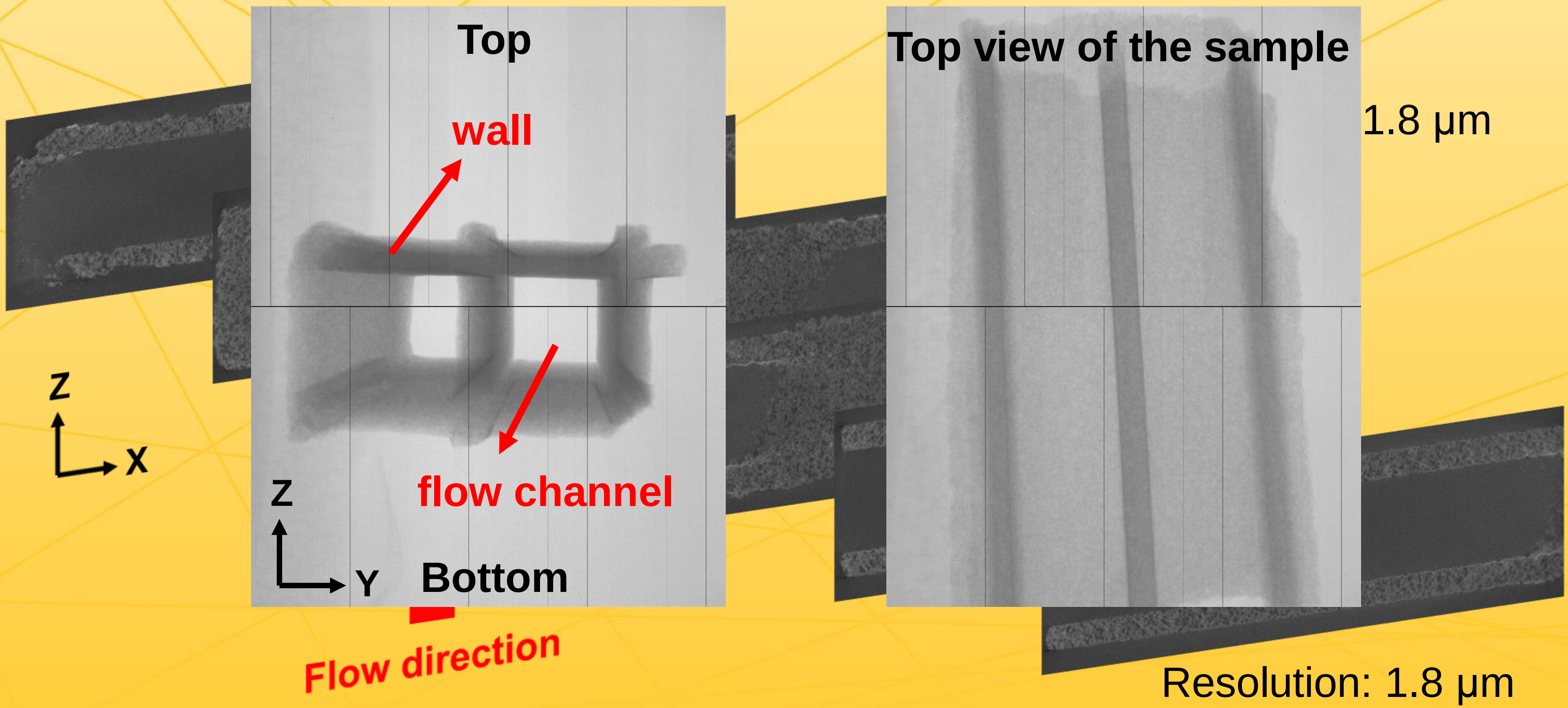
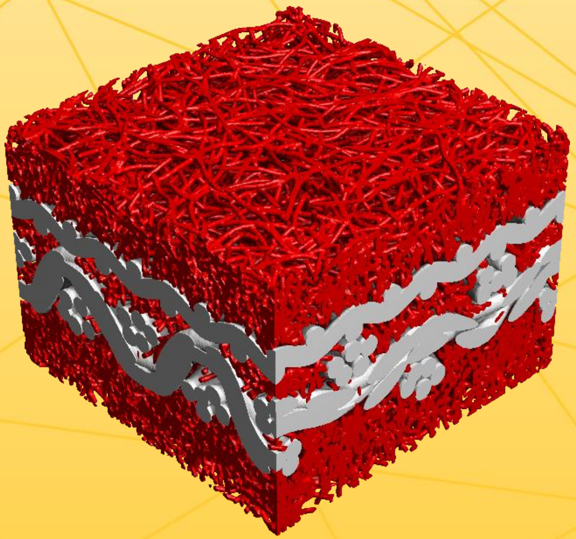


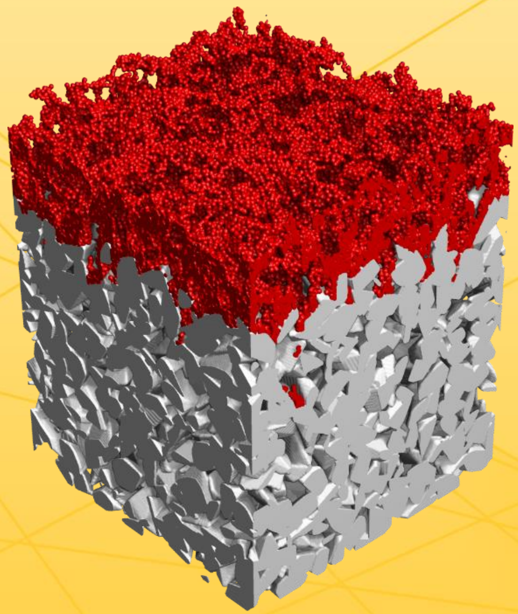
Resolution: 1.8 μm

Simulation method – GeoDict

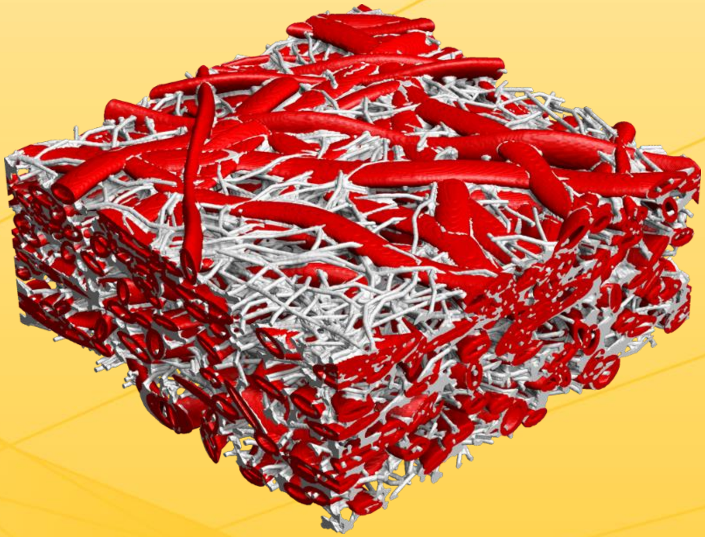
- All slices were imported to the **GeoDict** software, which can provide a solution for 3-D image processing, modeling of materials, visualization, and optimization of processes.



Fiber



Ceramic

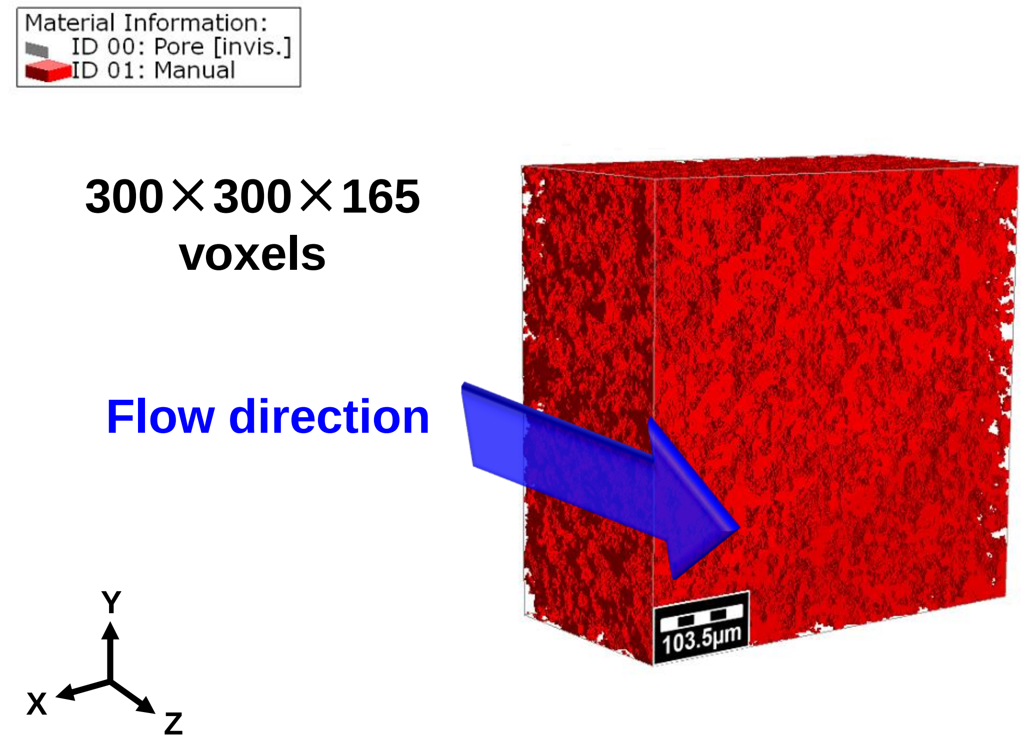


Paper

* The pictures are copied from www.math2market.com.

Simulation method – 3-D structure

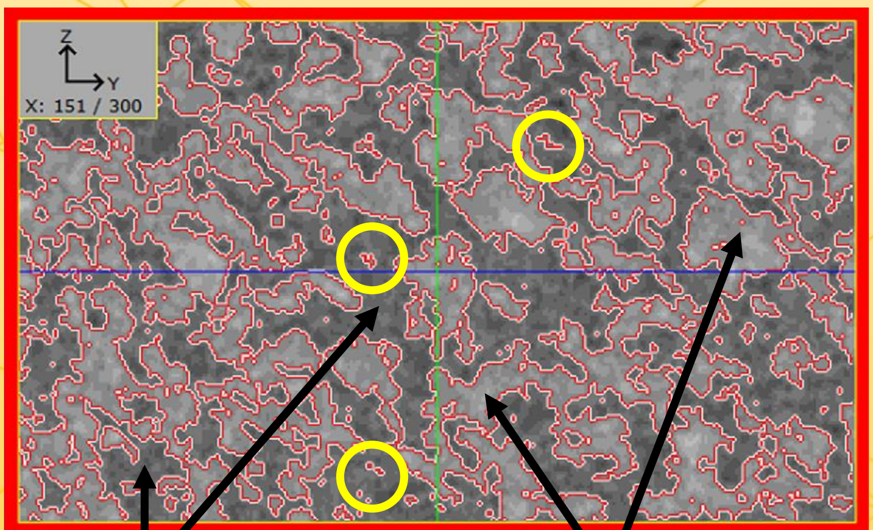
- The 3-D micro-porous structure was reconstructed via **GeoDict** software.

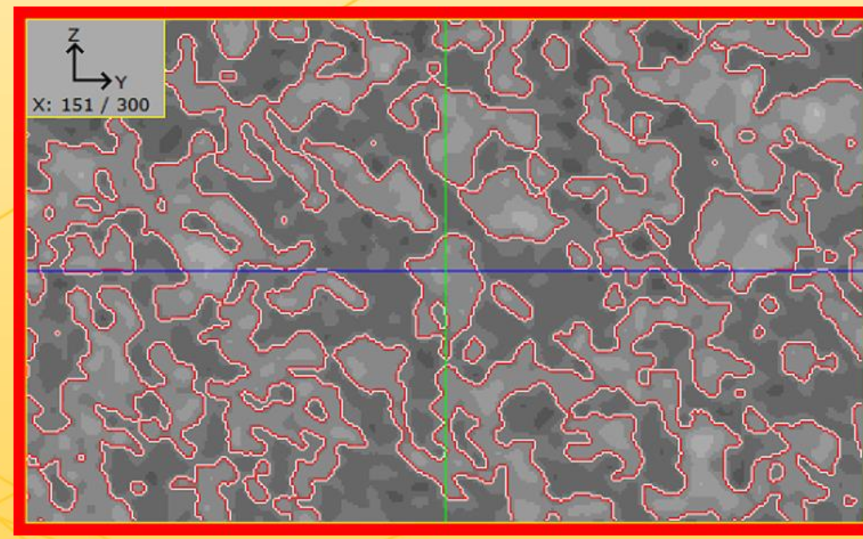


* A voxel represents a simulation element (1.8 × 1.8 × 1.8 µm) in a structure grid in 3-D space.

Simulation method – image noise reduction

- The median filter method can be applied to the 3-D image to remove noise.





pore **solid**

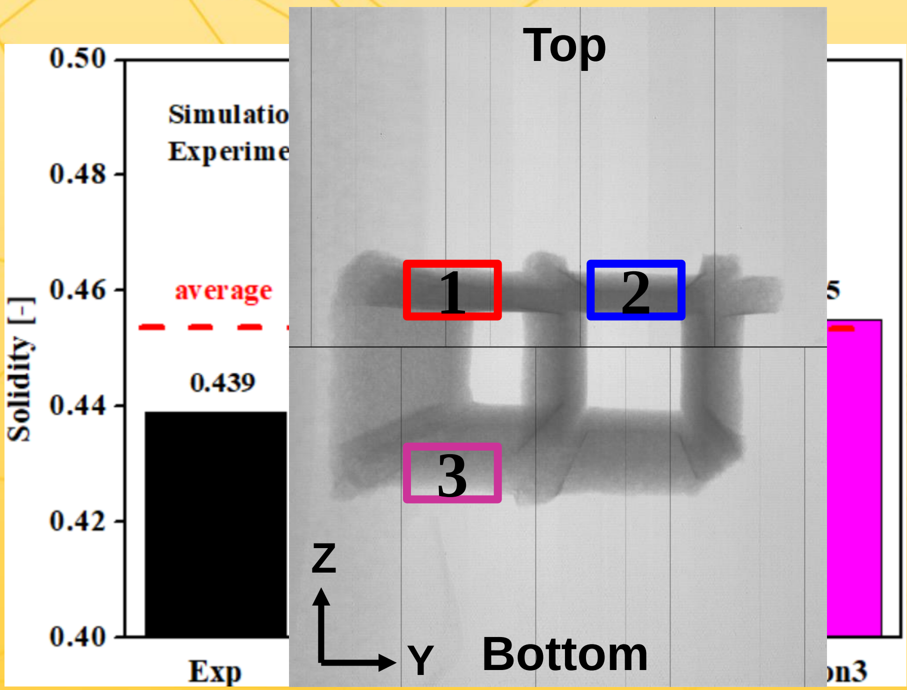
Original image → **Image with median filter**

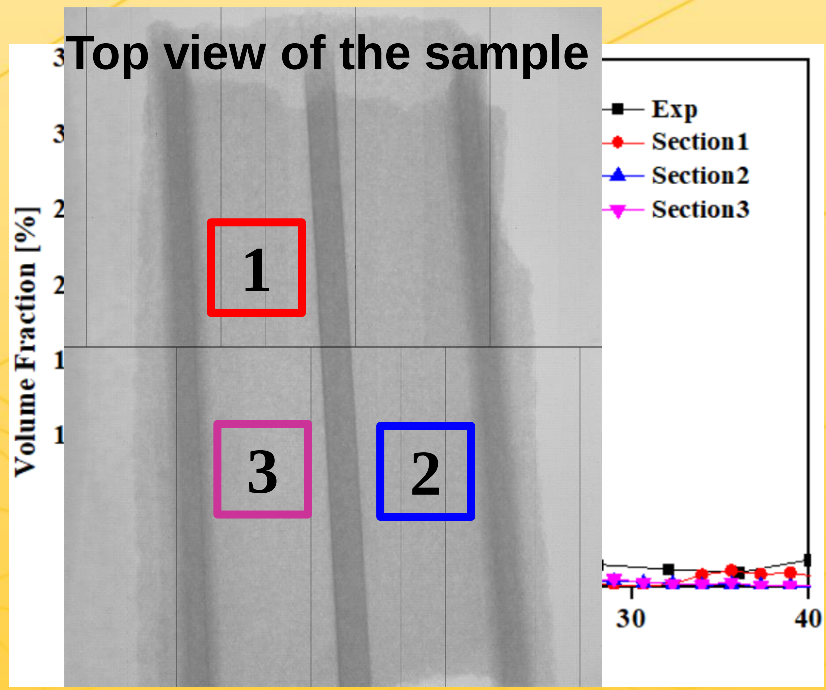
Solidity and pore size distribution

* The median filter is a nonlinear digital filtering technique.

Repeatability – blank sample

- Similar solidity and pore size distribution were found among all the three sections of the 3-D structure, which are very close to the experimental results.





* The results were measured by mercury intrusion porosimetry.

Pressure drop – blank sample

- A reasonable agreement between the experimental result and simulation result on pressure drop.

Method	Permeability $k\times10^{12}$ [m^2]	Flow rate [slm]	Pressure drop [Pa]	
			25°C	300°C
Experiment	2.54	12.9	62.3	134.5
Simulation	**3.13**		**50.9**	**125.3**
Experiment	2.54	32.3	171.9	281.5
Simulation	**3.13**		**163.2**	**273.6**

Pressure drop: $$\Delta P = \frac{\mu Q}{2V}(\alpha + w_s)^2\left[\frac{w_s}{k\alpha} + \frac{8FL^2}{3\alpha^4}\right] + \frac{\beta\rho Q^2(\alpha + w_s)^4 w_s}{2V\alpha^2}$$

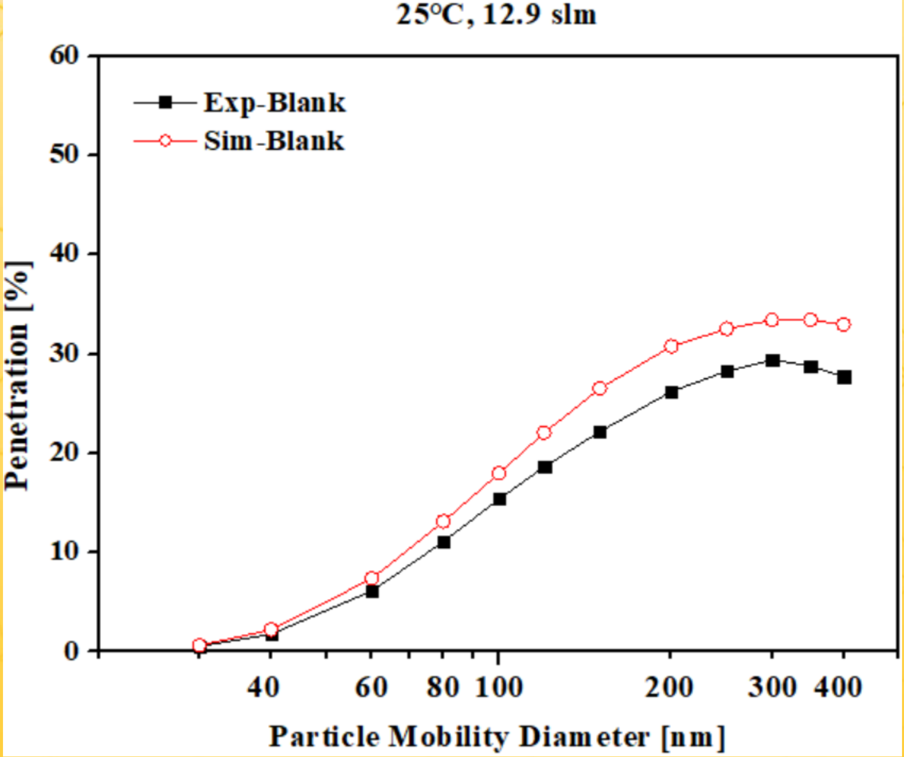
Wall loss+ Channel frictional loss   Contraction& expansion losses

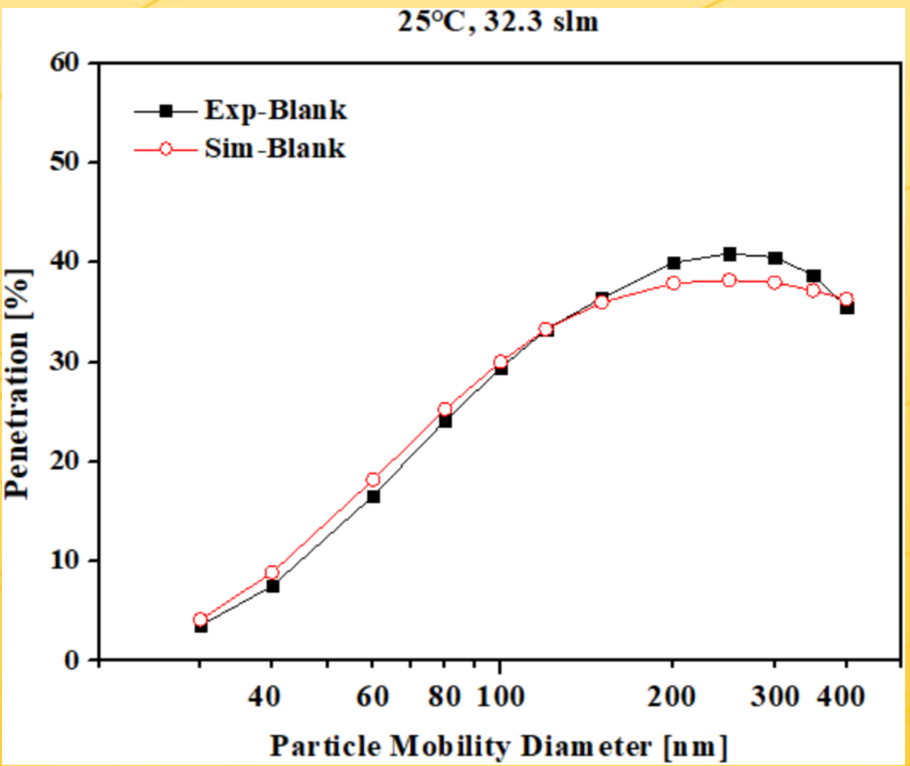
(Konstandopoulos et al., 2001)

ΔP:	pressure drop	L:	effective filter channel length
μ:	air viscosity	k:	permeability
Q:	volumetric flow rate	w_s:	wall thickness
V:	filter volume	ρ:	gas density
α:	cell size	β:	Forchheimer coefficient
F:	28.454		

Initial efficiency – blank sample, 25°C

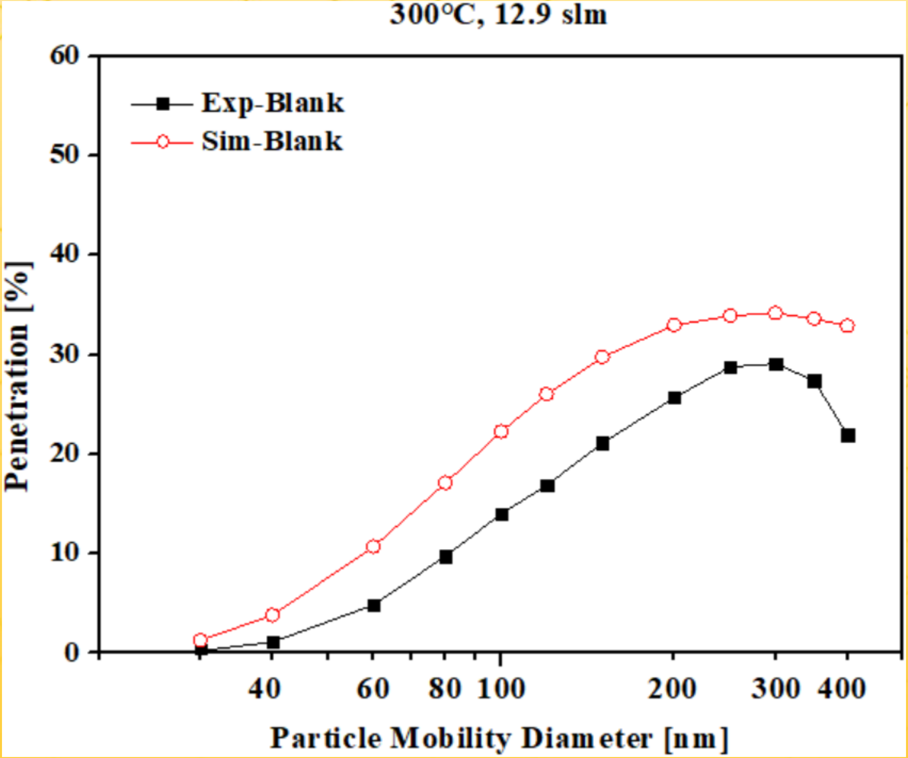
- There is a good agreement between the experimental result and simulation result on initial efficiency.
- The biggest difference is within 5% for all sizes (30-400 nm) at 25°C.

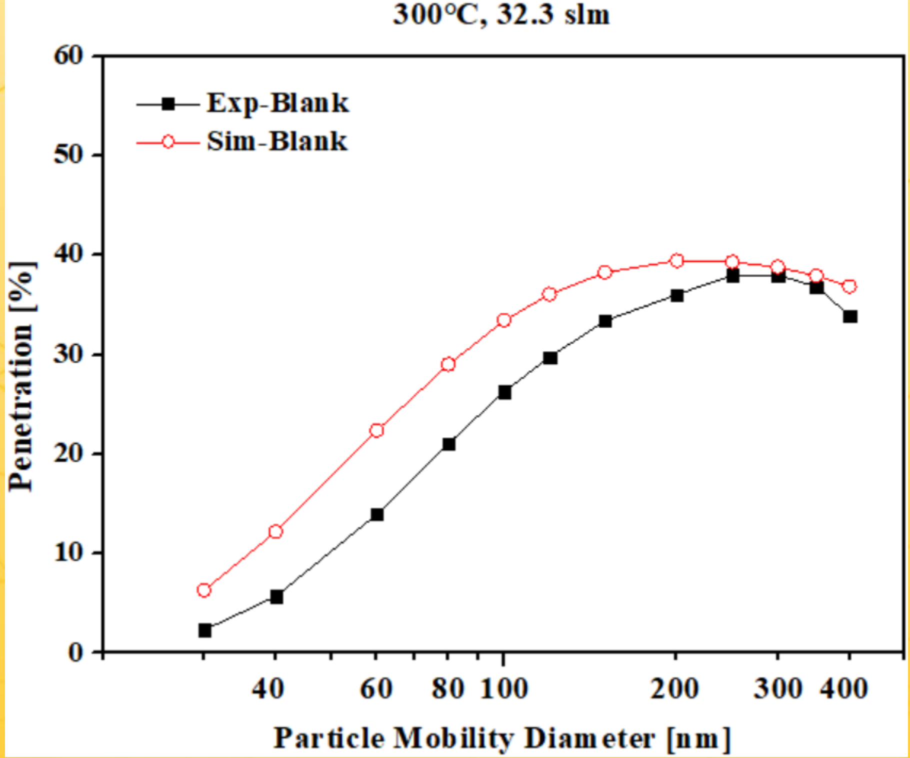




Initial efficiency – blank sample, 300°C

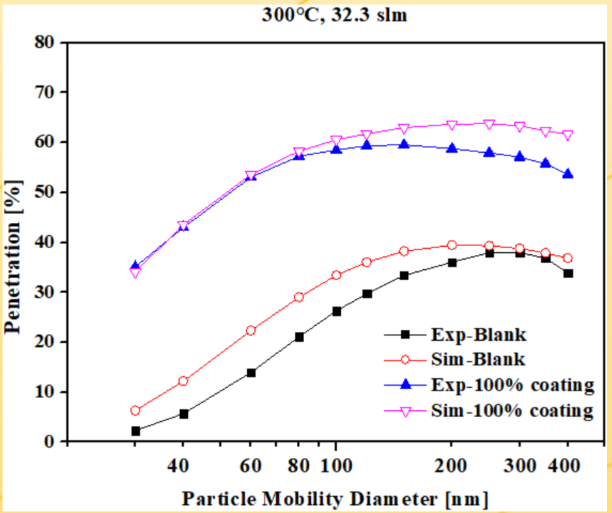
- There is a good agreement between the experimental result and simulation result on initial efficiency.
- The biggest difference is within 10% for all sizes (30-400 nm) at 300°C.

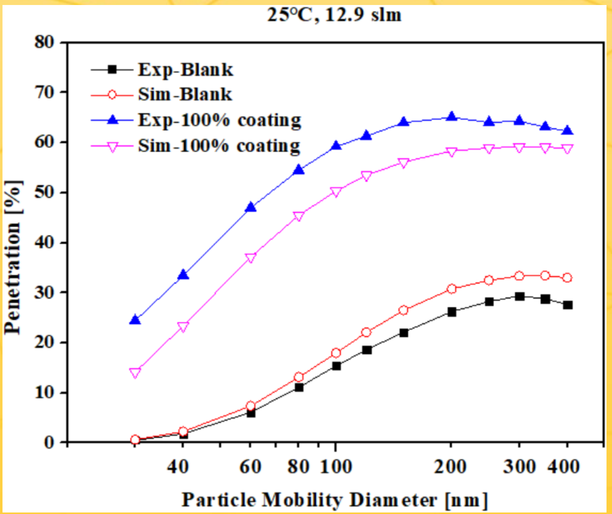


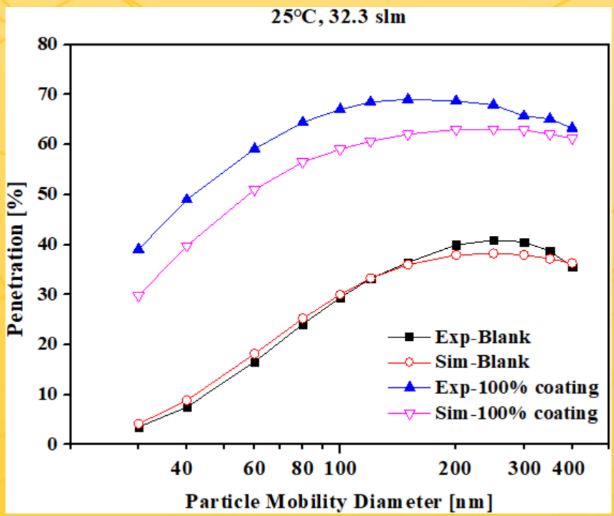


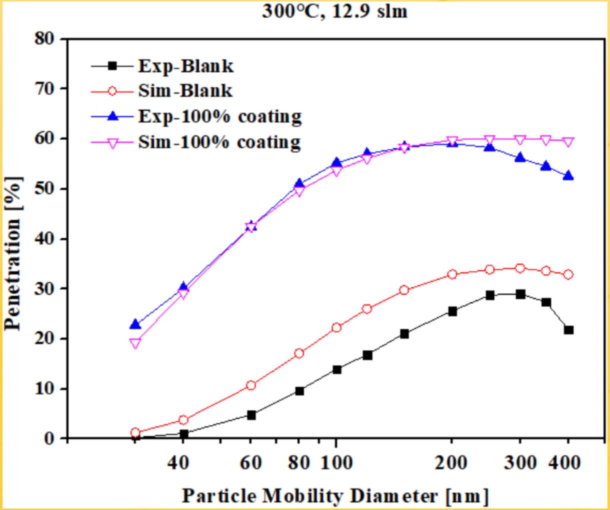
Initial efficiency – blank and coated samples

- At all test conditions, penetration of blank samples is lower than that of samples with 100% coating amount, which is similar to the experimental results.



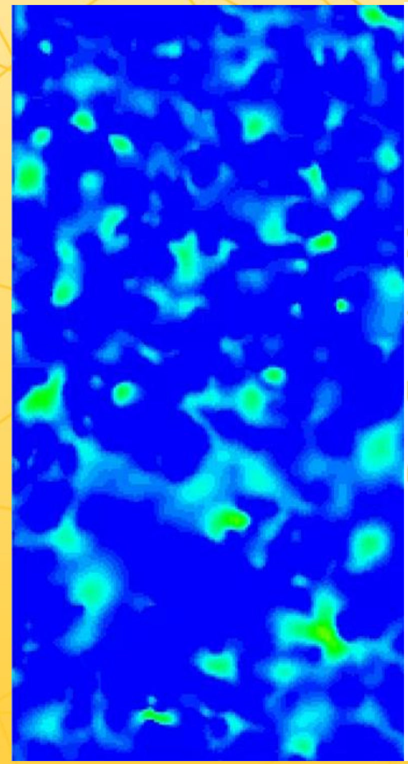


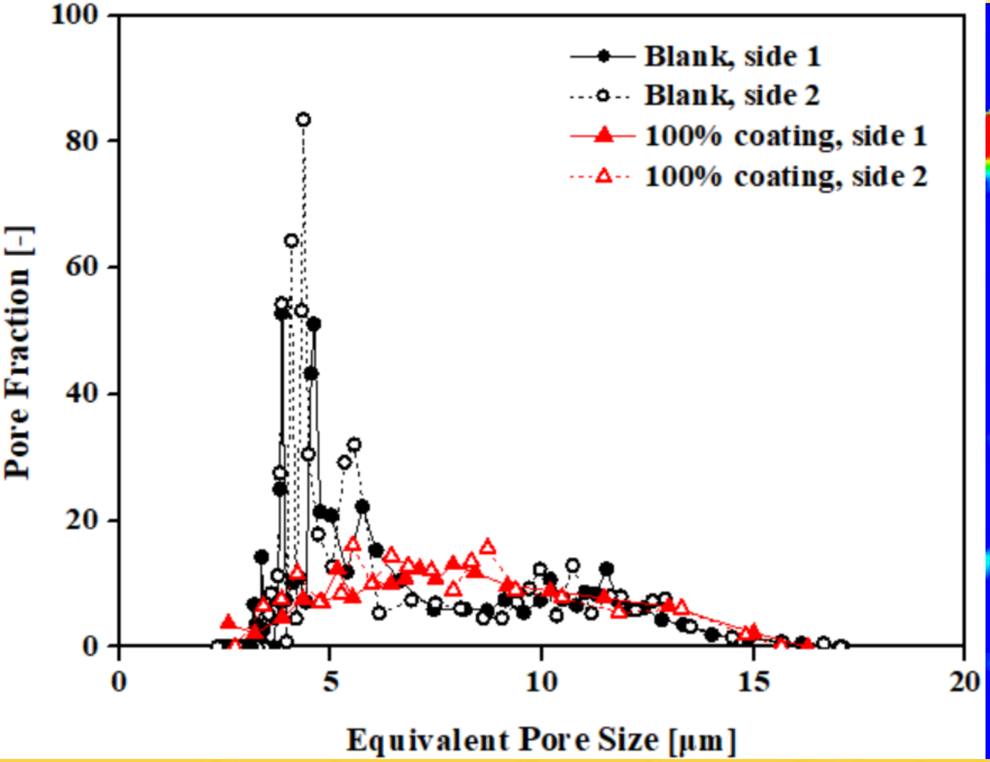


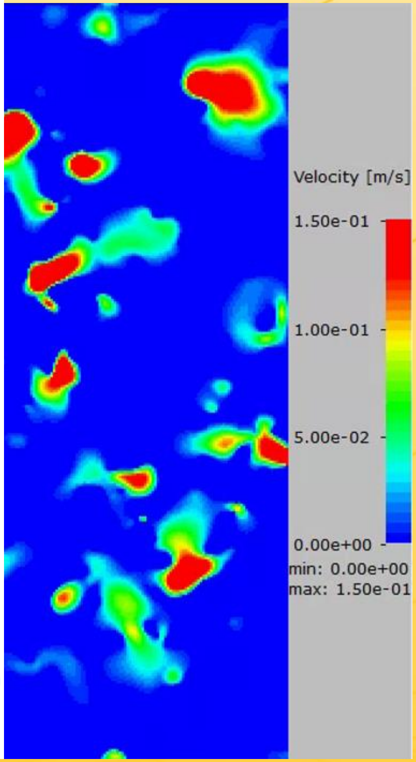


Velocity distribution – blank and coated samples

- The pore size distribution shifts towards larger size after coating, which is found both by capillary flow porometry measurement and 3-D simulation.





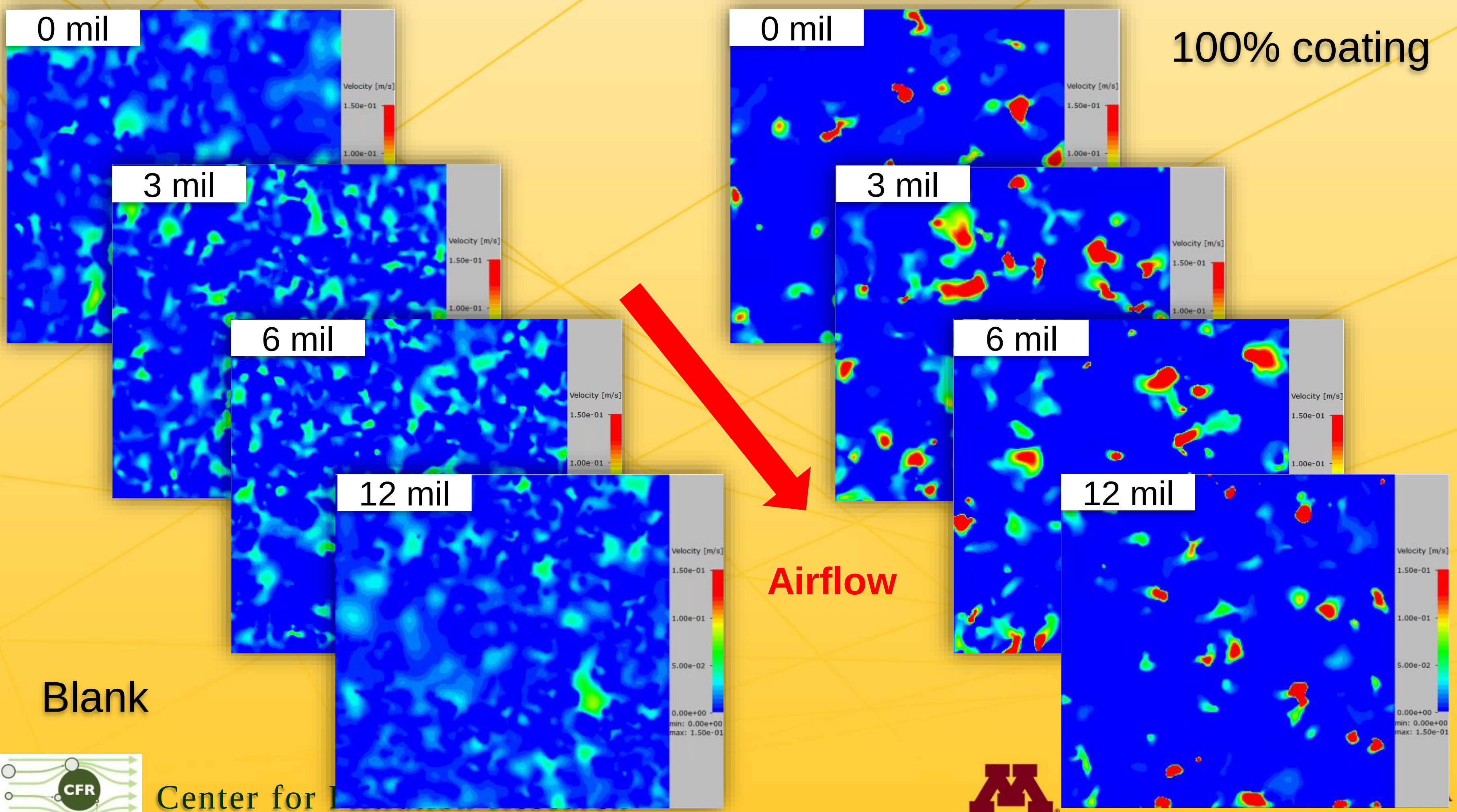


Blank

100% coating

Velocity distribution – blank and coated samples

- Similar velocity distributions were found at different depths along media thickness.



Summary

- **The filtration performance of catalyst coated wall substrate are affected by the coating amount.** Higher penetration is found as the coating amount increases.

- **Reduced efficiency after coating is caused by pore size distribution shift.**

- A fairly good agreement between the experimental result and simulation result suggests that **the simulation method can be used to study the effect of wash-coating on filtration performance of wall-flow substrate**.

Future work

- To improve the resolution of micro-CT scan images (1 μm or finer) and to study the effect of voxel size on the simulation results.

- To establish different artificial 3-D structures by changing the parameters of filters and optimize the design of DPFs, especially catalyst-coated DPFs.

Thank you for your attention!

Q & A