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Effect of Soot Size on Particle Filtration and Soot Cake Formation in Diesel Particulate Filter

K. Yamamoto, S. Yagasaki
(Nagoya University)

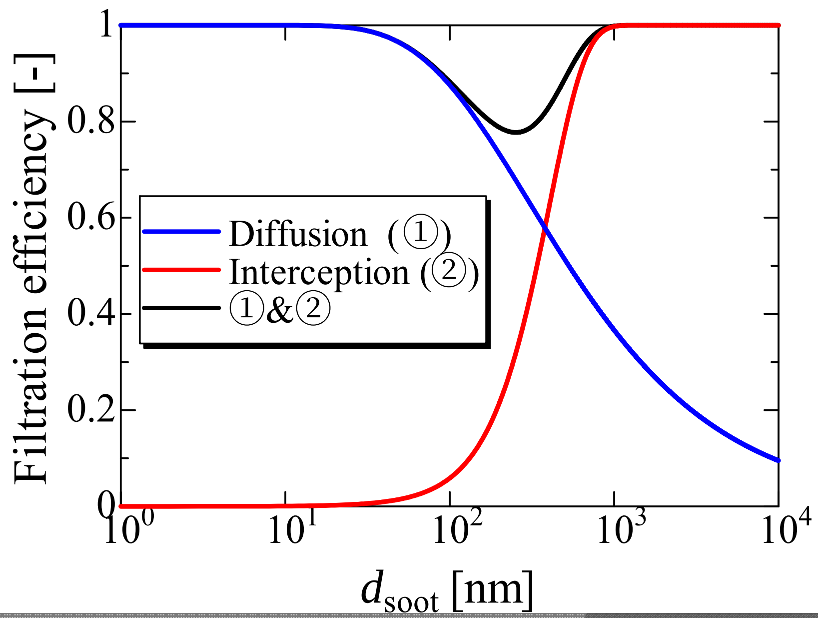
Establishment of AICE

In order to realize further improvement of fuel economy and reduction of tailpipe emissions, Japanese automakers have established a joint research organization, AICE (Automotive Internal Combustion Engines) in 2014, consisting of 9 automobile companies and 2 organizations. The goal is to utilize research achievement and accelerate the development activities of each automaker. In 2015, our group joined AICE projects as one of the research players.

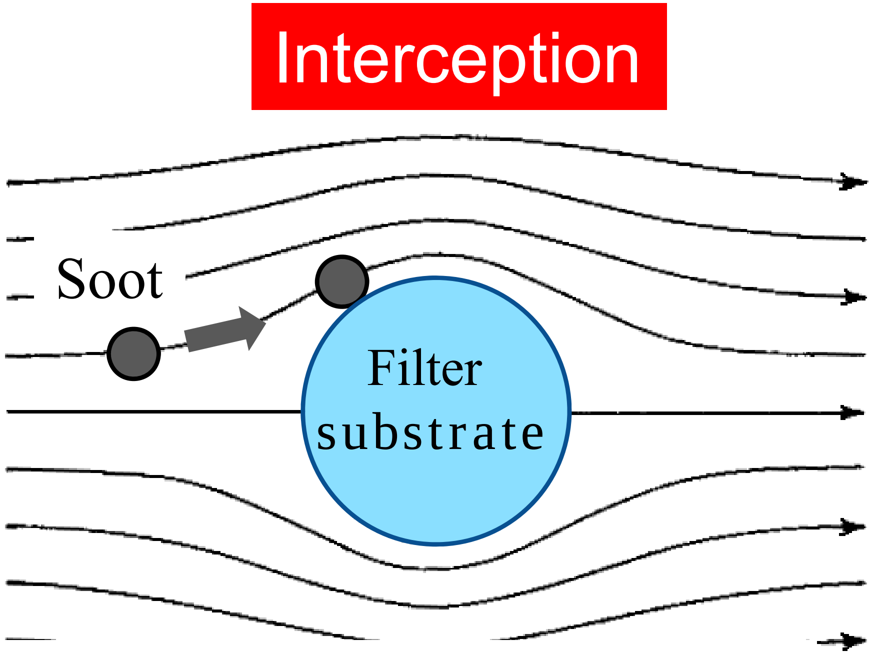
Background & Objective

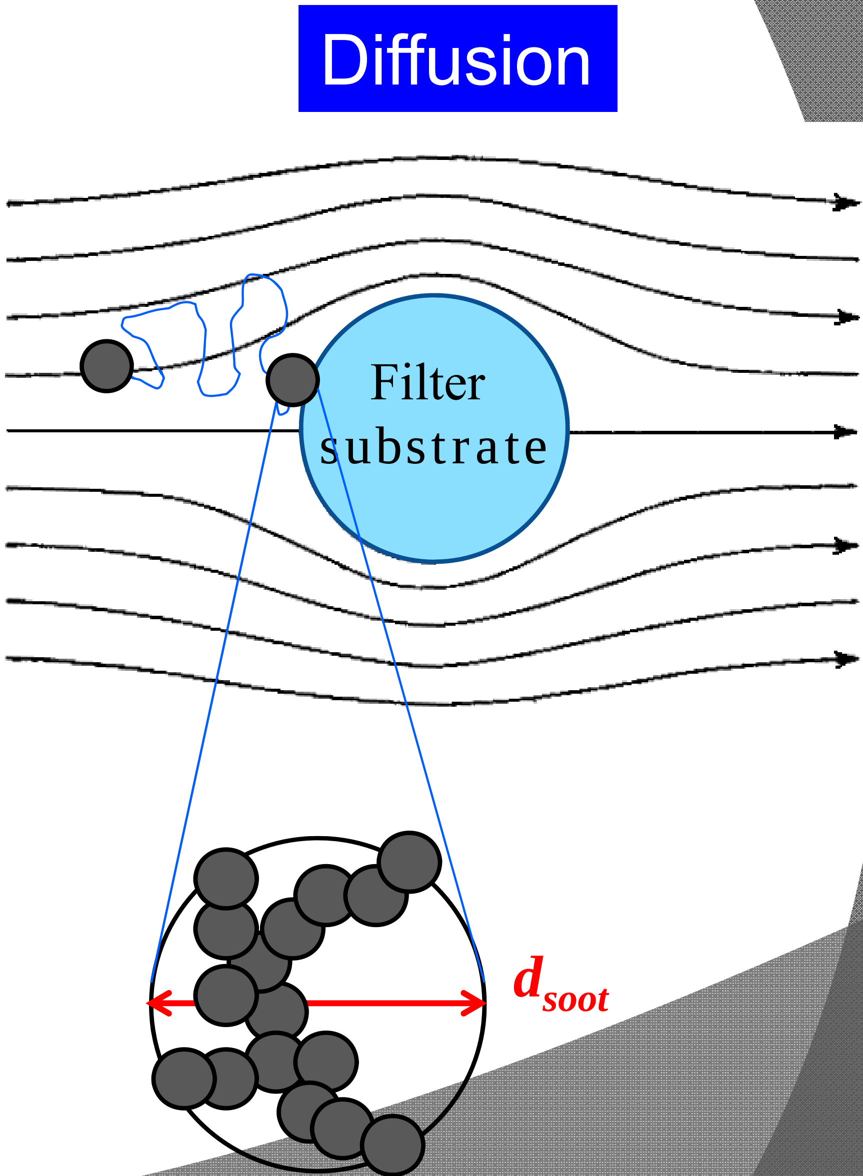
- So far, diesel particulate filters (DPFs) have been widely used
- As the soot is continuously collected, the exhaust pressure (filter backpressure) increases
- We need more information for soot deposition process and pressure drop for development of future filtration system

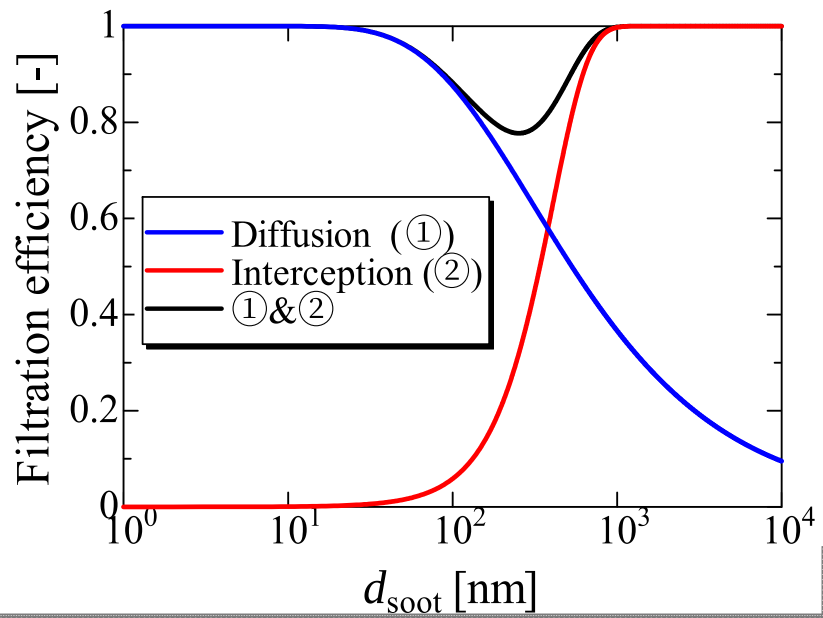
In this study, focusing on soot size, we simulated soot deposition to discuss pressure drop and soot cake formation by lattice Boltzmann method. The structure of SiC filter was obtained by an X-ray CT. The soot size was 75, 100, 125 nm.



Interception & Diffusion







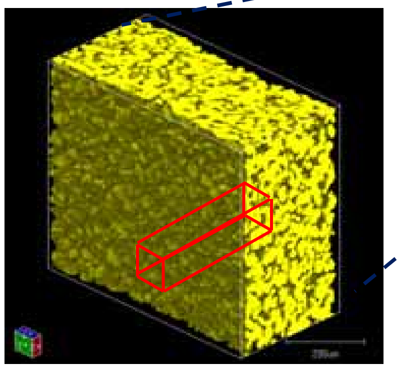
Numerical Conditions

Inflow boundary	velocity	1 cm/s
	temperature	300 ℃
Exit boundary		Atmospheric pressure
Soot mass fraction		0.005

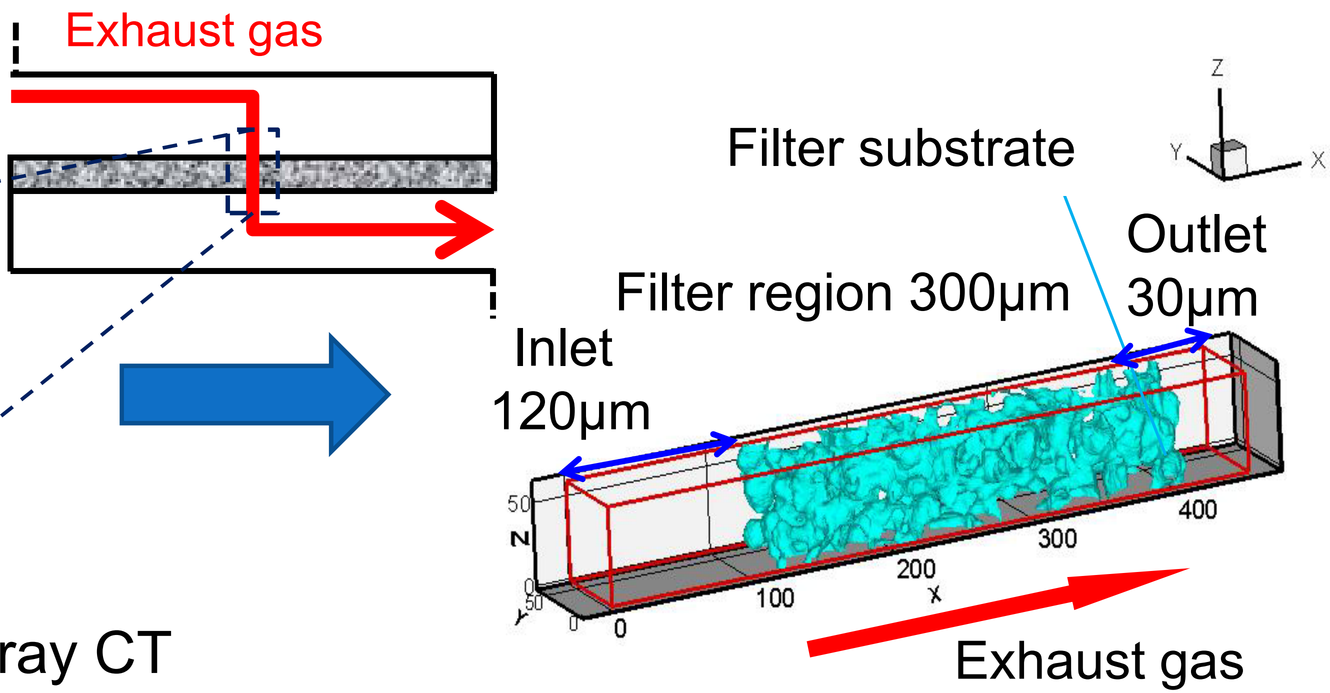
Calculation domain:
Size: 450μm×60μm×60μm
Grid size: 1 μm (= CT resolution)

Filter properties:
Porosity: 0.38 (SiC)

Calculation domain

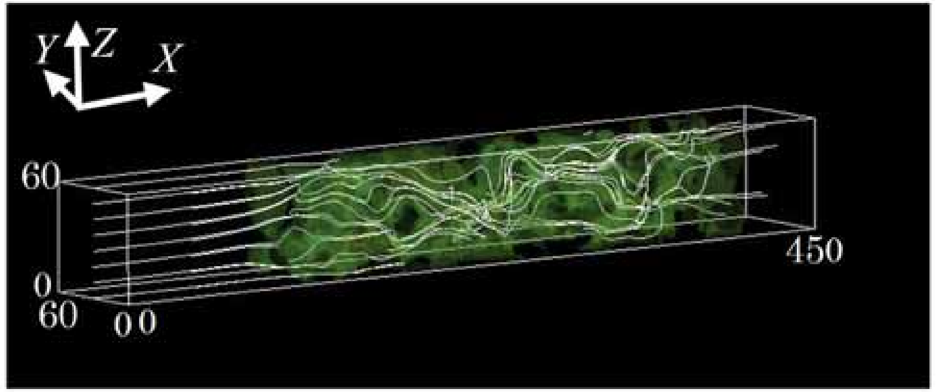


Porous structure by X-ray CT

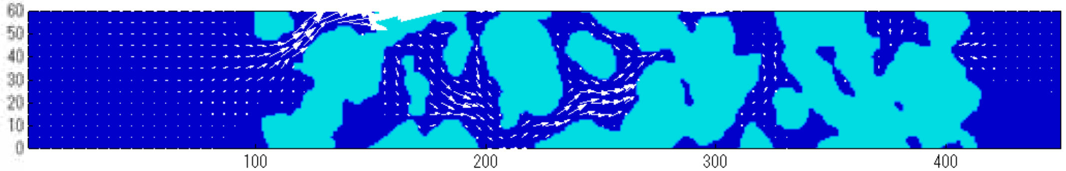


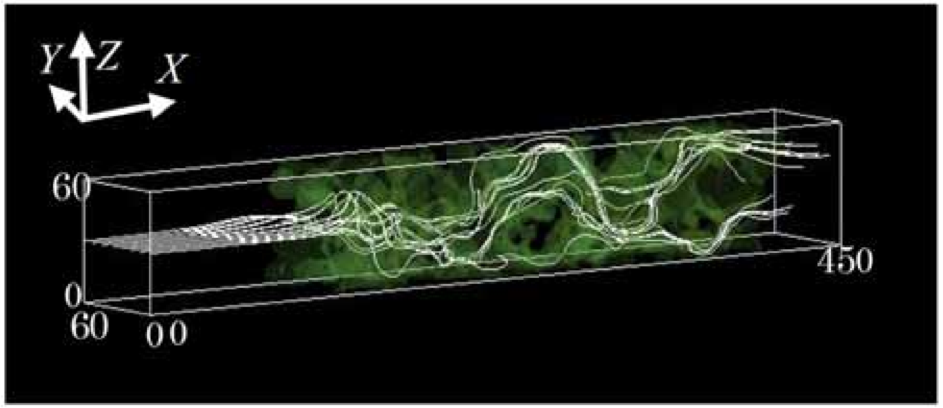
Flow Visualization across Porous Wall

Visualization of 3D flow field

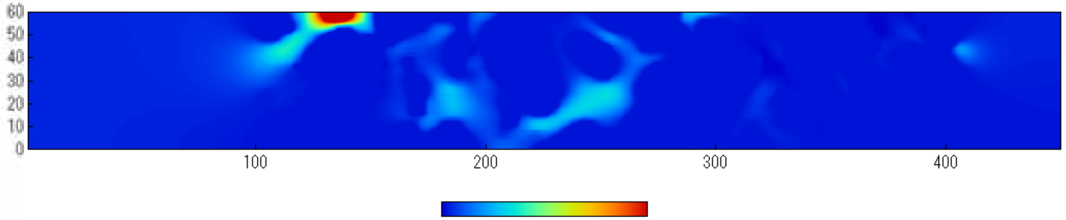


2D Flow field at Z = 21 μm



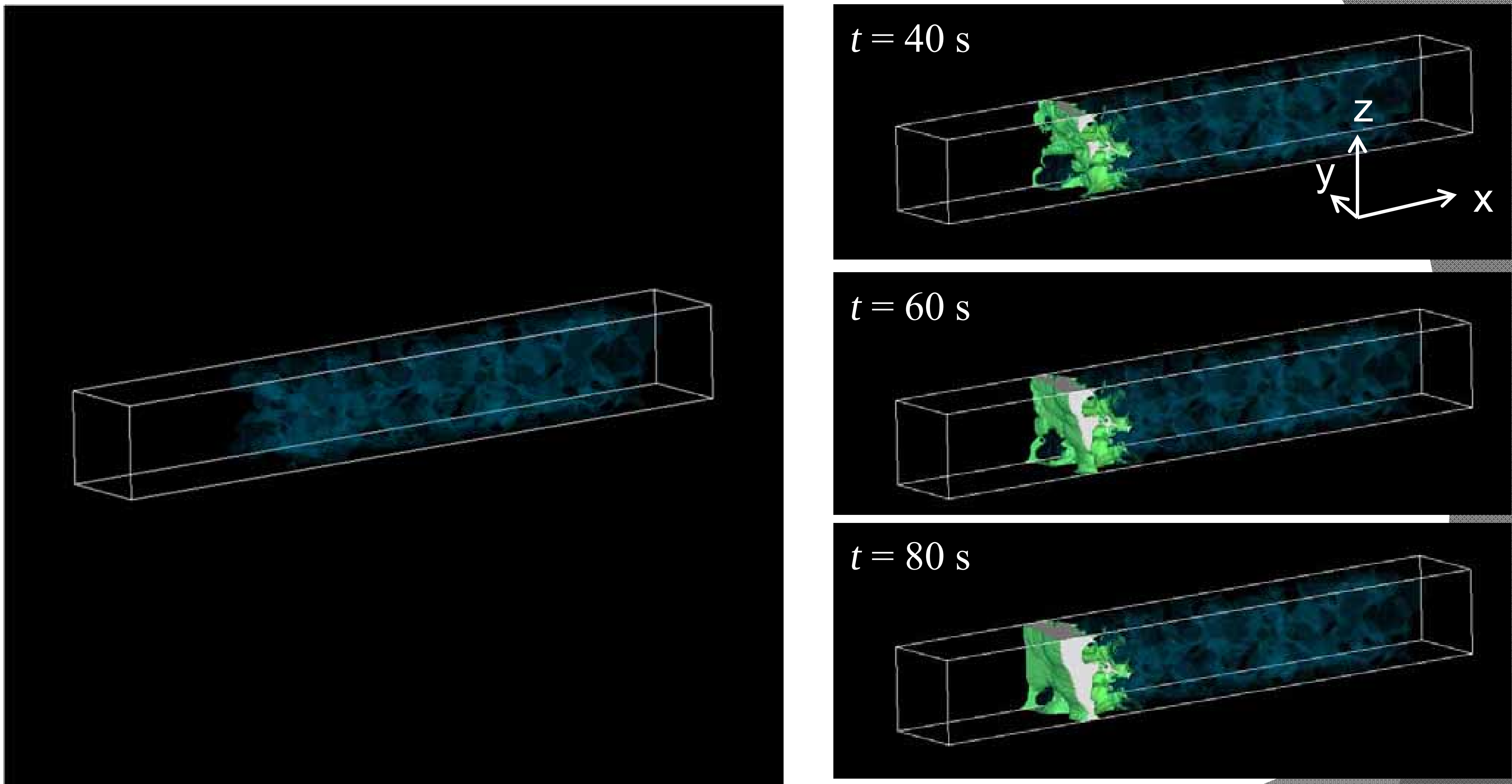


X direction velocity



-1.19 45.8 [cm/s]

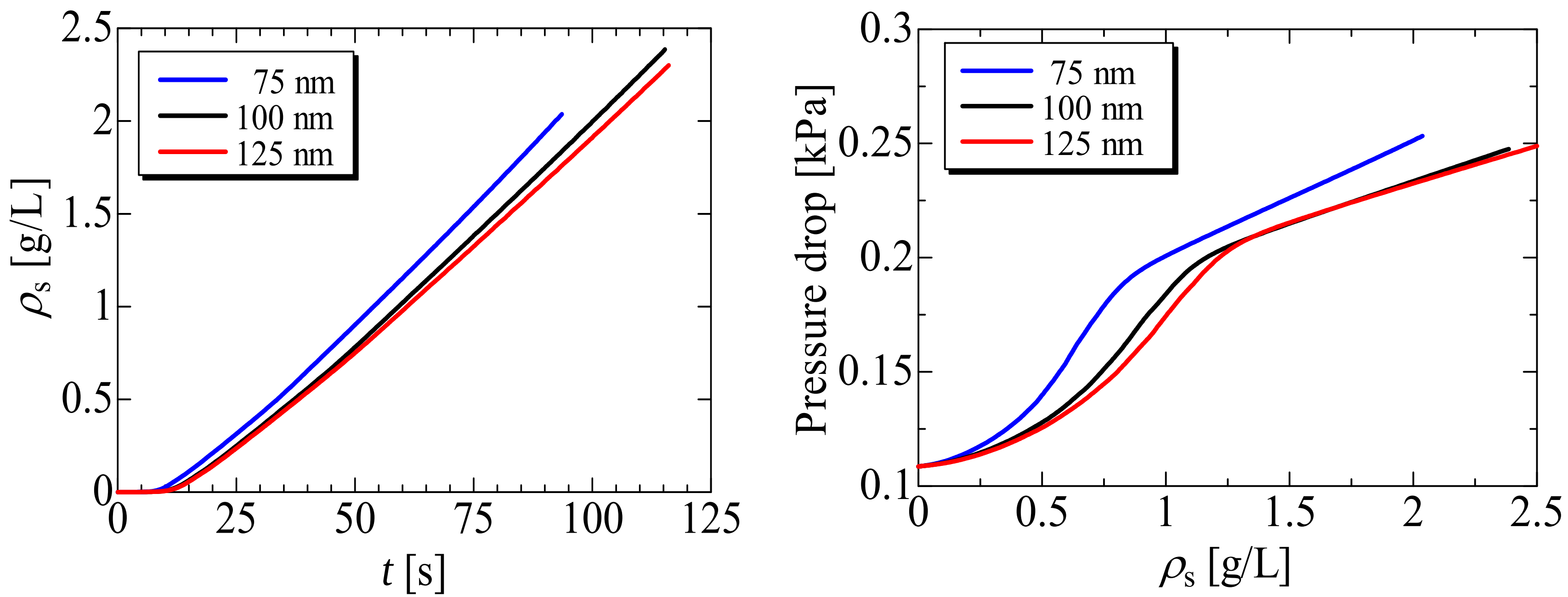
Soot Deposition Region (d_{soot} = 100nm)



Filter substrate ☐ Soot

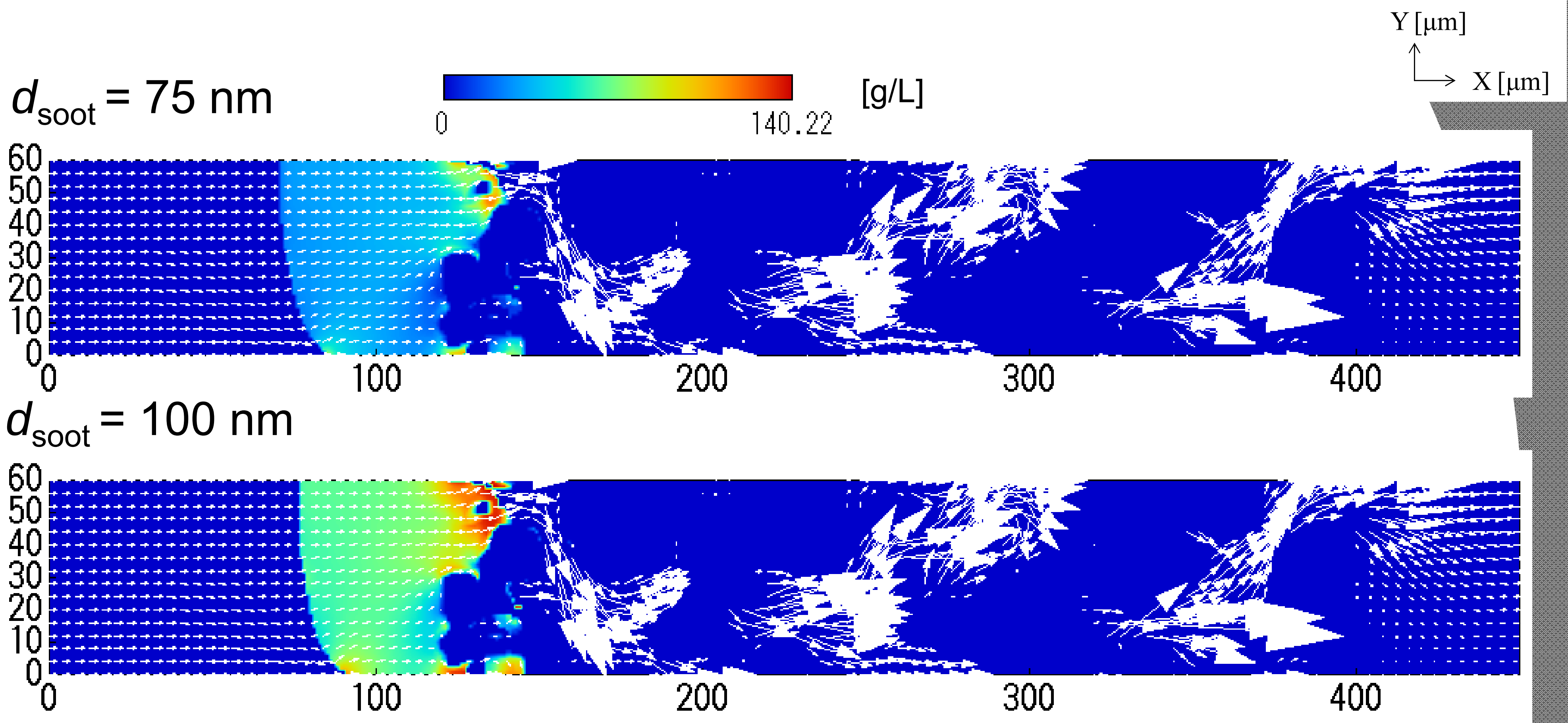
Initially, the depth filtration occurs, and the surface filtration is observed later.

Relationship between Pressure Drop and Mass of Soot in DPF



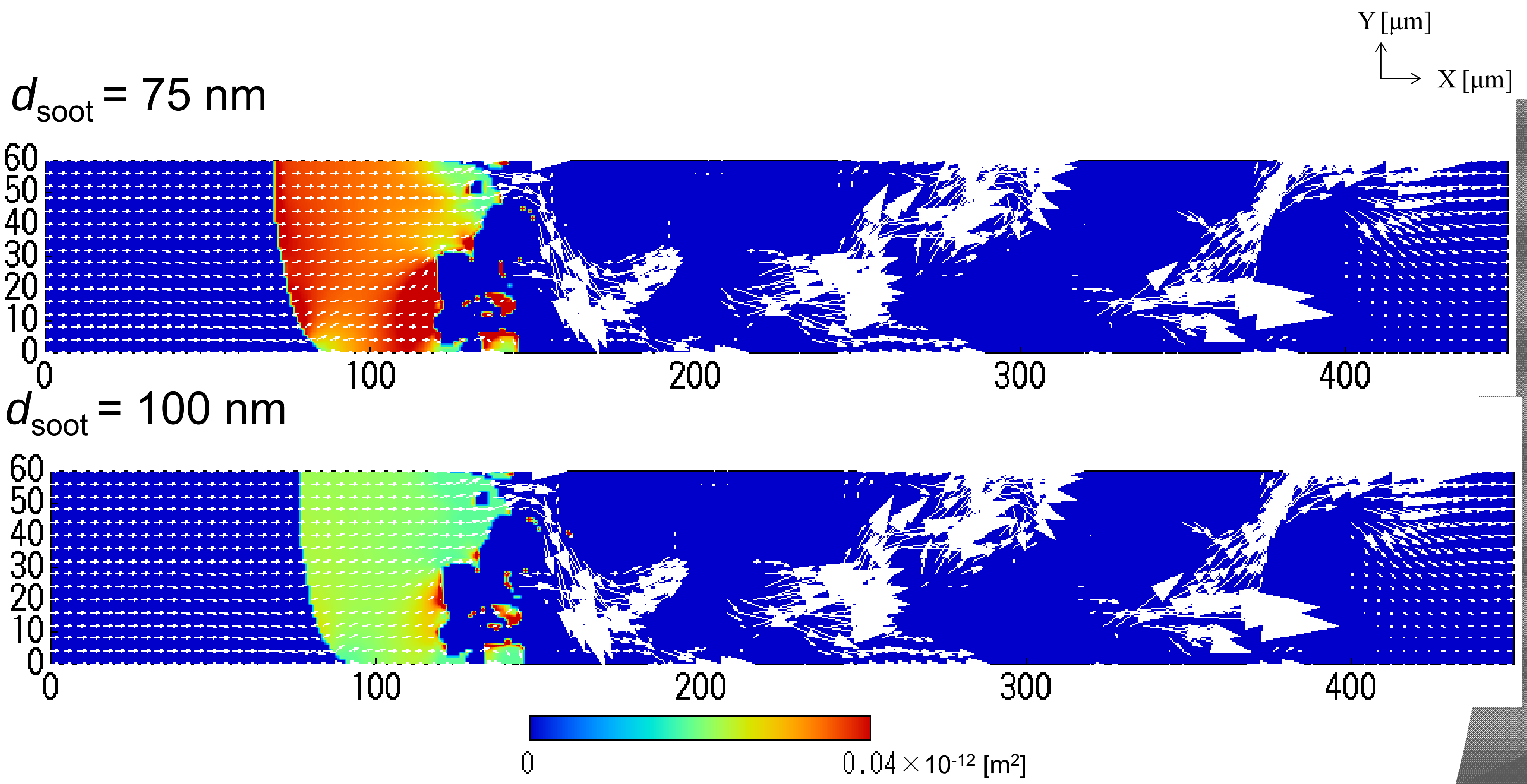
- For smaller soot particle, more soot is trapped due to Brownian diffusion.
- As the particle size is smaller, the pressure drop is increased.
- For d_{soot} = 100 ~ 125 nm, the same pressure drop is observed.

Distribution of Soot Density



- By comparing profiles of d_{soot} = 75, 100 nm, the soot layer density becomes even lower as the particle size is smaller.
- Especially, at the bridge of surface pores, the soot layer density of 100 nm is approximately 2 times larger than that of 75nm.

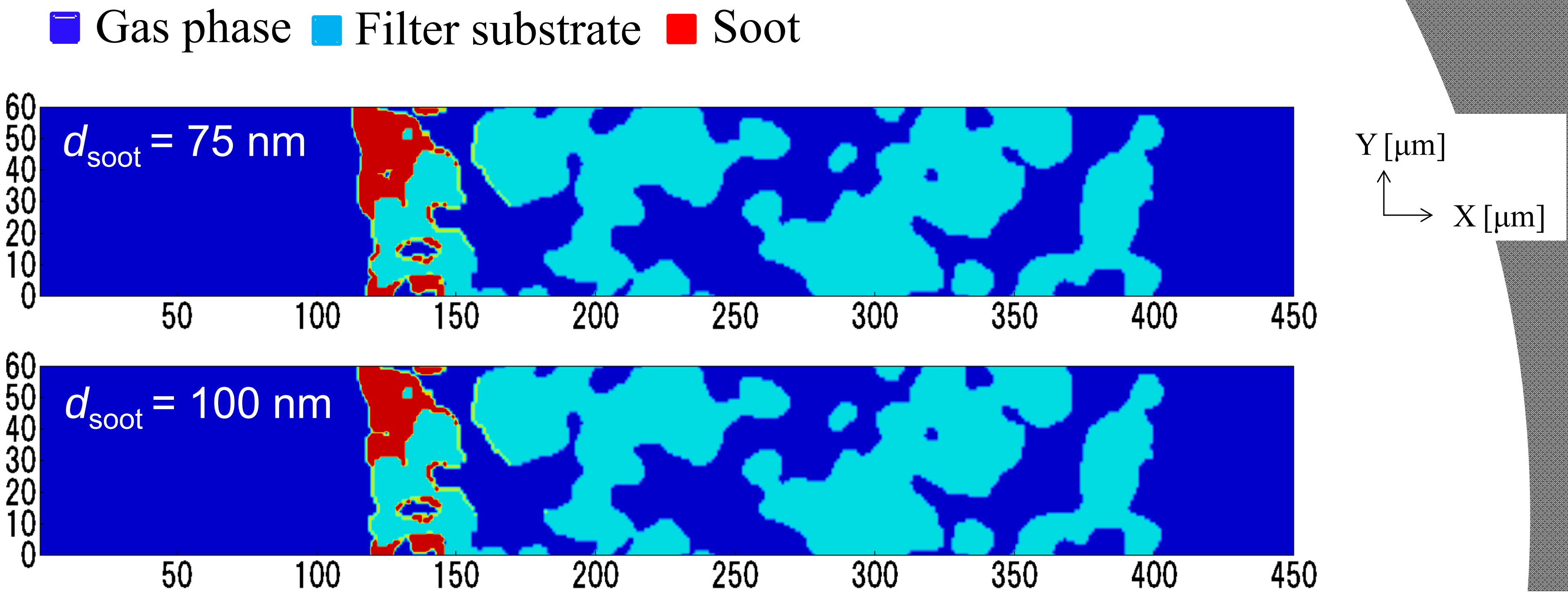
Distribution of Soot Permeability



- The permeability of soot layer largely depends on the location.

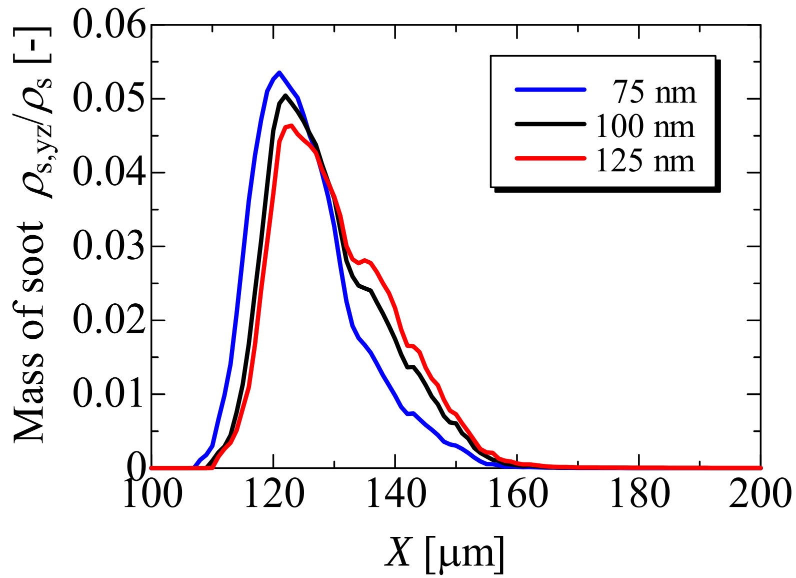
- By comparing profiles of d_{soot} = 75 and 100 nm, the permeability of soot layer becomes larger as the particle size is smaller.

Soot Deposition Region for ρ_s = 2.0 g/L



- By comparing two profiles, in the case of d_{soot} = 75 nm, more soot is trapped on the surface of the filter wall.

- The soot cake is thicker when particle size is smaller, resulting in larger pressure drop.



Summary

Focusing on the soot size (soot aggregation diameter), the soot deposition process was numerically investigated. Following results were obtained.

- Independent on the soot size, as more soot deposited, the filter backpressure increased.
- Once all pores on the wall surface were plugged, the surface filtration was observed. The shift from the depth filtration occurred earlier as the soot size was smaller.
- As the soot size decreased, the pressure drop was higher, which was caused by the fact that the smaller soot was easily trapped by the Brownian motion, forming the thicker soot layer.

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