25th ETH-Conference on Combustion Generated Nanoparticles

Numerical simulation of SiC sponge potentially applied for gasoline particulate filter

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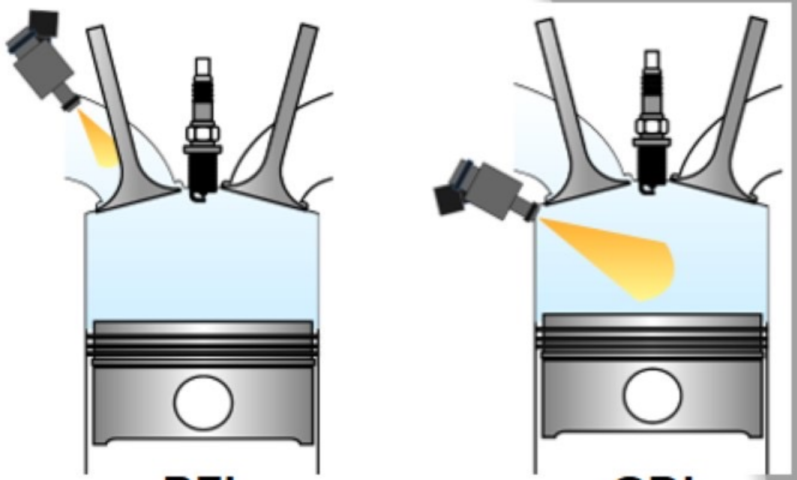
Session 2: Aftertreatment

Introduction

GDI Engine

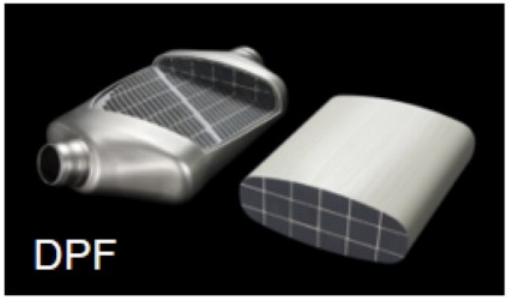
PFI: Fuel is injected into intake manifold and mixed with air before it enters through intake port to combustion chamber

GDI: Fuel is directly Injected into the combustion chamber. The mixture of fuel and air is formed in the combustion chamber.



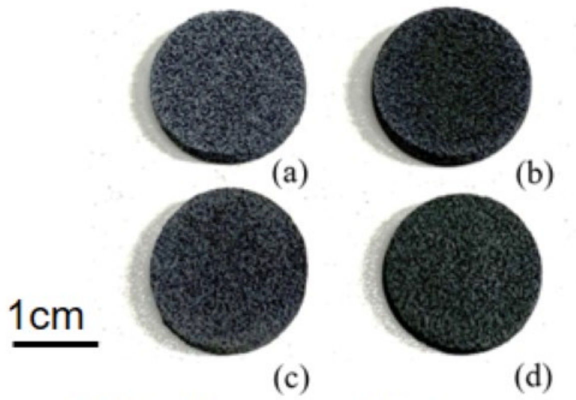
(https://talking-car.com/diengine/)

- In order to reduce CO_2, the fuel efficiency of vehicles is important
- Recently, the number of GDI (gasoline direct injection) engines have been increased
- Higher efficiency of GDI than PFI (port fuel Injection) ⇔ similar to diesel
- More particle emission, causing health hazard
- New regulation in Japan is introduced in 2020
- As for diesel soot, a well-know diesel filter (diesel particulate filter, DPF) is widely used

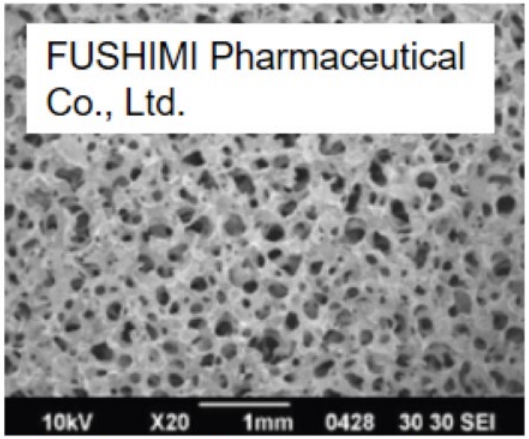


⇒ However, compared with diesel exhaust gas, the temperature of gasoline exhaust gas is much higher, with smaller particles.
A new filtration system with enough thermal durability is required.

SiC Sponge Potentially Applied for GPF

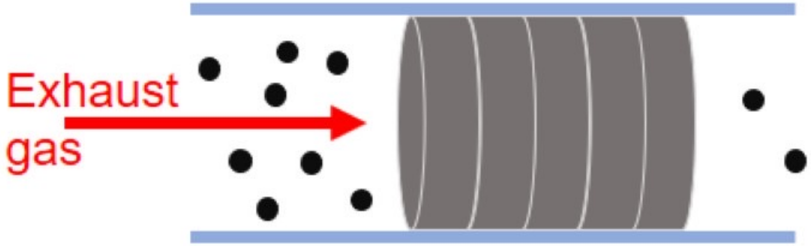


SiC (silicon carbide) sponge



Electron microscope image

Sample	Pore size (μm)	Porosity (-)
SC55 (a)	460	0.86
SC68	370	0.81
SC75 (b)	340	0.85
SC90 (c)	280	0.88
SC170 (d)	150	0.82



- Porosity is over 80%
- Pore size can be changed freely by combining sponges with different pore size

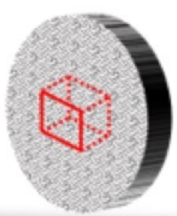
In our previous studies, effects of filter thickness, pore size, and porosity on filtration efficiency have been experimentally investigated to keep the better filtration efficiency with lower pressure drop.

Objectives in This Study

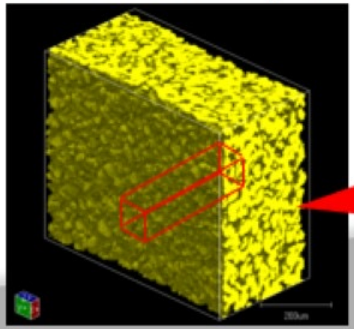
So far, the filter has been designed only by experiments. Then, a numerical simulation is needed to develop GPF by SiC sponge, in order to understand soot particle deposition inside the filter.

In this study, we simulate the soot filtration by SiC sponge, using the lattice Boltzmann method (LBM). As for the filtration, a Brownian diffusion and interception effects are considered. Effects of filtration velocity and soot size are investigated, and amount of deposited soot and the resultant pressure drop are discussed. 3D pore structure is obtained by X-ray CT measurement. ⇒ **Tomography-assisted simulation**

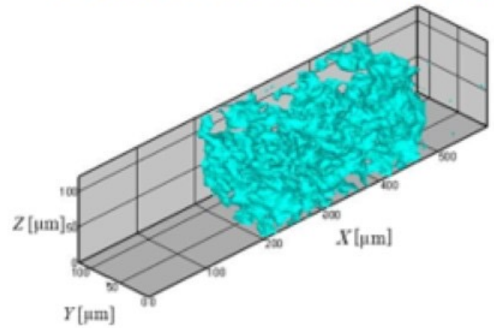
SiC sponge



Inner structure by X-ray CT

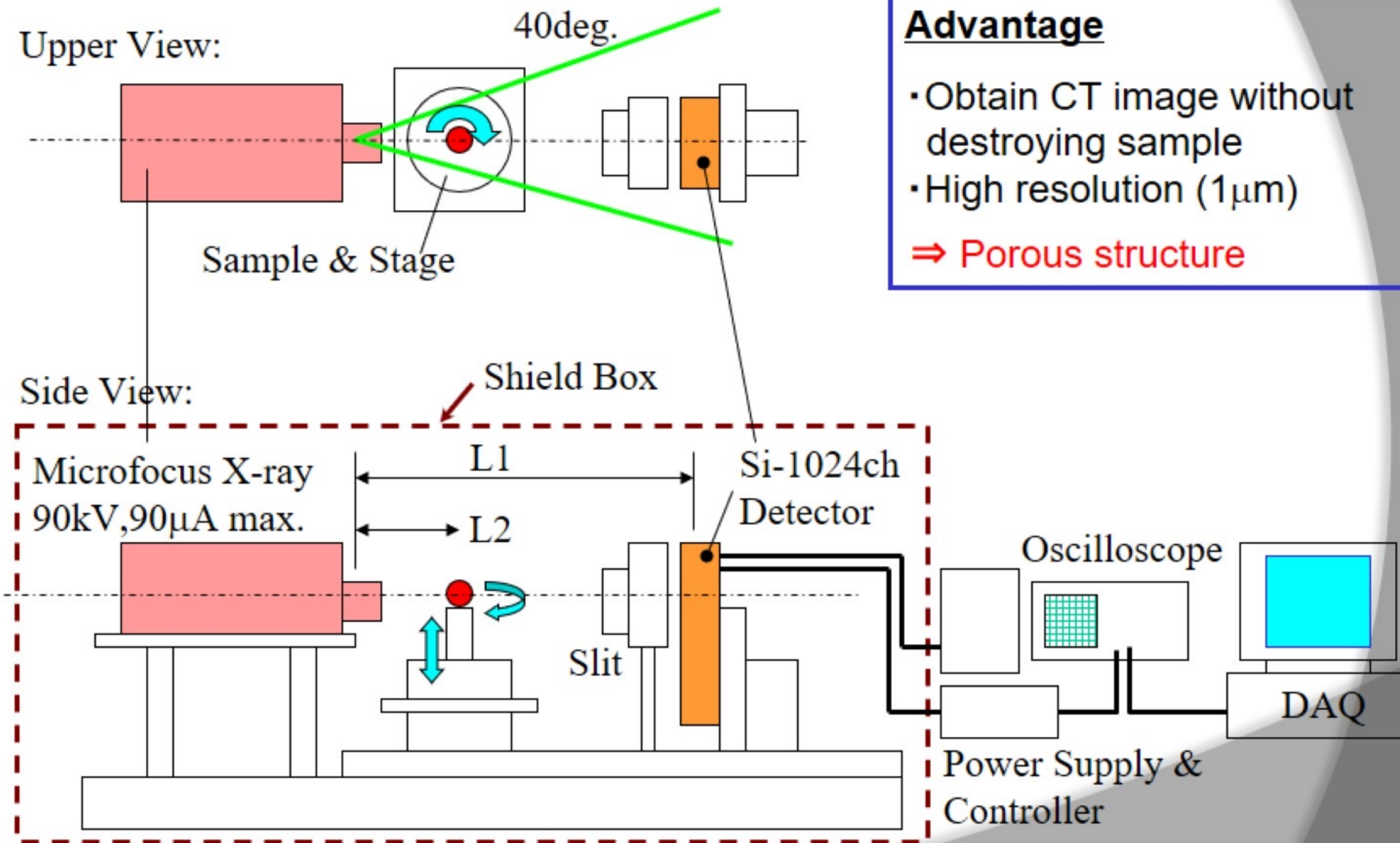


Numerical domain



Numerical Method

X-ray CT Measurement



Advantage

- Obtain CT image without destroying sample
- High resolution (1μm)

⇒ Porous structure

Porous Structure of SiC Sponge by X-ray CT

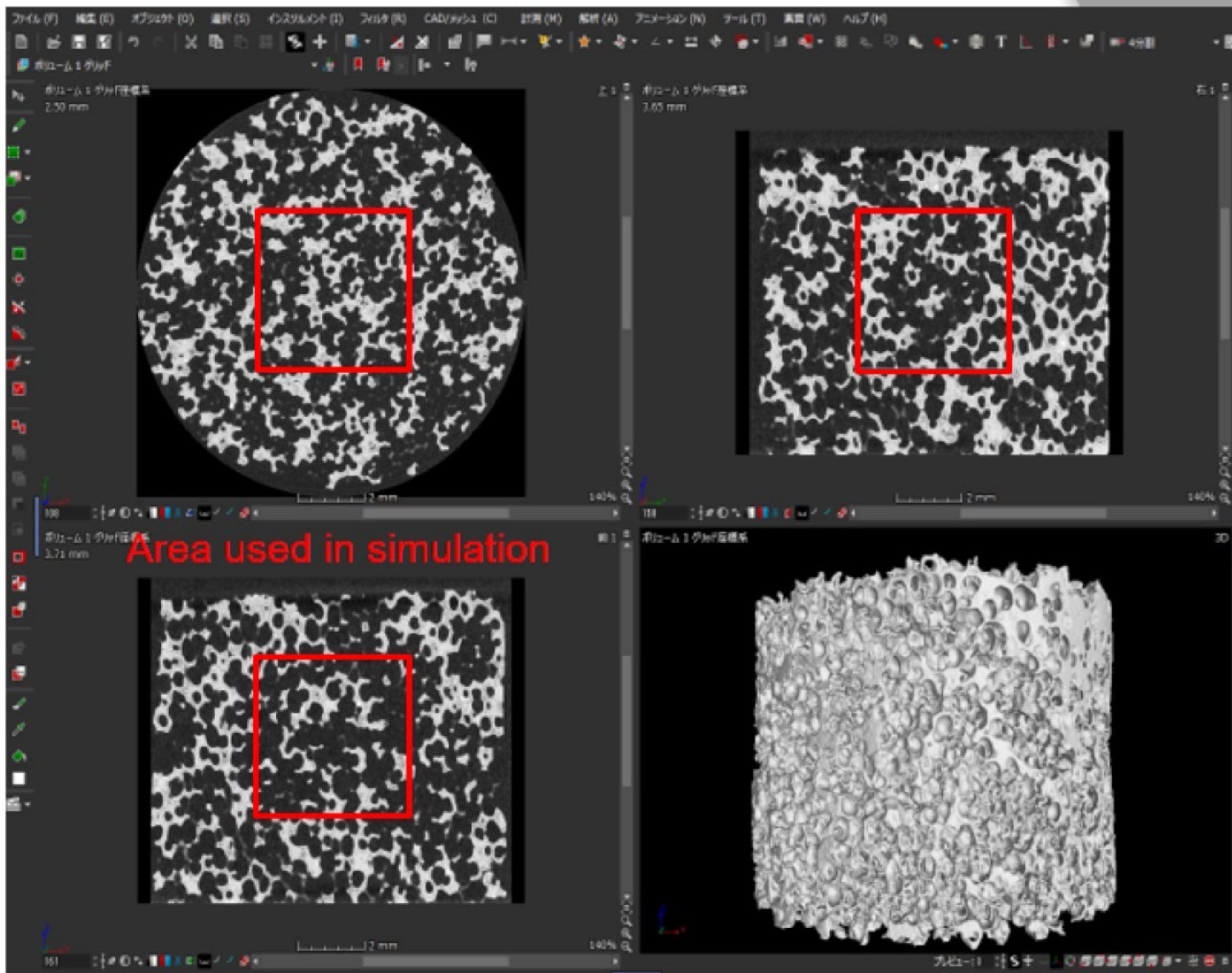
SiC Sponge: SC-90

Measurement area by red region (porosity of 88%)

Spatial resolution:
X: 23μm/pix
Y: 23μm/pix
Z: 23μm/pix

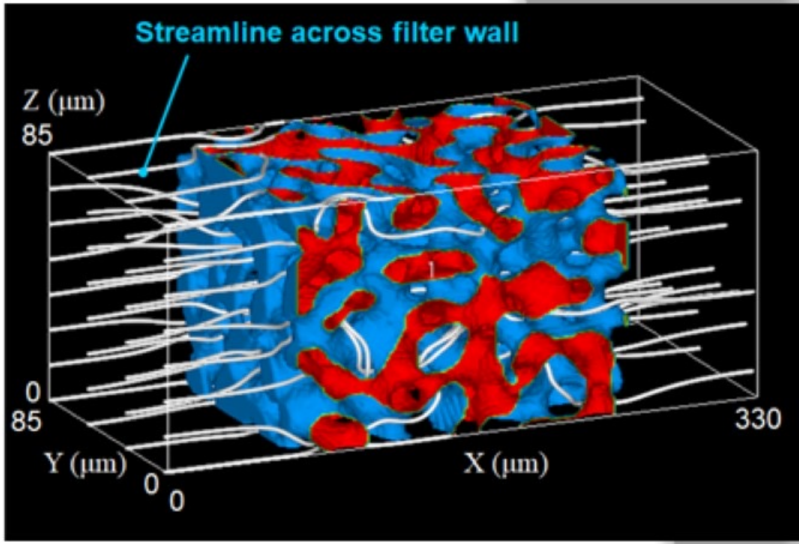
Voxel number
X: 200 (4.6mm)
Y: 200 (4.6mm)
Z: 200 (4.6mm)

Total grids of 8000000
Volume of 97.34mm^3

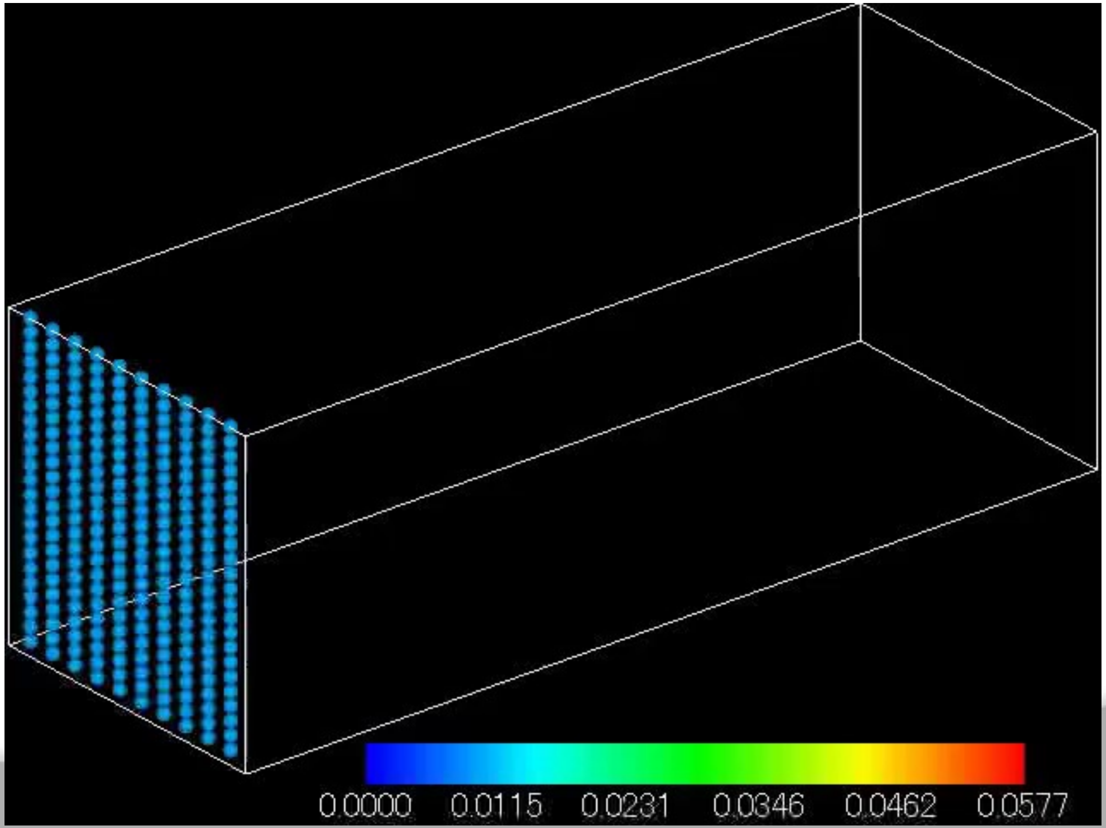


Example of Tomography-Assisted Simulation

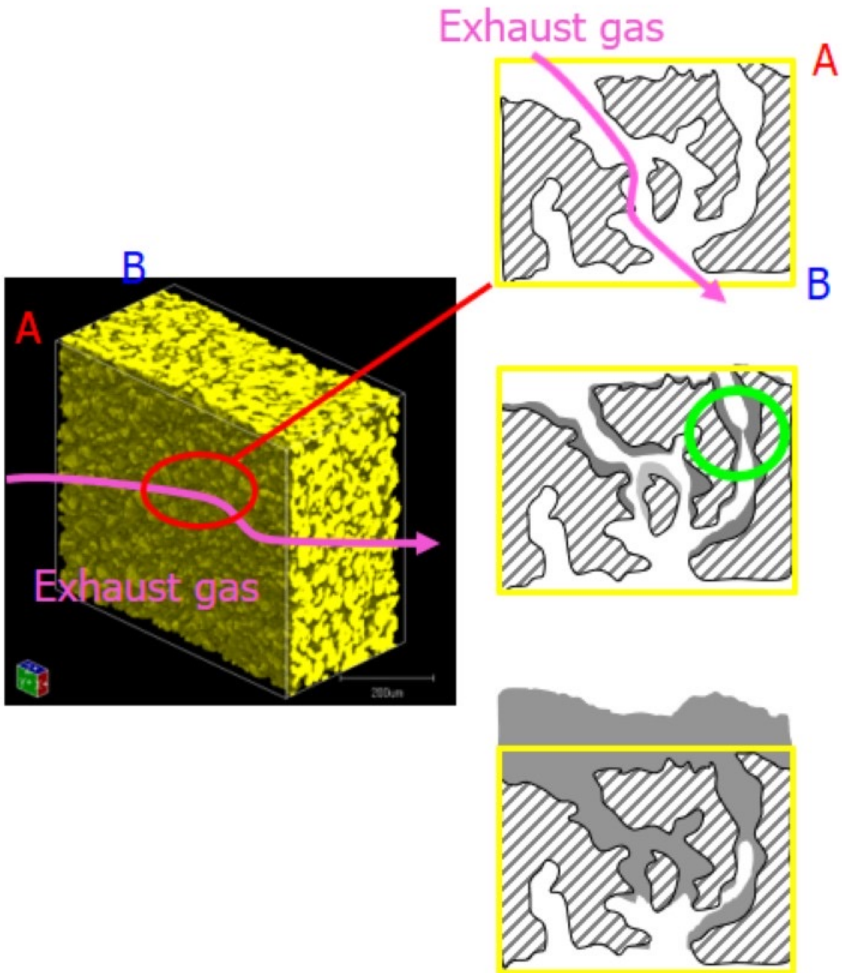
When the flow passes through filter wall, the direction and the velocity of the flow are largely changed, which cannot be obtained in experiments



DPF simulation by LBM



Two Types of Filtration Mechanism



Initially, soot filtration starts in clean filter.

(1) Soot is trapped deeply inside filter (depth filtration). Then, soot is deposited across necks of surface pores.

(2) Soot is deposited on the filter wall surface. Once the soot layer is formed, filtration efficiency becomes 100%, which is called surface filtration.

It is reported that the pressure drop is largely affected by the shift from depth filtration to surface filtration. Then, we try to discuss the filtration mechanism by changing the inflow velocity and soot size.

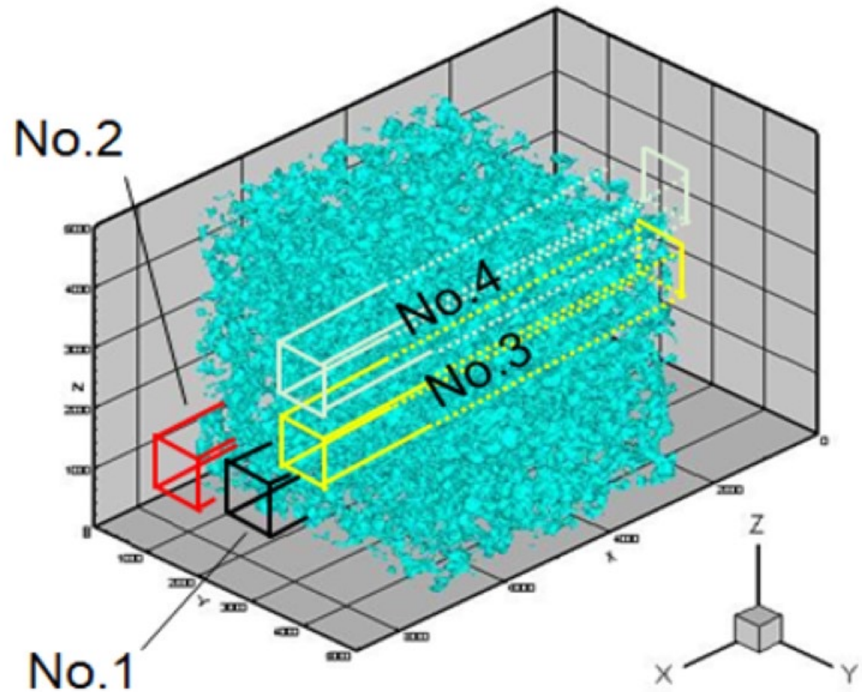
Results and Discussion

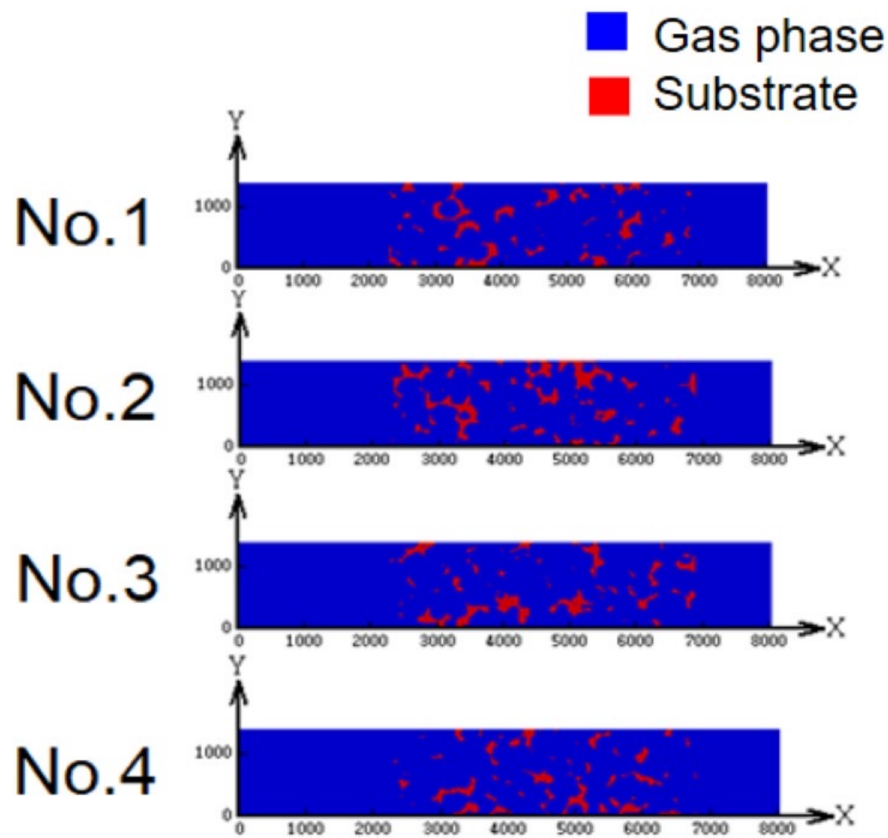
Numerical Domain and Conditions

Four different areas of No.1 to 4 are extracted for numerical domain

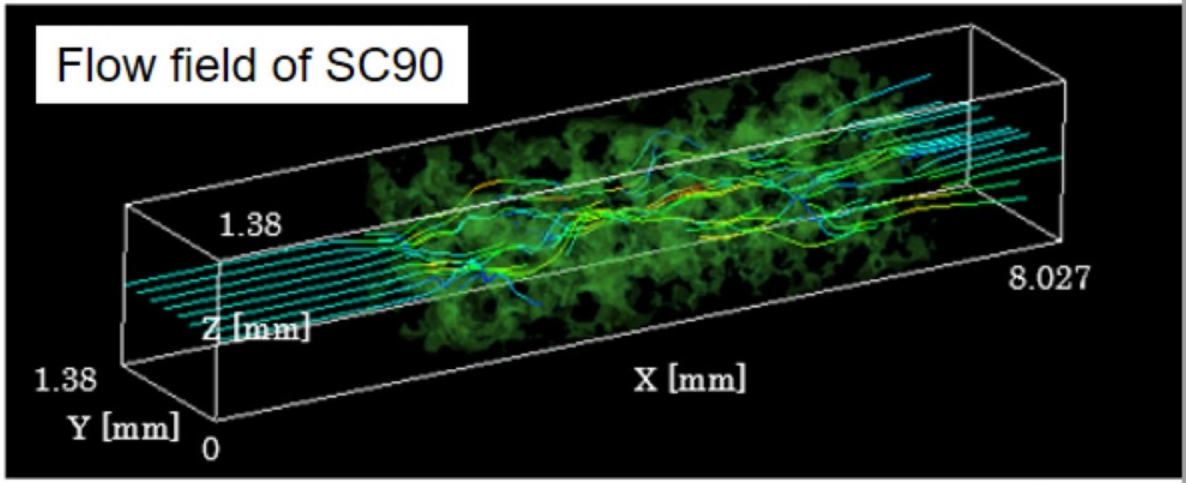
Inflow boundary	V_{in}	0.1, 1.0, 5.0 m/s
	Temp.	600 ℃
Exit boundary		Atmospheric pressure
Soot size (d_s)		40, 60, 100 nm

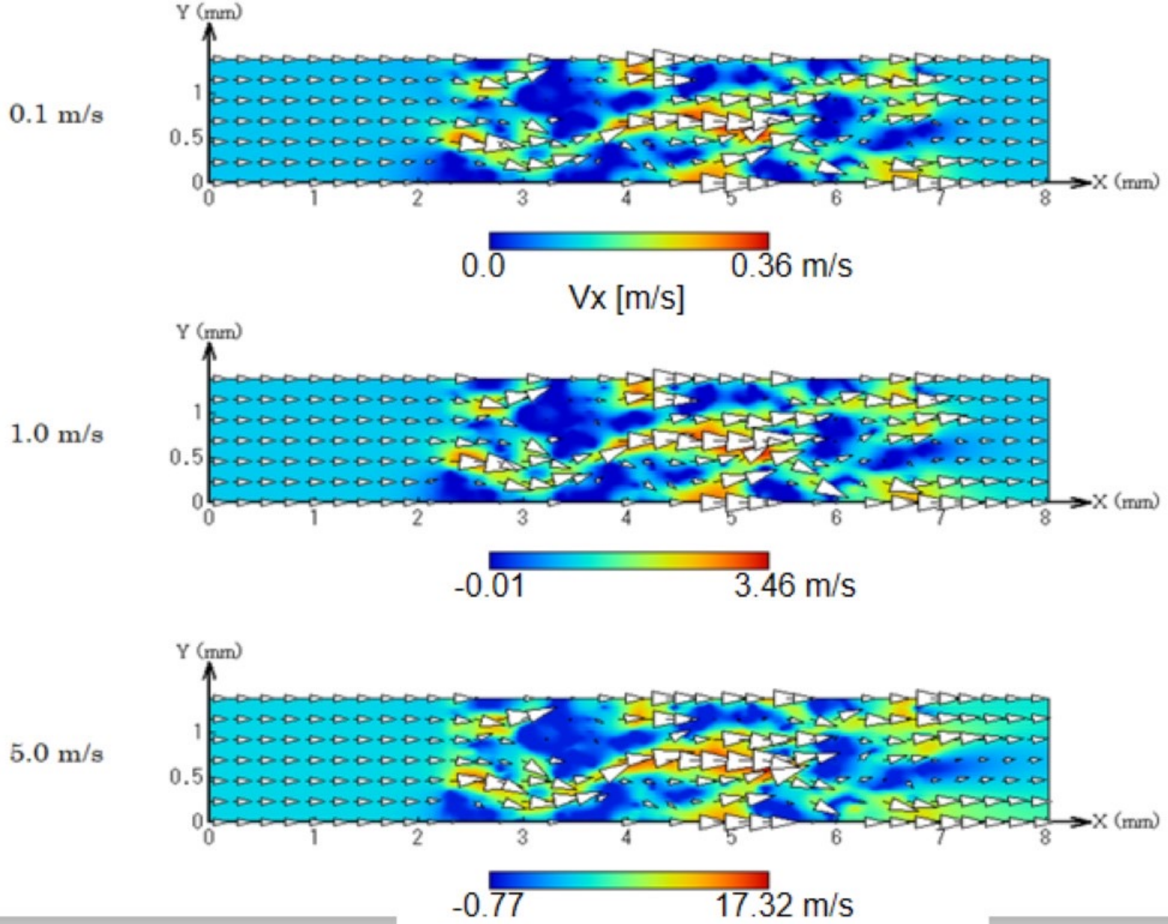
Numerical domain:
Size: 8.027mm × 1.38mm × 1.38mm
Grid number: 350 × 61 × 61
Grid size: 23 μm (= CT resolution)





Flow Field

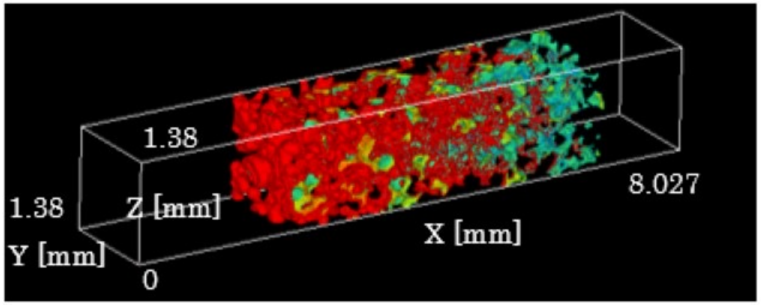




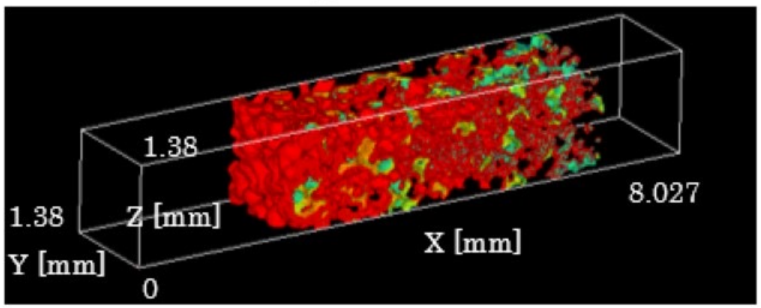
- Several streams lines
- Non-uniform flow
- $V_{x,max}$ is roughly four times larger than V_{in}
- Pressure drop across the filter

ΔP at 0.1 m/s =0.27 kPa
ΔP at 1.0 m/s =2.80 kPa
ΔP at 5.0 m/s =17.6 kPa

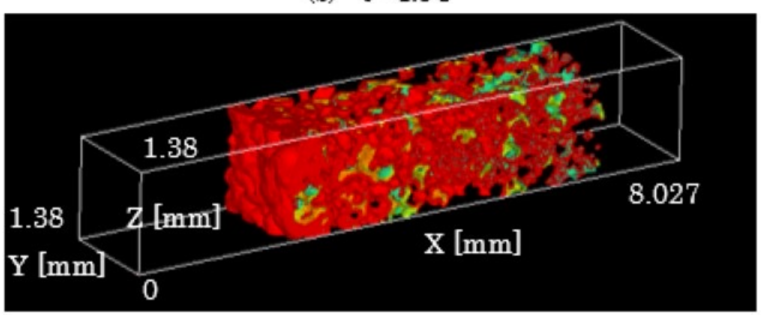
Soot Deposition Region and Pressure Drop



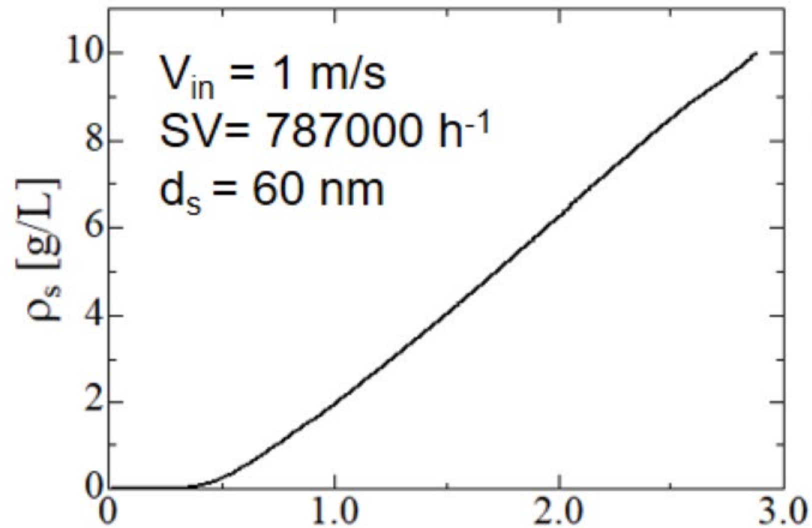
(a) t=1.0 s

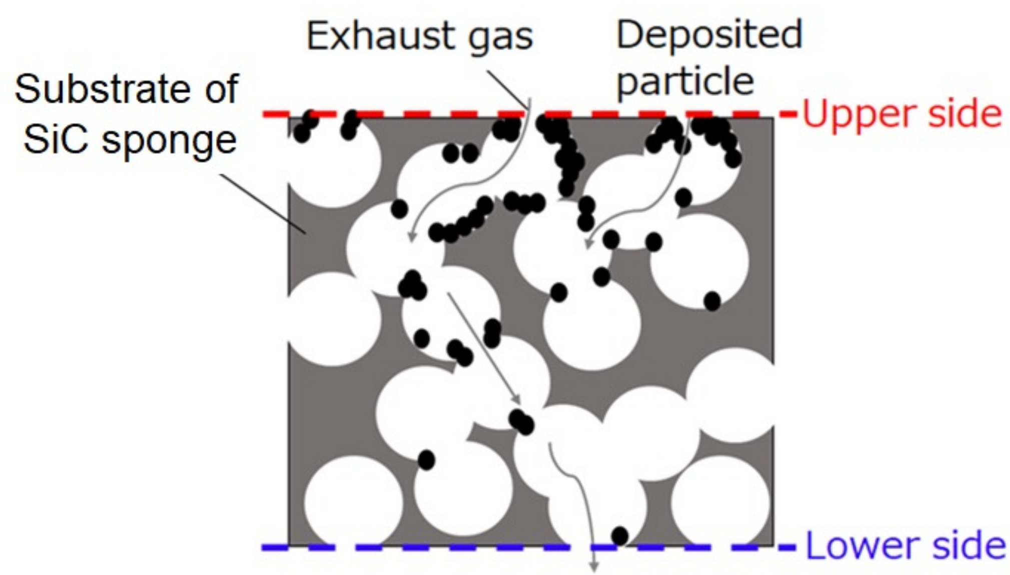


(b) t=1.5 s



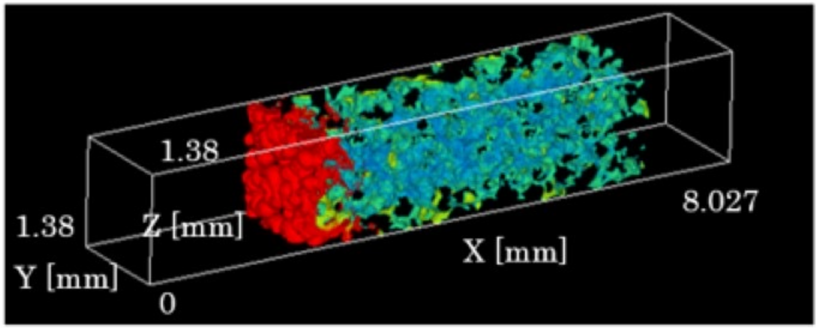
(c) t=2.0 s



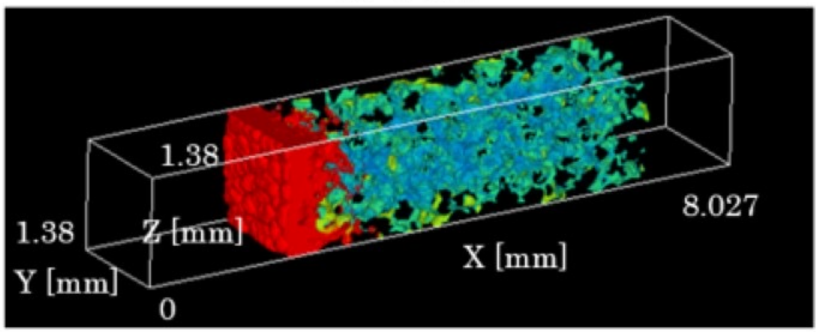


Soot Deposition Region and Pressure Drop

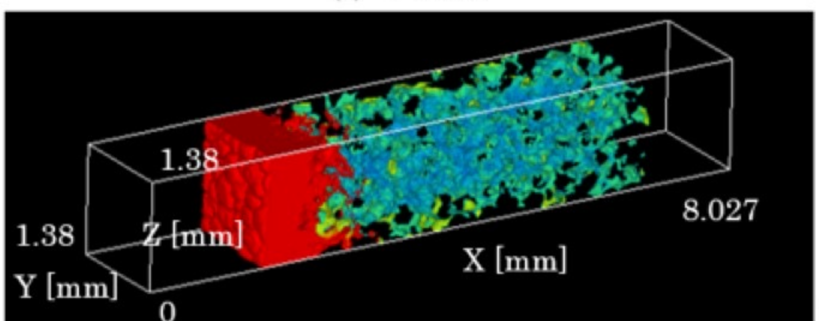
V_{in} = 0.1 m/s, d_s = 60 nm



(a) t=50 s

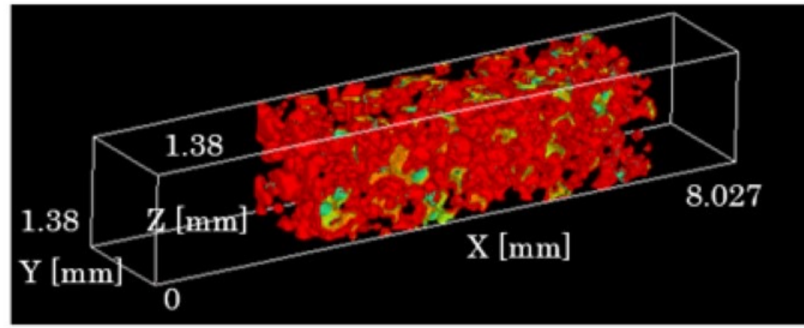


(b) t=100 s

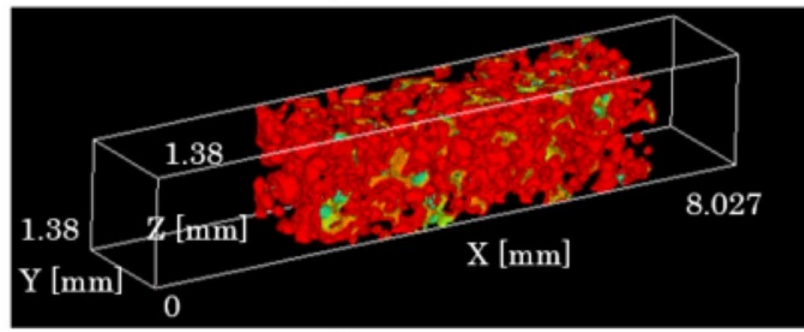


(c) t=150 s

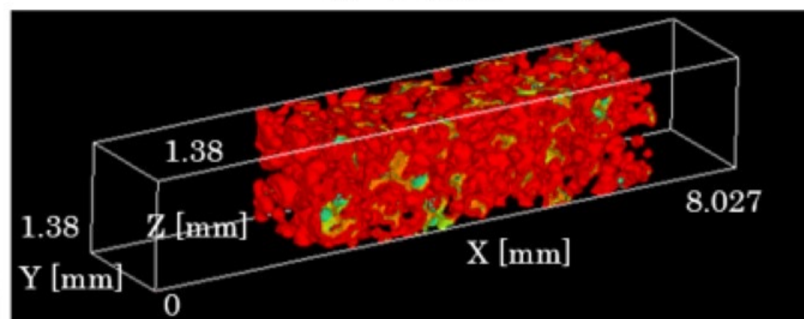
V_{in} = 5.0 m/s, d_s = 60 nm



(a) t=0.15 s



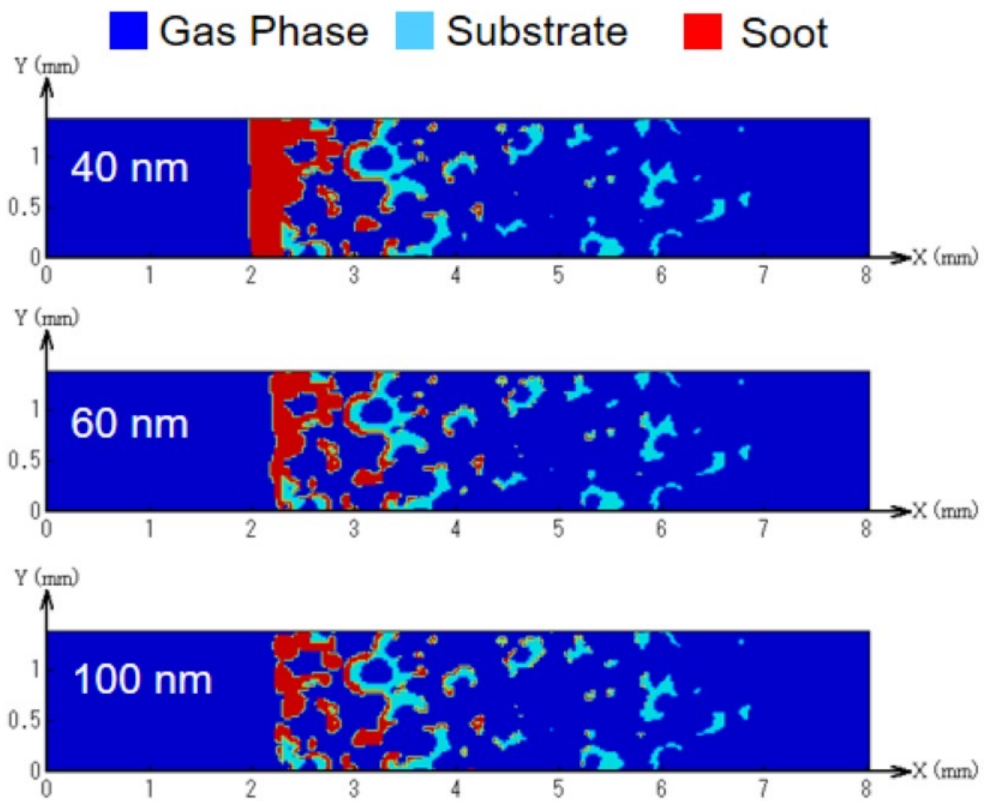
(b) t=0.20 s

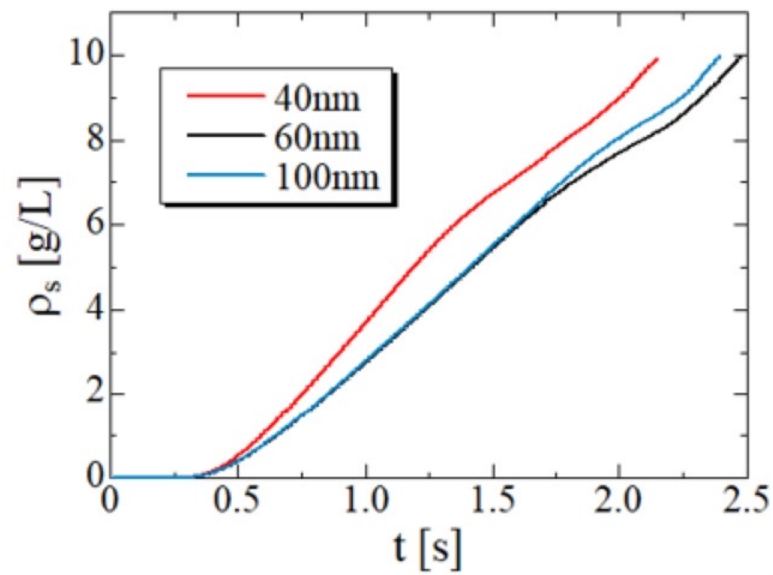


(c) t=0.25 s

Effects of Particle Size

- Period in simulation (t) is 2.0 s
- Inlet velocity of V_{in} is 1 m/s
- Visualization plane at Z = 0.69 mm





- More soot is deposited in the filter when soot size is smaller
- For all cases, both depth filtration and surface filtration are observed
- Surface filtration appears earlier for d_s of 40 nm, showing thicker soot layer

Summary

In this study, using SiC sponges potentially applied for GPF, we have simulated the soot filtration by the lattice Boltzmann method. 3D pore structure of the substrate was obtained by the X-ray CT. The complex flow pattern is formed even in the large pore of the sponge. The soot deposition distribution are largely changed by the filtration velocity. As the soot size is smaller, more soot is trapped by a Brownian diffusion, resulting in thicker soot layer on the filter surface.

Acknowledgements:

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